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A Systems Approach to Sustainable Development through Resource Beneficiation - a Case for System Dynamics Modelling

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Research Summary

The role of Manganese and minerals towards sustainable development in South Africa is a topic that has not been widely researched, despite the country's dominant endowment of these mineral resources (SAMI, 2009). An alternative approach to evaluate beneficiation opportunities in the Manganese mining value chain as a resource, by investigating dynamic parameters that describe the pattern of sustainable development in the industry's value chain, was addressed in this research. A systems thinking approach was investigated as a tool to review and solve sustainable development problems in the Manganese resources value chain.

The research focused on the application of system dynamics modelling within the systems thinking framework. This was intended to establish a pattern of relationship and causality between the input parameters of the Manganese mining value chain and the key drivers of sustainable development. A system dynamics model was developed based on the primary published works of Forrester (1969, 1971), Schumpeter (1962), Meadows *et al* (1972) which were most recently reviewed by Meadows *et al* (2007) in their work on "Thinking in Systems" and Saeed (2010) in his work on "Economic Development, Creative Destruction and Urban Dynamics". A specific focus on Manganese mining in the Northern Cape's Kalahari basin was chosen to illustrate the impact of mineral resource beneficiation and the different value chain decisions over a 10-year period, based on the dynamic sensitivities of the selected input parameters.

A systems dynamic model was developed, inspired by the works of Meadows *et al* (2007) in systems thinking to describe the dynamic behaviour of the Manganese mining value chain and its impact on the economic activity of the Northern Cape region of John Taolo Gaetsewe (JTG), over the simulation period. Three value chain scenarios from "upstream mining" through "primary beneficiation" to "secondary beneficiation" of Manganese minerals were simulated on a system dynamics software platform and based upon the same Manganese Ore and input cost parameters. The patterns of feedback on each value chain scenario performance were evaluated based on a sensitivity analysis against power cost, rail cost and market price, as key dynamic parameters in the value chain.

An improvement of the system dynamics model was developed, integrating the performance of the ”Secondary beneficiation” stage of the Manganese value chain to the system dynamics model describing the impact of infrastructure development on the economic activity of the Northern Cape, notwithstanding other industry contributions. Further system dynamics modelling of the secondary beneficiation as an integrated part of the economic system that includes human development and housing development, was conducted to further establish the impact of the secondary beneficiation scenario on infrastructure development and overall economic activity of the JTG region. The socio-economic development model was based upon the principle of relative attractiveness (Forrester, 1969) and the assertion by Perkins *et al* (2005) of the causal relationship between infrastructure development and economic development.

Based upon the analysis of the research result of the dynamic simulation of the secondary beneficiation scenario, a framework for developing, evaluating and selecting beneficiation opportunities in South Africa‘s Manganese industry was established. The framework describes the key policy and investment decisions along the value chain in the Manganese industry, and identifies key drivers of performance at each stage of the value chain investment. The framework also highlights the potential areas of impact.

The research introduces the ability to integrate the feedback loop system when simulating the potential performance of a Manganese resources value chain stage. The feedback mechanism that system dynamics modelling provides in the Vensim tool makes the tool relevant for the simulation of policy intervention in the Manganese mineral beneficiation scenario analysis and the same could be applied in other mineral commodities. The system dynamics model has demonstrated, by using the balance feedback variable, the impact of power (Eskom, 2012) and logistics capacity (Transnet, 2012), constraints on the ability of the Manganese resource value chain to meet the targeted depletion rates, irrespective of market demand.

The second important contribution of this research is the ability to integrate the impact of single and multiple variables, and observe the impact of each variable using the integrated Monte Carlo function in the Vensim DSS (Vensim, 2010). By establishing a pattern of performance in various output elements in the model and their sensitivity to input variations, the investors can make bold and informed decisions at various stages of the Manganese resources value chain.

In conclusion, the research recommends that the proposed framework be limited to use as a starting point to establish the necessary interventions. However it emphasises the need to conduct at great length, the normal business case and necessary feasibility studies that are required for any capital investment. The research highlights the dynamic nature of environmental conditions as a limitation to the application of the framework, and suggests that the framework be used carefully as a pre-condition to conventional business case studies when making investment or policy decisions.

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I would like to acknowledge the current leadership of the Manganese industry and the Department of Mineral Regulations (DMR) for the sterling work on the South African Mineral Industry (SAMI) publication, which continuously analyses the performance of the industry and compares ours against other mining economies around the world. Their work makes it possible for the industry to engage continuously with Government and other stakeholders on the best implementation of the Mineral and Petroleum Resources Development Act (MPRDA) 28 of 2004.

My research would have been more difficult without the availability of data from Transnet and Eskom. The continuous research by statisticians at Stats SA has provided this research with valuable data for the system dynamics modelling. Lastly I would like to thank everyone who assisted and challenged me to think and search more for answers during this research process. The system dynamics community has thus far provided a lot of insight (through research articles and books) into the discipline and its application to social science problems and I would like to acknowledge them.

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1. Introduction and research statement

Précis

> *The global challenge can be simply stated: to reach sustainability, humanity must increase the consumption levels of the world's poor, while at the same time reducing humanity's total ecological footprint (D Meadows, 2004)*

South Africa's economy has been built on the country's vast mineral resources, which account for 88% of known global resources of the Platinum Group Metals (PGM), 80% of Manganese, 72% of Chrome, 32% of Vanadium and 30% of gold amongst others (SAMI, 2009:6). The industry has been a driving force behind the economic development and urbanisation of many towns and cities of today in South Africa. The challenge with the form of the mining economic structure is the affliction called the "Dutch disease". "Dutch disease" is the term used to describe the de-industrialization of an economy that occurs when the discovery of a natural resource raises the value of that currency, making manufactured goods less competitive with other nations, increasing imports and decreasing exports (DME, 2007:15). The rate of exploration of new mineral resources has not kept pace with the rest of the world. While South Africa's mineral exploration budget has marginally decreased in dollar terms from $399.6 million to $378 million, the total world exploration expenditure increased from $9.99 billion in 2007 to $12.6 billion in 2008 (SAMI, 2009:7).

The Manganese mining industry has been in existence since the late 1920's, although it has not had the prominence that the gold and platinum group metals (PGM) industries have had in production volumes, contribution to employment and revenue as a percentage of GDP. According to the Statistics SA report (SSA, 2009:4), Manganese accounted for 6.5% of mining related income. However, the industry has enjoyed the highest profit margin of 51% against the industry average of 19.4% in the same year. The Manganese industry, however, has proven to be of strategic importance due to its relations to the steel manufacturing industry and potential use in battery manufacturing.

Mining and economic development

The quantities of Manganese mineral reserves and other minerals in South Africa are high enough to suggest that economic development through mining can be accelerated if a systematic and inclusive approach is taken to maximise value from these minerals. This can, and should be, achieved without exhausting the resources in a way that creates an overshoot in the consumption of primary resources. Solving this socio-economic imbalance would require a good understanding of the dynamics of the industry in relation to the regional and national economic development.

In analysing natural systems, Meadows (2010:59) finds that any growing system will have dynamic forces based on feedback that will accelerate and constrain its growth, because no physical system can grow forever in a finite environment. A good example of this is the growth of a population that would encounter factors such as food security and health systems that will either encourage or constrain growth. The point that Meadows (2010:59) highlights is that any system, whether natural or artificial, will experience a certain correction due to its nature of existence. The difference in feedback between different systems is the magnitude of the feedback. This point is essential to understand when dealing with extracted mineral resources as a means of sustainable development.

With the high levels of unemployment in South Africa, and the increasing Gini coefficient in the country, a solution for sustainable development in mining is required. The Gini coefficient is a measure of inequality of income distribution, and it is defined as a ratio with values of between 0 and 1, and requires that no enterprise has a negative income or wealth (SSA, 2010:65).This Statistics South Africa (SSA) report (2010:65) highlights this measure of a gap between those who have sufficient resources to make a living and those who don’t. This gives an indication of the social challenges that a society has to deal with to achieve a social balance.

Despite the decline in mining output in leading minerals, mining is still perceived as the main solution to South Africa’s economic developmental challenges. There is a perceived proportional relationship between growth in mining activity and economic development in South Africa (SAMI, 2009:1) which raises concerns about the future of the economy in the next few decades. This perception has led to a call for nationalisation of mines by the youth wing within South Africa's ruling party and the argument for beneficiation instead by the unions and other sectors of the South African society. The common and desired end result of either nationalisation or beneficiation is the creation of sustainable jobs and distribution of wealth to the previously disadvantaged communities. .

The new Constitution of South Africa (SA Government, 1996), regarded as one of the best in the world, guarantees equal rights and access to the country's mineral resources. This provision of the Constitution led to the promulgation of the new Mineral and Petroleum Resources Development Act (MPRDA) in 2004, which brought in more responsibility for the industry in terms of sustainable development (DME, 2004). The MPRDA set the following key requirements for all industry players to ensure sustainable development of the areas where mining activities take place, and sought to achieve these through the process of renewal of old order mining rights into new mineral rights: The MPRDA:

- required that all mining operators who apply for new order mining rights comply with new environmental targets set out in the NEMA act of 1998
- required all mining operators to make a commitment to the community economic development through Social Labour Plans (SLP)
- set a quantum for financial provision for rehabilitation of mining areas post mine life cycle
- encouraged and incentivised beneficiation of minerals in South Africa

Whilst beneficiation has been highlighted in the MPRDA as a desirable outcome (DME, 2004), this has neither been made mandatory nor described adequately in the act. When compared with the value derived from beneficiation of South African minerals elsewhere in the world, the value of raw material exports is only a fraction of what could be realised if beneficiation took place in South Africa (SAMI, 2009:14, 15). The volume of raw material that is exported from South African mines to the world markets is very high when compared with raw material imports (SAMI, 2009:16). This makes South

Africa a bigger consumer of beneficiated products from other countries for the same minerals that she exports in larger proportions in non-beneficiated forms.

State of mining industry in South Africa

Sustainable development through mining is a very sensitive subject in South Africa. Iron Ore and Manganese have made very little impact on the development of the Northern Cape towns of Kathu and Hotazel respectively, when compared with the impact of the gold and diamond rush towards Johannesburg and Kimberley respectively. The discovery and subsequent mining of diamond and gold spurred infrastructure and urban development in and around Kimberley and Johannesburg in the early 20th century (Perkins, 2005:215). For instance, the bulk of the rail and road infrastructure that connects the major cities in South Africa today was developed during the diamond and gold rush (Perkins, 2005:215). This industry's output has declined over the years. In 2010, the industry only contributed about 6.2% to the country's turnover, compared with a 7.1% contribution in 2009 (SSA, 2010:6).

Despite this abundance of mineral resources, South Africa is neither the leading producer of Manganese Ore, nor is it the leading exporter of Ferro-Manganese and other Manganese- related products. The challenge with the industry remains that the majority of these minerals are exported with minimal downstream beneficiation happening in the country (SAMI, 2009:16). Sustainability of the industry is not guaranteed, and new ways of looking at this concept were researched as part of this study. Sustainability of the mining industry was looked at from two possible angles: slowing down or control of the depletion/extraction rates of raw material resources or accelerate exploration activities to discover new resources. The subject of this research was focused on the first angle and becomes the subject of the study.

In his paper at the LBMA precious metals conference, Roger Baxter (Baxter, 2005) conceded that the concept of beneficiation elicits a lot of emotive response. According to Baxter (2005), the view held by many South Africans is that most of the country's mineral resources are exported to countries seen as previous colonial powers, where they get processed and exported back to the South African economy at much higher prices, the consequence of which is that the processing jobs are lost to this country. He defines beneficiation as a process of adding value from mining right to the final fabrication of the consumer branded product. The call for beneficiation is made with the hope that this effort will see sustainable economic activities beyond the upstream mining by establishing a secondary economy that is self-sustaining. This research aims to explore this hypothesis through the dynamic modelling of the key parameters driving the Manganese industry in South Africa.

Whilst project metrics for evaluating the development of mining projects are mature in SA and the rest of the world, the beneficiation industry is at its infant stage. The **markets** for raw material from South African mining are well established, whilst the same conclusion cannot be made for beneficiated mineral products. South Africa has more than 100 years of experience in mining project developments around most of the prominent mineral commodities. The **metrics** that have been developed for evaluating these projects take into consideration the lessons learned from all the projects developed over the past more than 100 years of upstream mining activities. Whilst the technology for upstream mining has matured from both efficiency and availability points of view in the South African mining industry, the maturity of beneficiation **technology** and its availability is uncertain or low. Despite all these challenges mentioned here being true for South Africa, other countries have done well in developing successful projects for mineral beneficiation.

SA has developed a National Industry Policy Framework (DTI, 2007:19) which has set out the development of value-adding industries for mineral resources mined in South Africa as a strategic programme. This is an acknowledgement that the role of secondary industries is crucial to making the provisions of the MPRDA (2004) viable to the country's mineral economics. The current set up of the mining business in South Africa is based on an upstream business model with downstream activities limited only to marketing and sales of raw minerals. When most of the green fields mining projects are developed, Net Present Value (NPV) calculations and other business case metrics are focused on cost only, related to extracting minerals out of the ground and shipping them to the markets abroad. The vast majority of beneficiation actually takes place in countries that do not mine the product at all or do not mine much of the product (Baxter, 2005:26). Challenges related to power and logistics support contribute to the low beneficiation of Manganese and Iron Ore minerals in the steel making and other manufacturing activities in South Africa.

South Africa is still not innovating and developing sufficient technology to support its production and manufacturing capability, making the country one of the technology colonies (De Wet, 2004:2). The country depends on European and Western technologies to put into effect some of the beneficiation initiatives. The dependence on foreign technologies poses a challenge to the identified initiatives. In conducting this research the following set of research questions should be raised:

- What are the leading indicators for a systems approach to sustainable development planning in the Manganese industry?
- What is the impact of the legislative environment on sustainable development through Manganese beneficiation?
- What will sustainable development of the Manganese industry look like?
- Is the approach taken to sustainable development in Manganese mining independent enough to sustain itself beyond direct mining?
- Does the human capital supply match the beneficiation demand?
- At what stage of project development should beneficiation projects be approved?
- What are the key parameters of sustainable development through beneficiation that should be understood by key stakeholders?

The literature review on mineral regulation framework, systems thinking, system dynamics, and economic infrastructure development concepts and theory described in detail later in this thesis is used to formulate the theoretical basis for designing a solution for the questions raised above. The system dynamics simulation that is conducted as part of this research will address the verification and validation requirements of the solution described using the concepts listed in the previous sentence. The manufacturing industry, particularly the steel and construction industry to a large extent is a consumer of the downstream beneficiated products of Manganese and Iron Ore minerals mined in South Africa.

Whilst the questions on beneficiation gaps are raised in South Africa and other developing countries, most developing countries have placed themselves in a competitive position to beneficiate their minerals successfully by improving their manufacturing capacity (PAIRS, 2011:10). These countries have imported most of the raw minerals from countries like South Africa. Asia, in particular, has become the major destination for South Africa's Iron Ore and Manganese. This background points to a capability in the destination countries to consume raw mineral resources through beneficiation, a capability which is lagging behind the rest in South Africa. This could mean technology skills, industrial integration and political will from government strategically to position the country's economy to make good use of the mineral resources.

What the research focused on:

This research was aimed at evaluating the effect of policy decisions on sustainable development drivers, based on the Manganese mineral industry direction. The focus of this research was centred on the state of the Manganese mineral resource industry and the options available for addressing sustainable development in the industry. The applicability of the options identified is tested through a system dynamics model for the Manganese industry based on a 10 year simulation period.
The simulation was based on systems dynamics modelling concept, and has assumed beneficiation of Manganese minerals as a key variable.

A first set of data collected through industry databases and various SA agencies (Transnet, 2012) (Eskom, 2012) (SAMI, 2009) (SAMI, 2010; SAMI, 2011) (SSA, 2010) was used to set initial conditions, and to develop the simulation logic for the model. The position of the global investment communities towards mining-related investments, from a project finance point of view, and the guidelines set out by the equator principles (IFC, 2006), were reviewed to inform the set of assumptions made in setting up the system dynamics model.

The research focused on establishing the requirements for long-term success in beneficiation of Manganese along the value chain from upstream exploration and mining through to final application of the end product. According to Michael Porter (1985:38) the value chain displays value and consists of value activities and margin. Porter (1985:38) describes the value activities as those physically and technologically distinctive activities that a firm performs, and the margin as the difference between the total value and the collective cost of performing the value activities.

The Manganese resources value chain in this research is described as the mineral extraction and processing activities stemming from upstream mining, through alloy production in Smelter furnace operation, to final application in steel manufacturing.
The challenges related to energy, logistics and other inputs required for beneficiation are investigated and used in the system dynamics modelling process in the context of the sustainability of the industry’s dependence on non-renewable energy for the entire mining and minerals value chain.

1.1. Rationale for the research

Sustainable development is a complex subject and requires a different approach from a straight-forward cause and effect analysis. The idea that the cause of a symptom must lie nearby and must have occurred shortly before the symptom is true only in simple systems. In the more realistic complex systems, causes may be far removed in both timing and location from their observed effects (Forrester, 2009:15). Although mostly developed and used in complex engineering problem solving, system dynamics simulations have been used to explain dynamic impacts of various components of the mine value chain under different market environments. This research may establish behavioural patterns that can assist in understanding the causal relationship between Manganese resources value chain level decisions and the impact on secondary industry growth.

The founding father of system dynamics, Professor Jay Wright Forrester has championed system dynamics modelling. Forrester did so, as Meadows *et al* (1972) point out in their discussion of limits to world growth, by successfully leading the development of a sponsored model to predict the restriction on growth of the world economy caused by limited natural resources (Meadows *et al*, 1972). The system dynamics model describes the situation that confronts resource-rich economies, such as South Africa, which has the largest value of in situ minerals value (COM, 2011:5).

Sustainable development through Manganese beneficiation requires that a number of independent elements within the Manganese mining industry, and the supporting industries, work in unison, making this a complex endeavour. The implementation of policies in this area, and their performance, cannot always be analysed using only linear statistical methods, such as a cause-and-effect analysis. Amongst these elements are, Power, Logistics and Steel manufacturing. The research seeks to establish a pattern of inter-relations between mining-driven sustainable development and the long term impact of policy decisions on these elements.

Why the research?

The complexity of sustainable development that is driven by mining and mineral beneficiation in South Africa is exacerbated in part by the emotive nature of the subject. For an industry that is over a century old, creating a new behaviour requires a common insight into the dynamics of the industry and how it is influenced by the environment within which it operates. The legislative, infrastructural, labour and secondary business environments have a direct influence on the dynamic behaviour of the mining industry. The systemic relationship of these elements to the Manganese mining industry needs to be studied so that feedback to any policy decision that seeks to influence or change the nature of these relationships can be predicted both in the short and long term. This can be simulated in a system dynamics modelling environment with input data collected from the industry.

The reason for this research is to establish a model for integrating sustainable development, particularly through beneficiation strategy, in the makeup of the business case for mining development. The desired outcome of the model is to establish a pattern of possibilities for secondary business opportunities within the Manganese mining value chain. The outcome of this research is a set of new questions that need to be asked when policy decisions on Manganese minerals beneficiation and industrial growth are made. A systems approach to thinking about and implementing sustainable development in the Manganese and the broader mining industry is proposed.

1.2. Problem statement

The mining and minerals industry project development in South Africa has for years been predominantly focused on upstream mining. Manganese mining has been one of the mining sectors in South Africa that has not followed global trends in volumes sold and revenue generation notwithstanding the access and logistics challenges that the industry faces (Perkins *et al*, 2005: 216). The effect of this under-performance by the sector on the economic development of the Northern Cape and the towns where the mining operations occur, compared to other sectors, is negative. The developmental impact of the gold mining industry in the historical gold mining cities, such as Johannesburg, Carletonville and Welkom, is incomparable to the impact of Manganese mining in the towns of Hotazel and Black Rock.

For example, the overall mining sector's contribution to the Johannesburg and Gauteng's provincial economies has declined from main contributor in the early 1900's to less than 3% of GDP in 2006 (Broll, 2007), whilst percentage contribution of mining in the Northern Cape (NC) was 26%, (CoM, 2011:9)). This shows the level of maturity in the Gauteng economy against the levels of maturity seen in the NC. The decline in percentage in the mining contribution to Gauteng's GDP is attributed to the significant growth in the manufacturing and services sectors' output over the years (SSA, 2010).

A systems approach to reconcile short-term policy benefits and long-term sustainability of the mining industry is required. The challenge for this research is to develop a model that would enable policy makers to simulate the impact of policy interventions on sustainable development in the Manganese mining industry, both in the short and long term. The research should test the influence of policies such as side stream and downstream beneficiation of Manganese products, in order to achieve sustainable development. The pull factor from the secondary industry by local and locallyentrenched multinational companies in semi-fabricated and raw material for final fabrication in local manufacturing is envisaged for further investigation.

The beneficiation industry in South Africa is struggling to take off, mainly due to the challenges related to bottlenecks in logistics, energy costs, lack of technology and shortage of skills (PAIRS, 2011:13).. As Bunker (1994:442) in his comparison of Aluminium and Copper beneficiation points out, most developed economies still dominate the patent ownership and production of beneficiation technologies. This domination Bunker (1994:38) result in the distances between extractive sources and industrialization centres being increased as is the case in South Africa. While South Africa boasts more than 100 years of mining project development on the upstream side of the business, the downstream activities are new to South Africa, and the sustainable development metrics are still underdeveloped for most of the mineral types. This is despite the sustainable developmental imperatives of South Africa and continuous calls from civil society-affected communities, Non-Governmental Organisation (NGOs) and some business sector players, for local beneficiation of minerals as a main driver of sustainable development beyond mineral exports.

South Africa hosts the largest reserves of most leading minerals such as Platinum Group Metals, Gold and Manganese in the world, but is not a dominant player in the market when it comes to export value and value of beneficiated products. Despite South Africa hosting both the largest known reserve of Manganese in the world and sufficient reserves of Iron Ore (both main ingredients of steel production), the country is an insignificant player in the steel export market. The research conducted on the South African economic future growth indicates that the growth potential lies in the development of secondary industries such as manufacturing and financial services. Perkins *et al* (2005:212) highlight the complex causality between the infrastructure development and the growth of an economy. The complexity exists because the timing and the lagging effect of the impact that infrastructure has on economic growth is not always linear. Perkins *et al* (2005:212) conclude that this relationship is synonymous with that of a chicken and egg, because economic growth depends on infrastructure to allow seamless business transactions, but the growth of the economy is required for the development to fund more infrastructures.

The South African government, through the Department of Trade and Industry (DTI, 2007), developed a blue print for industry-driven economic growth in South Africa called the Industrial Policy Action Plan (IPAP), which then drives the National Industrial Policy Framework. The National Industrial Policy Framework targets the development and government support of secondary industry and side stream beneficiation of mineral and mining product output.

Support industry requirements, such as energy and logistics, are investigated in order to create understanding of the synergies that exist and how these can be explored to facilitate growth in the sector. Sustainable development principles aimed at developing more sustainable industries, post mining, are investigated to establish alignment to project investment requirements for green field projects and concurrent development. Figure 1 summarizes the problem statement and the research objectives.

Problem statement

In a mining-driven economy such as South Africa, sustainable economic development is difficult to achieve and sustain. The balance between profitable mining and sustainable development is a subject of long discussions between policy makers at Government level and mining operators. The mining industry is seldom sustainable beyond peak productions when grades of mineral resources are high. The unemployment challenge in South Africa requires that the mining industry creates more sustainable jobs locally. A systems approach to reconcile short-term policy benefits and long-term sustainability of the industry is required. There is a strong case for integration of sustainable development goals that are required as part of mining license conditions and sustainable growth of the industry itself

Questions

- What are the key drivers of sustainable economic development in a Manganese mining context?
- What are the key system challenges that prevent sustainable economic development in the South African Manganese mining industry?
- Is there a balance in approach between short-term policy interventions and long term sustainability of the Manganese minerals industry?
- Is there a case for a systems thinking approach to dealing with the sustainable economic development challenge in South Africa?
- What influences the development and performance of the Manganese resources value chain in the South African economy?
- Is there any causality between infrastructural developments and sustainable economic development through mining?

Objectives

To define a systems level relationship between economic infrastructure, mining activities and community social development in relation to sustainable economic development. To establish a framework based on patterns of causality between elements of sustainable development in Manganese mining. To establish a model-based framework that can be used to predict patterns of system behaviour and feedback on policy decisions taken in the Manganese resources value chain. Sustainable economic development standards and international benchmarks are conducted to establish the key variables for dynamic simulation of the systems behaviour. The impact of local beneficiation of mineral resources on sustainable economic development is investigated through this research.

Propositions

- A structured and feedback-based approach to evaluation of key policy decisions.
- Identifying key parameters of sustainable development in a Manganese mining driven economy.
- Defining the logical relationships between mining activities, community involvement and infrastructure environment in aiding sustainable economic development.
- Using small dynamic models to simulate real-life system behaviour.
- A move away from ordinary econo-centric simulations towards a sustainable economic development approach with long-term growth patterns.
- Contrasting the proposed systems thinking approach to sustainable economic development with similar efforts in other countries

Figure 1: Summary of a research problem statement and objectives

1.3. Research objectives

To establish the required model for sustainable development through full value chain beneficiation of the Manganese mining and mineral resource base, the research has investigated the following:

- The current status of sustainable development in the mining industry
- The state of legislation on sustainable development in SA
- The historical role of systems thinking in influencing decision making from policy to implementation
- The behaviour and structure required for sustainable development through Manganese beneficiation
- Using dynamic simulation of key parameters to establish a more predictable and sustainable development model
- Understanding the Manganese industry, its value chain and secondary industries
- South African steel production potential and its consumption of Manganese going forward
- The human development requirements to meet the sustainable development potential of the Manganese resources in South Africa

The above was reconciled with the data from investigation of the capability of the secondary, or the manufacturing industry, in terms of the following:

- Current global steel manufacturing output
- Availability of the necessary technology and human resource capability
- Capability of the supporting industry and logistics

To complete this research, an effort was required to investigate the concept of mineral and mining resources beneficiation in the context of a strategic industry development framework for South Africa. Building a business case for the beneficiation of Manganese minerals as a driver for sustainable development requires a deep understanding of the Manganese mining industry. Having said this, it is important to define the system boundary for the research, and the subsequent modelling effort, in order to study the behaviour of the system more accurately. This research proposes a systems thinking approach to defining and describing the parameters for the research and development of a system dynamics model. The model is used to define the objectives for data collection, analysis and formulation of the framework for Manganese beneficiation as a driver for sustainable development.

International benchmarking is incorporated to ensure that the research output is in line with the best approaches used internationally, where similar policy interventions have been undertaken.

1.4. Type of research

The research is based on applied research (Page *et al,* 2005) methods and has taken a descriptive approach to creating an understanding of the problem in the Manganese mining industry as it is. The current dynamics of the mine, the structure of the social and economic systems of a mining community, including the skills potential of these communities, need to be better understood. It is the objective of this research to produce a framework that can be repeated for studying the dynamics of other mineral commodities, albeit with commodity specific adjustments. A case study based on the Manganese industry will provide the basis for detailed description of the dynamics.

The research seeks to explore a more economically-viable approach to sustainable development planning driven by Manganese mineral beneficiation. A quantitative approach using published industry input numbers, such as mine cost and production performance is used to determine the parameters for the simulation of the industry behaviour. It is believed that by creating a good understanding of the dynamic performance of the Manganese resources value chain under different beneficiation policies, the underlying problems of unsustainable growth in mining are better understood. It is aimed at creating insight into the impact of beneficiation policy interventions towards the Manganese resources value chain in the long term. A modelling approach using a Monte Carlo sensitivity analysis of the Manganese industry to the industry environment under various policy positions is used to establish the dynamic stability of the industry over a long term.

A case study of the Northern Cape Manganese mining operations and the socio-economic impact on the John Taolo Gaetsewe region is used to demonstrate the concepts. The research seeks to establish data to support the hypothesis for the viability of a business case for self-sustaining post-mining beneficiation business opportunities. Data is collected from the Manganese industry experts and industry performance speculating agencies. The data collected is used to feed the model in dynamic simulations to establish patterns for further analysis to improve on the established theory. As Hyndman (2008) emphasised in his article, “data beats expert opinion as it beats anecdotes”.

The research relies on the extensive work done by Jay Forrester in North America (Forrester, 1971); Schumpeter (1962), Saeed (2010), Senge (1990) and Sterman (2000) to describe the complex nature of socio-economic systems and how system dynamics simulation can be used to better describe the inherent dynamics within the South African Manganese mining industry.

1.5. Importance of the research problem

The economic development concept in mining in general and Manganese in particular, is the subject of varying debates between the various stakeholders, including the industry, government, civil society and the affected communities. The uncertainty in the debate is related to the perceived performance dynamics of such development in the long term. A report from the Northern Cape Department of Economic Development (NCDED, 2008:6) highlighted that, compared with tertiary industries; mining creates only 13 jobs for every ZAR1 million of production cost, against 47 jobs created in tertiary industries. Agriculture creates 36 jobs for a ZAR1 million of production cost. Although beneficiation of minerals is deemed the potential solution to joblessness and economic development of mining communities in the long run, there is insufficient data to demonstrate the result of this hypothesis. This research will form part of a much-needed source of reference for what the Manganese industry can achieve under specific beneficiation policy decisions.

The research is aimed at establishing a much more integrated process of achieving sustainable development through Manganese mineral beneficiation, by adopting systems thinking approach and dynamic modelling to ensure new and fundamental understanding of dynamic feedback of specific policy actions. The research aims to establish new insight into the behaviour and structure required for successful value creation, through Manganese minerals, to ensure long-term leverage of the minerals. The research will investigate establishing a framework for inclusion of beneficiation business in the development of mining projects as a driver for sustainable growth beyond the immediate Manganese mineral resource. The research is critical in the establishment of a framework for industry participation in mineral value addition and the resolution of the job creation and improvement of living standards for South African mining communities.

Like many other policies, such as Black Economic Empowerment (BEE) and Reconstruction and Development Programme (RDP), that were well intended to develop the economy and create sustained growth but failed to do so effectively, beneficiation policies are likely to follow the same trajectory unless an integrated approach that takes into consideration the feedback generated by the policy actions, is followed. Both BEE and RDP policies were criticised for creating unintended and unforeseen problems. BEE created a new group of elite whilst increasing the gap between poor and rich people in the country. RDP, on the other hand, created more demand for urban housing instead of reducing the demand, as more and more people from rural South Africa and neighbouring countries became attracted to the cities with the prospect of getting free housing.

The questions that are going to be raised by the research, based on the systems thinking approach and dynamic simulation, are critically important to ensure that these gaps do not re-manifest themselves. The framework will help other stakeholders such as community groups and NGOs, to participate meaningfully in planning the long term sustainable development of their communities from exploration of mineral resources to final downstream beneficiation.

1.6. Limitations and assumptions of the research

The research topic focuses on alternative hypothesis testing using system dynamics to determine the impact of different policy decisions in a mining industry. The analysis is biased towards a quantitative approach, albeit with estimated input data. The market dynamics determining the revenue and demand for Manganese are largely driven by the steel industry which, in itself, is driven by global socio-political factors such as conflicts and industrialisation. The orientation of the research is based on action research in the Manganese industry and some personal observation of industry behaviour as a frame of reference.

The social context of the research is subject to varying generational dynamics of the areas of focus. These may differ from province to province and from South Africa to Europe, as well as differing from the generation of the 20th century to the generation of the 21st century. The impact of these differences may affect the repeatability of the result in different country settings, but may not affect the pattern in the South African context.

The South African mining industry is still dominated by a significant number of multinational companies playing in the space. One existing hindrance to the research objectives is the relative novelty of the beneficiation concept in South Africa, and lack of historical data. The automobile industry is also dominated by multinational companies, some of which produce goods for overseas markets and as such may not consider the use of locally-manufactured goods as being advantageous to their overseas clientele.

International laws play a role in market competitiveness through subsidies for research and policies in use. This may affect the competitiveness of South Africa compared with other benchmarked countries on key inputs such as energy and logistics and, as such, the result may not be repeatable in this context. To minimize any bias towards a specific market, data used for the model is focused on the local market.

1.7. Research roadmap

Figure 2 describes the process and sequence that this research has followed from concept stage to final reporting. The research followed a 7-stage approach and, in between each stage, key activities were undertaken that allowed decisions to move to the next stage. The arrows connecting each stage indicate movement between stages. A critical point to note is that, bidirectional arrows from the problem definition stage through all five stages to the final reporting stage indicate the extent to which iterations between stages happened throughout the research process. A summary of the 7 stages is described as follows:

Stage One - Research Concept and Proposal

This process focused on identifying the area of research and established the extent to which the topic and key concepts have been published in the body of knowledge. The process resulted in a selected area of research in systems thinking and system dynamics modelling. Using these concepts, a topic of research and basic approach was agreed upon with the potential supervisor.

Stage Two - Problem Definition

This stage sought to establish the base for the research by identifying similar work in the research and industry space. The work focused on previous academic research and industry application on system dynamics. Particular search for application examples of dynamic modelling in mine performance improvement and mine sustainability projects was conducted. A set of research questions and hypotheses around sustainable development in Manganese were developed to finalise the research proposal and initiate the research work on the selected topic. The mandate to further define the research methodology, conduct literature search and review was sought from the university.

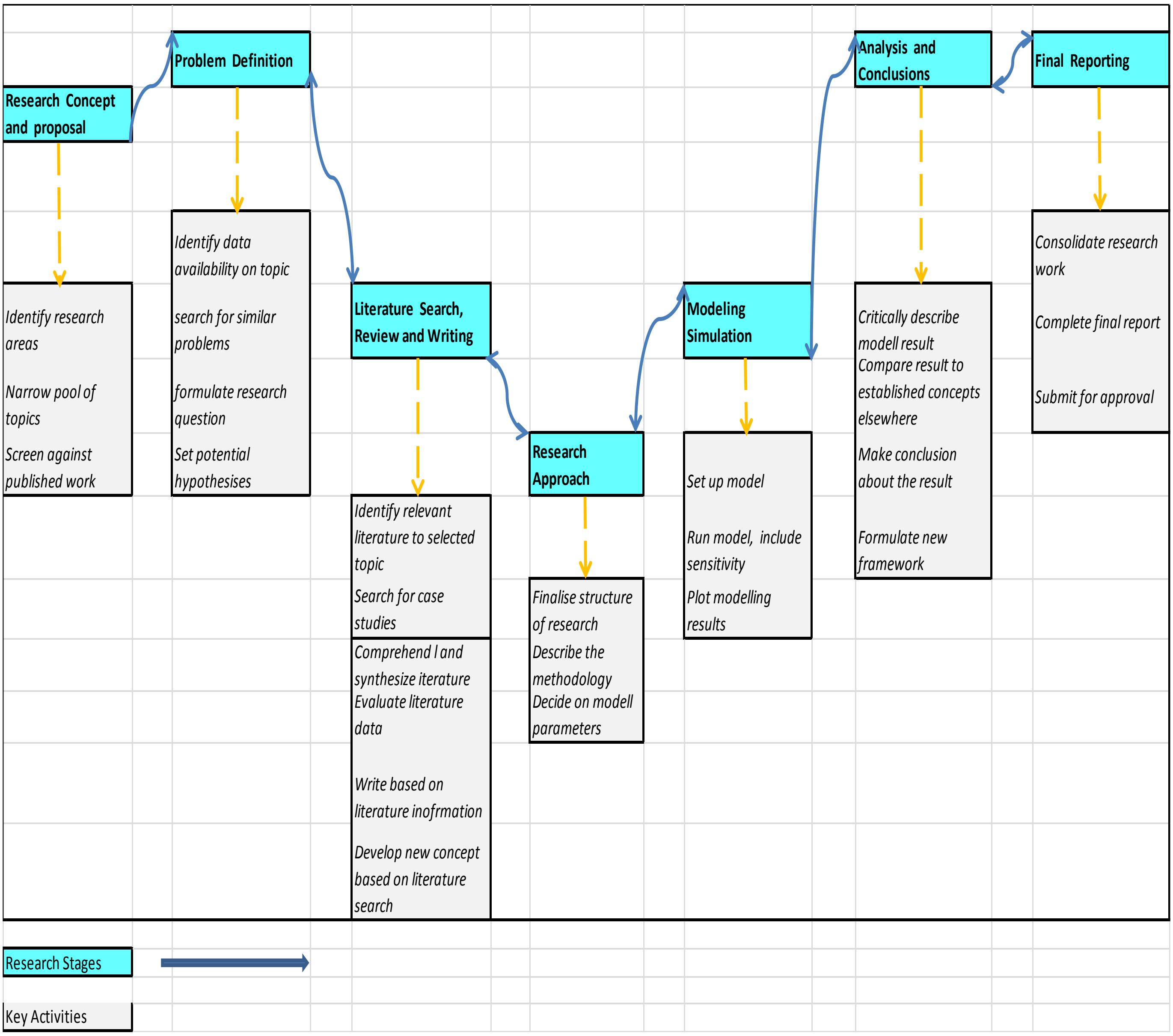


Figure 2: Summary of the research roadmap

Stage Three – Literature Search, Review and Writing

Based on the concept proposal for the research, literature data search was conducted on the key research areas that were identified within the topic of research. These were structured to focus on systems thinking literature; Manganese resources value chain, system dynamics modelling, sustainable development concepts and legislative environment. An overview of the Manganese resources value chain was conducted in order to identify the leading variables influencing the performance of the industry. These variables were later used in the modelling exercise, the results of which are discussed in Chapter 5 of this research thesis.

Case studies in industrial mineral beneficiation were investigated to establish the extent to which challenges and opportunities have been documented around mineral beneficiation elsewhere in the world. An extensive search on system dynamics and systems thinking publications was evaluated to form a basis for conceptualising the data gathering and parameter setting for the modelling exercise.

Finally, a search on published research articles on the causality between infrastructure development and sustainable development, particularly in the areas of transport and logistics, was conducted. Whilst the literature search continued through the modelling and the results analysis phase the evaluation of the literature under those identified themes paved the way for research methodology and model design

Stage Four - Research Approach and Methodology

The final concept of the research and the methodology was established at this stage based on the identified body of knowledge from the literature search. The key parameters for the model were established and the model was formulated based on a Vensim system dynamics simulation platform. Data collection and evaluation was completed at this stage.

Stage Five – Modelling Simulation

Simulation of the Manganese resources value chain performance and options for sustainable development were conducted at this stage. The modelling process included the risk analysis based on parameter sensitivity. The fluctuation in input variables, such as cost of power and transport logistics, was simulated.

Stage Six - Results Analysis and Conclusions

The results of the simulation were analysed based on the key concepts described in the literature review in Stage Three of this research. The benchmarking information from similar industrial applications was used to compare the outcome of the model to form a conclusion on the modelling process and the research findings.

Stage Seven - Final Reporting

This final stage of the research was focused on consolidating the body of knowledge gained through the research, capturing new contributions to the body of knowledge and making recommendations to the Manganese industry. The research thesis completed in partial fulfilment of the degree is presented at this stage for examination by the University. This stage marks the conclusion of the research process.

1.8. Summary

The objective of the research is to establish the dynamic behaviour of the Manganese industry in its current form, understand its potential to impact economic growth in the region and the country, and establish a model for sustainable development. The holistic and inclusive approach to describing the sustainable development challenge is used in the research. The goal of the research is to establish a pattern of performance with feedback that will assist policy makers understand the dynamics of the Manganese resources value chain better.

The research focuses on establishing the existing parameters of sustainable development in the Manganese mining industry through beneficiation. The relationship between beneficiation and sustainable development in the Manganese industry is investigated. The impact of specific policy interventions on the sustainability of the industry is tested through dynamic simulation. The systems thinking theory is used to establish a different approach and establish patterns of causality among factors at play when evaluating the dynamics of a Manganese resources value chain.

The strength of the systems thinking theory is tested through system dynamic modelling to demonstrate the behaviour of the system under specific parameters over a number of cycles. Although this research is not a classical hypothesis-testing based research, a case study of the Hotazel Manganese field is used. Comparison with the world steel and performance is made to strengthen the assumptions base for input parameter stetting to the dynamic model.

2. Theory and research literature review

The literature search focuses on four main areas that are relevant to this research. These are the bodies of knowledge in the fields of 1) systems thinking and system dynamics modelling 2) the overview of the Manganese mining and steel industry in South Africa, 3), sustainable development in mining, and 4) review of appropriate beneficiation efforts in South Africa and the rest of the world.

These four areas of literature search have been identified in order to address the questions raised in the problem statement described in Chapter 1 of this research thesis. It is the view of this research that, in reviewing the systems thinking literature, the systemic composition of the Manganese resources value chain and its causal relationship with other economic drivers in the economy can be better understood.

The system dynamics modelling may be of assistance in answering the question on causality between the mining activities and infrastructure development, as well as the causal relationship between infrastructure development and economic development. The research also seeks to establish through the review of the Manganese and steel industry, the challenges that the South African industry experiences which may be hampering downstream beneficiation progress. A review of existing primary and secondary beneficiation efforts can help to create the appreciation of the challenges and opportunities that could be encountered by any beneficiation activities in the future.

2.1. **Theory used -** Systems thinking and system dynamics modelling

> *Science is the study of those things that can be reduced to the study of other things. In the end it is the article of faith, one that drives scientists to carry out certain investigations in the faith that they will thereby better understand. Weinberg (1975; 20)*

Science, as pointed out by the work of Weinberg (1975), focuses on understanding things based on reducing them to smaller components that are easy to define and explain. Weinberg (1975) relies on the notion that basic science suggests that the structure becomes simpler when taken apart and there is an inherent assumption that structure is associated with physicality. In his later work, Weinberg (1988:133) defines structure as that which stands - that which remains uninfluenced by change coming from outside of a system. In this later work there seems to exist, a move away from the notion that structure has everything to do with the physicality or the materiality of a system. Here the structure is associated with feedback or response. This is what gives the system its unique purpose to exist, in that its behaviour is not necessarily proportional to the input.

Systems thinking has brought in a complementary approach to the scientific and analytic way that focused on studying the parts to understand the whole. Jackson (2001:234) found that systems thinking brought in concepts such as relationship, control, feedback, boundary, identity and hierarchy amongst some of the elements that were missing in the analytic, reductionist approach. In a more recent work, Cabrera *et al*, (2007:301) correctly highlight that systems thinking may act as a bridge that provides feedback between “what we know” about systems (e.g. systems science) and the conceptual patterns of “how we think” systemically (e.g. systems thinking).

Working within a defined boundary helps in maintaining control on feedback, making it possible to solve complex problems in all forms of sciences. It is for this reason and owing to the multi-dimensional and complex nature of the mineral beneficiation challenge in South Africa, that this study focuses on using the systems thinking approach to address the sustainable development problem. In the end it is important to take a multiple perspective (Cabrera *et al*, 2007:301) towards such a complex socio-economic problem in order to encapsulate a broad range of stakeholder perspectives

Systems thinking is a relatively new discipline and is generally associated with the field of systems. However, according to Capra (1997) quoted by Mingers *et al* (2010:1147), the fundamentals of systems thinking were developed from psychology, ecology and cybernetics disciplines in the early part of the 20th century. Minger *et al* (2010) further argue that the fundamental ideas of systems thinking focus on people acting on systems will do so in accordance with differing purposes and rationalities, and also that they recognise that there should be mutual causality both within and between the various levels of the system hierarchy.

The emphasis on systems is more on the relationship and interactions between elements than the system elements themselves. The ability to formulate and implement successful policies around sustainable development in the mining industry requires a good understanding of the structure and behaviour of the industry as a system. Mingers (2007:1153) found that a causal glance at strategy would seem to give the impression that systems thinking and strategic thinking were almost synonymous.

Whilst contrasting systems thinking with critical thinking in their article on systems thinking, Cabrera *et al,*(2007:300) point to an observation that in all the searched literature where either critical thinking or systems thinking was mentioned, both concepts were mentioned in literatures on social sciences, arts and humanities. However, systems thinking also strongly appeared (48%) in literature from a diverse spectrum of disciplines including business, finance, economics, engineering, astronomy, physics, planetary science and mathematics.

Corporate Socially Responsibility (CSR) has become a means for corporations to interact meaningfully with communities in their areas of operations. The level of stakeholder complexity in CSR is similar to the complexity of stakeholder profile of a sustainable development system in the Manganese industry. CSR is defined by Scholtens *et al* (2006) as actions on the part of a firm that advance the promotion of some social good beyond the immediate interests of the firm/shareholders. This is consistent with the view of this research into sustainable development, in that it is more focused on the future and views the current business as the means to create a lasting source of livelihood for the affected communities.

While the long-term requirement of sustainable development is about creating alternative businesses that sustain them beyond the mine operation, CSR objective also seeks to create infrastructure and other platforms required to uplift the living standards of communities in a way that changes the livelihood of the communities for a long time at least. A recent special issue on systems thinking and CSR highlighted that CSR is predicated upon understanding multiple perspective and relationships and that the field would benefit from the use of systems thinking and systems methods (Cordoba *et al*, 2008). The example of CSR and systems thinking is interesting in that CSR for organisations is often based on activities not related to the core business of the organisations concerned, and often requires lateral thinking and involves multiple stakeholders.

What has been consistent in the application of the systems thinking practice are the vigorous problem-solving efforts informed by a systems thinking perspective that promises to uncover the challenges in question. The most common of the systems thinking approaches is the Soft Systems Methodology (SSM). The SSM was developed as a substitute for traditional Systems Engineering (SE) methodology (Mingers *et al*, 2007:1151), especially in management and business problems where the purpose is not clearly identified.

Mingers *et al* (2007:1151) argue that traditional SE developed systems by first looking at the objectives or purpose and working through a backward re-integration to achieve the purpose, whereas SSM was developed as a means of understanding the diversity of views and interests among proponents by defining a system as an interrogative device.

This will create space for other human and social elements to be looked at as critical elements of a system, such as a mine value chain, something that had been missing in traditional SE approaches. Using the work of Midgley cited by Cabrera *et al* (2007), the boundaries of the systems universe can be better described by using fundamental conceptual patterns instead of a pluralistic taxonomy.

2.1.1. A system defined

> *A system is a set of any two interrelated elements of any kind for example concepts (as in a number of ideas/systems), objects (as in a mine) or people (as in a social system) (Ackof, 1974:13)*.

The word system was introduced to the literature space through systems engineering (SE) studies. Dating back to military problem solving and mission analysis, the systems approach to solving problems has become a real alternative to the analytic approach of reductionism. Cabrera *et al*, (2007:303) argue that the system of any individual concept, or that concept's "ecology" is made up of content and context, where content is defined as a set of symbolic or informational variables in a conceptual space. Context, on the other hand, is defined as a set of processing rules for content. Mingers (2014:8) argues however that systems complex theory has shown that systems can be unstable and exhibit behaviour that are far from equilibrium often sensitive to initial conditions

Blanchard (2004:16) defines SE as a multidisciplinary, collaborative, top-down approach to derive, evolve and verify life cycle balanced solutions that satisfy customer expectations and meet public acceptability. In analysing the systems engineering approach and what it means, Blanchard (2004:16&17), highlights a few important characteristics, amongst which is that the approach is interactive in all dimensions, horizontal and vertical. The emphasis here is on the elements of the system influencing each other all the time. Factors influencing an economic system or even a sub-system such as a mine have their elements constantly influencing one another in a dynamic nature.

In his work on using the SE approach to solving problems, Hall (1969) describes a three dimensional methodology for system engineering, called the morphology box. The dimensions of the morphology box describe the life cycle phase, the problem solving procedure, and the profession which defines the rules to be adhered to as well as the structure and form of the system being studied. This methodology highlights the kinds of dimensions that complex dynamic problems present, and confirms the shortcomings that a single dimension reductionist approach may have in dealing with complex problems, such as economic development problems in Manganese mining value chain. The emphasis of the morphology box methodology, described in Figure 3 is in identifying the profession within which the problem lies, use a life cycle approach to define the problem and find a solution through the application of pre-defined procedures.

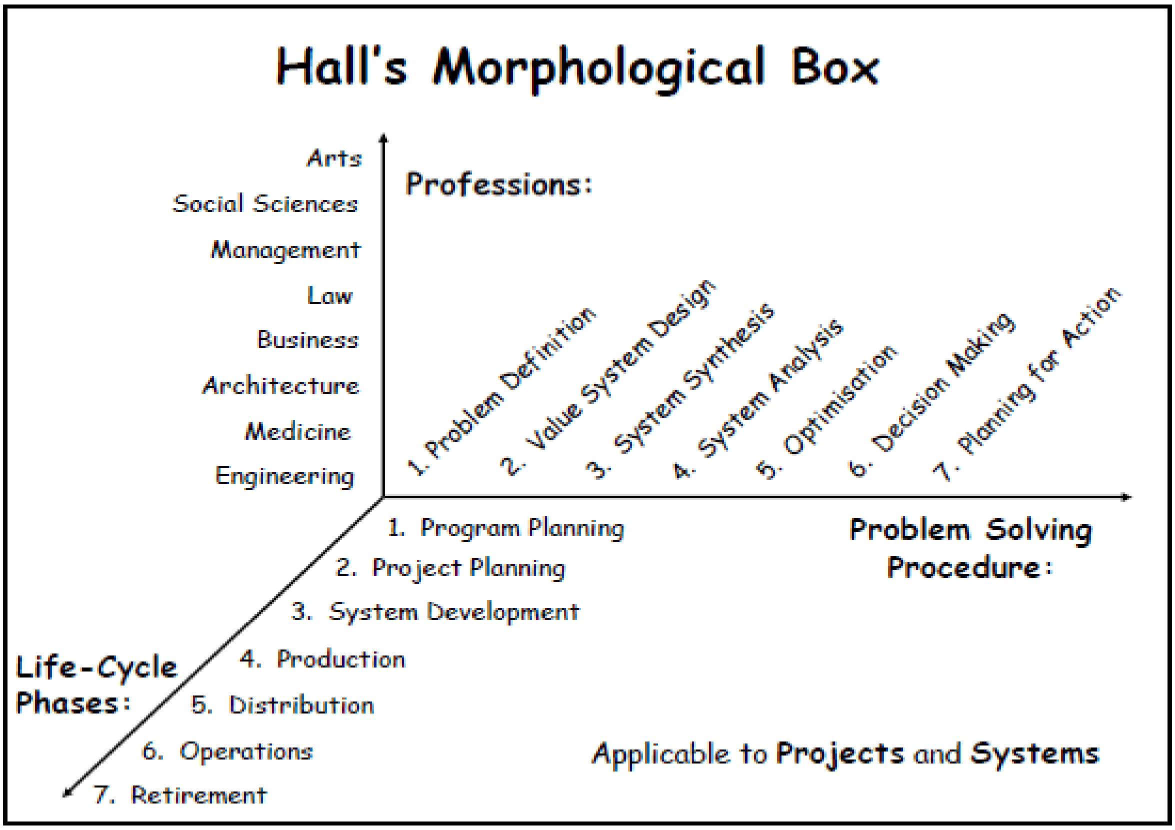


Figure 3: Hall's Morphological box (Hall, 1969)

Whilst the Morphology box describes a problem-solving methodology using three dimensional approaches to address the structure and form of the system characteristics, the methodology falls short of acknowledging the dynamic nature of the system. The methodology falls short on the professions dimension as it assumes location of a problem on a specific profession at a time. An economic development system has similar characteristics and form to a military-operation system. What makes the two similar is the fact that they each have a purpose that they serve and they are related to the environment in which they operate.

What is different between the two systems is the emphasis that is placed on the interrelationships between the components that make up the systems. Whereas a predictable relationship may seem to exist amongst elements of a military operation system, the opposite can be true for an economic system. The goal for a military operation is clear and very visible to everyone involved, whereas there seems to be generally no clear appreciation for the common goal in an economic development system. The individual components of an economic development system act to satisfy their own purposes. This element of difference in the two systems makes the Hall morphology box more suited to the military operation and seemingly inadequate for the economic system.

Often the regulatory framework is responsible for ensuring that the interactions between the business components adhere to specific guidelines which enable the system to operate as a whole. A system can be broken down into components, but the performance and outcome of the system is bigger than the sum of the components. A system is generally contained within a hierarchy and has interfaces with other systems in the bigger scheme of things. Kramer and de Smit (1977:13) defined a system as a set of interrelated entities of which no subset is unrelated to any other subset. From this point it is necessary also to understand the purpose of existence of a mine as a system beyond the narrow objective of making profit for shareholders. It is important to understand the purpose of a mine as a system in the broader sense of the economic system of the society, community, region or country within which the mine operates.

Weinberg defines a system as a way of looking at the world (Weinberg, 1975:51). He argues that it is the purpose of the system that gives it its right of existence. This definition gives meaning to the definition of a mine as a system beyond its primary objective of making money for the shareholders, to a vehicle of economic growth and sustainable development. The research expands the meaning to include required feedback indicators and the structure of the system which might need to change in a transition from upstream mineral extraction to a sustainable system, through downstream beneficiation and beyond. The approach is essential in properly defining the parameters of the system as well as the key attributes.

Putting it back to an economic development system within the Manganese mining industry, it would be important for the individuals studying the system to understand the individual elements and their interrelatedness. What is perhaps missing in Weinberg's definition of a system is that a system can have systems within it and can also be a part of a bigger system, depending on who is looking at it and the purpose for which they are looking at it. Often the key feature to consider before doing much analysis on a system, to prevent any confusion, is the boundary of the system.

Within the systems engineering and systems thinking communities, other definitions of systems have emerged. The International Council on Systems Engineering (INCOSE) defined a system as a construct of, or a collection of, different elements that together produce results not obtainable by the elements alone (INCOSE, ca 2010). Within the system dynamics discipline, an emphasis is also placed on a system definition being linked to reality and purposefulness. Barlas (2007:5) defines a system as a collection of interrelated elements forming a meaningful whole. Without the logistics and transport system, mining production would not be transported to the receiving market to earn the shareholders the returns in revenue. In the same breath, it can be argued that, without a skilled labour force, production of Manganese minerals would not be possible.

Skills development requires an education system and vocational training systems. Developing skills within a community of people is a process that takes time and should be a conscious effort. There are other dependencies in the economic development systems that also form part of the system. Applying the systems thinking approach to solve complex socio-economic problems in the same way that engineering problems can be solved, requires a common understanding of a system and its boundaries by those involved in the process.

2.1.2. Systems thinking theory defined

> *Systems thinking is a discipline of seeing wholes. It is the framework of seeing interrelationships rather than things; for seeing patterns of change rather than snapshots (P Senge, 1990)*

The systems thinking concepts find varying interpretations from different industry and academic sectors. Systems thinking can be understood as being a process of understanding how individual parts of a system interrelate with each other as part of the whole. According to Mingers *et al* (2007:1153), nowadays systems thinking in strategy has incorporated ideas from a complexity theory, particularly seeing strategy as "order out of chaos", and regards strategic decision making as complex, involving different issues and many interfacing factors and stakeholders. Checkland (1988) also points out that in the development of systems thinking attributing meaning to what is perceive have become prime element. The emergence of systems thinking prompted scientists across a wide variety of fields, from Biology to Political Science, to investigate new ways to model and investigate their disciplines (Holmberg, 2010).

Peter Senge (1990) describes two types of complexities as detail and dynamic complexities. He further highlights the challenge that we as humans have with dynamic complexity. It is important to understand the crucial elements of a system (reinforcing feedback, balancing feedback and delay) prior to undertaking the modelling exercise on a system. Peter Senge (1990) refers to circles of causality between the three crucial elements described earlier.

It is by understanding that the same actions that may likely show positive spin-offs for a specific stakeholder group, may come back to haunt the same group in the medium-to-long term, if the relationship between the action and the reality of the interconnectedness of a system is not understood. An important aspect for the team working on any policy changes is also to acknowledge at this stage that they are entering a phase of focused generative learning. Nothing is cast in stone - only the purpose should stay constant.

In support of this view, a systems thinking approach to sustainable development through Manganese mineral beneficiation would require that the Manganese commodity impacts, and be impacted by, the rest of the socio-economic system in South Africa. Aspects of sustainable development need to be defined and understood in the context of the mining operations in the communities that are being studied. Often development is looked upon narrowly as job creation and development of infrastructure to support improved livelihood of communities. The danger of looking at development in narrow objective terms is that its sustainability is dependent on the job-creating industries remaining viable throughout, and many factors remaining constant. The reality is, however, different and more complex.

The systems thinking approach suggests that a fully integrated view of the problem should be taken, and that each component of the system should be understood in the context of the broader system. This is based on the premise that a system is more than the sum of its parts, and it exhibits adaptive, dynamic, goal-seeking, self-preserving and sometimes evolutionary behaviour (Meadows, 2007). This approach is a departure from the traditional analytic approach to solving problems, which is based on breaking down and analysing the individual parts. The traditional approach is based on three main aspects which are: reductionism, repeatability and refutation of the assessment. In his thesis report, Goede (2004:1) correctly points out that, unlike the traditional analysis approach, systems thinking implies a holistic approach to problem.

In order to understand the systems thinking approach to sustainable development in Manganese, it is necessary to create a common understanding of a system with all its variables, asking the necessary questions in order to understand the parts of the system and come up with creative solutions. Understanding the flow of information between the system and the type of information is essential. The Manganese resource and the other resources needed to extract it, such as coal and water, have natural limits.

In describing the concepts of limits on these resources, Meadows *et al* (2004:51), refer to sources and sinks. They argue that, in order to be sustainable, non-renewable resources, such as mineral and oil, should not be extracted at higher rates than they are discovered. Based on this way of thinking, it should be understood that, for an economic system dependent on revenue streams from mineral resources, sustainable growth may only be achieved when the ability of the mineral resources to self-replenish (or the possibility of an alternative source of revenue) exists.

Systems thinking is the most direly needed discipline in today's complex, often overwhelming and seemingly out of control, world (Senge, 1990). Systems thinking focuses on how a thing being studied interacts with the other constituents of a system of which it is a part (Aronson, 1996). The Manganese industry is broad and interlinked with other industries, such as the steel, logistics, construction, Iron Ore and Coal industries. Taking a systems thinking approach allows one to look at this industry as part of the broader system of the economy. The supporting industries, such as power and logistics industries, form part of the equation when looking at the mine as a system of economic development. The same will apply to the targeted industry for Manganese products, such as the steel manufacturing industry.

In South Africa, mining in general is a significant part of the Gross Domestic Product (GDP) of the country. However, specific mines are even more integrated into the economic system of the communities where the mines are located. This means that, apart from the support industry and the consuming industry of the mining products, the community around the mine is a significant part of the mine system and as such should be considered when studying the behaviour of the mine as a system.

According to the United Nations information (UNDP, 2009), in 2007 South Africa was ranked number 129 out of 182 countries with a Human Development Index (HDI) of 0.683, leading to the country occupying a lower country position for life expectancy at birth, and stronger positioning on adult literacy rate, combined gross enrolment ratio and GDP per capita. The literacy levels of the community determine its potential to take advantage of investment opportunities in CSR while; on the other hand, having a generally highly skilled community makes it a lot easier to invest in CSR projects. Systems thinking approach requires that these industries, communities and their behaviours be understood in the context of the Manganese mine system.

2.2. Why system dynamics modelling?

> *The behavior that we wish to describe in economic systems seems much better described by non-linear differential equations than by the algebraic equations and matrix operations which are so often used. Delays, momentum, elasticity, reservoirs, and accelerations are the fundamental quantities which differential equations have been developed to describe. They are the quantities which we wish to use for our underlying principles of the economic world. The equations will have non-linear coefficients, complexly inter-related variables, "pipe-line" delays, variables which can be only positive, etc. In practice, they will need to be handled as incremental difference equations so that numerical solutions can be obtained. Jay W Forrester (1956:343)*

In describing the structure of the world system, Forrester (1971:17) emphasises the importance of feedback loops in establishing the structure of a system. He describes feedback loops as the closed path that connects an action to its effect on the surrounding conditions, and these conditions in turn come back as information to influence further actions. In reality these feedbacks do not happen immediately or indeed within a predefined period; hence, it is often difficult to foresee some of the resulting dynamics at a glance. As Sterman (1989:321) points out, feedback refers not only to outcome feedback but also to changes in the environment, the conditions of choice which are caused directly or indirectly by an agent's past action.

The structured approach to developing a model and clear identification of key parameters would stimulate entrepreneurial thinking among community members. The feedback that system dynamic modelling creates will stimulate forward thinking and analysis of the short term goals. Undertaking a modelling process may lead to changes in the mental models of the group of people directly participate in modelling sessions (Etienne *et al*, 2010). Small differential equation-based models can be used to influence deep understanding of the dynamics of a system both in the short and long terms.

Small models are those models that consist of a few significant stocks and at most seven or eight major feedback loops (Ghaffarzadegan, 2010). Stocks in system dynamics are state variables in the models that act as accumulators or buffers. Stocks work with flows which are connected on either side as inflows or outflows to the stock.

Flows are often rates of change and auxiliary variables. Although a number of factors play a part in the performance of a Manganese mining value chain, the dynamic behaviours and performance pattern can be determined by monitoring the impact of a few key variables.

According to Jay Forrester (Forrester, 1958), System dynamics is the study of information-feedback characteristics of industrial activity to show how organisational structures, amplifications (in policies) and time delays (in decisions and actions) interact to influence success of a business enterprise. What is important here, is to understand the relationship between the reinforcing process (or a push), the feedback and the delay, using smaller scale-controlled scenarios.

Further to this, it is necessary to understand the dynamics of the system and varying environmental conditions. This can be achieved by creating dynamic models to mimic the dynamics of the system in real life. Similar to the work of JW Forester on Urban dynamics (Forrester, 1969), subsequent work by John Sterman (1997), Meadows (2007) and Saeed (2010) in system dynamics modelling, has illustrated how a well-intended policy action can have short term gains but have worse reversal of the gains due to feedback.. In his 50 year review of urban dynamics, Alfeld (1995) finds that there is a causal relationship between new building construction and fraction occupied by old buildings. This relationship determines other constraints such as land prices and land accessibility all of which determine the possibilities for investment and growth.

System dynamics modelling, based on differential equations, is used as a tool to simulate real life behaviours of the system based on the structure and parameters conceptualised using the systems thinking approach against the decision made to influence the system. Differential equations have become widely used in engineering to describe systems in which time is the independent variable (Forrester, 2003:336).The focus is on feedback to specific policy decisions over a period of time
Simulation software is used to develop and simulate the behaviours of the economic development system in a sustainable way. These behaviours are determined by the structure of the system and the system boundary within which the effect of and to the system of interest is limited. The principle of system structure tells us two kinds of

variables is found; i.e. levels and rates, the levels being the accumulations within the system, and rates being flows that cause the levels to change (Forrester, 1971:18)

Modelling is defined as a simplified representation of a complex entity or process (Franklin, 2005:5), and this can be a cost effective way of testing the impact of strategic decision changes in a socio-economic system. Borshchev (ca 2010) also highlights that modelling is a way of solving problems that occur in the real world. Due to the multiple input side factors (i.e. power, reductants, water and electricity) and surrounding environmental factors (i.e. infrastructural development, availability of requisite skills and legislative requirements), all acting simultaneously to influence the performance of the value chain, the value chain problem becomes a high order problem, making it complex. Solving a complex problem, such as the one described, requires the power of computer-based modelling to complete it.

Franklin (2005:5) defines simulation as an imitation of some real device or state of affairs that attempts to represent certain features of the behaviour of a physical or abstract system by the behaviour of another system. By creating a mental model of the prospective system, policy makers will find ways to engage each other from similar information bases. These models are spatial rather than visual, meaning that they are structured as diagrams instead of images, and may be static or kinematic, depending on the problem (Holmberg, 2010)

This study is conducted on a basis of systems thinking theory as an approach to defining, describing and setting objectives for complex problem solving and behaviours analysis. The feedback loops, in terms of the cause and effects of policy decisions, differ between simple and complex systems. Because the causes and effects in complex systems may be far removed in time and location, a new policy, which is intended to solve a problem, may cause reactions in other parts of the system that counteract the new policy (Forrester, 2009).

The work of JW Forrester (2009) with Digital Equipment Corporation (DEC) to determine the reasons for the steady growth of technology companies, that is followed by stagnation and sudden demise, has provided more insight into the value of dynamic modelling for socio-economic systems. These lessons are generally learnt over time where implementers of these policy actions may not even be available to either account for or correct.

In South Africa, a BEE policy to try and bring a previously-disadvantaged group of people into the mainstream economy, created a new middle class in the first few years of implementation. However, the broader society and Government learnt a few years later that the implementation of the policy may have contributed towards the widening of the economic gap between the rich and the poor. If this policy implementation was simulated and feedback observed, a different approach may have been taken which could have preserved the success of the policy.

Other dynamic systems modelling and simulations in the mining industry

A research project was conducted on an underground operation to analyse the impact of financial and operating policies on the behaviour of a mining firm when faced with the perturbing effects of strong and frequent shocks from its economic environment (Montaldo, 1977). This was a system dynamics simulation that focused on the relations between market influence on demand for Ore and the strategic decisions taken by the firm on production and investment policies at different times. Figure 4 describes a model for the dynamic behaviour of this mine under different policy and market conditions.

The model of Montaldo tests three production management policy interventions and their impact on productivity of the mine against the available capacity. The policy interventions in his model are limited to pricing, capacity creation (expansion) and capital gearing. The model was ultimately used to determine the effectiveness of each production management policy under different price and copper demand environments. The value, according to Montaldo (1977:81), was that the model could be a very valuable aid to decision makers because it is capable of producing synthetic experience about the consequence that the decision rules (policy) used, or planned to be used, will have on enterprise performance under a set of hypotheses about future economic climates.

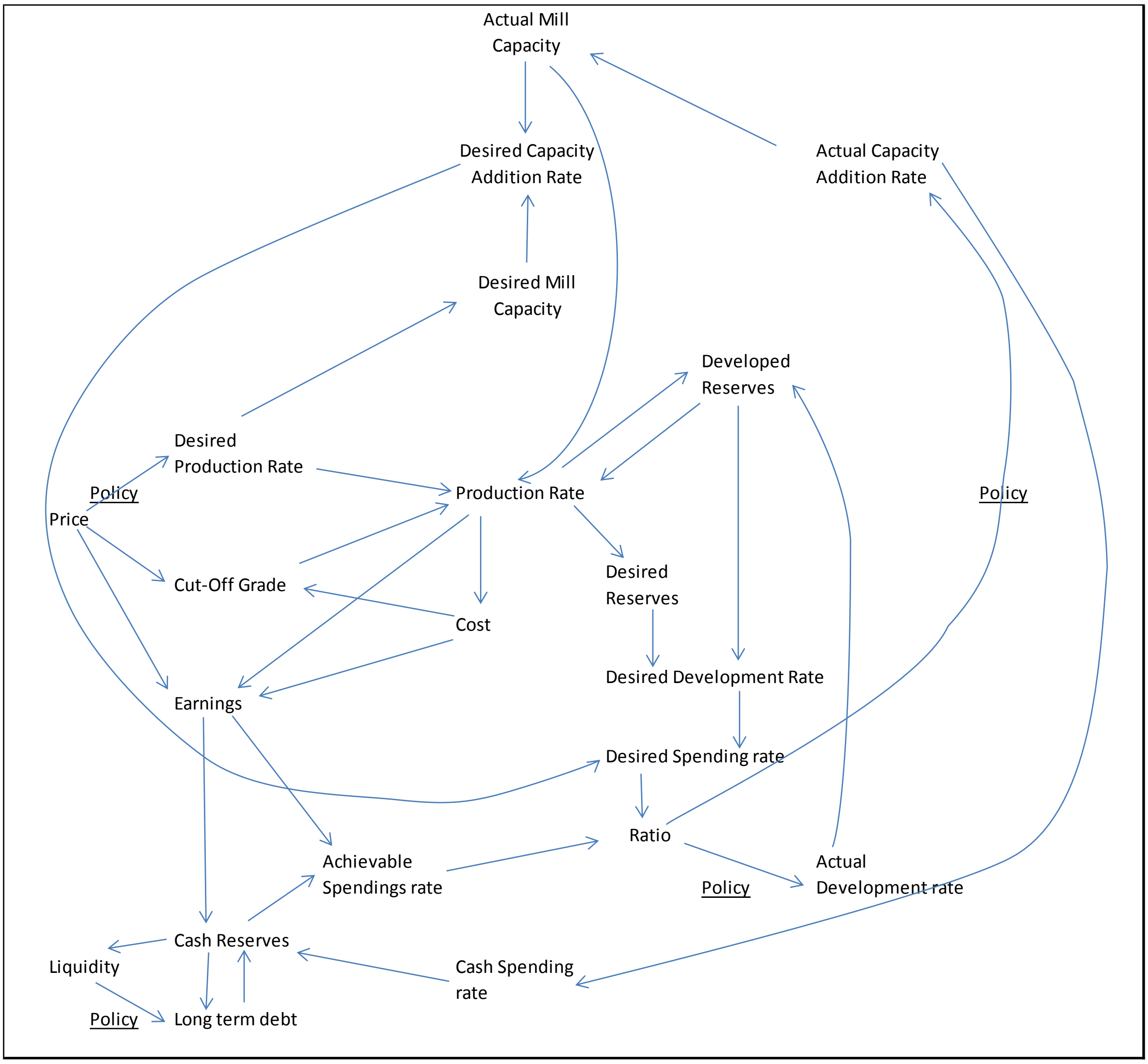


Figure 4: A system dynamics model of an underground mine (Montaldo, 1977:75)

Montaldo (1977:75) system dynamics model for the underground operations is an example of some of the simulation work that has been done in a mining environment. The system dynamics model simulates the dynamic behaviour of a mine operation by looking at performance of key variables against targets. The modelling process is useful when an analysis of the production bottleneck is performed. However, the system boundary for Montaldo (1977:75) 's model was limited to the variables within the direct control of the mine operation.

The model assumes that the market will take what is produced and not factor the fluctuations of the input costs such as electricity, water and logistics cost. The risk for the mining operators in Manganese and other minerals comes from the uncertainties around input cost, and uncertainty about the demand side. Although the concept of dynamic model simulation used by Montaldo (1977:75) is useful for the purpose of understanding the dynamic behaviour of a mine, more scope is required to simulate the dynamics of a mine value chain.

Within the Manganese mining industry, dynamic modelling and simulation have been used to predict the performances of plant equipment on different Manganese Ore types during new project evaluation. This kind of simulation employed modelling tools different from system dynamics, as they focused on equipment selection and utilisation to influence the performance of a plant and, as such, employed **Discrete Event** type modelling.

An example of this was in an operational environment at the Anta Mina mine, where Goldsim (2009) was implemented. In this case, the purpose of the mine operation simulation model was to provide the on-site personnel with a predictive tool to assess quickly the potential impacts of operational changes such as Ore type and quantities, with respect to the environmental compliance (Goldsim, 2009:9). This simulation tool was also developed to address current and future water management issues at a mine in Tasmania, Australia.

In other situations where modelling was used for purposes other than project evaluations, it was done to address specific uncertainties pertaining to risk and compliance requirements. A number of technology suppliers take proactive steps to develop software models for use by mining operators. Siemens AVI (Metal and Mining, 2009) developed models for the steel industry that predict performance of Iron Ore Sinter plants during varying economic cycles. These are similar processes to Manganese Sintering, and the technologies are similar as well. In this study, a system view of the Manganese industry is going to be necessary in order to create a more complete picture of the key elements that influence the dynamic behaviour of the Manganese mining value chain.

2.3. Models used in other complex socio-economic development initiatives

A number of simulation models using software ranging from object-oriented programming to hard-coded software have been investigated as part of this literature search. Amongst those models investigated is the OMPHALOS model depicted in Figure 5,

The OMPHALOS model

The Object-oriented Model for Predicting Human Activities of Learning Organisation Systems (OMPHALOS) was developed in the 1990's at Cardiff University for modelling complex, technical social and economic systems, and was based on system dynamics theory (Cassora, 2005:1). The model incorporates the principles of systems thinking and finds basis in the works of J Forrester (1969) from MIT.

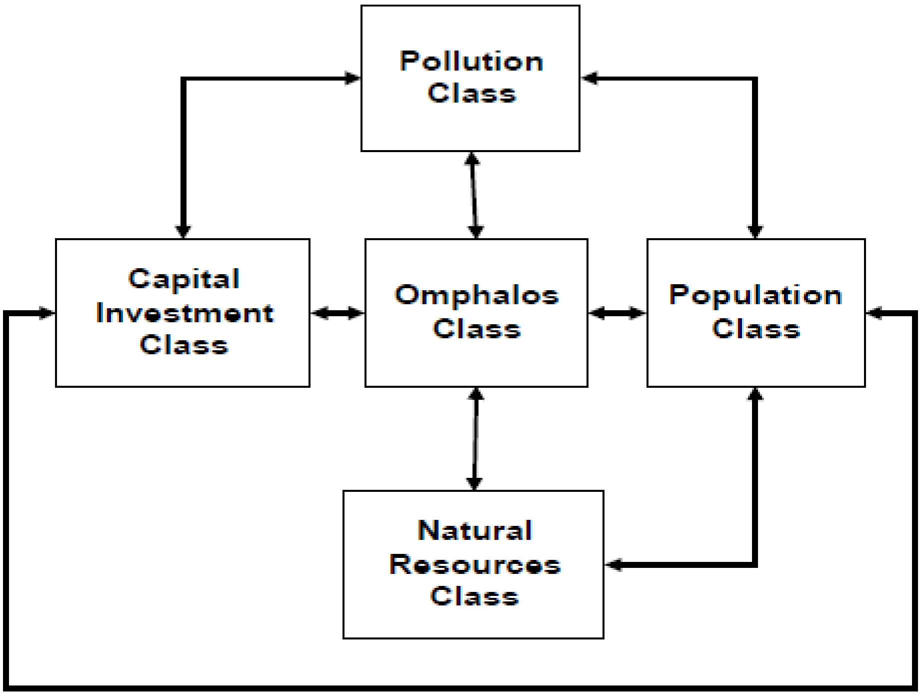


Figure 5: OMPHALOS model for complex technical problems, (Cassora, 2005)

The model in Figure 5 describes the interrelations between the pollution, natural resources, capital investment and food production classes as integral components of the OMPHALOS class. Cassora (2005:3) emphasises the influences that each one of these world elements, identified in the model as classes, has on the resulting character of the dynamic behaviour of economic development systems. The OMPHALOS model described in the diagram can be contrasted with the Manganese industry value chain and its surrounding environment. Mining draws raw inputs from the environment, and pollutes with waste and emissions back to the environment. As a result, to be fully understood, the interaction between the industry, the environment and the community should be included in a model for the dynamic behaviour of the environment.

Urban dynamics models and lessons learned

In his review of urban dynamics lessons from Forrester and Collins' work, Saeed (2010:14) reflects on the dynamics around infrastructure and population development in a maturing urban environment. Figures 6, 7 and 8 depict the logic of the urban dynamics model that represents the remodelled work of J Forrester by Saeed (2010)

The logic in Figure 6 describes the human population dynamics and how this affects the available workforce to drive any economic development initiative. The workforce is divided into three categories: managerial/professional, worker and under-employed.

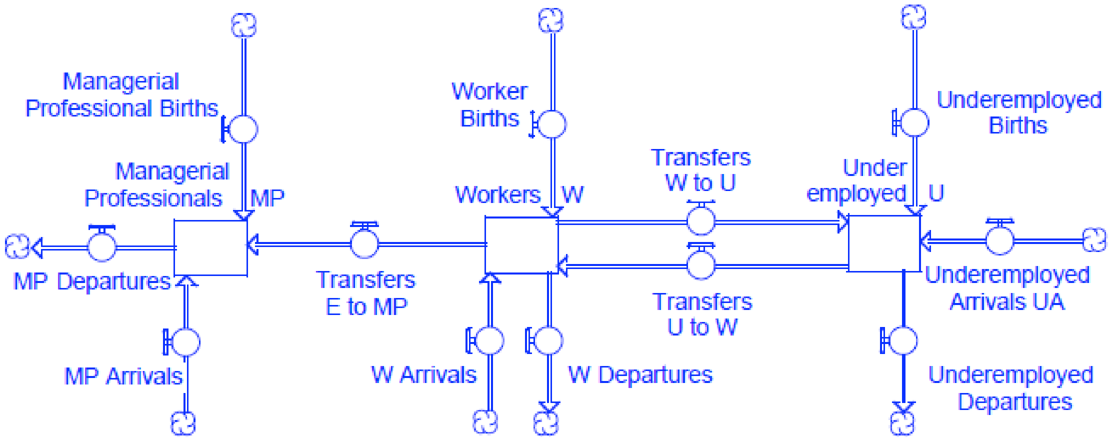


Figure 6: Workforce Mobility in Urban dynamics (Saeed, 2010:15)

This distinction between categories assists the policy maker in understanding the potential movement of the workforce. What is important, in Saeed's model, is to understand the key drivers for movement between the three categories.

Figure 7 depicts the dynamics in housing infrastructure from development to decline. Housing infrastructure is also divided into three categories, being: the premium housing, worker housing and under-employed housing.

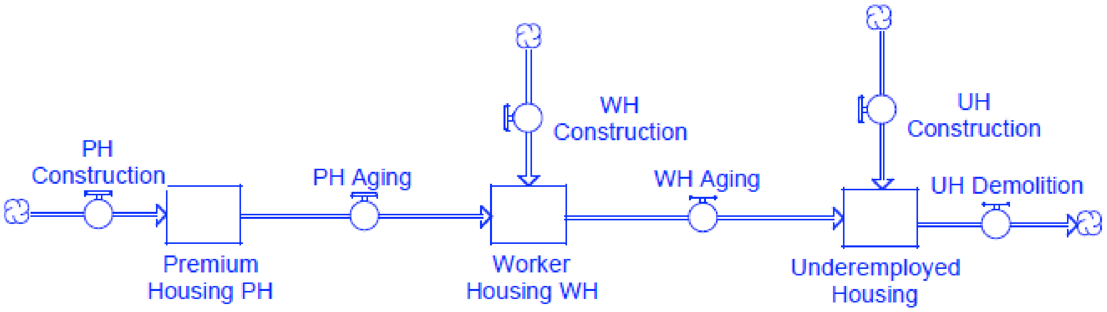


Figure 7: Housing Infrastructure aging chain in Urban Dynamics (Saeed, 2010:15)

This can be accurately linked to the category of the workforce. While the aging process drives transformation of one type of housing into the other, their autonomous construction rates are driven by their respective demands, the expectations of builders to profit from their construction, and public policy. Saeed (2010:14), as depicted in the system dynamics model in Figure 8, New Enterprises (NE) provides more opportunity for employment of professional workers than the Mature Businesses (MB) and Declining Industry (DI).

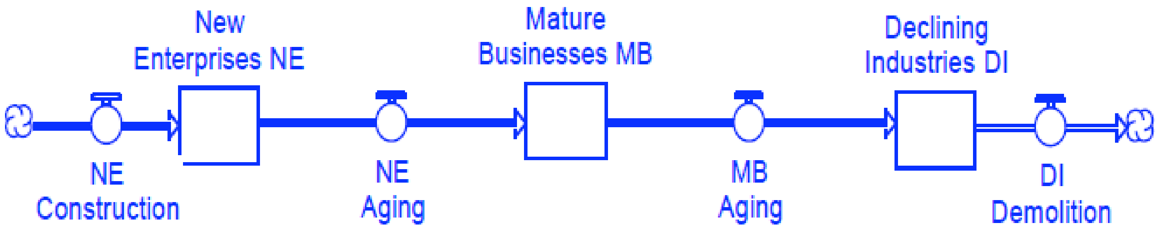


Figure 8: Business infrastructure aging chain in Urban Dynamics (Saeed, 2010:14)

Saeed (2010:15) also indicated in the logic in Figure 8 that, similar to housing and workforce dynamics, the model for business infrastructure can be split into three categories. The three categories also describe the life cycle of a business from a new enterprise, through mature business, and finally a declining industry. New enterprise creation is facilitated by low wage rate, presence of professionals, labour availability, land availability and a bandwagon effect of sorts driven by the growth impetus factor (Saeed, 2010:14)

The three model components described by Saeed, indicated the dynamic interdependence between business infrastructure, housing and workforce profile. The urban dynamics work can be referenced when analysing the status of the mining towns in and around the Manganese industry, to establish the dynamics of the economy in these towns.

Lessons from Urban Dynamics

One of the greatest lessons to have come out of the literature reviewed is that urban dynamics is the difference with which social systems react to policy interventions both in the short and long term. The change in a complex system such as urban dynamics commonly causes short term responses that are in the opposite direction to the long term effect, sometimes causing the "worse-before-better sequence (Forrester,1969:112). It was established that the low cost housing policy for under-employed increases the attractiveness of the city in the short term, but leads to infrastructure decay and, by implication, the city's decay.

The opposite is true for the policy to preserve land against low-cost housing development in favour of business development, which may be unfavourable in the short term but creates long term viability of the city, due to availability of thriving industry space impacting on employment and affordability.

World dynamics model

The research study was conducted to create understanding of the options available to mankind as societies enter the transition from growth to world equilibrium (Forrester, 1971). Although it may be surprising and confusing to say a transition from growth to equilibrium (the state of equilibrium), is what the world system needs, because this represents a state where natural resources, technology and human needs are balanced. The state of equilibrium is only achieved when the population growth, pollution and disparities between the rich and the poor are managed to a minimum.

Following the success of the urban dynamics, the world dynamics model was established and, unlike the urban dynamics model, the world dynamics model interrelates five elements of a system structure. These are: population, capital investment, natural resources, fraction of capital devoted to agriculture and pollution (Forrester, 1971:19). The world dynamics model is influenced by the question of sustainability of human kind’s need for a growing capability of the earth’s natural resources to meet the growing demand of the population.

Success in the world dynamics is measured in the raising of the quality of life, which means releasing stress, reducing crowding, and reducing pollution, alleviating hunger and treating health (Forrester, 1971:124). The model uses capital investment as a control variable to achieve minimum pollution, minimum population growth, and minimising the consumption of natural resources ultimately to make the transition from increased growth to a state of equilibrium.

Studying this observation of the South African Manganese mineral industry, one can draw a parallel to the high volume mineral resource exploitation in Manganese and other mineral groups in South Africa, with minimal economic benefit to the country and the mining communities themselves. This is largely due to the non-beneficiation of these minerals in the country, depriving many people of the ability to make a living out of mining activity.

To increase participation in employment in the mining communities, more volumes of minerals extracted from the ground are often encouraged, further depleting this non-renewable resource and increasing pollution at the same time. Just like other social systems, the mining industry in general, and the Manganese mining in particular, represent a complex system. As the discipline of systems thinking shows, there simply is “no right answer” when dealing with this complexity (Senge, 1990:281). It is for this reason that more work is still required in establishing more patterns in the socio-economic systems that influence sustainability of the Manganese mineral industry, particularly and, in general, the mineral resource industry in South Africa.

2.4. Sustainable development in context

> *Can we move nations and people in the direction of sustainability? Such a move would be a modification of society comparable in scale to only two other changes: the Agricultural Revolution of the late Neolithic and the Industrial Revolution of the past two centuries. Those revolutions were gradual, spontaneous, and largely unconscious. This one will have to be a fully-conscious operation, guided by the best foresight that science can provide...If we actually do it, the undertaking will be absolutely unique in humanity's stay on the earth (William D Ruckelshaus, 1989)*

Ruckelshaus (1989) makes an important comparison between two historic revolutions, and rightfully so, because sustainability is a serious challenge for human kind in the circumstances. This is so because today's global challenges of hunger, inequality and ill health are huge and growing every day. Sustainable development can be understood within a conceptual framework that describes the interaction between pairs of a humanity-economy-nature triad, as well as between all three of them (Todorov *et al*, 2009:1219). What is today commonly known as the three pillars of sustainable development, enjoys regular reference in the Mining sector business case documents, albeit with limited evidence of implementation.

Deardorff (2009) also argues that economic development should be about the increase in the living standard of a nation's population, with a sustained growth from a simple, low income economy, to a modern, high income economy. This definition assumes an ever-replenishing source of economic input. However, in reality this is not the case. According to Saeed (2010:21), economic development should be seen in the context of a mature economy that grows beyond stagnation where resource constraints persist.

Pearce (1988: 1), simplifies the definition of sustainability as simply making things last, be permanent and/or durable. What is being sustained, Pearce (1988:1) argues is an object of choice and can range from agriculture, health or economy as is the subject of this research. Sustainable economic development in the resources sector of the economy requires that there is above-inflation growth in revenue generation to ensure that the man-made capital retains same or better buying power, however its utilisation of natural resources should not far exceed its to replenish the resources or find alternative capability. Pearce *et al* (1993:2) assert that economic sustainability happens when the economy in question save more than the combined depreciation of the natural and man-made capital.

Saeed (2010:21) links economic development to a recovery from a low point of a mature economy, which implies that an economic development may only be seen where the constraints of natural resources do not limit economic growth. In terms of this analysis, the mineral sector will look more like a mixed bag, with minerals such as Manganese, Platinum and Coal leading the growth, whilst others such as Diamond and Gold are on a decline. When talking about sustainable development, it is necessary to understand the fused relationship between economic development and sustainable development as it is commonly known today.

According to the British English definition, sustainable development is a development of a country or a region that does not use more natural resources than can be replaced. This is a very general definition of sustainable development, yet it is the most simple to understand. Applying this to mineral-resource business might meet with resistance, as it would imply that mineral extraction should not take place unless those minerals can be replaced either in terms of function or substance.

The most widely-accepted definition is that of the World Commission on Economic Development (WCED) Brundtland commission, which defines sustainable development as the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs (WECD, 1987). This is the definition that is used by this research.

Sustainable development in Europe

In most instances, economic development is seen in the context of trade off against ecological development of a country or a region. This places pressure on policy makers to choose the right policies, especially where big potential for economic growth comes from an abundance of natural resources. Giddings *et al* (2002:187) argues that the separation of sustainable development in to three sectors of economy, and society and environment introduces a tendency of bias towards economy at the expense of the other two sectors. Giddings *et al* (2002:188)'s argument rest in the fact that the thrust for economic growth and sustainability in such industries as mining, comes at the expense of natural resource depletion and compromise to societal benefits.

A research conducted by Golusin *et al* (2010) found that there is certain regularity in the relationship between ecological and economic development of some South Eastern European countries. The countries were studied using linear regression models as a two-dimensional analysis and covered 12 countries. Included in the 12 countries studied were Germany and France, both selected from the big European economies, and Bosnia, Albania and Macedonia, all selected from Europe's smaller economies. Whilst most of the indicators in the result confirmed that higher economic development was matched by negative ecological sub-system performance, Bosnia, Herzegovina, Serbia and Albania deviated from this pattern.

The research concluded that there was no absolute, proportional relationship between economic development of a particular country and the proportional destruction of natural resources (Golusin *et al*, 2010:776). A similar conclusion that economic development can be reached without proportional destruction of the natural resources is arrived at by Sadar (1997:236). Their research recommends the minimal use of coal and the development of a renewable technology solution in the energy sector in Australia. The gap that has been identified in the methods used by the two studies mentioned here is that they used two-dimensional approaches.

In the past three decades since the 1980's, sustainable development has become a reality for most of the global leaders, both in business and in governments. The concept has evolved and gained acceptance, not only as a compliance exercise, but also as a business imperative leading to the establishment of commissions at the United Nations. Since the Brundtland (1987) report, many policy level commitments to sustainable development have been made through various commissions, some of which were contained in the Rio Declarations (UNEP, 1992) summarized through the

24 principles. In the Rio Declarations (UNEP,1992), principles 4 and 16 emphasize the need for states to encourage linking environmental performance and compliance with business performance, as opposed to treating environmental performance separately.

The International Chamber of Commerce also launched a business charter for sustainable development (Gibbs, 1996). According to the Brundtland (1987) report, the development of dispersed and self-contained economies will have major environmental benefits, such as relieving urban areas of population and pollution pressures. The emphasis for the South African scenario is the development of small mining towns into vibrant cities, with longer and sustainable development that span beyond direct mining activities.

The Earth summit in Rio 1992 was followed by the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa (Von Frantzius, 2004:1). The objective of these summits, and the subsequent declarations, was to evaluate progress and assess obstacles to the goals set in Rio 1992 during the earth summit (Lightfoot, 2005:2). The Summit sought to find consensus between developed and developing nations on how to drive economic development in a responsible and equitable manner for both human beings and the environment. For example, the implicit assumption in the contemporary model of economic development has been that the developing economies are just coming up (or nascent economic systems are on their way up) to become mature economies (Saeed, 2010). This allows bigger economies that are classified as developing countries to neglect their environmental responsibilities to the disappointment of some developed economies.

Example of sustainable development initiative in Australia

A number of countries around the world have started research initiatives on sustainable development, especially in the non-renewable resources sectors. Within the energy sector of their economy, the Australians have started modelling their energy resource capacity through the Australian Energy Planning System Optimisation Model (AEPSOM) to inform policy decisions on oil supplies (SADAR *et al*; 1997). At the time of developing the model, Australian oil reserves were forecasted for depletion by 2027, based on projected extraction rates at the time of the study. What was at stake in the modelling exercises was the ability of the country to find substitute energy sources of oil fast enough to ensure energy security for the future generations of Australians. In the Australian modelling exercise, interaction between the government policy decisions and the economic agent decision was found to be missing. Each agency determined the policy decisions that were optimal for their individual needs, resulting in a policy problem working against sustainable development.

Urban migration and skills levels

According to Saeed, (2010), the Harod-Domar model and Solow growth model are the most presented growth frameworks in the economic development texts Professor Saeed (2010) argues that structural transformation, income distribution, demography, education, resource constraints and sustainability are only then discussed as additional topics. The Harod-Domar model demonstrates that a country’s GDP growth is proportional to the Investment saving rate of the country, and inversely proportional to the national capital/output ratio. The main emphasis on the Harod-Domar model is in retaining capital output and reinvesting in the economy to get more productivity through capital efficiency. The model uses the Incremental Capital-Output Ratio (ICOR) to determine the productivity of the country using GDP and Capital Stock as key variables. The Domar model (Sato, 1964) highlights the impact of unproductive population on overall growth of the country’s GDP.

The gap in the quality of life between the South African population living in the rural areas and those in the cities is wide, and it widens with time. This phenomenon drives a significant migration of rural population into the cities for better access to the means of self-development and upliftment. The dream of better access and opportunity is not sustainable in any city because, given free migration, no place can long remain more attractive than any other place (Forrester: 1971). The creation of informal settlements in the big cities, with little or no services and reliable transport to the industrial and /or business centre of the city, can eventually undermine the very sense of the city attraction of rural people.

In South Africa, the RDP housing policy has created in excess of 3 million small houses for the poor; according to Statistics South Africa (SSA, 2010).Many of the RDP houses were built in the townships, adjacent to major cities. With average household members of 5, this housing strategy would create opportunities for 15 million people to have a shelter, most of them in and around cities. This number equals the number of people who depend on social grants for a living. This does not suggest that there is a direct correlation, but there is a pattern of causalities. The influx of people to the cities in South Africa has increased significantly since 1994, mostly due to the availability of accommodation that the RDP policy has created.

Job opportunities have not followed the trend of RDP housing development and rural-to-urban migration. One of the contributing factors to lack of job opportunities for the poor is the concept of mobility-related exclusion described by Donaldson (2003:346). He describes this concept as the process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunity, services and social networks. This is due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility. In many South African cities, services that are required for social upliftment are far removed from the residential areas and, at times, people need to use more than one mode of transport to access them, making it unaffordable for the poor.

A second of many explanations for the lack of job opportunities for the majority of the beneficiaries of the RDP policy, is the general lack of requisite skills. The average skills levels according to statistics South Africa surveys (SSA, 2007), are low. Only about 10% of the population in the major cities, such as Johannesburg and Pretoria in Gauteng, are in possession of a tertiary qualification. The ability of city metros and municipalities has also not kept pace with the growth trends. Services and unemployment-related protests have increased, signalling the level of frustration with the inability of the Government to deal with the two challenges raised above.

The graph in Figure 9 depicts the comparison between six metro and municipal areas in Gauteng, based on education levels from primary education to tertiary education levels, according to the Statistics SA survey cited in the Gauteng Department of Economic Development (2007, cited by GDED, 2010:22). The points of interests here are that the cities of Johannesburg and Ekurhuleni have a higher percentage of their populations with secondary education levels. The interesting observation about this is that the two metros are the most industrialized of the six areas in comparison with the highest contribution to the manufacturing sector of the economy.

The City of Tshwane has the highest percentage of population with tertiary education. However, it lags behind both Johannesburg and Ekurhuleni in the percentage of people with secondary education. It makes sense that the City of Tshwane would attract more tertiary qualified people since it hosts all the national government administrative functions and the economy is dominated by government services.

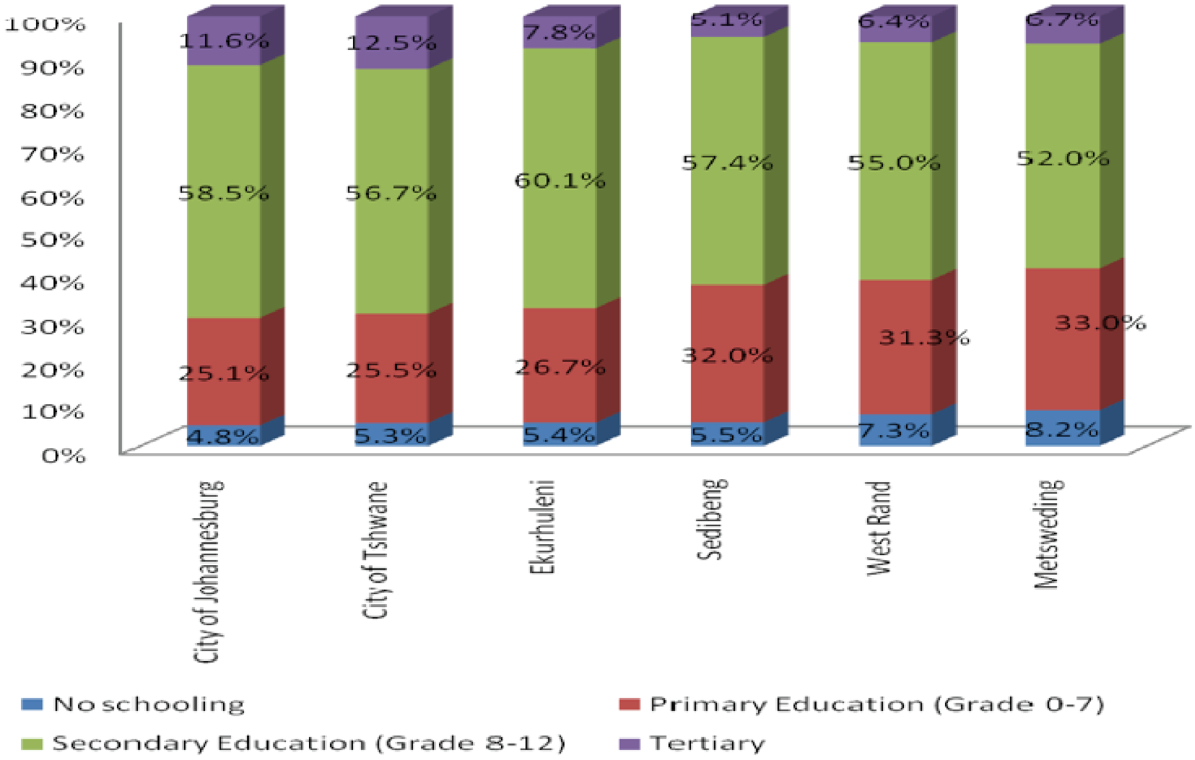


Figure 9: Skills levels in the Johannesburg and Tshwane metro districts (SSA, 2007)

The way to make comparisons in the mining community may be to ensure that the kind of capital stock employed can be utilised fully to generate more revenue. This can then be re-invested in the economy to create jobs that will balance out the growth in unemployment. The 2007 SSA (2008:25) labour force statistics indicated that the

Northern Cape (NC) had the third highest unemployment rate in South Africa at 24. 2%, placing it above the national average unemployment rate at 23.6%.

Table 1: Mid-year population estimates for 2011 (SSA, 2011:3)

	Population estimate	***% of total population***
Eastern Cape	6 829 958	13.50
Free State	2 759 644	5.46
Gauteng	11 328 203	22.39
Kwazulu-Natal	10 819 130	21.39
Limpopo	5 554 657	10.98
Mpumalanga	3 657 181	7.23
Northern Cape	1 096 731	2.17
North West	3 253 390	6.43
Western Cape	5 287 863	10.45
Total	**50 586 757**	**100.00**

Table 1 indicates that the NC has the lowest population of the entire country with a total of just over 2 % of the Country's population (SSA, 2011:3). With the share of mining activities and mineral resources that the province hosts, compared with other provinces, this province should have relatively low unemployment rates. By beneficiating in the regions and provinces where Manganese mining occurs, new skills may be developed which can, in turn, create more productive capacity to allow further investment year on year.

Governance on project financing for mining projects as a means to achieving sustainable development

> *In adopting the Equator Principles the banks stated in a preamble that "....The Equator Principles Financial Institutions (EPFIs) have consequently adopted these principles in order to ensure that the projects we finance are developed in a manner that is socially responsible and reflect sound environmental management practices. By doing so, negative impacts on project-affected ecosystems and communities should be avoided where possible, and if these impacts are unavoidable they should be reduced, mitigated and /or compensated for appropriately........These principles are intended to serve as a common baseline and framework for the implementation by each EPFI of its own internal social and environmental policies and procedures and standards to its project financing activities We will not provide loans to projects where the borrower will not or is unable to comply with our respective social and environmental*

> *policies and procedures that implement the Equator Principles.”* (*Equator-pinciples.com, 2006:1)*

Private and public governance initiatives have improved since the turn of the new century by various governments and funding institutions (including the World Bank) to ensure sustainable development in countries where mining and other major infrastructure investments are undertaken, particularly in the developing world (IFC, 2006). The preamble of the equator principle signified the beginning of a new era in voluntary governance and control in the project financing business by the leading banks, most of which are involved in heavy industry funding in the developing economies.

Dealing with sustainable investment in a developing world, and particularly in mining and other heavy industries, has proven to be a challenge to funding institutions and all stakeholders concerned. It is through Non-Governmental Organisations (NGO’s) such as the Rainforest Action Network, who confronted banking giant City Group in their campaigning against irresponsible funding, that leading project finance institutions started realising the need to select their projects responsibly (Schepers, 2010). This led to the establishment of Equator Principles (EP) under the stewardship of the International Finance Corporation (IFC). The ten leading project financing banks that proposed and adopted the EP in 2003, responded to the pressure from NGOs to take legal and moral responsibility for the environmental and social impacts of the major infrastructure projects they were financing around the world (Macve *et al*, 2010:892).

It is clear that EP has become widely applied in project finance around the globe (Macve *et al*: 2010:899). The EPFI has taken a position to do their part in ensuring that investment in mining supports the sustainable development goals by being socially responsible (Equator-principles.com, 2006:1). Having started with 10 institutions in 2004, by 2010 a total of 40 institutions did this by adopting the Equator principles as benchmark for determining, assessing and managing social and environmental risk in project financing (IFC, 2006). This number continues to grow as the developing countries become more aware of their environmental responsibilities, mostly due to pressures from NGOs lobbying. The equator principles can be summarized as follows (Equator-principles, 2006:3):

- Principle 1: Review and Categorisation
- Principle 2: Social and Environmental Assessment
- Principle 3: Applicable Social and Environmental Standards
- Principle 4: Action Plan and Management System
- Principle 5: Consulting and Disclosure
- Principle 6: Grievance Mechanism
- Principle 7: Independent Review
- Principle 8: Covenants
- Principle 9: Independent Monitoring and Reporting
- Principle 10: EPFI Reporting

Whilst the EP and adopters of these principles were applauded, the EP process was criticised by some NGOs for not being sufficient in terms of filling the accountability gap amongst adopters. O'sullivan *et al* (2008) argue that, while the EP provide a relatively coherent and structured means to address NGO legitimacy concerns regarding the principles, lack of clear governance or accountability commitments therein to ensure their aspirations, would transpire into practice. This concerned many NGOs. Several Banktrack reports have highlighted other gaps in the implementation of the EP principles by the adopters themselves.

The World Bank, through the IFC, is also responsible for setting performance standards for projects funded by the World Bank, mostly in developing countries. The IFC insists on funding only projects that are environmentally and socially compliant, and it sets the following performance standards (IFC, 2006):

- Performance Standard1: Social and environmental assessment and management system
- Performance Standard 2: Labour and working conditions
- Performance Standard 3: Pollution prevention and abatement
- Performance Standard 4: Community health, safety and security
- Performance Standard 5:Land acquisition and involuntary resettlement

- Performance Standard 6: Biodiversity conservation and sustainable natural resource management.
- Performance Standard 7: Indigenous peoples
- Performance Standard 8: Cultural heritage

Governments in developing countries have for decades of mining activities allowed mining operators to relax their efforts in driving towards achieving these standards. However, In South Africa legislation has been promulgated (DME, 2004) to change the approach and toughen requirements in the financial provisioning for closure, to restore the damage caused by lack of compliance to the same performance standards.

In South Africa, the MPRDA (DME, 2004), which was promulgated in 2004, requires that the mining operators convert existing old-order mining rights to new order mining licences. This act, and its requirement, sought to respond to the public outcry on the current exploitation of SA minerals, with minimal benefit by communities under the old regime. Application for conversion requires submission of the current approved Environmental Management Programmes (EMP), Social and Labour Plans (SLP) and the Mine Works Programmes to the Department of Minerals and Energy (DME). The MPRDA also requires that financial provision be made in respect of premature closure, de-commissioning and final closure, as well as post closure management of latent and residual impacts

As part of the MPRDA the DME has developed a guideline for the evaluation of the quantum of closure-related financial provision provided by the mine (DME, 2004). This has been made a requirement for all mining operators in the industry to obtain new mining rights in South Africa. This approach aims at ensuring that the government has surety on the financial provision for mine closure. The steps are listed as follows:

- Step 1 - Determine mineral mine/processed and saleable by-products
- Step 2 - Determine risk class
- Step 3 - Determine area sensitivity
- Step 4 - Determine level of information if class A or B mine, and flat rate/hector if it is a class C mine

- Step 5 - Determine minimum rates per hectare for closure
- Step 6 - Conduct independent reviews by a competent person

The financial provision of the environmental rehabilitation and closure requirements of mining operation form an integral part of the MPRDA (DME, 2004). The following principles are described in the document:

- Legal standing:- use of the guideline to assess the appropriateness of the provisioning submitted to the DME by the mining operator
- Generic nature :– that the guideline does not answer all the questions or situations related to financial provisioning, and that further advice may be required
- Standard approach:- that the guideline provides a standard approach to avoid application of non-aligned empirical approaches and interpretations between DME regional offices
- Complete picture:- that the guidelines cover the most essential components generally required for closure, and that special conditions should be considered
- Third party:- assumption that computing of the quantum is based on using a third party employed by the DME to undertake the remedial work provisioned for
- No Salvage value:- the assumption that the infrastructure of the operation has no salvage value at closure
- Limitations: - there are certain sectors of mining industries that are not catered for by the guideline.

Sustainable development in mining and mineral processing according to the MPRDA

Sustainable development in mining can be described as the development that uses natural resources to meet the needs of society today, without compromising the ability of the future society to do the same. In the context of Manganese mining- driven economic development, Manganese reserves are the natural resources to which the definition refers, and it is important that these resources are exploited in a way that does not compromise the possibility of continued economic activity in the area.

Sustainable development is achieved when the exploitation of mineral resources is used only as a primary source of broader economic development. When Manganese Ore is mined from the crust of the earth, the earth has no way of replenishing the resource; therefore it means that at some point these resources will be depleted. This scenario presents two difficult challenges for the country and the communities. The first is to ensure that the economic development that is driven by Manganese mining operations must be replaced by another industry if the future generation is to be able to sustain itself economically.

The second challenge is for the consumer industry, in this case the steel manufacturing industry, to find another ingredient for the manufacture of steel that will replace Manganese. None of these are obvious challenges to overcome, based on current knowledge in the industry. The world is largely influenced by sustainability imperatives. The mining industry is not immune to these imperatives, and is probably more deeply affected than other sectors of the economy. Mining, processing, beneficiation, use, disposal and recycling of minerals have in some instances led to significant local and larger-scale environmental and social impacts.

In the MPRDA Act 28 of 2004, the authors of the Act at the DME (2004) believed that by 2010, the SA minerals sector would be contributing optimally to sustainable development. This contribution is further articulated into a number of key strategic objectives, goals and projects leading to desired outcomes. “Optimally” is defined as the most effective, efficient and favourable contribution by the minerals and mining sector to sustainable development, taking into account the social, economic, biophysical and governance opportunities and constraints facing the South African minerals and petroleum sector, as determined and endorsed, either through stakeholder consensus or the majority stakeholder view".

One of the key and very significant strategic objectives is to ensure that value extraction from the South African minerals sector benefits vulnerable groups and that value addition from South African mineral resources are maximized locally. Figure 10 indicates clearly that as much as some metal reserves are smaller by global percentages, there are still substantial reserves to allow more proactive downstream and side stream beneficiation to be incorporated in the business modelling of the industry. The high percentages of minerals such as Manganese, Chromium and Platinum Group Metals, are an opportunity for long term beneficiation.

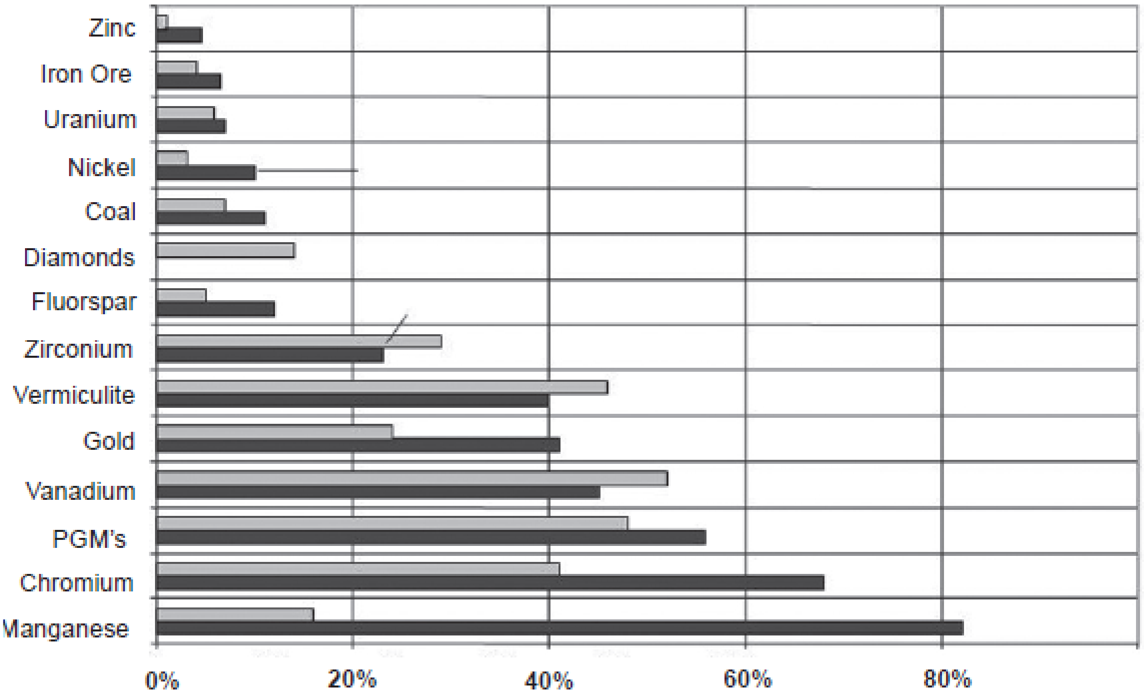


Figure 10: South African Reserves and Productivity in 1998 as percentage of the world (DME, 2007:15)

When a mine operation is viewed in the context of a wider area's economic development asset, the land capability where mining occurs is considered during operation, which leads to efforts to rehabilitate continuously and/or develop land for alternative use capability. Guidelines currently provided by the DMR in South Africa (DME, 2004) describe the provisioning of the financial quantum for closure.

The objective is to minimise the long-term impact on the environment, economy and social system. Since 1998, the World Bank has included in its initiative ”Pollution Prevention and Abatement Handbook” provisions to ensure a project financed by the Bank, or the related International Finance Corporation (IFC) anywhere in the world, includes appropriate standards of mine closure reclamation, including the nature and amount of financial assurance required (IFC,2006).The guidelines do not cover in great length, the framework or strategies to engage communities positively, and other stakeholders in developing options for post-mine closure sustainability of the economies, social systems and land use.

The desired outcome would be for the mining houses in Southern Africa to identify post-closure long-term benefits, and even fund some of the closure programmes from revenue generated from the early CSI initiatives, that are initiated while the mines are in operation. Post-mining land uses are far more likely to be supported by local communities in the long term, if they have been an integral component of the decision-making process (ICMM, ca 2006). Turning the sustainable development rhetoric into tangible, sustainable outcomes for mines remains an issue of contention (Worrall, 2008)

Among the key goals of the SDM Programme, is enabling South Africans to have a beneficiation strategy which promotes growth and competitiveness and works towards closing the gap between the first and second economies (DME, 2004). In the framework on sustainable development through mining, the DME argued that, although mining continues to be the principle earner of foreign exchange in South Africa, the values of export related to mineral products underscore the contribution of mining export earnings, as it did not fully take into account the role of beneficiation and value addition.

The document argues that the mining sector suffered in recent times from what it terms “Dutch disease”. It describes Dutch disease as the de-industrialisation of an economy that occurs when the discovery of natural resource raises the value of the currency, making manufacturing of goods less competitive with other nations, thus increasing imports and decreasing exports. This phenomenon is real in South Africa today, as various players in the economy have differing views on the strength of the Rand. In recent public discussions, the labour federations have made calls on the Reserve Bank to weaken the currency in favour of low manufacturing cost and competitive export earnings from the manufacturing and agricultural sectors.

Table 2 summarizes the export earnings by sector adapted from the Government Framework on sustainable development through mining, looking at the trends from 1970.

Table 2: SA Exports earnings by sector (SSA, 2007)

Sector	**Average for decade**		
	1970s	**1980s**	**1990s**
Agriculture and Forestry	6.9%	3.5%	4.2%
Mining	54.0%	61.3%	40.9%
Manufacturing	24.6%	23.6%	40.3%
Electricity, gas and water	0.1%	0.1%	0.1%
Construction	0.0%	0.0%	0.0%
Services	14.4%	11.5%	14.3%

South African cities' economic development dynamics and the RDP policy

In South Africa, the Reconstruction and Development Program (RDP) was aimed at achieving the same objective as the Boston policies (Forrester,1969), when the government of the Republic of South Africa decided to build more than 2 million low-cost housing units in and around big cities, at no cost to the beneficiaries, by 2010. After 10 years of this policy implementation, and more than 2 million housing units later, the government faced more community protest, from the same housing settlement, for jobs and service delivery. The number of tin shacks grew rapidly around the cities due to the fact that people believed that by having shacks around the cities, they would qualify for consideration for a free RDP housing unit.

Being closer to industrial areas was seen as a good opportunity for employment by most South Africans; however the majority of these people lack the requisite skills for employment in a technology-driven industrial sector. The example cited in Figure 9 earlier, about the education levels in the Gauteng region, makes it impossible for these people to find jobs and therefore cannot afford basic services. The capacity of the municipalities to service the influx of new households has not matched the demand due to RDP housing policy.

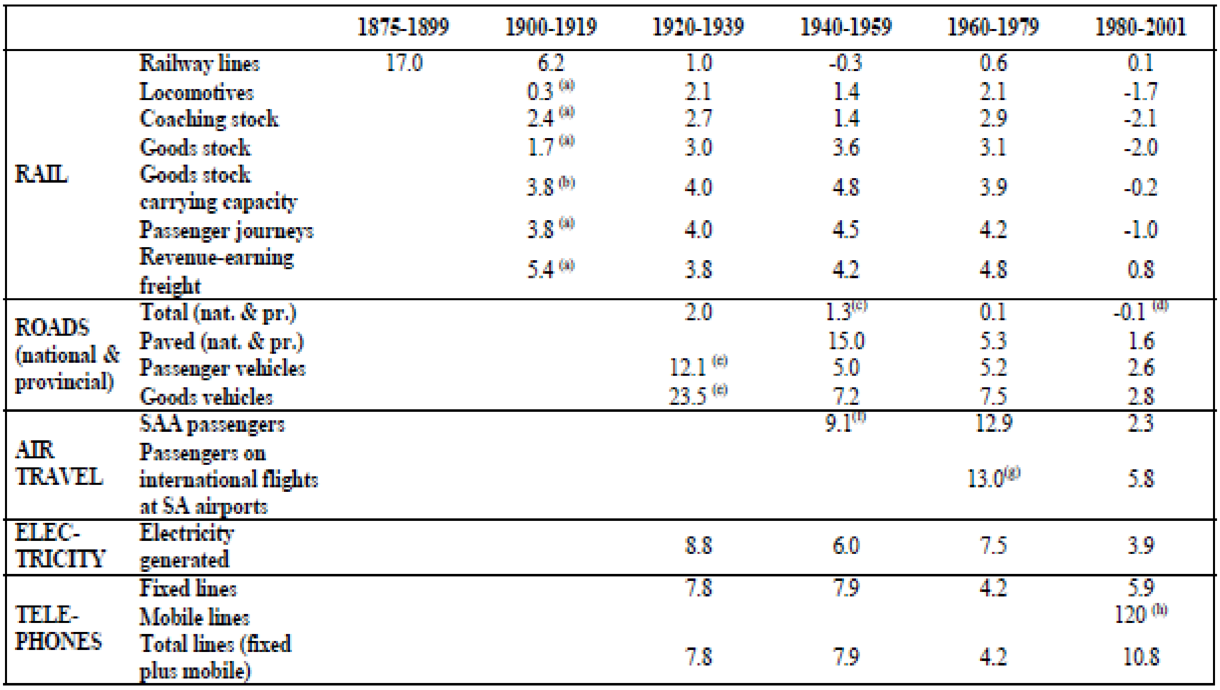
<u>The development of a mining driven economy – A case study on the development of Johannesburg.</u>

In 1886, during the gold rush, a lot of activity in the Witwatersrand led to the development of new social and economic infrastructure. The difference in the two infrastructures is that social infrastructure is described as infrastructure that promotes health, education and standards of the population (Fourie, 2006: 531). On the other hand economic infrastructure is concerned with the promotion of economic activity (Fourie, 2006: 531). Initially all these were dependent on mine revenue. These infrastructures included power, rail and road access from other parts of the country, and water supply infrastructure from the Vaal River. Whilst all these were developed primarily to support mining development, other sectors of business, such as manufacturing and retail, started benefiting from the establishment.

This made Johannesburg more attractive to new business investment from both local and foreign investor communities. A hundred years of analysis of economic infrastructure development patterns in South Africa highlight the correlations between mining development, infrastructure development and the progressive growth of secondary industries (Perkins *et al,* 2005). In studying the impact of public capital on private sector performance, Munnell (1992: 193) finds that in almost all cases the impact of public capital on private sector output and productivity has been positive and is statistically significant.

Table 3 highlights the development patterns in rail, road and air transport growth from 1875 to 2001, as well as the development of electricity and telecommunication support infrastructure (Perkins *et al*, 2005). With these numbers, Perkins *et al* (2005), point out the steady decline in transport infrastructure development as a percentage of GDP growth since the mid 1900's whilst the demand for the transportation of goods continued to grow. The decline in railway infrastructure development was followed by a decline in the use of rail for goods transportation from the 1980s and substitution by road transportation. Passenger use followed the same trend. The period from 1886 to 1960 could be defined as the period during which much of the growth of Johannesburg, and the surrounding cities of Pretoria and Vereeniging took place.

Table 3: Average annual growth in infrastructure goods and services



		1875-1899	1900-1919	1920-1939	1940-1959	1960-1979	1980-2001
RAIL	Railway lines	17.0	6.2	1.0	-0.3	0.6	0.1
	Locomotives		0.3 (a)	2.1	1.4	2.1	-1.7
	Coaching stock		2.4 (a)	2.7	1.4	2.9	-2.1
	Goods stock		1.7 (a)	3.0	3.6	3.1	-2.0
	Goods stock carrying capacity		3.8 (b)	4.0	4.8	3.9	-0.2
	Passenger journeys		3.8 (a)	4.0	4.5	4.2	-1.0
	Revenue-earning freight		5.4 (a)	3.8	4.2	4.8	0.8
ROADS (national & provincial)	Total (nat. & pr.)			2.0	1.3(c)	0.1	-0.1 (d)
	Paved (nat. & pr.)				15.0	5.3	1.6
	Passenger vehicles			12.1 (e)	5.0	5.2	2.6
	Goods vehicles			23.5 (e)	7.2	7.5	2.8
AIR TRAVEL	SAA passengers				9.1(f)	12.9	2.3
	Passengers on international flights at SA airports					13.0(g)	5.8
ELEC-TRICITY	Electricity generated			8.8	6.0	7.5	3.9
TELE-PHONES	Fixed lines			7.8	7.9	4.2	5.9
	Mobile lines						120 (h)
	Total lines (fixed plus mobile)			7.8	7.9	4.2	10.8

The logic that supported the formation and development of Johannesburg is more relevant to the objective of the research in the context of development around the Kalahari Manganese basin and is described in Figure 11. There is, however, a lag between infrastructure development and the general usage of the infrastructure for business purposes. Transport and logistics infrastructure played a major role in the development of the city in the 20th century. It is still common knowledge, within government and industry, that transport and logistics affect the basic efficiency around moving people and goods from one place to the next (GDED, 2010). Logistics and transport are treated together as one of the key drivers of economic growth, due to the efficiency it adds to the business environment.

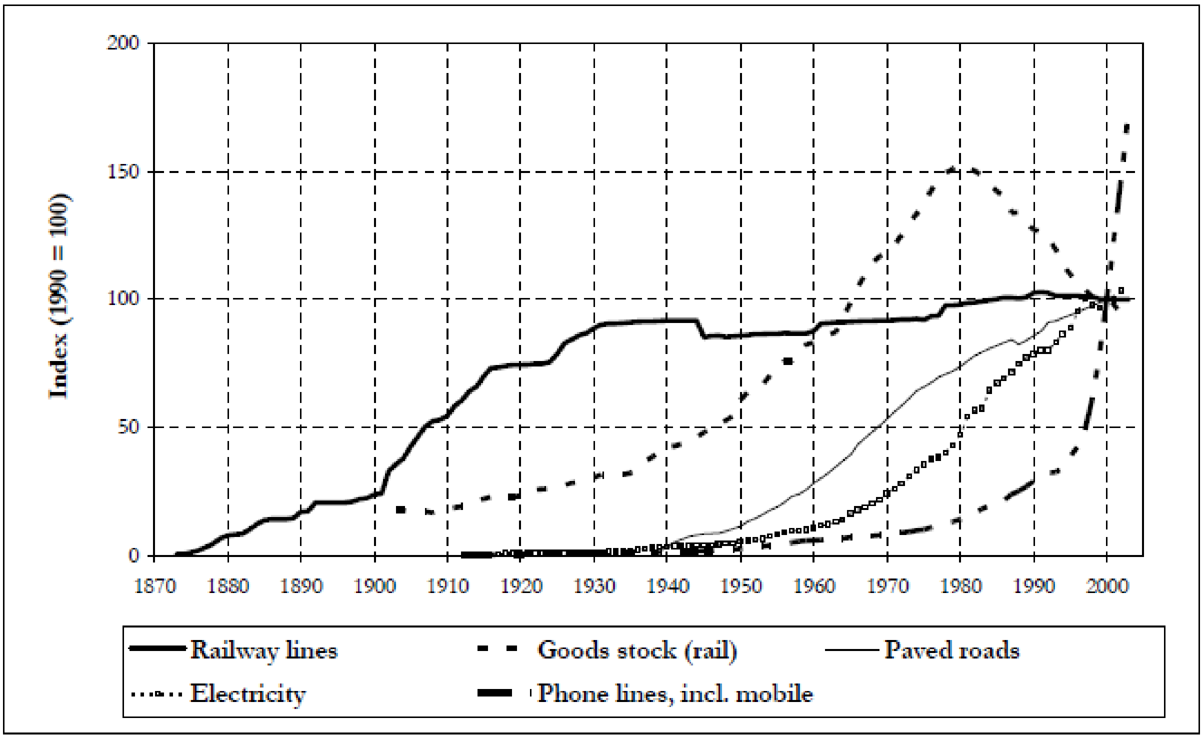


Figure 11: Phases of infrastructure development in South Africa - source Perkins *et al (2005)*

The extent of carbon footprint per capita is also influenced by the type of transport used in the economy. In the research conducted by the Gauteng's Department of Economic Development in 2010 (GDED,2010), it was established that South Africa as a whole, based on the 2006 annual carbon emissions released by the International Energy Agency in 2009, ranked 13th in the world with 414,6 million metric tons of carbon emission per annum. This represents 1, 5% of the world's total carbon emission, competing with countries like China (ranked 1st), the United States (ranked 2nd), Russia (ranked 3rd) and India (ranked 4th). A significant portion of this is due to South Africa's reliance on road transport for goods and passengers.

Mining production is largely transported by rail. However, due to capacity limitation in rail freight services, a significant volume of mines' production from the Northern Cape, Mpumalanga and Limpopo provinces is transported by road, thus contributing significantly to pollution. Manganese, in particular, is facing this challenge due to the lack of capacity to accommodate the development of new Manganese mines in the Northern Cape since 2009. An overview of the Manganese industry is discussed in section 2.5.

2.5. Overview of the Manganese industry and the downstream business

The Manganese resource is largely found in the Northern Cape province of South Africa, in the area to the North of Postmansburg, stretching about 150 km to Black Rock north of Hotazel (DME, 2008). The mining activity of Manganese minerals dates back to the late 1920s and has been active since then. Although Manganese reserves formed from weathering Dolomite is found in the North West extending from Krugersdorp to the Botswana border, the Kalagadi Manganese fields account for the major deposit of South Africa’s metallurgical grade Ore.

Manganese is an important mineral to the steel-manufacturing industry. The mineral is used mainly as a Ferro-Manganese alloy (containing on average 80% weight Manganese, 9-13% iron, 7% carbon and 1% weight silicon), in the manufacturing of various grades of steel. The common use is in cast-iron steel with every ton of this product containing between 4 and 7 kg of Manganese metal (Cairncross *et al*, 2010).

Although both Manganese and Iron Ores are extracted from oxide and /or carbonate minerals, Iron Ore is found in meteorites in its metallic state, whereas Manganese isn’t. The other difference is that iron Ore is more easily reduced in an open fire hearth to form metallic iron than Manganese (Cairncross *et al*, 2010). It is mostly due to the above reason that Manganese gained utilization by human kind much later than iron. Despite its late inclusion in the steel-making process, Ferro-Manganese has become a commonly used alloy (Zhang, 2007:138) in the steel making process

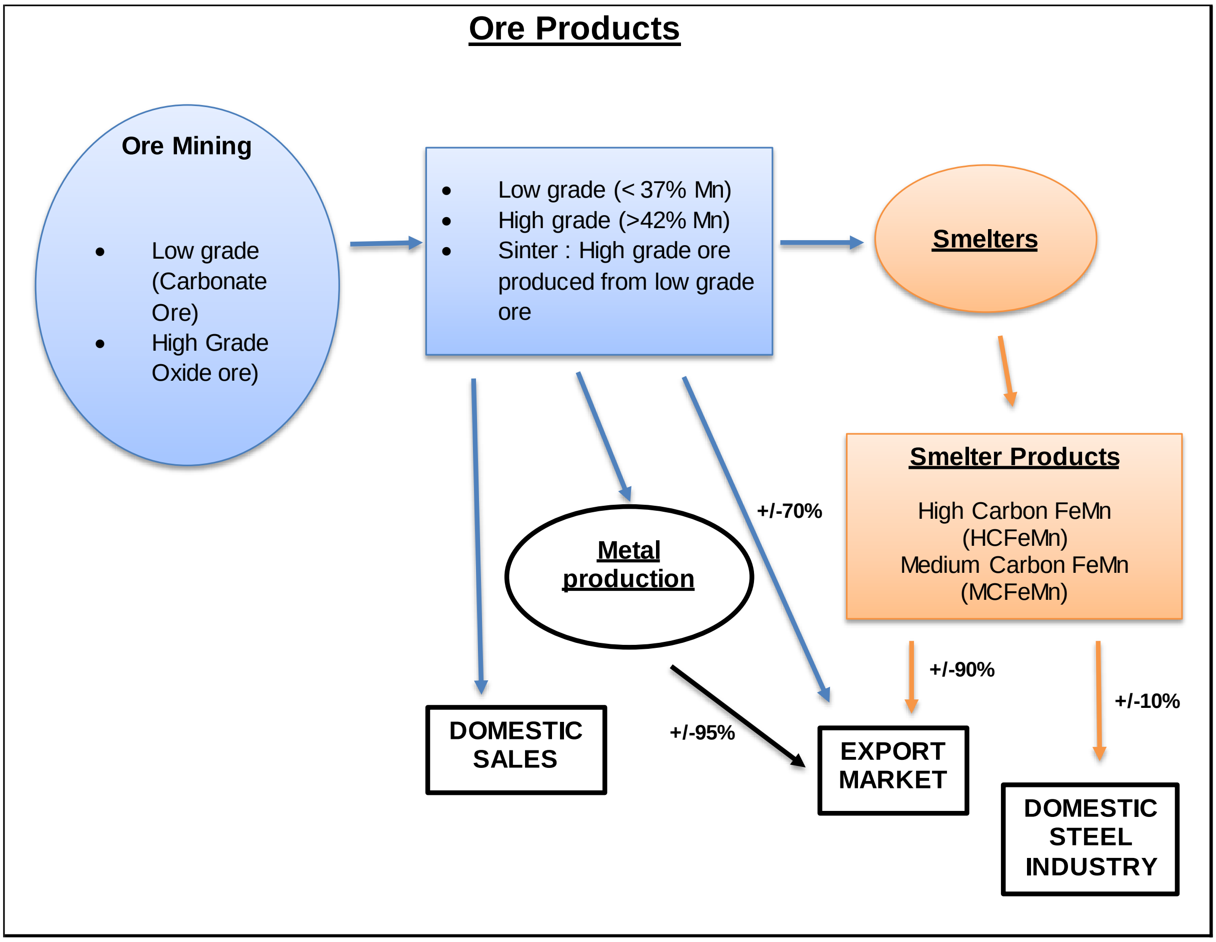


Figure 12: Manganese mineral value chain in South Africa (Manganese Forum, 2009)

The current industry structure in South Africa is such that more than a third of the Manganese Ore is exported from South Africa in non-beneficiated form, as illustrated in the value chain picture in Figure 12. The export of raw material represents a lost opportunity in potential revenue and mining jobs. The economic activities would otherwise have taken place in the producing province in South Africa, and the country at large. This is not withstanding the current constraints that inhibit the potential of the industry to achieve higher levels of beneficiation up to fabrication of consumer products from these minerals. The government's beneficiation strategy (SAMI, 2009:18) provides for a framework within which South Africa can implement the orderly development of the country's mineral value chains in order to leverage benefit from inherent competitiveness. Figure 13 also demonstrate that Manganese has a demand pattern that can be tracked using the demand of Iron Ore and Steel products. Adjei *et* *al* (2011) have found that the two minerals and their combined downstream use in steel drive the similarity in demand pattern of the two minerals.

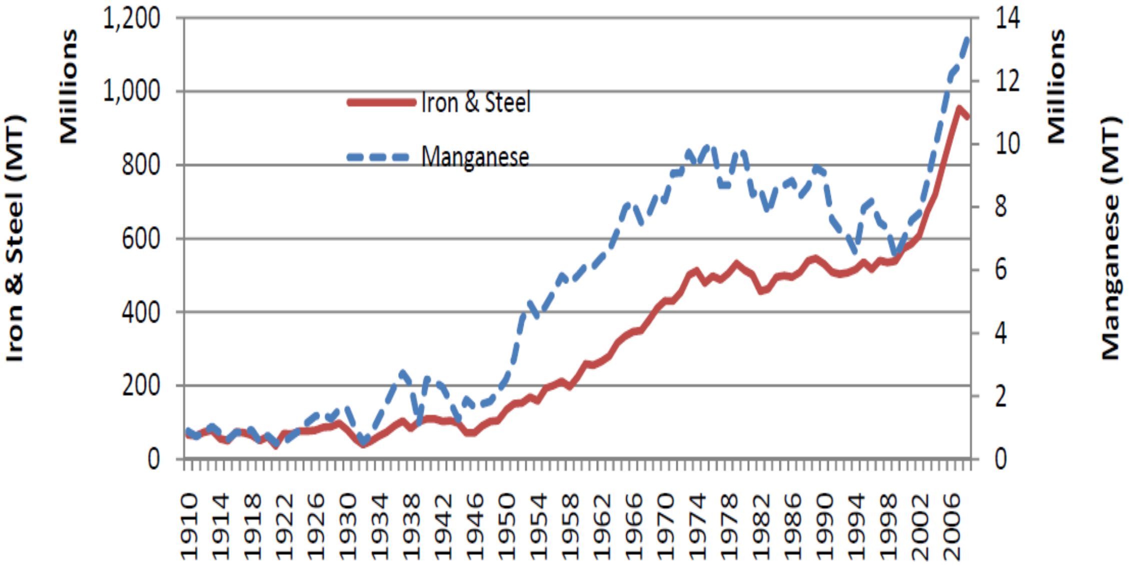


Figure 13: Manganese production vs. steel and iron production. Source (Adjei et al, 2011)

Manganese Production in South Africa

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Production of Manganese Ore has, for a long time, been dominated by Samancor and Assmang (Pienaar *et al*, 1992:131), with operations in the Kalahari basin in the Northern Cape. However, a number of new players have since come to the fore. This can be attributed to the revisions made to the Mineral Act since the late 1990's, and the promulgation of the new MPRDA Act 28 of 2004 (DME, 2004). This act required the owners of old-order mineral rights to re-apply for the mining rights, failing which, the rights reverted to ownership by the State. Where owners failed to re-apply for their mining rights, under the new order (MPRDA, 2004), the mineral reserves were made available to new applicants.

With new entrants in the mining space such as UMK, Kalagadi Manganese, Kudumane and Tshipientle, the production capacity of South Africa is likely to increase from 15.9% of the global outputs seen in 2006. Two new projects by Kalagadi Manganese and Tshipientle will see the production output of Manganese increase by 5.4 million tonnes of high metallurgical grade Ore, 60% of which is beneficiated into Sinter Product. With a global Manganese reserve base of 80% at about 4000Mt that South Africa holds, the current productions and exports only represent a fraction of South Africa’s potential. With only 5% reserve base in 2006 (SAMI, 2009), China leads South Africa as a bigger producer of Manganese, with up to 600 producing mines.

Table 4: World Manganese reserve, production and sales (SAMI, 2009:115)

	RESERVE BASE #			PRODUCTION			EXPORTS		
COUNTRY	Mt	%	Rank	kt	%	Rank	kt	%	Rank
Australia	75	1.5	5	4 967	10.9	3	3920	22.0	2
Brazil	56	1.1	6	2 868	6.3	6	1807	10.2	4
China	100	2.0	4	19 000	41.8	1	-	-	-
CIS	560	11.2	2	3 565	7.8	4	735	4.1	6
Gabon	150	3.0	3	3 248	7.1	5	2756	15.5	3
Ghana	*	*		914	2.0	8	1059	6.0	5
India	36	0.7	7	2 295	5.0	7	134	0.8	7
Mexico	9	0.2	8	378	0.8	9	23	0.1	8
South Africa+	4000	80.0	1	6 895	15.2	2	5526	31.1	1
Other	14	0.3		1 351	2.9		1823	10.3	
TOTAL 2008	5000	100		45 481	100		17 783	100	
2007				38 230			15108		

Sources: USGS, 2007 (For Reserve base)
**DMR, Directorate Mineral Economics*
IMnI, for production and export figures
Notes: # Manganese content
** Included under "Other"*

According to the data in Table 4, South Africa has significant Manganese resources compared with countries such as China and Australia. Considering the rate at which these countries are producing, the current known resources in those countries will in time be depleted, creating more demand for South African Manganese. South Africa will still host in excess of 50 years of resource based on 2010 production levels.

While this picture sends a warning to the steel manufacturing industry to look at creative ways of managing consumption of natural resources, the industry has various options, including research into alternative ingredients and, indeed, recycling. The strongest message that this picture sends to the country and the communities that depend on Manganese revenue is to find alternative revenue streams.

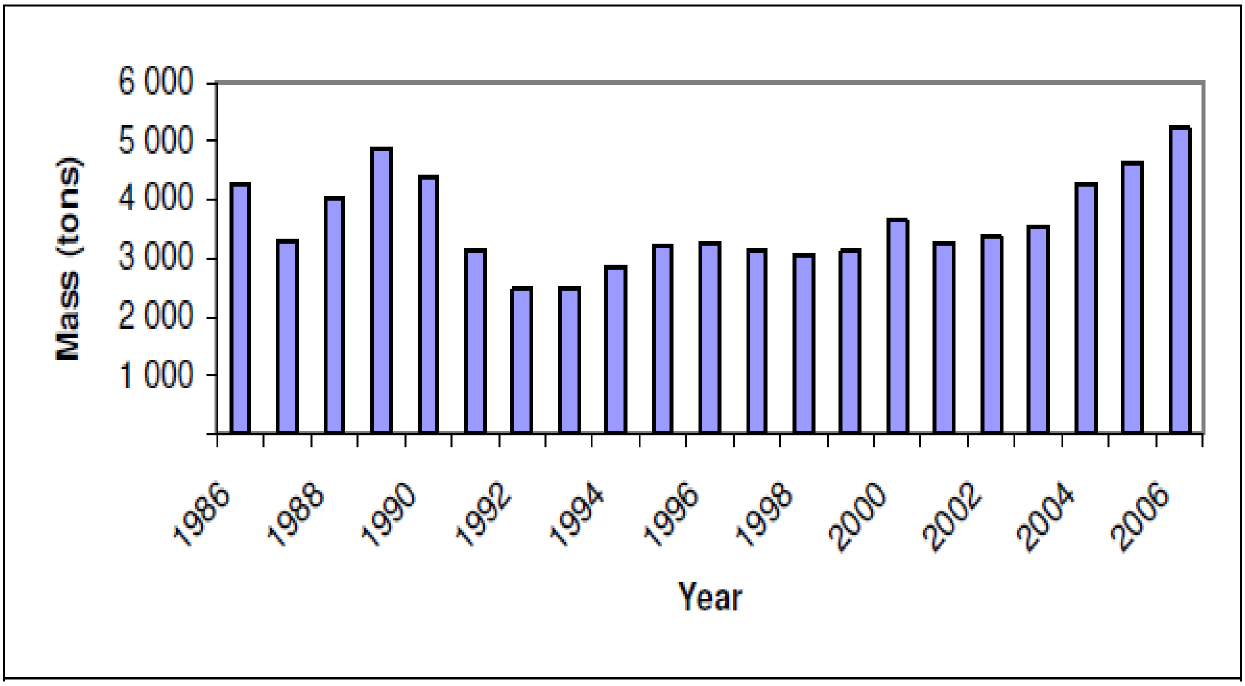
As has been the case in other previous mining towns, such as, Jaggersfontein in the Free State province, where this town was abuzz with diamond mining in the early to mid-20th century and where the second largest diamond stone was mined, was turned into a ghost town with only a big hole and a few dilapidated buildings. The community of this town depended on continued mining, not only for revenue but for services such as a running water supply.

When the mine closed in 1970, the town started declining into extreme poverty and poor service delivery, and was left with angry residents. Another 60 km to the west of Jaggersfontein, lays another mining town of Koffiefontein where some of the high value gem stone (diamonds) were mined. Although mining continues in this town, the economic development of the town has stagnated from the glory days and the town has no alternative industry to sustain economic growth beyond diamond mining.

Manganese mining in the Northern Cape Province has made very little impact on the sustainability of economic growth in the towns and communities around Hotazel and Black Rock, where most mining occurs today. The bulk of supporting services are still sourced from other towns in the Province, and those towns themselves have developed as a result of mining activities. What is desirable is an outcome with a similar effect to that of the gold mining era of the late 1800 and the early 1900 has had on the development of the Johannesburg and broader Gauteng economy.

While Gold was the primary business that led to the establishment of Johannesburg in the late 1800's, the economy of the city in the 21st century is no longer dominated by mining activities, but mainly driven by secondary industries and the services sector. Sustainable development refers to achieving economic and social development in ways that do not exhaust a country's natural resources (Ashford, 2010). It is necessary to ensure that the current operations of the Manganese mines should be conducted in a way that does not compromise the ability of the community to continue their economic development, post mining.

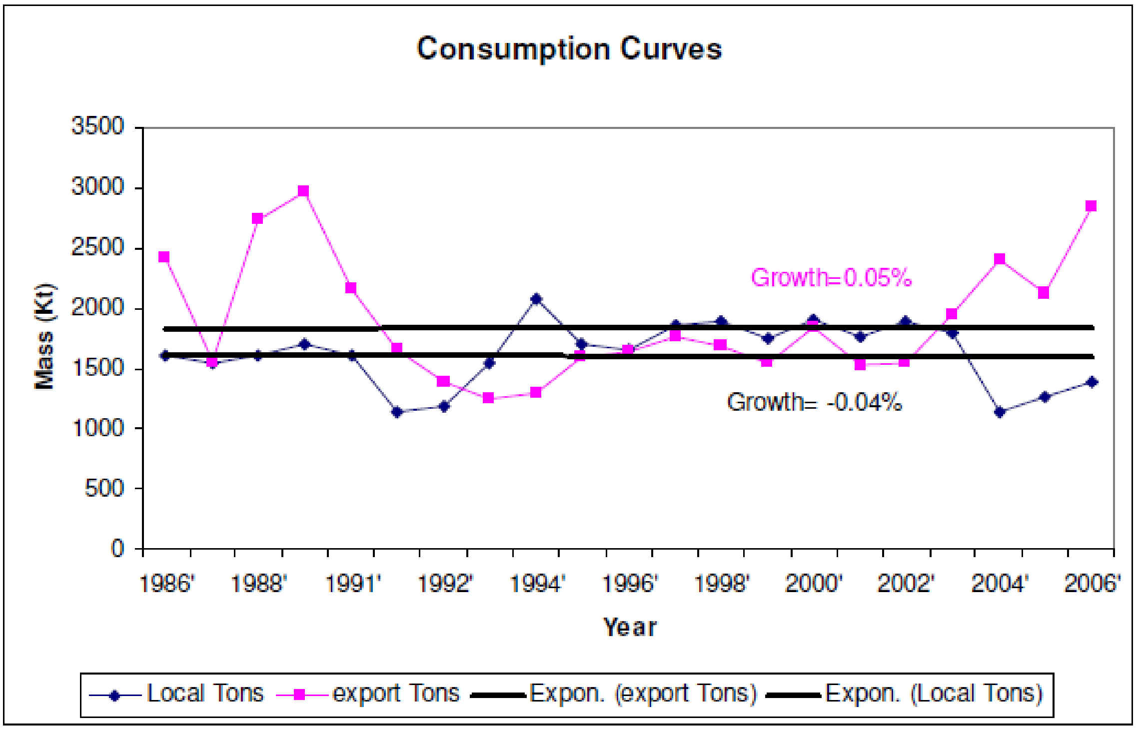
The demand for Manganese in South Africa has, for a long period, trailed that of Iron Ore and the manufacturing of steel in general. The graph in Figure 14 shows how little South Africa's Manganese production has increased in the 20 years to 2006. According to the Directorate of Mineral Economics (DME, 2009), the increase in volume of Manganese output for the 20 year period has averaged 0.54%.



Source: DME, Directorate Mineral Economics

Figure 14: SA's Manganese production for 20 years to 2006

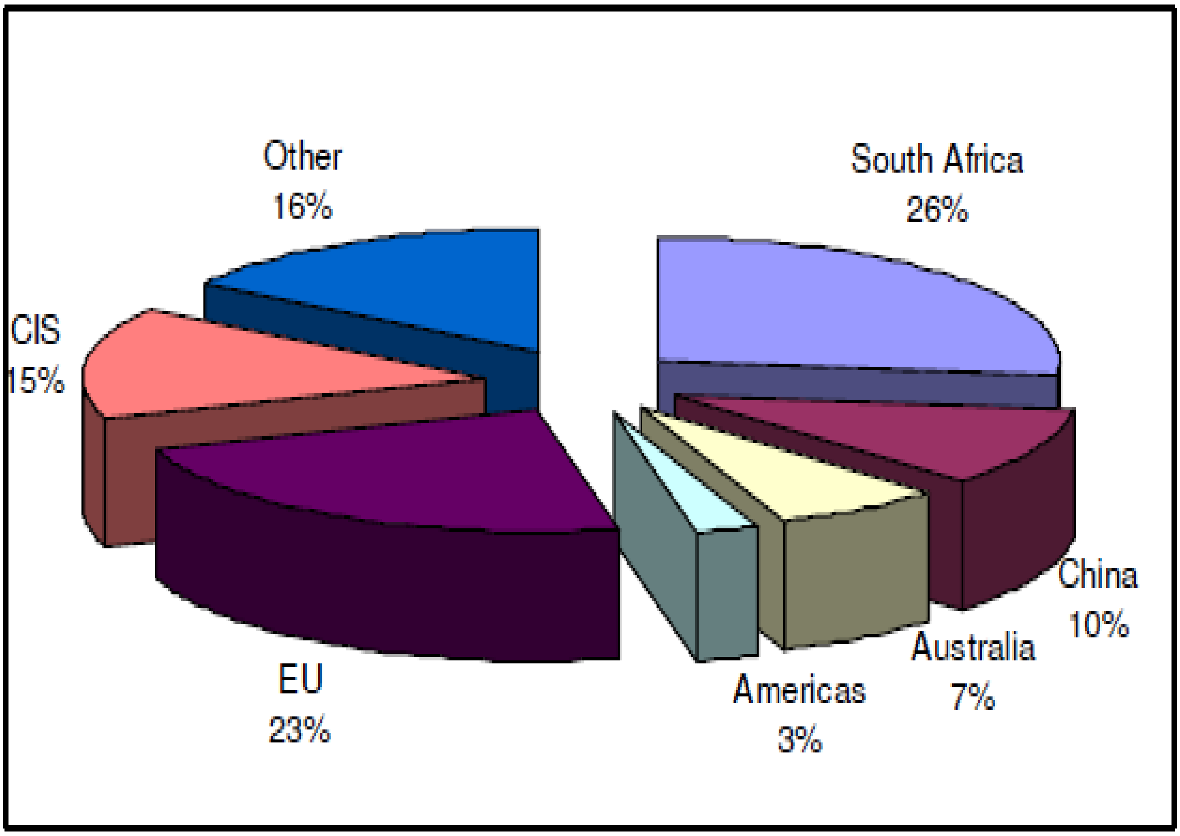
In contrast to the growth in Manganese volume over the 20 year period, the demand for Manganese Ores in the country has been on the decline, as indicated by the graphs in Figure 15. The consumption locally has been declining at an average of 0.04% annually, while exports have increased by 0.05%. One factor, to which the decline in local demand for Manganese Ore can be attributed, is the decline in percentage contribution of steel manufacturing as a percentage of GDP contribution. This is discussed in more detail in the later sections of this report.



Source: DME, Directorate Mineral Economics

Figure 15: SA's Manganese consumption curve for 20 years to 2006 (SAMI, 2009)

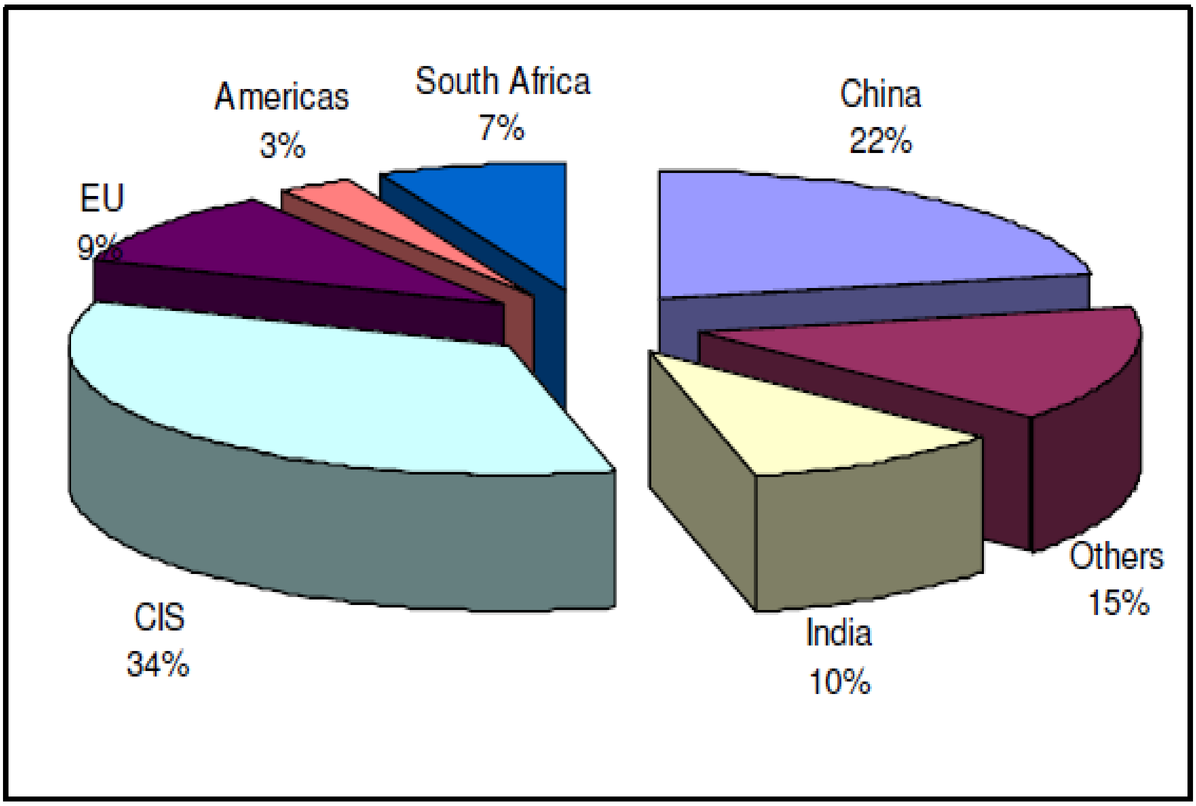
High Carbon Ferro-Manganese (HCFeMn) is the second form of Manganese beneficiation through a smelting process after sintering. Based on the 2008 statistics by the DME (SAMI, 2009), South Africa is the number 1 exporter of HC Ferro-Manganese. The export numbers displayed in Figure 16 confirm that some form of beneficiation of Manganese is happening in the country. However, the country remains a net exporter of HCFeMn. China, on the other hand, is a net importer of HCFeMn.



Sources: The TEX Report, 2008

Figure 16: World exports of HCFeMn by country in 2008. Source (SAMI, 2009)

The other form of beneficiated Manganese exports is in Silica-Manganese (SiMn). South African exports less of this form of beneficiated Manganese for two reasons. The first is that the availability of Manganese with Silicon content is less. The second reason is that the cost of SiMn treatment through a furnace is higher compared with High Carbon Ferro-Manganese. Figure 17 depicts the global export percentages as described.



Sources: The TEX Report, 2008

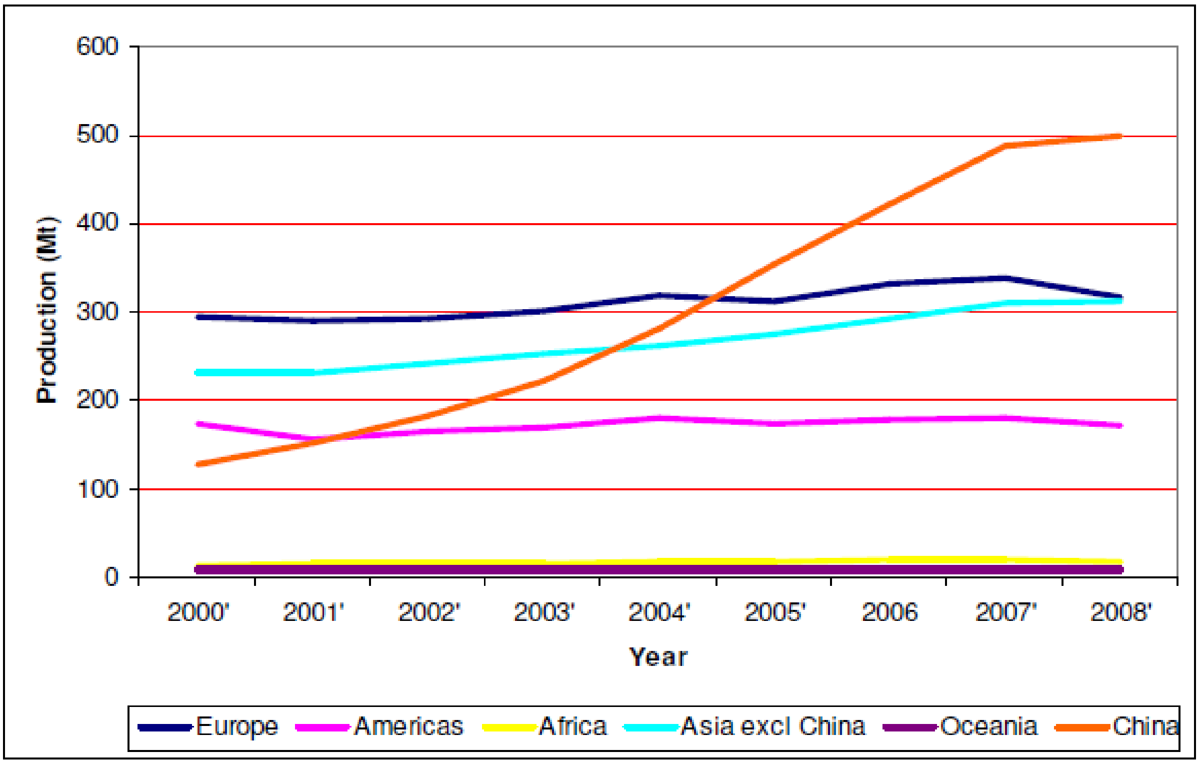
Figure 17: World Supply of Silica-Manganese by country in 2008. Source (SAMI, 2009)

Production of steel in South Africa and the world

South Africa is a net importer of steel just as the rest of the Southern African Development Community (SADC) region is. Lack of power and inadequate logistics have always been stated as the key constraints causing low manufacturing capacity in South Africa. The roads transportation sector faces a number of challenges that not only affect the movement of goods, but limit the mobility of people. The challenge of inadequacy in the transport logistics impacts negatively on accessibility and affordability of public transport by almost 13 percent of the South African population (Erero *et al*, 2010).

Although there is a developing trend of early value chain beneficiation in some mineral groups (i.e. Manganese, Chrome and Diamonds) within the mining industry in South Africa, the effort is still seen by many mining operators as a non-core business. The high cost of input variables such as power, anthracites and other reductants, is most likely to make the business case for downstream beneficiation of Manganese resources weak.

The graph in Figure 18 indicates that South Africa's steel output as a percentage of global output is insignificant. With no indication of a different replacement mineral for Manganese in the manufacturing of steel, South Africa's reserves, and the diminishing reserves in China and the rest of Asia. This means that South Africa is strategically positioned to dominate the industry going forward. The South African Steel industry can benefit from direct access to the high-grade Manganese available locally.

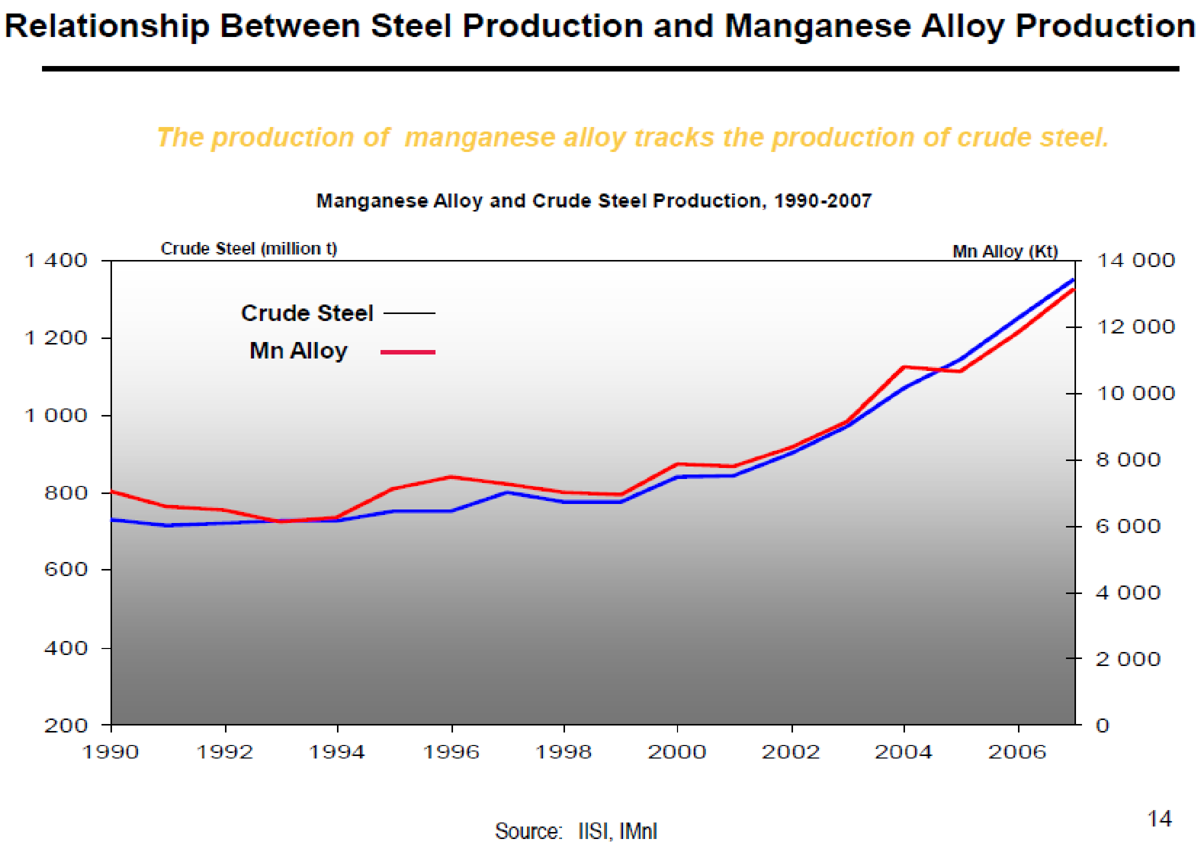


Source: WSA

Figure 18: World Steel Production between 2000 and 2008 (SAMI, 2009)

The secondary industries, such as manufacturing, the majority of which are multinationals, still depend on imported technology for their processes. This phenomenon is due to long-term contracts that are based on strategic relations between suppliers and these multinationals at global level. In some instances the phenomenon is driven by brand loyalty to particular technologies.

Ferro-Manganese remains one of the critical alloys in the steel production process for the various types of steel, along with Ferro-Chrome, the former being used more. Based on DME (2009) collected data on global production from 1990 to 2007, there is a consistent correlation between the production of crude steel and production of Manganese alloys over the long term. These figures include both Silica-Manganese and High Carbon Ferro-Manganese. This is not withstanding the annual oversupply of Manganese, which has in some way always self-corrected, based on annual steel demand. The graph in Figure 19 depicts this situation only at a global level and not necessarily as the South African scenario. The South African steel production industry has not consumed enough of the Manganese production to correlate the two in a ratio that is in line with global trends.



Relationship Between Steel Production and Manganese Alloy Production

The production of manganese alloy tracks the production of crude steel.

Source: IISI, IMnI

14

Figure 19: Relationship between Crude Steel production and Manganese Alloys (SAMI, 2009)

The other challenge is that the South African steel export industry has not tracked the global trends in terms of growth during the period 2000 to 2008. The global supply has been dominated by Asia (predominantly China), Europe and the Americas. In the 8 years to 2008, China's steel production and export has increased dramatically compared with other exporting countries in the top 10. This has been primarily driven by consumer confidence and infrastructure development in China itself, and later the global demand. This is despite South Africa being the no 1 ranked host of Manganese, and 9th in known Iron Ore reserves, both of which are primary minerals required in steel manufacturing.

2.6. Legislation on mineral and mining industry development

Whilst it is not the intention of this thesis to provide a legal analysis on the South African mineral resource legislation and any other related legal document covered hereunder, a review of the impact of certain provisions of the legislation on the operation and sustainability of Manganese mineral resources is intended. A general analysis of the national economic development and its impact on the employment statistics in South Africa since the new democracy, as described by the National Planning Commission (NPC, 2011) diagnostic report, raises an issue on the ability of the economy to create employment. The rapid increase in the working-age section of the population places pressure on the economy to create employment. The NPC makes comparison of the data in Figure 20 with established economies such as the US. Both the unemployment rates, and the labour productivity, improved from 2006, after deterioration between 1998 and 2002.

It is not clear how the promulgation of the MPRDA Act 28 of 2004 is going to achieve the required beneficiation and employment. In 2004, when the Act was promulgated, its aim was to improve the sustainability of the mining industry and its influence on the economy. A number of legislative frameworks have been presented by the Departments of Mineral Resources and the Department of Trade and Industry, and these are discussed in the sections that follow.

Figure 20: Labour and employment rate in South Africa (NPC, 2011:14)

The legislative environment for manufacturing is also a key variable that influences the potential for downstream beneficiation of Manganese to the levels required to match the output of Manganese Ore. MPRDA requires mining companies to develop, along with their proposal for mining activities or projects, an environmental plan that demonstrates the mining house's ability to restore the environment to a state that is as close as possible to its original capability. The MPRDA also requires, from the mining projects proponents, the development of social and labour plans (SLPs) for the communities that are going to be affected by the mining activities. Some beneficiation opportunities do come out of these SLPs, but they are often very expensive and require a lot of upfront investment to get off the ground.

In an article in mining weekly, in November 2009, the editor, Martin Creamer (2009), debated on the effectiveness of the provisions of the MPRDA on beneficiation once again. The Deputy Minister of Transport/ Deputy Secretary General of the South African Communist Party, was quoted as saying "We now have a sad irony in that the Chinese, for instance, are willing and keen to invest in Manganese beneficiation manufacturing plants here in South Africa, but this possibility is compromised by the fact that many of the Manganese deposits have been leased out for 30 years to the same old established mining conglomerates and their new "patriotic" bourgeois hangers-on,"

This article came in the wake of looming calls for the nationalising of mines, because a sector of the community, and some political organisations, are disillusioned with the effectiveness of the value added by mineral activities towards the economy. In the same article Cronin is further quoted highlighting some of the bottlenecks towards beneficiation, and he said, ”More than 90% by volume of all exports (mostly minerals) are by sea, yet all of the shipping involved is foreign-owned, the crews are overwhelmingly non-South African, and the shipping lines pay taxes in other countries," (Creamer,2009) .

Cronin, who was a Deputy Transport Minister at the time, said this, lamenting the fact that the country's once relatively significant maritime sector had been whittled down to a single registered ship. As much as the article quoted above points to possible legislative weakness in the MPRDA act 28 of 2004, the last part indicated that there are logistical and other challenges constraining the industry from realising its potential value.

This research is aimed at investigating these constraints, along with the engineering of mining projects, to highlight the opportunities that may exist to structure these projects, and other industries, in such a way that makes cost of beneficiating more predictable and manageable.

The preliminary analysis of the South African mining economy, and the effort from the South Africa government towards industrial development, indicate the need effectively to develop a secondary economy to traditional upstream mining. This is backed by a number of policy interventions in downstream beneficiation of precious minerals, such as diamonds, that were primarily driven by government. The Diamond Export Levy Act no 15 of 2007 (RSA, 2007) seeks to encourage local diamond beneficiation and import by attaching a levy to any amount of exports while incentivising imports. This is further supported by the establishment of the State Diamond Trader with entitlement to 10% of SA diamond production.

The Precious Metals Regulations Act no 37 of 2005 (DME,2005) requires that an application for precious metals assures the State of sufficient products to satisfy the demand for local beneficiation of unwrought and semi-fabricated precious metals as local demand may indicate during the export period.

Industrial Development and other Beneficiation Initiatives

The Diamond Amendment Act was passed by the parliament of the Republic of South Africa to make provision for the local supply of rough diamonds through the establishment of the State Diamond Trader (SDT) with the power to purchase 10 percent of mine production in order to improve access to rough diamonds for local beneficiation. The key thrust of this policy is to increase local beneficiated diamond production from 3% to at least 10% of rough diamond production. In order to maintain control of the industry, further legislative amendments introduced beneficiation licenses and a reduction of the export duty to 5%.

The Act gives tax exemption to producers who sell their production to benefactors as a means to encourage sale of unpolished diamonds to local markets for further beneficiation. The Act goes on to credit importers of unpolished diamonds, which is a proactive effort by the government to stimulate downstream business in South Africa, that does not only depend on local output but international sources as well.

Medium technology sectors in South Africa employ a substantial number of people and have the potential for further development in future. Some of these industries are long and well established. Examples of these are the metal fabrication, machinery and equipment, as well as new and less-established industries such as jewellery, oil and gas. Most of these industries have real potential for downstream beneficiation of primary minerals from the mining and mineral resource sectors.

It is for this reason that the Diamond Amendment Act and other related legislation are necessary to give the economy the necessary boost. Development strategies in the sector are therefore aimed at creating a more enabling business environment through the creation of diamond and jewellery hubs in South Africa. The beneficiating process of any of the primary minerals creates demand for more infrastructures and other growth-related spending, the result being the improvement of the business output in South Africa

The key challenges for the beneficiation of these minerals are the pricing of these minerals amongst other challenges such as skills, infrastructural capacity and transport requirements. According to the national industry policy framework (SA Government, 2007) , interventions required to unlock this industry include, among other things, a regulatory framework for more internationally-competitive raw material pricing inputs and the leveraging of domestic and continental capital expenditure, coupled with a sector-specific support mechanism.

National Industrial Policy Framework

In the framework the government of the Republic of South Africa **(**DTI, 2007) has highlighted a few challenges with the productive capacity in South Africa. The objective of the framework is to contribute to the economy of the continent. By building this productive capacity to enhance the ability of South Africa, as a country, they have annual growth at levels of 6% from 2010 onwards. The level of technology development and the significant gap between investment in R&D and the rate, at which the country is developing, is highlighted by the framework as a strategic area of focus.

From a technology point of view, without significant investment in R&D, any effort to create more downstream beneficiation and manufacturing capability will face limiting challenges. The policy framework sets out a target of 1% of GDP as the level of investment that is required in the R&D of technology. Current percentage investment in research for South Africa is around 0.6% based on SSA (2010) statistics.

The framework also sets out to facilitate the diversification of the economy from reliance on traditional commodities and non-tradable services which purports a significant focus on developing the manufacturing sector as a critical contributor to the economy. The framework suggests the promotion of value addition per capita, characterised by movement into non-tradable goods and services which compete in the competitive export markets and against imports. This assertion in the policy sets the tone for business development in the area of side-stream and downstream beneficiation. However, the market within the secondary industries, such as manufacturing and construction, should be developed equally. The way that mining projects are designed should support the early entry of downstream and side-stream beneficiation.

The framework highlights that the medium technology sectors, such as metal fabrication, machinery and equipment and jewellery manufacturers, are long established industries, and they tend to employ more people than the upstream traditional mining activities. A number of these industries represent true potential for downstream beneficiation of mining and minerals sectors. The framework argues, however, that this is not realised because there is still an abundance of mineral resources, and subsequent reliance on the upstream

An example of side-stream beneficiation that could happen online is the manufacturing of bricks from slimes material from the diamond processing plants, where the deposition of the slimes is done in such a way that it becomes easier for the brick manufacturer to influence the deposition strategy, and the two can operate side by side. Issues around environmental liabilities with the transfer of material from mining to brick manufacturing will need to be resolved, and the regulators can be consulted in making these arrangements. This example is particularly important because it is a typical example of where the liability of the mine can be reduced, by enabling another business to develop, which can then be sustained for years beyond the mining activities.

By operating the manufacturing plant, while the operation is running, both the brick manufacturer and the mining company have an opportunity to prove the viability of the side-stream beneficiation before the liability gets transferred in full to the beneficiates. These kinds of beneficiation possibilities can be included in the design of new mining projects to ensure that the operational strategy of the mine supports easy access and synergies to the beneficiation efforts. In his article, De Wet (G De Wet, ca 2004) identified beneficiation as a strategy for countries that are technology colonies to come out of this paradigm. This view is qualified by some figures that are known about the value that mineral beneficiation can add to raw minerals at various levels. De Wet refers to five levels of beneficiation as follows:

- Level 1. Primary products: agricultural products, mined Ores, coal etc.
- Level 2 .Secondary products: spun wool, wine, steel sections, cement, etc.
- Level 3. Material-intensive products: steel structures, motor cars, white goods, etc.
- Level 4. Capital products: machine tools, chemical reactors, etc.
- Level 5. Specialised products: medical equipment, computers, defence systems, space systems, etc.

South Africa, as one of the mineral rich countries has not seen the kind of beneficiation that is highlighted in the article, and De Wet (2004) highlighted some of the challenges, such as skills/knowledge of certain technologists, and managers at people level, but also highlighted the current advantages of exporting raw materials in terms of profit margins, and the benefit to the country in terms of balance of payments. The sizes of local markets for raw material are generally larger than those available for beneficiated material. He highlighted the natural comfort for skills, such as mining engineers with mining activity, as opposed to operating in a secondary industry such as steel making, etc.

Under the leadership of the DTI, the Industrial Policy Action Plan (DTI, 2007) was developed following the policy formulation on National Industry Policy Framework (NIPF). The plan has identified, as a major weakness in South Africa’s long-term industrialisation process, a decline in the share of employment in traditional tradable sectors, notably mining and agriculture.

The policy action plan indicates that the decline in employment in the traditional sectors has not been adequately offset by a sufficiently-large increase in the share of relatively labour-intensive employment in non-traditional tradable goods and services, particularly in manufacturing. As part of the NIPF, the DTI has aimed to facilitate diversification beyond South Africa's current reliance on traditional commodities and non-tradable services. This requires the promotion of increased value-addition characterised particularly by movement into non-traditional tradable goods and services that compete in export markets as well as against imports.

The NIPF recognises that there is also unexplored high-value potential in agriculture and mining. According to the DTI, there is a major opportunity to grow these industries, particularly the mining sector, on the back of the public expenditure programme in energy and transport, as well as the current mining and mineral processing boom. The upgrading of domestic suppliers to match this growth is important.

This would, however, require a concerted effort in building and strengthening capabilities for technological leadership. Input prices of raw material, inputs such as steel, aluminium and scrap, are often far from being suitably competitive. Important supportive technological infrastructure, such as tooling and casting facilities, are needed. Systems to support longer-term product development, innovation and research and development, must be strengthened. The potential for growth in the mineral beneficiation industry does exist in South Africa. According to the statistics shared in the Industrial Action Plan (DTI, 2007), the world market for uncut stones was valued at US$13.4 billion a year.

By comparison, retail diamond jewellery sales in 2005 were valued at US$70 billion. Diamond-producing countries in southern Africa are therefore looking to bridge that gap by promoting local beneficiation to ensure a bigger share of the downstream profit (cutting and polishing adds approximately 50% to the value of rough stones), as well as much-needed employment creation. South Africa is the third-largest diamond producer in the world, with an annual output of 14.5 million carats, worth approximately US$1.2 billion. The industry currently employs approximately 14,300 people, 11,000 of whom are employed in mining, 2,400 in manufacturing and 900 in sorting and valuing. The country's diamond trade activity is valued at around US$2.5 billion, almost half comprising rough exports. Despite being a major producer, South Africa only beneficiates 3% of its total diamond production.

In the wake of a global recession, the IDC conducted a study on the impact of the recession on the continent, and South Africa in particular. In the articles titled "Africa and the Global Economic Crisis, Challenges and Opportunities" (IDC, 2009), the IDC studied the trend in commodity prices over a period of 5 years, including the 2009 prices as depicted in Figure 21. The focus was on leading mineral resources such as platinum, gold, copper, coal and oil.

As most of the mineral rich African countries, including South Africa, rely on advance economies key markets for their exports, their trade balances have indicated adverse movements which also had an effect on their currencies. The majority of African currencies depreciated by between 10-28% against the US dollar during the course of 2008, with the South African Rand being the worst performer on the continent and globally (IDC,2009). The Egyptian Pound and both Tunisian and Moroccan Dinnar were the least hit at depreciations below 10% to the US Dollar. The graph in Figure 21 shows the commodity price variations from 2003 to 2009.

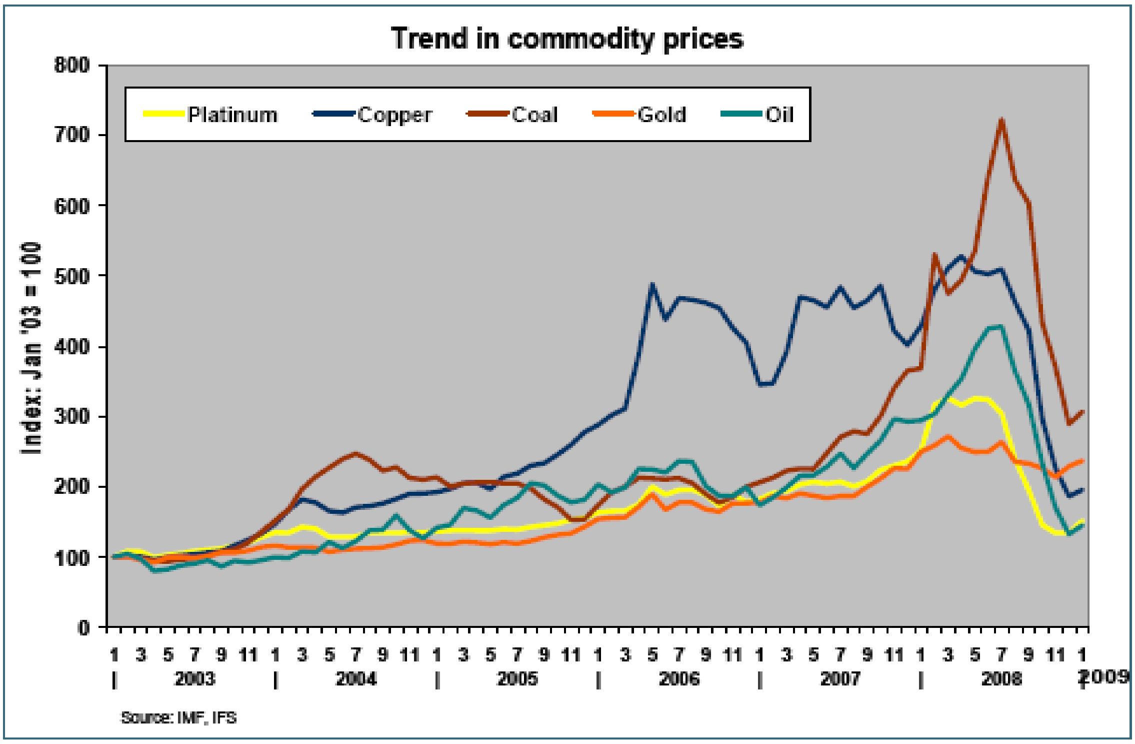


Figure 21: Trend in mineral resource prices from 2003 to 2009 (IDC, 2009) report

In his 2009 annual report (IDC, 2009) the CEO of the Industrial Development Corporation (IDC), Mr. Geoffrey Qhena, and identified beneficiation as one of a number of large projects with strategic impact in keeping with national industrial strategies. This gives an indication of the seriousness with which the government, through the trade and industry ministry, wants to develop the industry.

The IDC is a self-financing national development finance institution, whose primary objectives are to contribute to the generation of balanced, sustainable growth in Africa, and to the economic empowerment of the South African population, thereby promoting the economic prosperity of all citizens. The IDC is charged with the responsibility of stimulating industrial growth in South Africa, specifically in the sector of the economy where traditional retail financing institutions do not have the capacity or appetite to fund development.

2.7. Conclusion

South Africa hosts about 80% of the known Manganese reserves in the world (DME, 2008:16). However, the industry has failed to drive development in the areas where Manganese mining takes place. The Manganese industry has a significant potential for growth into the future due to its importance in the steel-making process. The review of the global numbers in the Manganese and steel production markets indicate that the demand in the Manganese industry lags behind the dynamics in the steel-production industry. The trends in the South African Manganese industry exports do not follow the global trends in exports. This indicates that the South African Manganese industry can be improved to catch up with international players in the Manganese and Steel production industries.

The research literature review needed to focus on broad issues affecting the South African Manganese mining and mineral beneficiation industry. The efforts of the South African government in creating a sustainable development in the mining industry are expressed in the MPRDA 28 of 2004 (DME, 2004). This blueprint strategy by the government falls short of providing a clear plan of implementation of the sustainable development in the mining sector and is almost silent on the Manganese sector specifically.

Beneficiation does elicit a lot of emotive response in South Africa, given the colonial history and heritage that has seen a lot of mining products exported overseas, leading to processing jobs being lost to those countries (Baxter, 2005:25). The overview of the Manganese resources value chain has demonstrated that there is a significant gap between the Manganese Ore percentage and the percentage of ore utilised in steel production.

The Urban dynamics (Forrester: 1969) application of system dynamics modelling using the systems thinking approach has been evaluated. Alfeld (1995)'s review of the Urban dynamics further confirms the relationship between old buildings, low rentals ,low income group occupation and challenges of maintenance The work of Professor Jay Forrester (Forrester, 1971) in business dynamics research has been reviewed. System dynamics is the study of information-feedback characteristics of industrial activity to show how organisational structures, amplifications (in policies) and time delays (in decisions and actions) interact to influence success of a business enterprise (Forrester, 1958). Other applications of simulation modelling using dynamic simulation methods have been reviewed.

Simulation models other than system dynamics modelling have been reviewed. One of the models reviewed is the object-oriented model for predicting human activities of learning organisation systems (OMPHALOS) a model developed in the late 20th century. OMPHALOS was developed in the 1990's at Cardiff University for modelling complex technical social and economic systems, and was based on a system dynamics theory (Cassora, 2005:1). The model incorporates the principles of systems thinking and finds basis in the works of J Forrester from MIT.

In his review of urban dynamics lessons from Forrester and Collins work, Saeed (2010:14) reflects on the dynamics around infrastructure and population development in a maturing urban environment. The basis for OPMHALOS modelling finds inspiration from the logic of the urban dynamics model that represents the reality based on the work of Forrester in Boston Massachusetts (Forrester:1969)

The application of Goldsim and other Siemens AVI has demonstrated the power of using simulation models to demonstrate future feedback of decisions made in the process plant and mining configurations over a long period, in order to enhance decision making. These simulations have demonstrated success in revealing the dynamic relationships between components of a mine system that are not easy to determine in the early stages of planning such projects. What is important here, is to understand the relationship between the reinforcing process (or a push), the feedback and the delay using smaller scale-controlled scenarios.

The Asian, European and American Manganese alloy and steel producers have dominated the consumption of raw Manganese resources from producer countries such as South Africa, while they produced Ferro-Manganese alloys for the steel industry. The steel products are then exported back to the original Manganese producers as beneficiated products (Baxter, 2005:25). The advantage that the Asian, European and American beneficiates have over their South African counter-parts is attributed to the technology and infrastructure capacity that exists in their countries.

The biggest limitation in South Africa is the scarcity of power, skills and the necessary technology. This literature search has, however, demonstrated that investment in infrastructure can unlock opportunities for growth in the mining and support industries. This requires a long-term view in determining the funding mechanism for the growth. These decisions require careful planning and consideration for feedback to policy decisions which may seem correct in the short-term, whilst showing the reversal of the benefits in the long-term.

In Ruckelshaus' (1989) analysis of the needs for sustainable development, Ruckelshaus makes an important comparison of two historical revolutions, and rightfully so, because sustainability is a serious challenge for human kind in the circumstances. He makes a case for more rapid action that is decisive in nature. This is so because today's global challenges of hunger, inequality, poverty and ill health are huge. Economic development is the increase in the living standard of a nation's population with a sustained growth from a simple, low-income economy to a modern, high-income economy (Deardorff, 2009).

South Africa, with 25% unemployment and over 40% youth unemployment according to the 2011 census (SSA, 2012), will relate to the sentiments of Ruckelshaus. He is also right to emphasize the fact that this move will have to be conscious, because in today's global challenges lies the threat of depletion of critical natural resources most of which are the primary input into the economic machinery.

International and local sustainable development standards require of mines to invest in communities where they perform their mining activities. They are also required to restore, as far as possible, the original capability of the land where mining takes place. This notion is supported by the set of guidelines in the Equator Principles to which funding institutions are required to adhere by the World Bank's IFC, when they evaluate funding opportunities in the mining industry.

Ruckelshaus concedes that moving nations into sustainability requires a shift in mind-set only comparable to the economic revolutions of the agricultural and industrial ages. The efforts of the United Nations from Rio 1992 through to Johannesburg 2002 summit, also demonstrate that sustainability will not only be achieved through banks enforcement, but through continuous attempts at responsible development by all businesses and governments everywhere where there are human activities.

In the description of the conceptual theory used in this research in chapter 3, the system boundary for the research is discussed in detail. The relationship of the mining operations as dynamic systems to the socio-economic environment surrounding them is described in the next chapter using concepts established in the literature review already discussed in this chapter.

3. The research concept and approach

A system dynamics simulation approach was adopted for this study. This concept is a departure from the traditional reductionist approach used in many scientific analyses. The model was used to consolidate the dynamic responses to variations of the Manganese mining factors over a 10 year period, in a way that integrates the three components of sustainable development in Manganese mining. Hard data was sourced from the industry and used in a dynamic model in order to determine the dynamics of the industry over the research period.

The model for a sustainable development system in a Manganese mining environment is comprised of the three main sub-systems of Economic Infrastructure, Mining Operation and Community Social Development, all of which are interdependent, albeit with unique systems attributes and characteristics. The dynamic relationship between these three sub-systems is simulated in system dynamics software using the Vensim PLE platform. The three sub-systems depicted in Figure 22, form the integral part of the simulation, and their inherent dynamics are determined before their interrelatedness is modelled.

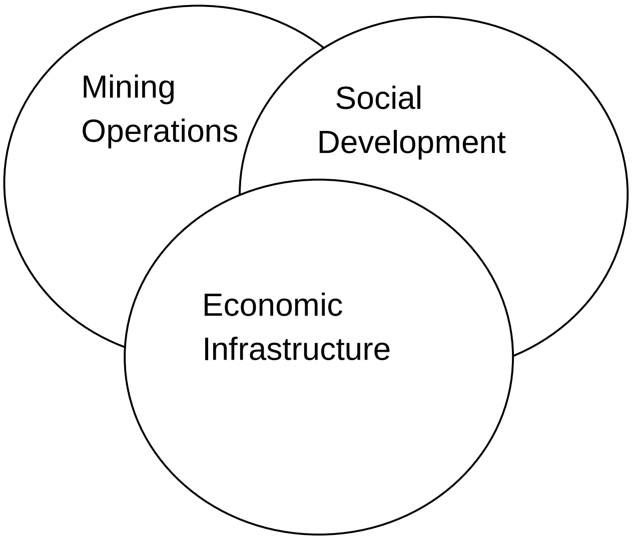


Figure 22: Sub-systems of a sustainable development system in Manganese

In order to predict the dynamic behaviour of the proposed sustainable development scenario in a mining-driven economy that is based on the systems thinking approach, a system dynamics model is created to simulate the dynamic behaviour of the proposed policy interventions. The dynamic modelling of the relationship among the three sub-systems is carried out at system levels 2-4 of the system hierarchy that is described in section 3.2 of the thesis.

To develop a complete concept of the system, such as an economic development system based on Manganese beneficiation, a system boundary is established within which the system interactions take place. This gives the system its characteristic behaviour (Forrester, 1973:12). The closed loop feedback model will resemble a set of differential equations with specific initial conditions that describe the relationships between the variables. Forrester (1973:12) argues that, in order to model the dynamic behaviour of a system, four hierarchies of structure should be recognized, and these are: 1) the closed boundary around the system, 2) feedback loops as elements within the structure of the system, 3) state variables representing accumulations within the feedback loops, and finally 4) flow variables representing activities within the feedback loops.

In order to study the beneficiation potential of Manganese minerals in South Africa as a vehicle for sustainable development within the existing mining communities, Forrester's hierarchy becomes important. From an economic point of view, revenue generated within the Manganese sector can be traced back several levels depending on the extent of beneficiation or use. However, this does not mean that this revenue is accumulated by the miners.

As an example, in a Manganese resources value chain, revenue is generated by selling the Ore coming from the ground (1st tier). The Ore can be beneficiated into a high-grade Sinter product that can generate revenue for the sintering business (2nd tier). Both Sinter and Ore products can also be transformed, in another business activity, into Ferro-Manganese through a smelting process to generate yet more revenue (3rd tier). The eventual beneficiation of the Manganese mineral comes at the steel and battery manufacturing stage (4th tier).

For the purpose of studying the dynamics of the Manganese beneficiation system in this research, the system boundary is only defined up to the 3rd tier of beneficiation, because it is easier to track the variables such as cost, technology, power and skills variables required at this level. Information from the industry on various cyclic performances from supporting industries such as power generation, coke supply and the steel-manufacturing industry, can be tracked in the model. Environmental constraints and other contributing variables are incorporated in the system dynamic model.

There are various applications of dynamic simulations at high and detailed levels. In a mining environment, dynamic simulations have been used to inform management decision making under complex conditions. These range from production planning, through optimisation and performance improvement, to applications in green fields' project evaluation. Goldsim (2007) is one of the modelling software developers who have been used widely to predict performance of mine operations under different conditions.

The individual components of the system are themselves complex in terms of their dynamic behaviours and as such are modelled separately to establish their individual dynamic behaviour. The human settlement in an urban development will have a pattern that is seldom in sync with business development in the area and the business ability to absorb the working age residents. However, the type of business, the extent of its labour intensity and specific skills requirements can influence the inward migration of external skills that are at first rare in the area. At the same time, mine value chain dynamics can be influenced by the local environment, but there are aspects and dynamics of a mine value chain that are common to any mine system, irrespective of the location or environment.

Due to the complex nature of the Manganese beneficiation process, sustainable development of the Manganese industry requires a holistic approach. As O'Regan (2000:349) finds, in complex systems , the same change to a fiscal or environment policy introduced in a number of states/times does not always results in the same effect in all of them because the effect of the change depends on the state of the system at a particular point in time. Sterman (1989:338) emphasises in his modelling of managerial behaviour that a heuristic may produce stable behaviour in one situation and oscillation in another solely as a function of its embedded feedback structure. Both Sterman (1989) and O'Regan (2000) agree on the fact that time and state of a system determines how it reacts to a change in policy which is an aspect synonymous with complex systems.

Systems thinking theory has been used to solve other complex socio-economic problems such as urban migration and sustainability of cities (Forrester, 1969). Systems thinking looks beyond the relationships between the components making a system and focuses on system feedback, which then allows individuals solving problems to integrate the effect of feedback into the decision making process.

The number of variables involved in making Manganese beneficiation viable, add to the complexity of implementing the policy. The complexity of solving sustainable development problems through Manganese beneficiation lies in the assumptions that are made around the parameters influencing the behaviour of both the Manganese mining and supporting industries. In order to understand a system, such as a Manganese operation, and its impact on the sustainable development of the economy within its zone of influence, it is necessary, as a first step, to create a complete picture of the system and understand the interrelatedness of the various components and their relationship to the overall functioning of the system.

Looking at the beneficiation problem from a systems point of view allows the problem solver to look beyond the mechanics of putting together a beneficiation plant and securing a market for the product, to looking at the short- and long-term benefits of the policy. Defining a solution for a downstream process for Manganese will require a thorough analysis of the relationship between the beneficiation process and the socio-economic environment. The systems thinking process is founded on the practice of top down and bottom up analysis and integration respectively. What is more useful in the systems thinking theory is the inherent ability to integrate feedback into problem analysis.

3.1. The type and characteristic of the model used

The choice of the model used for this study is informed by the system level of the components of the sustainable development. Since the dynamic behaviour of this kind of system is influenced by strategic interventions, general policy decision and market behaviours, a system dynamics modelling approach is used. Figure 23 shows the different simulation-modelling approaches that may be applicable for simulation of system behaviour at other levels, based on a systems hierarchy of detail.

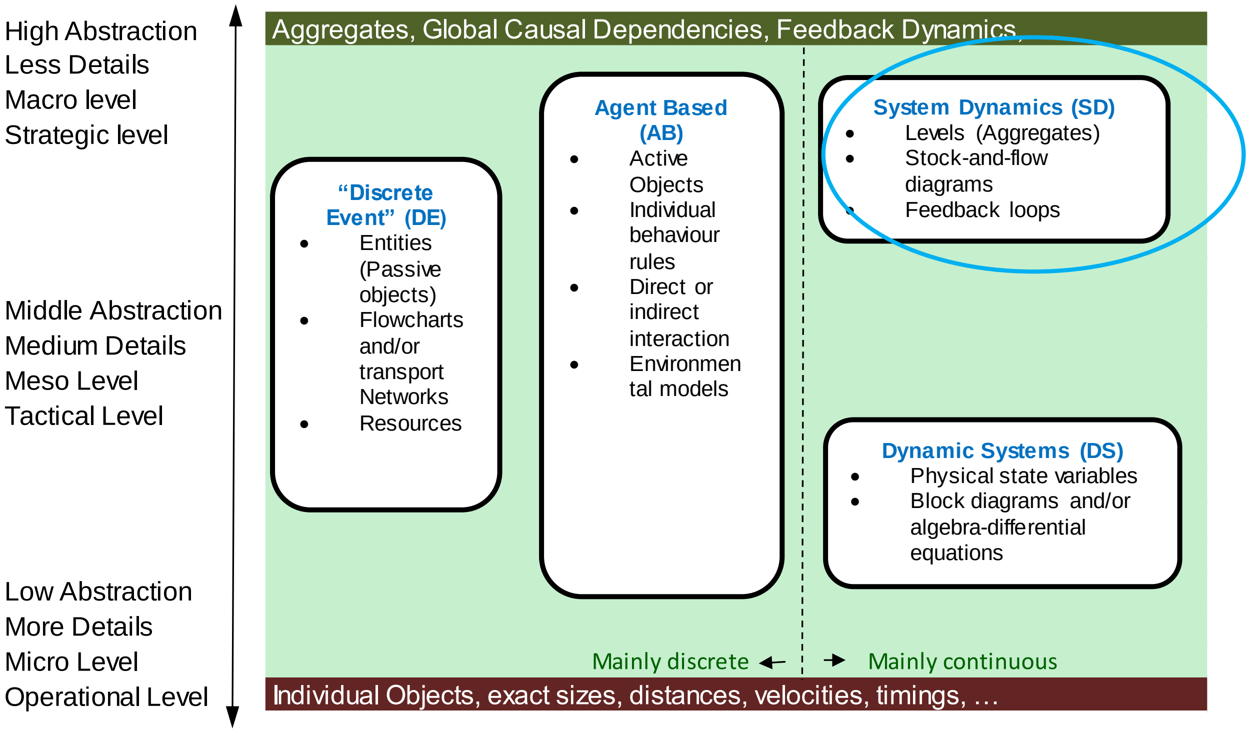


Figure 23: Approaches in simulation modelling based on abstraction levels (Borshchev, 2005)

The level of detail is limited, since input measurement is done at macro-economic level. The model does not make any detail split to cost components of the mine operation or revenue of the business, since the aim of the simulation is not to achieve the economic accuracy but to establish a pattern of behaviour of the business based on a particular policy or strategic investment decision. The System Dynamics (SD) approach focuses on feedback dynamics and patterns over time; hence it is appropriate for this study. This approach looks at levels of stocks and the flow between the stocks.

Similar to a closed-loop system, feedback is important in this approach. This is the case in an economic system where any policy intervention that is made, creates specific consequence over time. A decision dynamics process of a typical policy decision can be described by the decision loop in Figure 24. This process highlights the several delays that exist between policy decisions and actions, as well as delays between actions and feedback on the results of actions taken to the policy decision makers. The decision dynamics process described in Figure 24 also indicates the influence of the environment on the feedback, which should be taken into account when analysing the feedback.

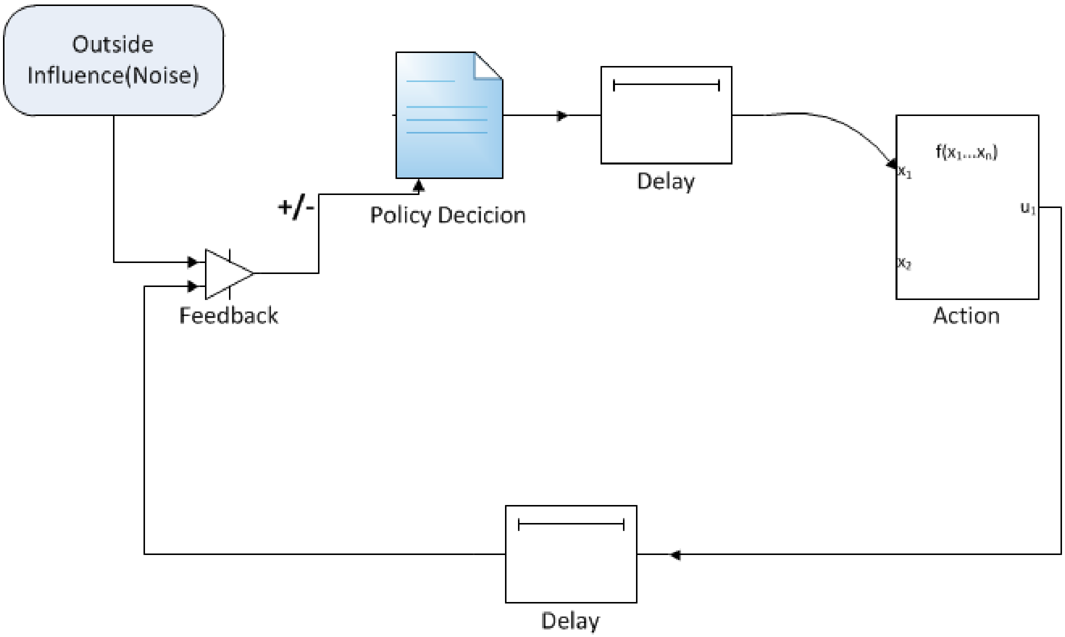
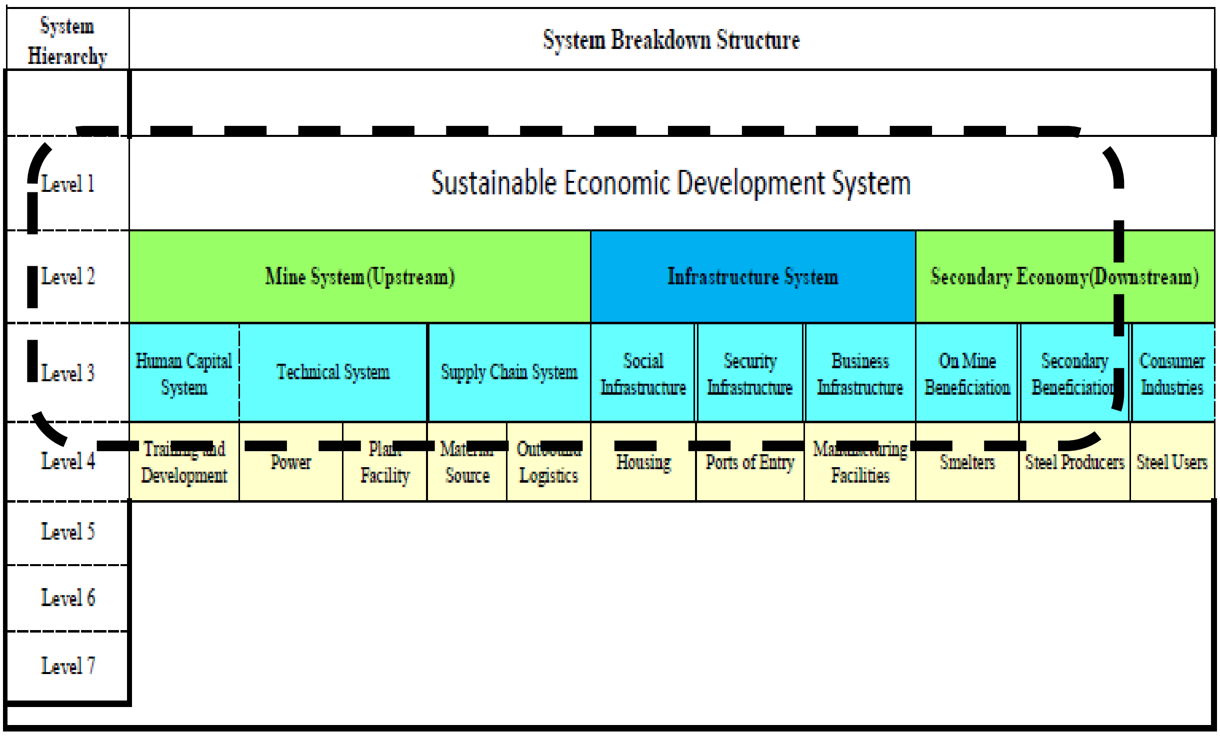


Figure 24: The description of a dynamic process of a single policy decision

3.2. Systems hierarchy and system boundary

A systems hierarchy of a sustainable development system describes the relationships of the system components across the system hierarchy. The system boundary of the system described in Figure 25 defines the battery limit for this study and is depicted by the thick dotted line. The model for the sustainable development is simulated based on factors at levels 2, 3 and -4 of the system hierarchy as indicated in Figure 25. The system boundary also limits the modelling of the system to the point of sale for beneficiated Manganese products to steel producers. The internal dynamics of the steel-producing industries are beyond the system boundary, and as such are not dealt with by this study.



System Hierarchy	System Breakdown Structure										
Level 1	Sustainable Economic Development System										
Level 2	Mine System (Upstream)					Infrastructure System			Secondary Economy (Downstream)		
Level 3	Human Capital System	Technical System		Supply Chain System		Social Infrastructure	Security Infrastructure	Business Infrastructure	On Mine Beneficiation	Secondary Beneficiation	Consumer Industries
Level 4	Training and Development	Power	Plant Facility	Material Source	Outbound Logistics	Housing	Ports of Entry	Manufacturing Facilities	Smelters	Steel Producers	Steel Users
Level 5											
Level 6											
Level 7											

Figure 25: System hierarchy of the sustainable economic development system

The overall model for the research will have the level 2 components as the state variables/ stocks. The modelling of the three components will focus on the dynamics of the level 3 elements to pre-determine their dynamic behaviour and the reference modes in the simulation. All level 4 elements of the hierarchy will determine the key inputs that determine the sensitivity of the system over the research period. These are the areas of change that would trigger a behavioural change and response. For the mine system simulation, power is one of the key cost parameters that is subject to change outside of the mining operators' control, and therefore triggers a dynamic behaviour in the mining value chain.

For the purpose of this research, dynamic modelling simulation is performed on the three key components of the research individually, in a structured approach. The approach ensures that the individual dynamic behaviours of these components are understood, to some extent independent of their relationship in the complete sustainable development model, which is the ultimate objective of the research. The key components in focus here are mining value chain, social development in an urban system and economic infrastructure development.

In completing the modelling of these three key components, an integrated model for sustainable development through mineral beneficiation is completed. A sensitivity analysis based on this and other parameters, such as logistics, cost and market demand variability, will determine a pattern of performance in a mine value chain that will indicate the independent behaviour of the mine value chain within a sustainable development system. This in turn would inform a decision to be made on the desired control over the source of the input. For instance, a decision to co-generate or source power from Eskom completely could be informed by the sensitivity performed during the simulation.

3.3. Modelling concept for a mining value chain and data evaluated

To understand a system such as a mine, it is necessary to create dynamic models to mimic the dynamics of the system in real life. The process of developing a model may assist in stimulating entrepreneurial thinking among community members. This is established around the systems thinking concept, which informs the view taken about a Manganese resources value chain. One of the areas where systems thinking has proven its value is complex problems that involve helping many actors see the “big picture” and not just their part in it (Aronson, 1996). The modelling approach taken is based on a differential equation. However, in performing the actual simulations, system dynamics software is used instead of analytical solutions.

Stocks and flow logic in Vensim founded on differential equation

System dynamics models are founded on the basic principles of mathematical modelling using discretized versions of differential equations. The graphical representation of stocks and flows in Vensim PLE simulation represent the discretised version of differential equations that are not always visible to the modelling participants, making it user friendly and easier to represent to a broader stakeholder base. In setting up the model, good understanding of differential equations and discretized versions thereof is important in order to maximise the power of the system dynamics simulations.

The concept of the simulations is based on the dynamic performance system that is meant to convert the mineral value of Manganese on the ground (Ore body) through a capital system (Mining activity) in order to derive economic value for the business owners, employees and community (human development) and contribute to the growth of the area. The economic value to the social system is represented through infrastructure development, human development and housing development variables. The Mineral Resource (Ore body) represents a somewhat fixed source of revenue for the business with a finite life.

The Manganese Ore body

The life of the Ore body is determined by two factors, the extraction rate and the exploration output. It should be noted that the exploration output can only increase the life of the Ore body by a fixed maximum life and should not be confused with infinite replenishment of the existing resource against continued extraction. It is not the aim of this study to demonstrate the effort required to produce the exploration output required to make the resource sustainable for an extended period. The dynamic monetary value of the mineral resource as an asset can be derived mathematically through a set of mathematical equations, from the basic equation representing revenue generation in a business, it follows that the Rand value of the Manganese sold is:

$R = VP$………… (1)

Where:

R is the total rand value of the Manganese resource
P is the price of the Manganese Ore per ton and
V represents the volume in tons of Manganese

But the value of an Ore body of the Manganese resource will take into consideration the depleted tons, and new tons, due to exploration results at any given time. Therefore the dynamic volume of the resource at time t is represented by:

$V_t = V_{t-1} + J_t - H_t$......... (2)

Where:

V_{t-1} is the volume (size) of the Ore body at time $t-1$,
H_t the volume of extracted Manganese Ore at time t
J_t is the volume (size) of added resource due to exploration results at time t and
C is integration constant

The Rand value of the Manganese Ore body $R_{(t)}$ at time t is mathematically represented in equation 3 as follows:

Substituting (2) in (1)

$R_t = P_t(V_{t-1} + J_t - H_t)$..........................(3)

The real value of minerals is only realised when tons of Manganese Ore are mined and sold to the markets. This happens over time where the price and volumes mined will vary for different time periods. The cumulative value earned from these mineral resources is therefore represented over a period $t-1$ to t as follows:

$R(t) = P(t)\int_{t-1}^{t}[\,V(s-1) + J(s) - H(s)]ds\,]$ +C ------------------ (4)

This equation represents the time related value created from the Manganese resource that is exploited.

Where:

$V(s-1)$ is the previous volume of Manganese in tons from time $t-1$

$J(s)$ is the additional ton from exploration activities at time t,

$H(s)$ is the number of tons extracted and sold at time t

$P(t)$ is the selling price of the resource per ton at time t.

The stock flow diagram in Figure 26 represents the graphical equation of a capital stock based on a resource extraction value. The stock flow model in Figure 26 , the though not the exact replica of the behaviour achieved with equations (4), can be used to describe the dynamic behaviour of a capital stock without the detailed mathematical equations, making it easier to describe the model to a diverse stakeholder group. It should also be highlighted that whilst the stock flow diagram in Figure 26 can be configured to describe the behaviour achieved with equation (4), a lot more equations beyond equation (4) would be required to match the number of causal loops possible in the stock flow diagram.

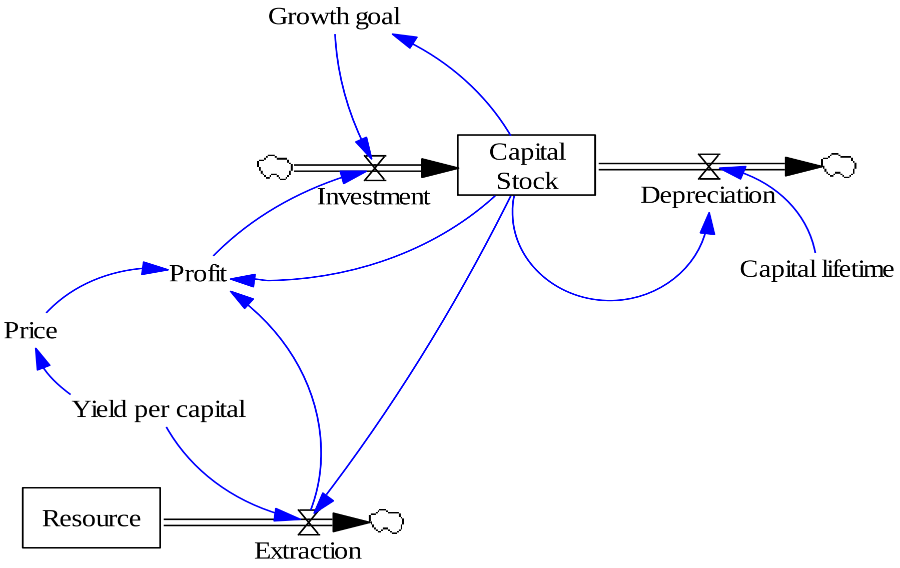


Figure 26: Vensim software configuration of the resource capital stock flow (Meadows, 2007:60)

Mining Activity

The mining activity, in the value chain, is the first opportunity for the mineral resource to be converted into real monetary value. Whereas the mineral resource is valued at a price per ton, the economic value D_t to the community or region is only added when the actual mining activity takes place. This is, however, subject to market demand M_t and inventory I_t at time t, both of which are dynamic in nature. This is described by expressions 1 and 2 as follows:

$$D_t = Q_t K - v_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where:

D_t is the value of the mineral resources accumulated through the mining activity or process at any given time t and

Q_t is the mining input at time t

K is the conversion factor from input to output v_t

v_t is the output of the mining process

Mining input Q_t is dependent on market demand M_t at time t. It is also necessary to consider that the transient nature of the markets is that the markets do not always consume all the production; hence mines will sometimes end up with a certain level of product inventory I_t. Therefore:

$$Q_t = M_t - I_t \ldots\ldots\ldots\ldots \text{(2)}$$

Substituting 2 in 1

$$D_t = (M_t - I_t)K - v_t \ldots\ldots\ldots \text{(3)}$$

An additional variable, which is cost C_t of mining and selling to the market, is introduced at this stage. The cost incorporates fixed and direct cost, both of which may require further simplification, since each input type may have different dynamic characteristics over time. The real dynamic due to the conversion of the mineral is related to the volume of Manganese produced v_t at any given time t

Considering all the information established earlier, it can be concluded that the actual revenue creation from the Manganese reserve over time is largely dependent on three variables: market demand, product inventory and the resultant volume sold.

Equation (4) summarises the production scenario for a mining revenue creation over time.

By substituting equation (2) in (3) we find that:

$$D(t) = KP(t) \int_{t-1}^{t} [M(s) - I(s)]ds - \int_{t-1}^{t} v(s)ds + D(t-1) \ldots\ldots\ldots\ldots \text{(4)}$$

The stock flow diagram in Figure 27 represents a dynamic equation that can be used to achieve similar behaviour as what is described in equation 4 with inclusion of a broader set of stakeholders. The ability of the software to embed mathematical equations in the in the graphical objects used in the stock flow diagram makes it possible to described more complex behaviour that would require multiples of equations beyond what is described in equation (4).

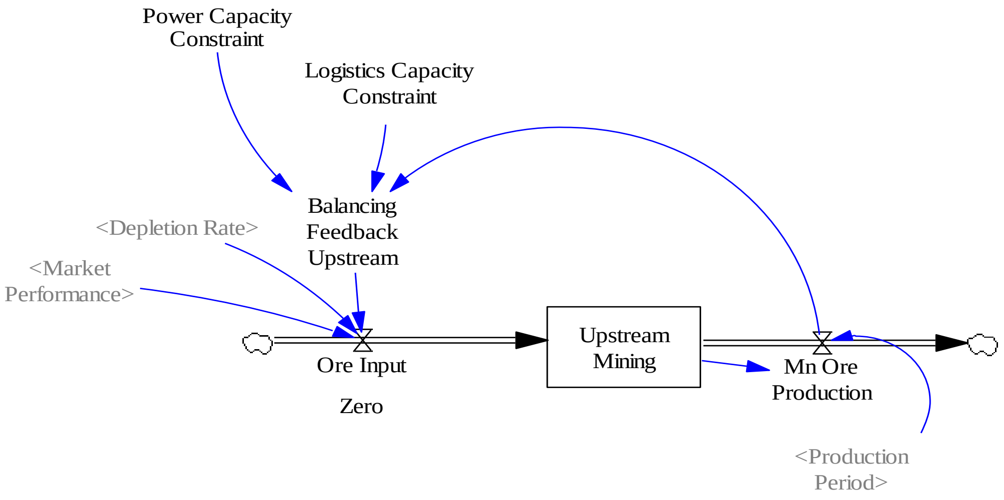


Figure 27: Stock flow diagram for a mining production activity

Description of flows (variables)

The following are the most critical dynamic variables in mine simulation model:

- Ore extraction is the rate at which the raw Manganese Ore minerals are processed through the mining capital asset. This is a manipulated variable and is dependent on the market demand and the capacity of the mining capital asset to process Ore through the Manganese resources value chain.
- Input and Logistics cost - This is a measure of the cost dynamics that are driven by markets beyond the control of the mine operators. The cost of power, water and logistics are all considered as an input to this variable.
- Human capital development - is measured by looking at the number of people employed in the mining value chain. This is based on the assumption that, when people are employed in the system, they either develop new skills or enhance what they already have. Any growth in this number of skills influences the ability of the area to attract new development.
- Capital Efficiency is a measure of how the mining asset generates revenue based on a ton of Manganese Ore extracted from the ground.
- Market demand is a measure of consumption of the Manganese products by the industry.

3.4. Social development and economic infrastructure

At the heart of any economic growth there is bound to be a sound economic infrastructure that enables the flow of economic activities. Fourie (2006:531), citing Hirschman, defines infrastructure as capital that provides public services. The sustainable development model is equally dependent on infrastructure development. Also referred to as social overhead capital (Fourie, 2006:531), this is an area where research can be conducted to impact on important policy implications (Munnell, 1992:196) The system dynamics model of an economic infrastructure simulates the impact of policy decision in mining beneficiation towards stimulating growth of infrastructure, and the knock-on effect on secondary industry growth.

The social development dynamics, in an urban development model, describes the behaviour of a socio-economic system when certain policy decisions are made. The impact of urbanisation and economic migration is modelled against the pull effect of new mining development and existing operations. Similar work was done by Forrester (1969) in the system dynamics modelling of the Urban Dynamics in the 1960s. Kularatne (2010:2) also highlights in his work that infrastructure investment is deemed to increase the growth of an economy as it increases the economy's productive capacity. The work done by Forrester (1969) and Kularatne (2012), though at different times, can be used to demonstrate the similarities in the long-term impact of human development policy decision around the mining communities, both in the short- and long-term. The unique nature of economic migration in the South African environment is modelled to recognise the difference that the level of relevant skills can introduce constraints towards developmental activities.

3.4.1. Critical variables of economic infrastructure and social development

The key aspects of the system dynamics modelling proposed in this research include trading off industrial policy against social development policy. Zoning of economic land for residential use will have an impact on both people living in that area and the ability of business to attract the right resources into the area. The "obvious" policy of building low-cost housing, in the hope of alleviating poverty, occupies land that could be used for job-creating business structures, while at the same time the creation of low-cost housing attracts more people who need jobs (Forrester, 2009). The skills levels in the mining community often come from the constant training of local residents. The model demonstrates how sustainable development of an area can be achieved or compromised by the various policy decisions.

The following are the most critical dynamic variables in the economic infrastructure and social development model simulation:

- Relative Attractiveness: measures the level of job opportunities against available capacity of the area to maintain the opportunities and the services that make it attractive. This is a manipulated variable and is dependent on the increase or decrease in business activity levels in the area.

- Rail logistics and other infrastructure investment levels: this measures the level of investment into the rail infrastructure as a percentage of GDP. The cost of doing business, and the capacity of the economy to grow, depend on the availability of the rail network to transport goods to the markets and people to the work places.
- Human capital development: measured by looking at the number of people employed. This is based on the assumption that when people are employed in the system they either develop new skills or enhance what they have already. Any growth in this number of skills influences the ability of the area to attract new development, due to a higher job to skills ratio.
- Inward/outward migration: inward migration is used as an input to the model to determine the feedback of the simulation and the impact on relative attractiveness.

The variables discussed in section 3.4.1 are not exhaustive of the stocks and flows that are configured in the proposed system dynamics model. However, they are critical and often least anticipated (in magnitude and measure of impact) when investment decisions are made.

3.4.2. A concept of an economic evolution of a city driven by mining activities

The investment in infrastructure determines the ability of the economy to get goods through to the market, and in time, making the economy more efficient as demonstrated in the works of Chandra on impact of highways on regional economies (Chandra *et al,* 2000:478). The caution in Chandra *et al* (2000:479) is that infrastructure investment only benefits relevant industries and areas and should not be seen as an automatic solution to lack of economic growth. By growing a demand for goods from the economy, other industries may develop, attracting more skilled people into the area. The growth of an alternative industry may, in the long term, replace primary industries to achieve a sustainable development that is independent of mineral resources. Munnell (1992:197) finds that in addition to immediate economic stimulation, public infrastructure investment has a significant and positive effect on output and growth**.**

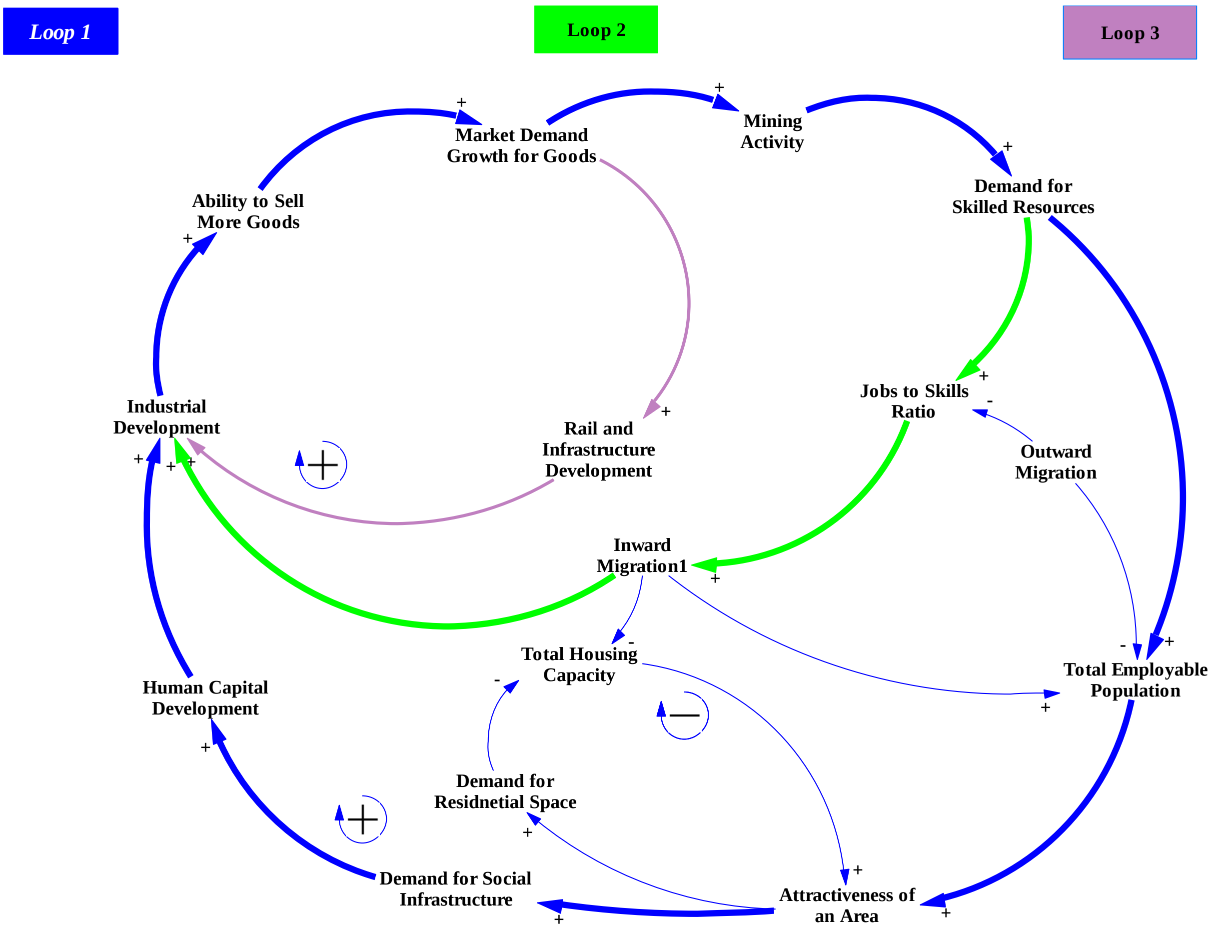


Figure 28: Business-infrastructure causal loop in a mine driven economy of a South African city

Figure 28 shows a proposed concept of a city's economic development through three emerging loops, based on mining-driven economic activities. The emergence of the loops will depend on the policy decisions that are taken. The concept described in Figure 28 suggests that, at any given time, all three loops will exist, albeit in different measures. The desired state is achieved when there is dominance of "Loop 1" in the system, where there is balance between demand for social services and the ability of the economy to attract high-end professionals with high income. This may only be achieved when there are conscious decisions to invest in infrastructure as indicated in Loop 3. The emphasis of the proposed concept is based on all three loops being active simultaneously.

The three loops are described below

Loop 1 (*Mining activity--Demand for skilled resources--Attractiveness of area--Demand for residential space—Demand for social infrastructure--Human capital development--Industrial development--Ability to sell more goods--Market demand growth*)

This loop represents a feedback pattern of the social and economic development that is created through the existence of a mining activity in the area. Due to the nature of input requirements, the mining activity creates a new set of skills in the community and also stimulates demand for a support industry such as logistics, engineering support and services industries. The extent to which mining activities alone can stimulate these industry developments is subject to the volume of requirements for services and the Rand value created by the transactions. The modelling exercise establishes the extent to which dynamics and volumes, in the mining activity, influence the feedback described in the loop. This loop only reflects the dynamics created by upstream mining alone.

Loop 2 (*Market demand growth-Mining activity--Demand for skilled resources-Jobs to skills ratio increased--Inward migration-- Industrial development--Ability to sell more goods--Market demand growth*)

This loop represents the secondary benefits in the social development of the economy due to continued involvement of the communities in the mining industry. When people join the mines they, over time, develop new skills. New skills also become attracted to the area due to the opportunities created by mining activities, leading to inward migration of people. The skills to jobs ratio of the area increases and so does the industrial development of that area. A significant and the primary driver of this feedback loop remains the mining activity

Loop 3 (*Market demand growth--Rail and other infrastructure development--Ability to sell--Market demand growth*)

> This loop represents the emergence of more infrastructure-stimulated business activities. The direct impact of mining is underplayed in this loop. This loop represents the new ability to create and move goods through established logistics and engineering infrastructure. The engineering tools and equipment that are produced to support mining activities can also be sold to other industries and outside markets in general.

All three loops discussed above represent an evolution of a town, city or region when mining activity is used to stimulate growth. It is believed that there is a threshold at which evolution from the first loop to the second and third loops becomes sustainable. In describing the basis for the system dynamics model simulation, the research relies the causal loops described in Figure 28 and the previous work linking infrastructure and economic development by Perkins *et al* (2005) and most recently*,* conclusions by Kularatne (2010:2) that infrastructure investment is deemed to increase the growth of an economy, as it increases the economy's productive capacity.

3.5. Conclusion on research concept

The analysis of the economic development system, in a mining and mineral beneficiation industry, is not straight forward. Like any system in the soft operation research, the dynamic behaviour of these systems makes them difficult to analyse and solve using a more traditional reductionist approach. Barile *et al* (2011:6) also point out that system logic is centred around the principle of interdependence, which describes the relationship between variables where variation on one variable reflects on the other(s). Barile et al (2011:6) emphasise though that the effect of changes are seen on the outside of the system however the actual change happens within the system.

While the systems thinking concept is useful in describing the causal relationship between variables/components of the system, the use of a system dynamics modelling simulation allows the research to identify patterns from any policy interventions both in the short and long term. The key point is that the model possesses similar dynamic behavioural characteristics to the real system, subject only to accuracy and detail associated with the perceptions and objectives of the managers who create it (Fowler, 2003:142).

The strength of using system dynamics modelling allows policy makers to develop these patterns, by trial and error, while experiencing the feedback of their policy decisions without the reality that would be in a practical world. Dynamic systems are also characterised by delays or inertia, which, in the physical world, are often so small that they appear non-perceptible to the human sense. However, in a particular case of management systems, such near-instantaneous responses are rarely if ever present; thus delays and inertia are usually considerable and sometimes even measured in years (Fowler, 2003:137)

Due to the level of abstraction and the macro-level nature of the system being studied, a system dynamics modelling approach was chosen. The feedback mechanism that system dynamics provide in the Vensim tool makes the tool relevant for the simulation of policy intervention in the Manganese mineral beneficiation scenario analysis. The Vensim tool is built on the strength of mathematical modelling through differential equations. However, the platform creates an interface that is user friendly for a broader stakeholder group. The presentation of a predicted future scenario can therefore provide foresight rather than having to wait and see how the real system actually behaves (Fowler, 2003:143)

The objective of this simulation is to establish patterns and not exact figures, and the level of detail is limited to a business unit level. The part components of the systems hierarchy are used to determine the system boundary of the research and the extent to which the dynamic simulation is evaluated. Whilst the individual behaviours of the three sub-systems (mining operations, social development and economic infrastructure) may be understood and implemented in the region and in the country, the concept of this study is meant to establish the combined behaviour of the three sub-systems in a system dynamic simulation. .

The model stocks/state variables are based on the component level dynamics of the system in the hierarchy at systems level 2 as described in Figure 25. The modelling of the three components is focused on the dynamics of the level 3 elements to pre-determine their dynamic behaviour and the reference modes in the simulation. All level 4 elements of the hierarchy determine the key inputs that determine the sensitivity of the system over the research period. It is acknowledged in the study and the planning of the model that, whilst a mine is a system on its own, it is part of a bigger system, and more levels of systems can be described to the point of total confusion about the boundary of the system

A two-staged simulation approach was taken in conceptualising the modelling simulation. The first simulation was aimed at determining the dynamic behaviour of the Manganese resources value chain, based on three value chain scenarios, and in the process describes the initial formation of the economic system. The information coming out of the first simulation is then used as input to establish the second model, which seeks to complete the triple bottom line of the mining, social and economic components of a sustainable system. The objective is to establish combined-systems behaviour, and to determine the sustainability potential in a Manganese mining-driven economy, such as the Northern Cape's Kalahari basin.

A system boundary for the research was necessarily defined to limit the influence and feedback of the system on policy intervention to the area being studied. The dynamic behaviour and the influence of a policy decision is limited to levels 1-4 of the system hierarchy, where the system dynamics tool is most suited to establish patterns of behaviour of the system over time.

The concepts described in this chapter are used to develop the appropriate research and simulation design methodology. The discussion of the methodology used to complete the research process is described in Chapter 4.

4. Research methodology

4.1. Introduction

The focus of the research is to enhance the understanding of the mining dynamics during production, and the dynamic relationship between mining activity and other sectors of the economy surrounding the industry, such as manufacturing, housing and infrastructure development in the areas where mining takes place. The research is based on applied research methods (Page *et al*, 2005) and has taken a descriptive approach in creating an understanding of the beneficiation challenge in the Manganese mining industry in South Africa. A quantitative approach is taken, using published industry input parameters for mining cost and production performance, to determine the parameters for the system dynamics model. The system dynamic methodology is used to develop theory, simulation and verifying and validation of results. Rodriguez-Ulloa *et al,* (2005:305) correctly identifies the system dynamics methodology as comprising of three steps as follows:

- problem identification and definition,
- model building/conceptualization and
- simulation

The research accept Rodriguez- Ulloa *et al (2005)'s* description of the approach as described above and is reflected in the research method with more focus on model building and simulation.

Conducting the simulation of system dynamics models can help in exploration, elaboration and extension of simple theories (Davis *et al, 2007:*484). As Davis *et al, (2007:*484) rightfully argues simulation is central to the implementation, verification and validation of the theory developed in this research. Citing Axelrod and Waldrop, Harrison *et al* (2007:1230) argue that simulation is recognised as a third way of doing science after the historical methodologies involving theoretical analysis or deduction and empirical analysis or induction. Harrison *et al* (2007:1231) further argue that simulation resemble empirical analysis in that relationships between variables may be inferred from analysis data produced from programs rather than being obtained real life observations. The power of simulations lies in the consistency of computation using numerical methods embedded in the simulation software.

An appropriate and extensive review of the literature on system dynamics, and systems thinking publications, was undertaken to form a basis for conceptualising the data gathering process, and parameter setting for the system dynamics model. The literature search was used to address questions raised in the problem statement defined in Chapter 1 of this report. The objective of the literature search, in system dynamics modelling was to define a model that would enable policy makers to simulate the impact of policy interventions on sustainable development in the Manganese mining industry, both in the short- and long-term.

The system boundary for the system dynamics simulation model is limited to the John Taolo District Municipality, which include the towns of Hotazel, Kuruman and Sishen. Power and Logistics infrastructure, such as rail, are the major input variables from which the sensitivity analysis of the socio-economic model is performed.

Data related to social structures, in and around the John Taolo District Municipality, was collected using an interactive method which included interviews with experts. Statistical data from Statistics SA (SSA, 2012) was used to establish parameters for building the system dynamics model. Mining data was collected through Industry forecasts (CRU, 2011) and Statistics SA (SSA, 2012)

System dynamics simulation was adopted as a method used to establish the difference in economic performance between the three value chain stages of the Manganese industry. In their assessment of research articles that are based on simulations, Harrison *et al* (2007: 1232) found that a significant proportion of simulation articles in the social science journal between 1994 and 2003 were in the economics and political science journals, confirming that simulation has been used a lot as a methodology in research and problem solving. The system dynamics simulation model was developed to perform a comparison of the three Manganese resources value chain scenarios. A system dynamics model of the capital growth, with reinforcing and balancing loops from the work of Donella Meadows (2007) was used as a basis for developing the Manganese resources value chain system dynamics model in this research.

The design of the system dynamics model is founded on principles developed through a number of historical system dynamics models which include the works of Jay Forrester (1969, 1971, 2009), Donella Meadows *et al* (1970, 2007), John Sterman

(1997) and Saeed (2010). In a recent PhD thesis, Van Dyk (2013) successfully used the system dynamics model and simulation through Vensim to generate research data. In his work van Dyk (2013) relies on the theory developed by John Sterman (2000) on interaction in allocating resource time between process improvements and production performance. At the core of the system dynamics model are the fundamental structures of a mining operation and the position of the mining industry within the structure of the South African economy.

The preferred scenario from the Manganese resources value chain comparison was used as an input to the socio-economic system dynamics model. The socio-economic model is designed to test the working hypothesis, which says: that infrastructure development drives economic growth and sustainable development of an area concerned. This is done by implementing logic in the system dynamics model that tests the attractiveness of an area to business and people, based on the working hypothesis.

The principle of relative attractiveness defined in the urban dynamics model Forrester (1969) and Saeed (2010) is used as a basis for the simulation of infrastructure development impact on socio-economic development. Whilst attractiveness as a place to live is taken as a function of availability of suitable housing and employment, attractiveness of business is assumed to be a function of availability of suitable premises and access to suitable workforce, supplier and customers (Swanson and Gleave, 2008).

Verification of the model design and implementation is essential in creating confidence in the performance of the model. The nature of system dynamics permits many tests of model structure and behaviour not possible with other types of models (Forrester and Senge, 1979:4). In order to perform the model on a common universe of units or equivalents, the simulation and the analysis that follows in Chapter 6 of this thesis is based on the revenue and cost impact of the system’s dynamics. All the variables simulated and analysed are expressed in relation to cost and revenue as a function of currency of time.

The research focused more on the dynamics of variables impacting on cost and revenue, as opposed to the detailed make-up of those variables. The units of all the variables, in the equations used by the system dynamics model, were checked for consistency across the model as part of the verification method. This method ensures balance of the left and the right hand side of the equations in the system dynamics model.

Validation of the system dynamics model is a critical step in the methodology adopted in conducting the research. According to Sterman (2000), the aim of model validation is to determine the usefulness of the model for the purpose for which the model was designed in the first place. It is the objective of this research to produce a framework that can be repeated in studying the dynamics of other mineral commodities, albeit with commodity-specific adjustments.

The validation of the system dynamics model was done by comparing the results of the model with existing patterns in published Chrome value chain results in South Africa, and in other European countries. The patterns established in the results of the system dynamics model are also compared with the results of the previous work in urban dynamics by Forrester (1969) and Saeed (2010).

4.2. Research method

Complex systems can evolve from simple systems only if there are intermediate forms; the resulting complex forms should naturally be hierarchic (Meadows, 2007:74). Forrester (1973:12) argues that, in order to model the dynamic behaviour of a system, four hierarchies of structure should be recognized, and these are: 1) the closed boundary around the system, 2) Feedback loops as elements within the structure of the system, 3) State variables representing accumulations within the feedback loops, and finally 4) Flow variables representing activity within the feedback loops. Whilst acknowledging the multiple variables that drive the sustainable economic development of a region like the John Taolo region in the Northern Cape, this research has identified mining as the dominant sector for the purpose of the simulation.

The method adopted for this research was simulation based and aimed at establishing the patterns of behaviour and influence on the sustainable development in the Manganese resources value chain, by a selected number of input parameters. Simulation is part of the methodology used in this research and it represents the computational creation of the theoretical logic that links constructs together within the simplified world (Davis, Eisenhardt, & Bingham, 2007). This was achieved by using the system dynamic modelling process described by Sterman (2000). The published works of Forrester (1969, 1971), Schumpeter (1962), Meadows (1972, 2007) and Saeed (2010), on system dynamics, were also reviewed and used as the basis for development of a system dynamics model. The system dynamics modelling process followed an extensive literature search process in the field of systems thinking and system dynamics.

Input cost and industry specific performance data collected, are from the South African Manganese industry and used to configure base parameters for the system dynamics model. A random function generator is used within the simulation software platform to generate fluctuation that emulates some dynamics of the environment within which Manganese mining is conducted. The mean value of the data population collected per parameter is used as a mean on the random function generator. White noise was chosen for all the variables in the random-function generator.

Based on the principle of relative attractiveness, and building from it, a working hypothesis is created upon which the model is set up for the socio-economic model. A feedback structure is created in the system dynamics model to allow the influence of the environment, within which Manganese mining takes place on the dynamic behaviour of the model.

To analyse the impact of variations in the input parameters, a multi-variate method o Monte Carlo of analysis is used. Although it is not a built in function of the systems dynamics model, the univariate method of analysis is used to determine the impact of independent input variables on the performance of the Manganese resources value chain system by altering single variables during simulation. The multi-variate analysis method is used to determine the dynamic impact of uncoordinated changes in multiple variables linked to the Manganese resources value chain and the socio-economic system.

The dynamic patterns observed in the results of the socio-economic system dynamics simulation are compared with the outcomes of previous system dynamics models performed by Saeed (2010), and the historical trends of similar relationships in the South African environment (SARB,2011). This is done to validate the results of the system dynamics model. Historic industry data (SAMI, 2011) and industry forecasts (CRU, 2012) are used to create the necessary dynamics in the system dynamics model to simulate the policy impact of these dynamics on the system.

4.2.1. Formulating the problem and selecting the system boundary

A selection of key input drivers of the Manganese resources value chain performance and infrastructure performance is used to determine the impact of changes in the mining environment on the performance of the industry, as a part of a socio-economic system.

Responding to the problem statement

In the problem statement discussed in Chapter 1, the research raised a number of questions, and these are summarised as follows:

- What are the key drivers of sustainable economic development in a Manganese mining context?
- What are the key systems challenges that prevent sustainable economic development in the South African Manganese mining industry?
- Is there a balance in approach between short-term policy interventions and long-term sustainability of the Manganese minerals industry?
- Is there a case for a systems-thinking approach in dealing with the sustainable economic development challenge in South Africa?
- What influences the development and performance of the Manganese resources value chain in the South African economy?

- Is there any causality between infrastructural developments and sustainable economic development through mining?

To address the questions raised in the problem statements above, a good understanding of the feedback from the Manganese resources value chain performance, and the impact of infrastructure development on the sustainability of economic development in Manganese driven economy, was required. The operation of a Manganese resources value chain, along with its dynamic input and output performance, was identified as an important factor in the formulation of the problem statement.

The performance of the Manganese resources value chain under varying market and environmental conditions needs to be understood. A simulation platform is required that will allow the modelling of the Manganese resources value chain and the socio-economic environment, where the dynamic impact of various input dynamics could be modelled.

Concepts considered

A systems thinking theory was used in the research to describe elements, system boundaries and relationships between the elements of the system (Jackson *et al*, 2001), for which the model was going to be developed. It is based on the theory and the levels of systems hierarchy that the level of detail in the construction of the mine, and economic infrastructure development, was described. The model focused on higher, macro levels of mine activity, housing development, human development and infrastructure growth, and their relationships as opposed to focusing on the details of economic evaluation of a mining project on which a typical investment research would focus.

The work of Peter Senge (1990) in the fifth discipline, and Donella Meadows (1972, 2007) on limits to growth and thinking in systems respectively, formed the view on the effect of natural limits and appreciation that, whilst exponential growth can be achieved through investment in mining facilities and technology, this may be limited by the ability of the surrounding ecosystem to support such growth. This emphasis finds congruence in the principle of inter-dependence in which Peter Senge (1990), in his work in the “fifth disciplines”, sees systems existing in a web of inter-dependence.

The advantage of using a feedback loop

As illustrated in Figures 29 and 30, there may be a significant difference in the perceived capability of a production facility, or a mine, when other environmental constraints are factored into the simulation of production over a longer period, versus a simulation that looks at the facility or a mine as an open loop system. In the first system dynamics model (in Figure 29) where there is no feedback connected to the model, Mn production output presents a continuous growth pattern that seems to accumulate to just below 150 million tons of Mn product, compared with only 100 million tons in Figure 29. Here the limitations of available electricity and logistics capacity are used to regulate production, based on feedback. The system dynamics model and the software platform used, allows the proponent to configure this essential dynamic in the system dynamics model to determine the integrated impact of the variables in a dynamic environment.

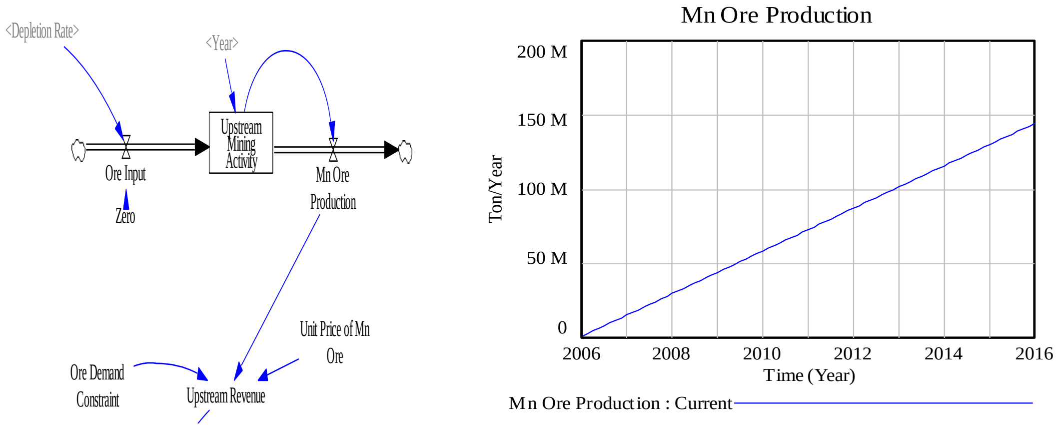


Figure 29: Manganese mining without power and logistics constraint feedback

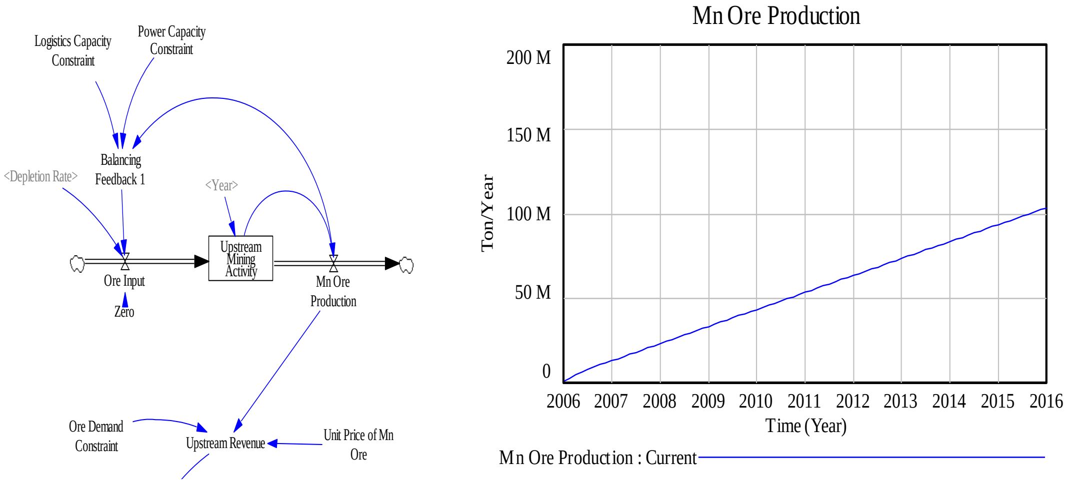


Figure 30: Manganese mining with power and logistics constraint feedback

Due mainly to its ability to consider the dynamic behaviour of all variables, allowing the model to be configured as a closed feedback loop system, the system dynamics modelling method is used in the research.

Simulation horizon and key variables

The timeline selected for the simulation is a 10 year period, chosen as the period between 2006 and 2016. In the simulation, all data and calculations from 2006 to 2011 are considered historic, whilst data for years 2012-2016 are based on forecast. In the validation of the model, trends of industry performance will include trends from 1990 to 2010. This is limited to socio-economic performance reported from the South African Reserve Bank (SARB) and Statistics South Africa (SSA)

The list of variables in Table 5 is critical and is the subject of the system dynamics model simulation, and further descriptions in Chapter 5 of this report.

Table 5: Key variables considered in the research

Variable	Unit of Measurement	Description
Balancing feedback	Dimensionless	Feedback of input constraints considered in evaluating the throughput

		capacity of the Manganese resource value chain scenarios in the model.
Capital Efficiency	Rand/Ton	The economic measure of returns earned for every ton of Manganese Ore mined
Revenue	Rand	Revenue earned on an annual basis from Manganese resource value chain production
Infrastructure Capacity	Rand	The measure of potential investment in economic infrastructure that can be influenced by Manganese resource value chain activities.
Relative Attractiveness	Dimensionless	An index devised to measure the extent to which business enterprises and a skilled workforce are attracted to the area
Skilled workforce	Person	People with relevant/necessary skills to complement business activities in the area.

Principles and concepts adopted

The model for economic development adopts the principles developed from the works of both Forrester (1969) and Schumpeter (1962) in “Urban Dynamics” and “Capitalism, Socialism and Democracy” respectively. The two concepts developed from the two studies are the principle of “relative attractiveness” from Forrester and the “cycle of creative destruction” from Schumpeter respectively. The system dynamics model in the research is designed around these concepts. As described by Saeed (2010), when he drew similarities between the works of Schumpeter and the Urban Dynamics work of Forrester, the delays in the system, when growth is happening, create oscillations as more growth efforts experience corrections that result in the oscillations that Schumpeter described as the “cycle of creative destruction “.

The Boundary of the research

The system boundary of the research, and the parameters for the system dynamics model simulation, are limited to the John Taolo Gaetsewe region in the Northern Cape Province, where the Kalahari basin with an estimated 80% of the world's Manganese reserve is found (SAMI, 2009). The resource commodity selected for the research is Manganese, and the simulation will focus on modelling the dynamics of the Manganese resources value chain and the socio-economic environment around it. The boundaries of the Manganese resources value chain are determined by the value chain from the mining of Manganese Ore (upstream mining) through the sintering stage (primary beneficiation) and smelting process (secondary beneficiation). Early exploration and further downstream beneficiation of Manganese, and associated industries, are not included in the system boundaries for the research and the system dynamics model simulation.

4.2.2. Formulating the hypothesis

Current theories

Forrester (1969) looked at the growth and stagnation dynamics of towns and cities based on policies towards the use of land in constrained areas. Forrester's model described policies which encouraged construction of new enterprises by replacing aging infrastructure. The principle that came out of this work, which was adopted in this research, is the principle of relative attractiveness, which states that "no place that is attractive will stay attractive forever".

Schumpeter's work describes growth that is possible through entrepreneurship achieved in a declining capital system. He describes two types of investment as autonomous (due to technological development and its demand on capital) and induced investments (which are due to the supply demand gap). Schumpeter's work describes the changes in cycles where over-investment in infrastructure, due to delayed feedback in the supply and demand gap, may lead to a lot of the infrastructure becoming obsolete. According to Schumpeter, this may create an opportunity for innovation and entrepreneurship to develop, using this system, or, through replacement of this obsolete infrastructure, to make way for new entrepreneurial development in a constrained space.

Initial hypothesis

The first concept regarding the Manganese resources value chain about sustainable development is that beneficiation of the minerals will create more value and increase employment opportunities (DMR, 2004)

The second concept is that, the relationship between infrastructure development and economic growth goes in both directions (Perkins *et al*, 2005).

The third concept is that the maintenance and expansion of infrastructure are important dimensions of supporting economic activity in a growing economy, provided that individual projects are chosen on the basis of appropriate cost-benefit analyses (Perkins *et al*, 2005).

When analysed together, the three concepts led to a single hypothesis for the research, which the system dynamics model simulation will seek to address. The literature reviewed also captured conclusions from previous works of Saeed (2010), Schumpeter (1962) and Forrester (1969, 1970, and 2007), all of which support the hypothesis in concept.

The dynamic hypothesis for the system dynamics model simulation

Oliva (2002:552) describes Dynamic Hypothesis as the theory that explicitly articulates how structure and decision policies generate behaviour. This thesis uses causal loops described in Figure 31 to define the structure that articulate the behaviour of a socio-economic system in minerals driven economic system. From a Manganese resources value chain assessment, the most appropriate scenario is selected for the simulation of a socio-economic model, where the relationship between infrastructure development and economic development is tested. The impact of increased economic growth on employment levels and sustainable development is not a linear relationship, and has many dynamic variables and feedback loops, as indicated by the causal diagrams in Figure 31. The causality diagrams describe in essence the hypothesis to be tested through the system dynamics model simulation, which forms the basis for this research proposition.

Causal diagrams and loops

The causality diagram in Figure 31 describes the logical relationship between mining activities in the Manganese resource value chain and the socio-economic structure of a region such as the John Taolo Gaetsewe region. The diagrams also highlight the existence of forward and backward feedback loops between various activities within the causality diagram.

In the causality diagram, for instance, “Inward Migration” as a socio-economic variable, is positively influenced by the existence of mining and beneficiation activities. However, “Inward Migration” increases the pool of “Total Employable Population” in the area which, in time, may have an impact on the “Area’s attractiveness” of the area to both skilled workforce and business enterprises. These logical links, and others, depicted in the causality diagram, form the basis for the dynamic hypothesis for the system dynamics model for economic infrastructure development, created in this research.

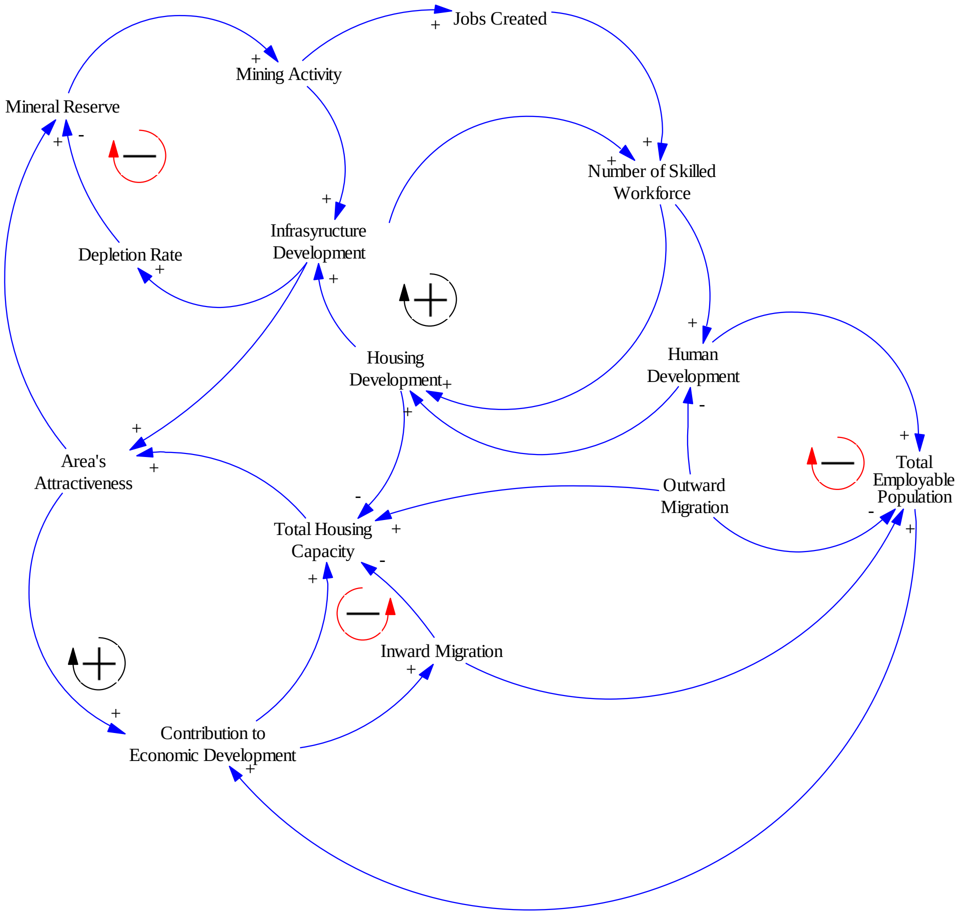


Figure 31: Causality diagram in a Manganese resource driven socio-economic system

4.2.3. Formulation of the system dynamics model

Model specification

The Vensim system dynamics simulation software provides advantages in terms of configuration of equations for the stocks and flows. The structure of the system dynamics model used in this research uses stocks as accumulation levels where the integration functions are performed, whereas flows provide the instantaneous changes in inputs to represent those environmental realities surrounding the systems being modelled. The equation editor in Vensim provides the capability required to configure the dynamic behaviours in the model. All the stocks or the state variables in the Vensim platform were defined, using the integral function based on Runga-Kuta (RK4) integration method. All flow rates were treated as auxiliary variables and were calculated outside of the integration cycle. The system dynamic model is based on an instantaneous change of the model parameters from the initial condition.

Initial conditions

A list of selected initial conditions for the system dynamics model simulations based on data gathered as indicated is presented in Table 6.

Table 6: Initial conditions and parameter values for the system dynamics model

Parameter	Unit	Value	Source
Manganese Resource	Ton	4000 million	(SAMI, 2009)
Power Capacity	Ton/Year (equivalent)	11 million	(Eskom, 2012)
Logistics Capacity	Ton/Year (equivalent)	11,4 million	(Transnet, 2012)

4.2.4. Method of analysis

The results of the system dynamics model simulations are subjected to a sensitivity analysis by varying both single independent variables and simultaneous variations in multiple input variables. These variations are meant to emulate the real Manganese industry conditions as far as input cost and market dynamics are concerned. The Monte Carlo technique in the Vensim simulation software is used to analyse the impact of various input variables (multi-variate) on the systems being modelled in a collective manner.

The form of analysis is focused on multi-variate analysis of variance (MANOVA). This functionality assists in establishing the performance patterns of the system under multiple uncertain conditions. The results of the system dynamics model simulation are not subject to any form of regression analysis, since the focus is not on the importance of difference in weighting of the independent variables. Instead, the results are benchmarked against a selection of similar mining and mineral resources beneficiation value chain results in other parts of the world.

The data from the benchmarking exercise is used to fit the result of the model into a technique similar to a Confirmatory Factor Analysis (CFA) described by Herve Abdi (2003). Based on the simulation results and supported by the concepts of “relative attractiveness” and “creative destruction” discussed in a previous section, a framework for sustainable development through Manganese beneficiation is proposed.

4.3. Modelling and simulation objective

Modelling is defined as a simplified representation of a complex entity or process (Franklin, 2005) and this is generally the most cost-effective way of testing the impact of policy intervention in a socio-economic system. The system dynamics model is based on a Runga-Kuta Integration of a systematic relationship between the fundamental components of the sustainable development system. The primary objective of the system dynamics model is to represent the dynamic relationship of the

Manganese resource to the socio-economic development structure that generally exists in a South African mining-led economy.

Franklin (2005) defines simulation as an imitation of some real device, or state of affairs, which attempts to represent certain features of the behaviour of a physical or abstract system by the behaviour of another system. The system dynamics model simulation is set up to imitate the dynamic impact of variations in input cost parameters and socio-economic changes affecting the performance of the mineral resources industry, and, by implication, the path of sustainable development. The sustainable development dynamics simulation is performed to establish and demonstrate the dynamic behaviour of a typical city development, and the impact of economic infrastructure on the attractiveness of the region in the system boundary.

This is useful in this research because the aspect of sustainable development that is simulated is of a very large economic scale in real life, and it requires observation over a long period of time.

4.3.1. Basis for the system dynamic modelling

A four-step approach called the four C's approach, advocated by Alexander Roos (Roos, 2000), was adopted in the design of the system dynamics model. This approach is based on comparison (with other situations), consequences (implications for decisions), connections (how a bit of knowledge or parameter links to others) and conversations (what other stakeholders think about the information). The system dynamics model simulation was built on a Vensim software platform (Vensim, ca 2010).

While historical industry data was used to establish previous patterns of behaviour, expert knowledge was elicited through interviews with selected Manganese industry experts to form a basis for the system dynamics model structure, in relation to the structure of the industry. Interviews were also conducted with selected agents from the property and community development organisations. The review of similar mineral resource value chain structures was also conducted in preparation for the design of the system dynamics model.

4.3.2. System dynamics model parameters

The simulation process follows a two-phase approach. The first phase focuses on three Manganese resources value chain scenarios, and the outcome of this phase is a selection of a preferred scenario which should be carried forward to the second phase. The second phase focuses on the relationship between mining, infrastructure development and social development.

Parameters for the Manganese resources value chain simulation

The objective of the Manganese mining value chain simulation is to establish performance patterns for the different scenarios of the Manganese mining value chain, from upstream mining to production of Ferro-Manganese, through a Smelter process (beneficiation). Scenario 1 involves upstream mining where Ore is mined and exported to the markets without any beneficiation process. Scenario 2 looks at the primary beneficiation based on Ore preparation and sintering to improve the Manganese Ore grade by 25%. Scenario 3 focuses on secondary beneficiation through a Smelter furnace-based Ferro-alloy creation process. The three scenarios described above are the stock variables upon which the simulation is conducted. The parameters against which the simulation is conducted for the three scenarios are: 1. **Input cost**, 2. **Capital efficiency**, 3.**Revenue generated,** and 4**. Profit**. All these variables are the flows that should determine the dynamic behaviour of the three stocks (level variables) in the model.

The system dynamics simulation software used is Vensim PLE (Vensim, ca 2010). Unlike other dynamic simulation software systems, Vensim is also used for high-level dynamic simulation as stated earlier; hence it is preferred for this simulation. The variables simulated are determined in whole, without detailed breakdown. An example of this approach is the Manganese Ore body which, in reality, is variable in grade and has, as such, influence on the percentage per unit value. For the purpose of this simulation an average grade is used, so that the only dynamic contribution from this variable is the volume of Ore treated and sold. Both the input cost and revenue forecast of the mine operation are subject to unpredictable fluctuations, and this aspect is catered for in the simulation by subjecting the average values to a Random Triangular function.

In a system dynamics modelling environment, some sensitivity analysis and future patterns are established for industry performance across the value chain. A Multi-variate analysis is configured for selected variables in the model, to determine the variability of specific variables based on fluctuations to input parameters. The sensitivity of revenue, profit and capital efficiencies of all three Manganese resources value chain scenarios is simulated against fluctuations in input cost drivers, including power cost, logistics and price. This is done to test the resilience of a Manganese resources value chain scenario against possible market changes.

A sensitivity analysis was performed on both the input cost drivers (energy, logistics, solid fuel, water and fixed operating cost) and the revenue drivers (price and volumes). The variables that are measured through the entire scenario are the capital efficiency (this describes average operating profit per ton) per ton of Manganese Ore mined and jobs created. It is the researcher’s view that Capital efficiency is an important sustainable development variable, in that it represents a percentage of profit made per ton of Ore mined, that business owners and government look at to determine the potential of any business to fund alternative economic activities, either through corporate social investment, employee development or tax collections.

Thinking in systems as an approach is more effective for complex, non-linear problem solving in a socio-economic environment (Cabrera *et al*, 2007). Often, when a discussion on the best value chain for mineral extraction in the Manganese industry takes place, a few assumptions are made. These can be summarised as follows:

- that all the stakeholders are looking at things from the same mental map or paradigm,

- that the effect of resistance to change should have on insignificant dampening effect on the outcome of the decision made, and
- predictable delay exists between actual events and necessary decisions.

It is when these assumptions are misaligned with reality that the same actions which were designed to alleviate dire situations may come back to amplify the initial situation, or even create new problems. It is therefore the view taken in this research that systems thinking approach is useful in first aligning the visions and objectives of the stakeholders concerned, with the current reality based on that understanding of delays of feedback and time, as an independent variable (Cabrera *et al*, 2007). These indicators are necessary for the decision makers to comprehend upfront.

Indicators are a necessary part of the stream of information used to understand the world, make decisions, and plan actions (Meadows, 2010).These indicators give the extent of a discrepancy between a desired state of a system and the perceived or real state. This discrepancy will determine the action required to bring the system to normality. One of the significant advantages of using system dynamics models is the approach which helps policy makers learn what an endogenous view is, and why it is necessary in effective policy making (Perkings *et al*, 2010), or objective setting. In systems that comprise many interacting feedback loops and long-time delays, causes of an observed symptom may come from an entirely different part of the system and lie far back in time (Forrester, 1969)

4.3.3. Verifying and validating the model

Because models are intended to emulate real-life dynamics, their validity is essential to increase confidence in the model. The validation (testing) allows the modeller the opportunity to compare the results of the model with empirical evidence, either to refute or validate the model. The nature of system dynamics permits many tests of model structure and behaviour not possible with other types of models (Forrester and Senge, 1979:4). Forrester and Senge (1979) describe a number of tests for this purpose in their work. They describe model behaviour, model structure and policy implication tests, using a number of sub-tests for each of the three dimensions mentioned.

Verification

Kleijnen (1993) described verification simply as determining that a simulation computer program performs as intended. In his description, it is clear that verification is not concerned with the pattern of behaviour of the program results but the correctness of the syntax and absence of programming errors. The description given by Kleijnen (1993) narrows the term to a computer program however this thesis expand the view to refer to similarity of structure and dimension of the simulation model to the concept intended by the model.

The structure test, in the main, should be verifiable by the real system conditions, and will form the basis for verification of the system dynamics model in this research. The structure of the system dynamics model should be verifiable and not contradict what is known about the Manganese resources value chain, or specific parts of the value chain. The structure verification test is important for this research, and should be done when the model is evaluated before the result can be assessed. A review of a Chrome mine value chain setup, from a company in Finland, is used to contrast the structure of the system dynamics model later in Chapter 6 of this report. The case from Finland is used because the Chrome industry is similar in structure and product value chain to the Manganese industry.

The Vensim DSS software platform provides tools to check the correctness of the system dynamics model through model testing, which includes consistency checks. The units check facility in the Vensim software ensures consistency of model parameters prior to running the model. The two tests are deemed sufficient to verify the correctness of the system dynamics model.

Validation

The second test dimension, described by Forrester and Senge, is the model behaviour tests. The context of this test, observed from their work, is the model behaviour pattern prediction test. This context tests the behaviour generated by the model structure to examine whether or not the model generates qualitatively-correct patterns of future behaviour (Forrester and Senge, 1979:23). Barlas (1989:2) highlights the fact that standard statistical prediction test do not apply in System Dynamics pattern prediction test because system dynamics model by their nature, are non-stationary in the mean and in the variance. This aspect makes system dynamics models violate the fundamental statistical test of normality, independence and stationarity (Barlas: 1989:2).

This context is important considering the debates around beneficiation and economic development that are currently taking place in South Africa. In Section 6.3 of this thesis, the result of the system dynamics model simulation is compared with socio-economic and Manganese performance patterns of the past, to establish the correlation in their behaviours. During the analysis of the results, key objectives of the research, as set out in the problem statement of this research is tested for validity against the outcome of the system dynamics model simulation.

Validation of the model also depends on the similarities of patterns of behaviour learned from the system dynamics simulation results to historical patterns established through similar systems. The outcome of the system dynamics model simulation is contrasted with the historical findings on causality of infrastructure development in mining and supporting industries, and the economic growth in those areas. The findings of Perkins *et al* (2005) and Erero (2010) are used as a basis for the comparison of the system dynamics model simulation results with what has been observed in South Africa over the past century. The comparison is based on patterns of influence between infrastructure development and economic growth, without focus on the quantum of the influence in either direction.

4.4. Data collection

Data is collected via a combination of statistical data collection and data gathering through focused groups. Information from Statistics South Africa (SSA) and various industrial bodies was assessed as input to the system dynamics model research conducted. The database of international conference papers presented at the International Manganese Institute (IMnI) 2011 and 2012 conferences was used to establish industry views on production and export performance of Manganese and its alloys over the past ten years.

The DMR’s South African Mineral Industry (SAMI) annual publications from 2008 to 2011 (SAMI, 2008) (SAMI, 2009) (SAMI, 2010) (SAMI, 2011) were also used as data sources. These publications use industry performance indices that in themselves make specific reference to expert researched information from renowned sources, such as CRU international (CRU,2012) and SSA (SSA, 2010). These sources are reputable and are used by captains of the Manganese industry to make investment decisions. The data collected is summarised as follows:

Manganese production and pricing data

Manganese production has defied overall mining output trends over the past 5 years, as indicated in Figure 32, which shows an average growth in output of mining production. The production data for non-beneficiated and beneficiated Manganese is presented in Figure 33. The price forecast for both non-beneficiated and beneficiated Manganese is depicted in a graph in Figure 34.

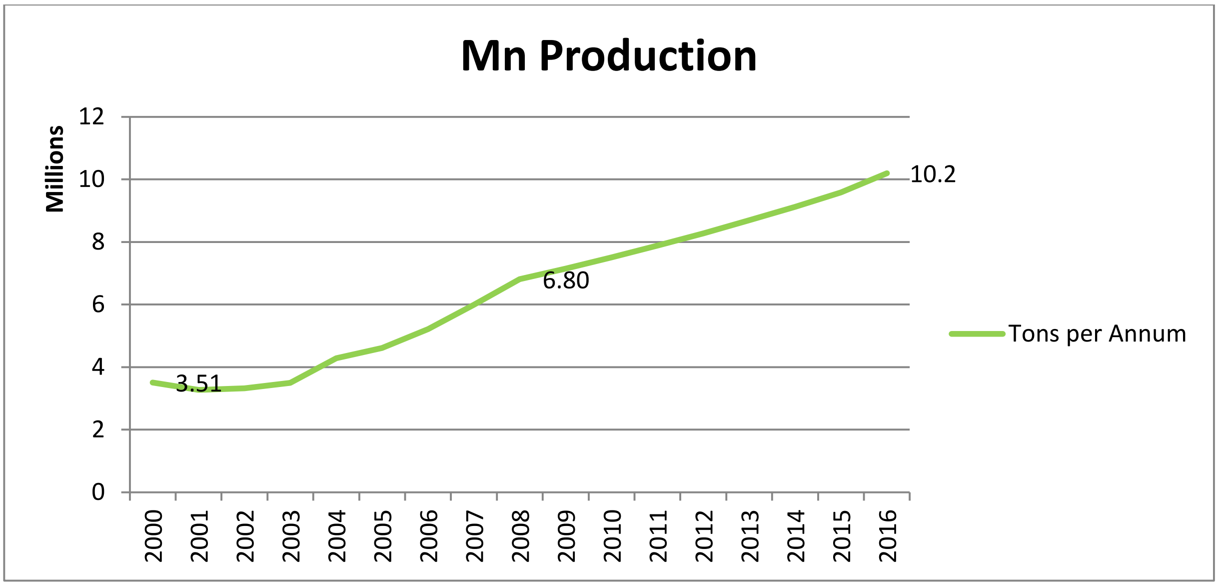


Figure 32: Volume of Manganese production source: (SSA, 2012:3)

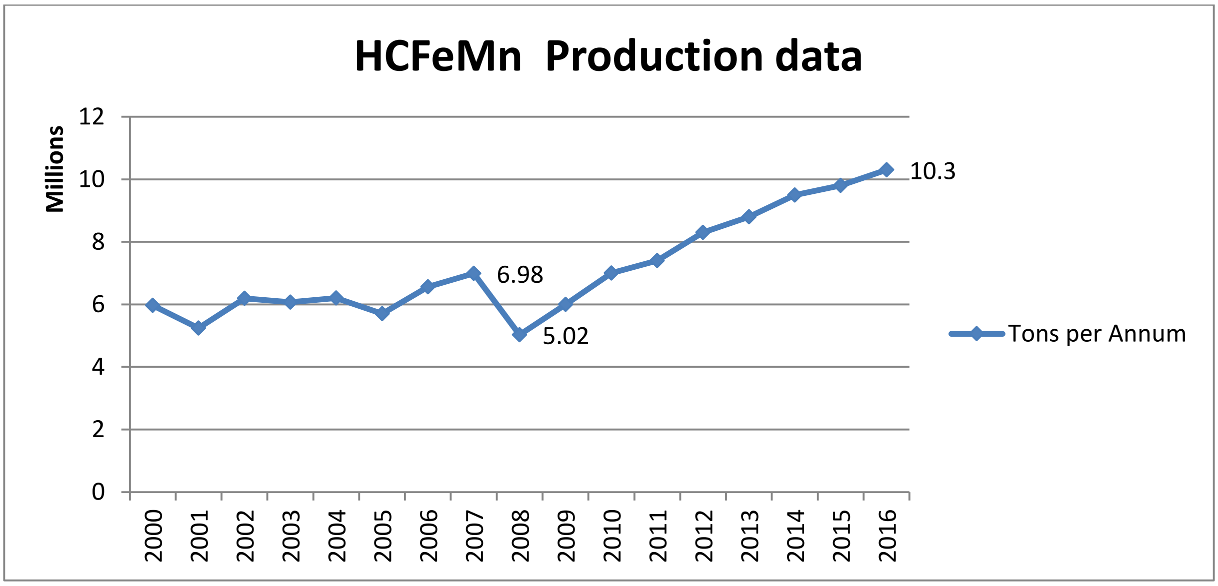


Figure 33: HCFeMn production data source: (SSA, 2012:3)

The High Carbon Ferro-Manganese (HCFeMn) production's demand growth in South Africa is attributed to the average decline in high grade Manganese Ore resources from other producing countries. The forecast demand for Manganese products is expected to grow following the recovery of various economies in the world after the recession of 2008.

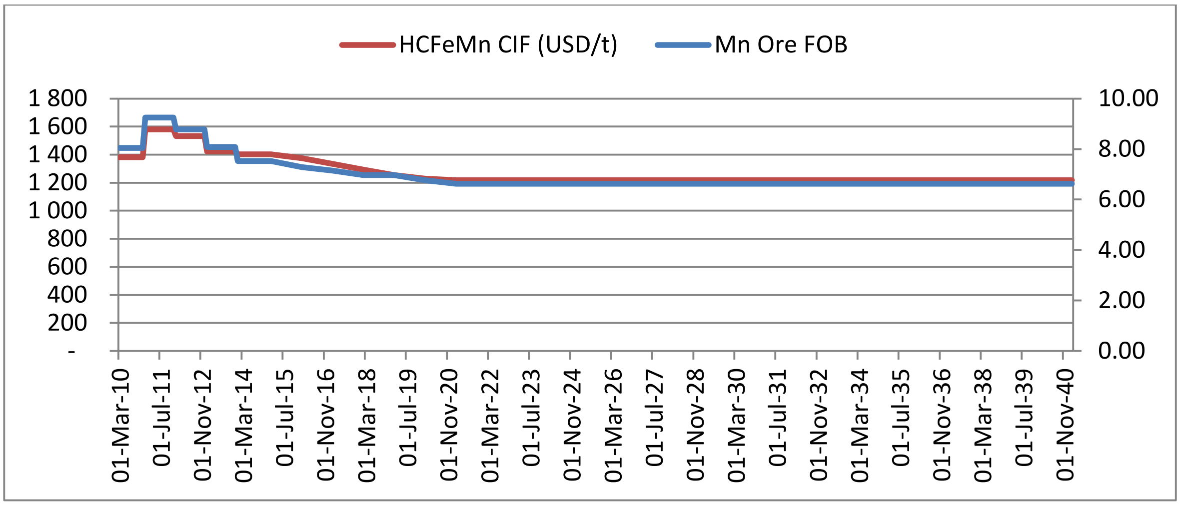


Figure 34: Estimate Manganese and Ferro-alloys product prices per ton (SAMI, 2009)

The data represented in Figure 34, depicts the 2009 estimates for sale prices of Manganese. The estimates were based on prevailing market conditions, at that time, for both Manganese Ore and High Carbon Ferro-Manganese for the period 2010 to 2040. These figures are likely to fluctuate depending on the steel industry dynamics in China and the rest of the world. However, the figures are sufficient for the purposes of modelling in this research. As depicted in Figure 34, the primary Y-axis represents prices of HCFeMn in USD/ton, whereas the secondary Y-Axis represents prices of Manganese Ore in USD/ton.

Power pricing data

To establish the patterns of input cost variability, data was collected from the National Energy Regulation South Africa (NERSA) on energy power movements for the past 10 years up to the year 2012. Although price increases for Eskom were only approved by NERSA up to 2012, an average increase is forecast up to 2016 for the purpose of the research, given the funding requirements of Eskom for the current built programme. By 2008 South Africa had installed a power generation capacity of 40 000 MW, with Eskom accounting for 96% of generated power in the country, and, out of this, only 15% of end-use electricity is consumed by mining activities (DME, 2008:8). With Eskom's reserve margins dropping to as low as 8%, Eskom had to invest in aggressive generation infrastructure to restore the reserve margin and to accommodate new growth in the generation and transmission, particularly by the development of Medupi and Kusile power stations (Eskom, 2012).

This massive programme has influenced the aggressive price hikes that are reflected for the start of the 2008/9 adjustment which marked the first of a three-year Multi-Year Price Determination (MYPD), as reflected in Table 7:

Table 7: Average tariff increases from 1994 to 2008 (Eskom, 2008:43)

Year	***Average tariff adjustment***	***CPI***
01 January 1994	7.00%	8.82%
01 January 1995	4.00%	8.71%
01 January 1996	4.00%	7.32%
01 January 1997	5.00%	8.62%
01 January 1998	5.00%	6.87%
01 January 1999	4.50%	5.21%
01 January 2000	5.50%	5.37%
01 January 2001	5.20%	5.70%
01 January 2002	6.20%	9.20%
01 January 2003	8.43%	5.80%
01 January 2004	2.50%	1.40%
01 January 2005	4.10%	3.42%
01 April 2006/7	5.10%	4.60%
01 April 2007/8	5.90%	5.20%
01 April 2008/9	27.50%	(projected) 6.60%

According to the 2003 report to the National Treasury (Steyn, ca 2003:18), the average cost per kilowatt hour in 1994 was ZAR 0.10/KWh, and ZAR 0.15/kWh in 2002. This number rose to ZAR 0.59/kWh in 2012, following the MYPD approved in 2008 by NERSA. The sudden price hikes reflect the adjustment in the MYPD that NERSA approved for Eskom in 2008 for increases over a three-year period. The overall price of electricity is regulated and approved, based on a cost-plus return on investment as determined by NERSA (Eskom, 2008:45). The 2009/10, 2010/11 adjustment was also based on the same MYPD rate. The 2011/12 adjustment and future increase were not officially approved and are estimated at 15% for the purpose of the research.

Rail pricing data

Rail and port-related costs are a significant proportion of the production-to-market cost for Manganese. Havenga (2012:16) argues that, given the country's high logistics cost, dense long distance road corridors and significant growth forecasted in freight flows, a restructuring of the freight transport system and related investment is critical. In 2009, the freight logistics cost as a percentage of GDP in South Africa, was 13.5% compared with 10% in developed countries (Havenga, 2012:2).

This points to the significance of this in any cost structure for a production cost analysis, and it is a very important component of the system dynamics model. Transnet Freight Rail (Transnet, 2012) data was used as a source for the logistics cost in the model, and an average cost of railing Manganese per ton was ZAR 350 in 2012 (Transnet, 2012). This is the cost of railing the Manganese product from source at the Kalahari basin, in the Northern Cape, to all the ports of Nqura in Port Elizabeth.

It was also important in the data collection process for the research to consider Government's strategic development plans from various authorities at national and provincial levels. The National infrastructure investment plans by the South African Government on rail (Manuel, 2009) were considered in developing the system dynamics. The limit in logistics capacity was used in the model as a constraint to forecast production.

Employment and Income data

In 2009, the total income from Manganese mining was ZAR 28,848 million (SSA, 2009:9) while total salaries were ZAR 2,545 million (SSA, 2009:10). Transportation of Manganese Ore product was ZAR 2,451 million (SSA, 2009:10). The total employment in categories, for the same period, for all companies was 11 504 (SSA, 2009:17).

Table 8 indicates the levels of employment in the John Taolo Gaetsewe region in the Northern Cape, according to the 2011 census (SSA, 2012). The data in Table 8 shows that the difference in employment levels between Joe Morolong, Ga-Segonyane and the Gamagara municipalities are high. The Manganese basin falls mostly within the Joe Morolong municipality, which has the highest unemployment figures at 38, 56%. The lowest unemployment is in the Gamagara municipality with 17.70%, where Iron Ore mining takes place.

Table 8: Employment figures for John Taolo Gaetsewe region for 2011 and 2012 (SSA, 2012*)*

Statistics South Africa- Census 2011				
Unemployment rate per municipality (age 15 to 64)				
	Employed	**Unemployed**	**Total**	**Unemployment rate**
NC451: Joe Morolong	7828	4912	12739	38.56%
NC452: Ga-Segonyane	19940	10154	30093	33.74%
NC453: Gamagara	16058	3453	19511	17.70%

General income distribution data in SA including mining

The graph in Figure 35 shows that the income level of the various groups has been increasing over the 30 year period to 2000 in SA. According to van der Berg (2003:5), a notable increase in black people's income has been evident. The information presented in the graph in Figure 35 show a pattern of labour cost increases that may be used in estimating the labour cost component of the system dynamic models.

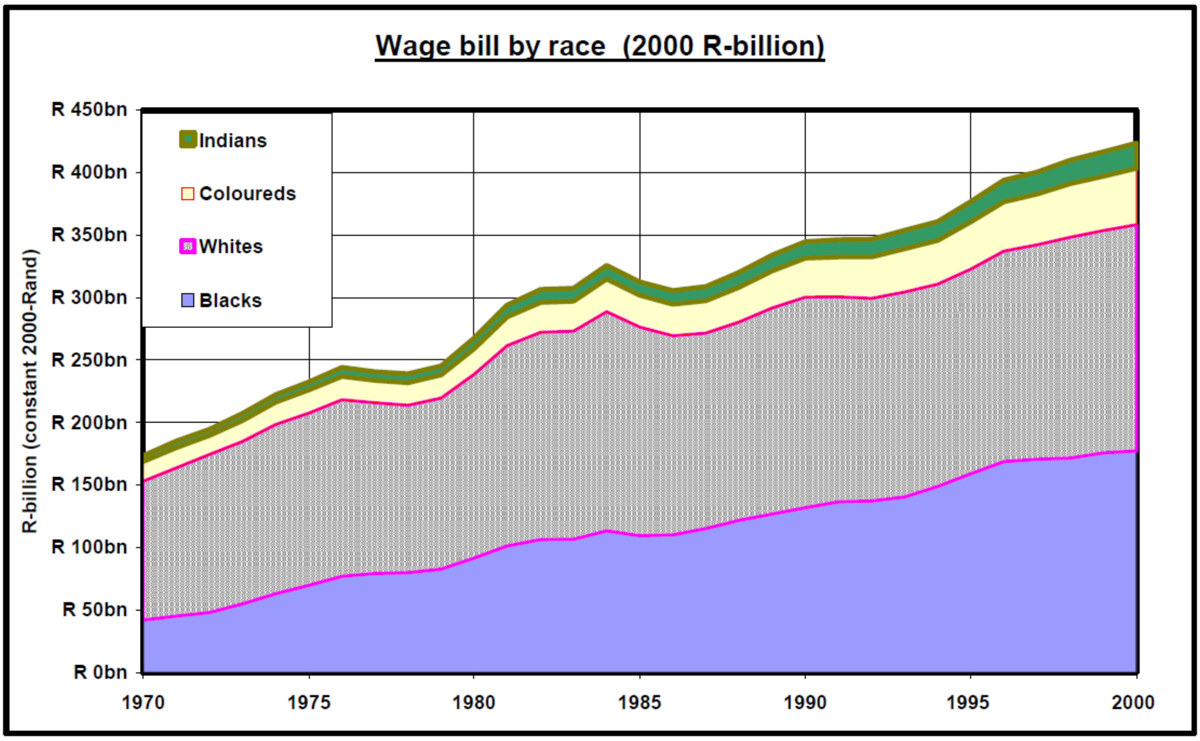


Figure 35: Income distribution by race in 2000 constant Rands (van der Berg et al, 2003:5)

Summary of estimated parameters from focused group interviews

A focused group, comprising 7 people from four distinct sectors of the John Taolo Gaetsewe (JTG) region's economic spectrum, was interviewed with a view to establishing estimates on specific development parameters for the region. The profile of the focused group is summarised in the pie chart in Figure 36. The estimates were arrived at, based on each group member's experience and discussion with the rest of the group, and are deemed sufficient for the purpose of this research. The summary of the estimates is shown in Table 9.

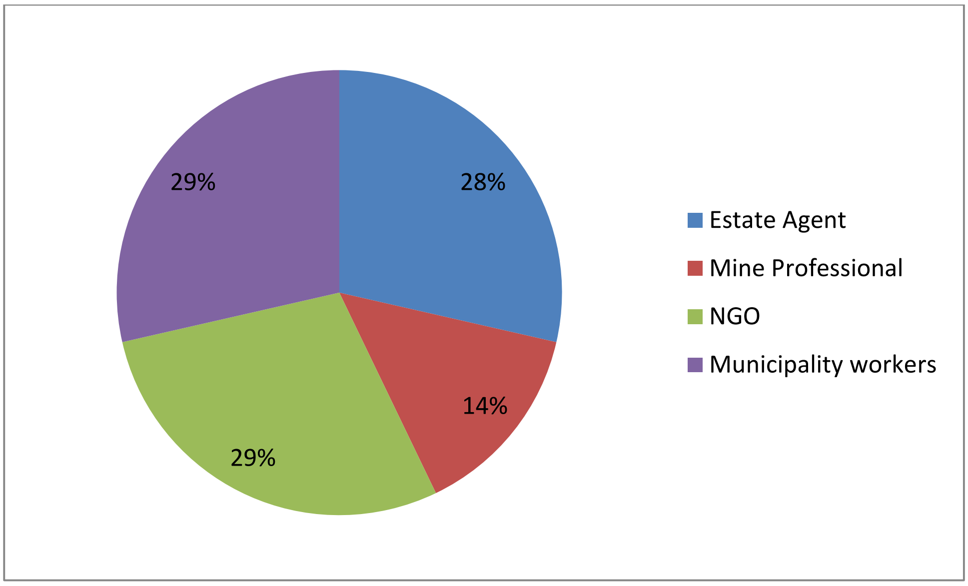


Figure 36: Focused group profile by demographic representation

Table 9: List of estimate parameters for economic development in the JTG region

Parameter	Unit	Value
Inward Migration	Person/Year	1000
Outward Migration	Person/Year	500
Housing Demand Ratio	House/Person	0.67
Total Housing Capacity	House/year	6000

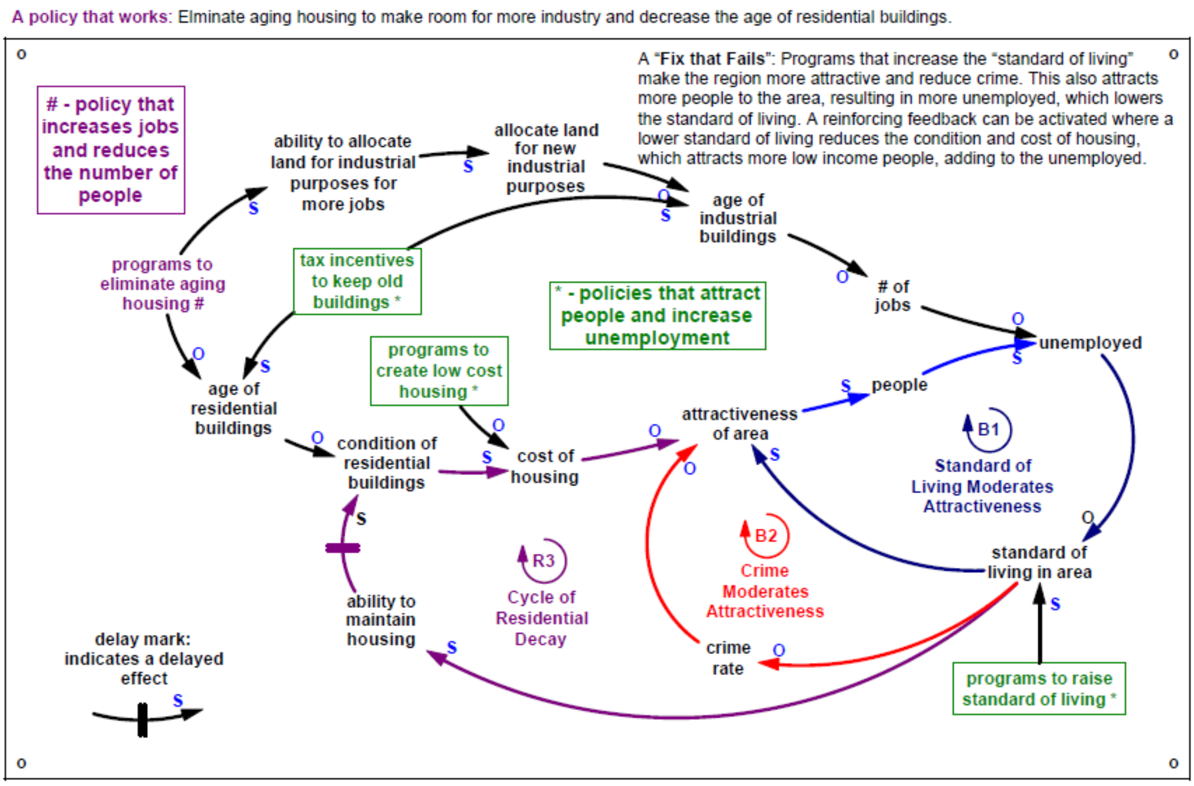
Benchmarking information

International benchmarking was conducted on urban development projects that would satisfy the concepts identified in the initial hypothesis of this research. The focus of the benchmarking exercise was to provide comparison data for the verification of the system dynamics model structure and validation of the models behaviour. An integrated (4 in 1) Chrome mine to steel manufacturing facility in Tornio, Finland, was identified for the purpose of the benchmarking. The facility provided a benchmark of an integrated, closed loop productive system similar in structure to the Manganese resources value chain structure modelled in this research.

The Outokumpu case study displays the integration of production, technology management, waste management and energy optimisation that is achieved when a complete value chain of a mining economy, from upstream mining to downstream beneficiation in steel making, is pursued. The appropriately detailed analysis of this case study is covered in Chapter 5 of this thesis.

4.5. Applications of system dynamics in social systems exercise in the US

System dynamics simulations have been used in the US to analyse the response of social policy interventions in urban settings. The work done in Boston in the 1960's bear's testimony to the complexity of policy decisions aimed at dealing with social problems ranging from jobs, education and social services in urban settings. The model in Figure 37 describes the dynamic complexity of urban systems in a counter-intuitive behaviour of social systems by Jay Forrester (1969)



A policy that works: Elminate aging housing to make room for more industry and decrease the age of residential buildings.

A "Fix that Fails": Programs that increase the "standard of living" make the region more attractive and reduce crime. This also attracts more people to the area, resulting in more unemployed, which lowers the standard of living. A reinforcing feedback can be activated where a lower standard of living reduces the condition and cost of housing, which attracts more low income people, adding to the unemployed.

Figure 37: The Boston model with feedback on attractiveness and corrective reinforcement (Forrester, 1969)

When developing the system dynamics model, Jay Forrester and the team found that policies in Boston that were deemed to be good for the poor had a negative impact for the same grouping in the medium to long term. Two distinct policies for discussion from this work are the legal and tax policies and the housing policies. The model demonstrated that the legal and low-tax policies have been used to maintain old buildings in the city (Forrester, 1969). The policy, however good in the first few years, lead to the overall decay of the city, thereby affecting the ability of the owners to demand decent rentals for the buildings. This in turn made it impossible for the owners to maintain these buildings.

By implementing policies that favour the poor and unemployed, such as low cost housing, the affluent areas become more attractive to people who cannot afford the services, thereby making it difficult for the city to maintain the standard of living for the residents. What the model has shown in the research is that, for both commercial and residential buildings, ageing structures attract more residents of lower income, while business structures provide lower employment per area, and lower profit margins for business. The outcome of the scenario is that all the jobs evaporate and the city residents end up without jobs and poorer than they were before.

Although the urban dynamics model was developed under different circumstances from those of the South African city, there are strong similarities to some of the policies used in South Africa. The model demonstrates the effect of both good and bad policies observed during the modelling of Boston’s urban population dynamics. The model in Figure 37 corrects the city’s decay by recommending reinforcing policies to ageing housing and commercial buildings. The model does so by recommending policies that replace ageing residential houses with new industrial buildings that create jobs. By doing this, the city increases its working class population, and the affordability of residents towards the city’s services increases.

The ability to maintain buildings becomes possible and the cost of housing improves. The resulting urban dynamics model implemented policies that eliminated ageing houses, and replaced these with industrial buildings that in turn helped to create job opportunities. This policy would not find applause in the beginning, as it would seem to undermine the right of the poor to have easy access to business centres and industry, but, by making space for more industrial business, the economy of the city would grow fast enough to attract a more skilled workforce. This would allow for the expansion of the municipality services, maintenance of residential buildings and sustained attractiveness of the city.

4.6. Conclusion of the research methodology

The strategy for this research was to investigate a new way of unlocking the value of a Manganese industry in South Africa that, in itself, is old but has made insignificant progress in the sustainability of mining-driven economies. This is about ensuring that there is continuity of business activities in the area beyond the depletion of current natural mineral resources. The objective of the system dynamics model is to demonstrate the sensitivity of the mining and Manganese beneficiation business to changes in various input costs as well as the decision on exclusion or inclusion of certain stages of the Manganese beneficiation value chain. The extent, to which selling non-beneficiated Manganese Ore versus sintered Manganese product or Ferro-alloys influences the potential economic development of an area, was simulated in a dynamic simulation model.

The relationship between infrastructure development and economic growth is reviewed, based on various literatures stemming from works such as those of Perkins (2010) to the international works of Jay Forrester (1971), on the principle of attractiveness in urban dynamics. Studies conducted in South Africa indicate that the country’s freight transport requirement is estimated to grow by 108% in ton-kilometre terms between 2009 and 2040, and this will not be serviceable unless there is significant improvement in infrastructure (Havenga, 2012:5)

Statistical data from Statistic South Africa, from the early 1900’s to the early 2000’s is used to determine the causality between the investment in logistic infrastructure and the growth of a city’s economy, indicated by the GDP growth, as well as the population’s skills levels. Focused groups, international benchmarking data and industry research information was used in completing the system dynamic model simulation. Information from the South African Mining Industry (SAMI) publication was particularly used to provide data about the industry performance, as it represents data that is ratified through research by the Government's Department of Mineral Regulations.

Economic trends in South Africa and the contribution of mining towards the country's gross domestic product (GDP) was reviewed for the 5 year period to 2010, and 5 year forecast from 2010 to 2015. The 10 years period is deemed sufficient to establish a pattern of behaviour due to a policy intervention in a system. The use of real historical industry data, and industry forecast information, assists in the simulation of industry dynamics.

A Vensim software platform is used to develop a system dynamics model to test the specific policy assumptions and establish patterns of feedback. The model created emulates the concept of relative attractiveness of a business and social environment, based on Manganese mineral value add. The concept is modelled on the tested theory in the urban dynamics simulation by Jay Forrester in the late 1960's in Boston Massachusetts (Forrester, 1971).

The Vensim system dynamics model structure described for sustainable development, integrates the development of the 4 elements of the Manganese driven business activities, and models them to determine the potential for a secondary business stream that has potential eventually to grow beyond dependence on Manganese mining and beneficiation activities. The model describes the dynamic relationships between the 4 business activities and their impact on potential for the secondary business development. The concepts of relative attractiveness of the area and the principles of development from Forrester's urban dynamics model (Forrester, 1971) and the work of Schumpeter (1962) and Saeed (2010) on creative destruction of buildings and enterprises, are adopted in the setup of the system dynamics model.

A comparison to urban dynamics is performed to establish the dynamics of a growing city with a new influx of people, and a demand for infrastructure and services. In comparison with the development of South African cities, such as the development of Johannesburg, and the impact of RDP policies on the standard of living and social development of people affected by the policy, the model incorporates historical data in the development of a South African type city.

Forrester’s model, and the subsequent works of Saeed (2010), demonstrated what is similar to the effect of RDP policies in South Africa where, by implementing policies that favoured the poor and unemployed, such as low-cost housing and low legal tax rates, they created urban decay. This finding pointed to the imminent reversal of initial benefits of poorly conceptualised pro-poor policies in the long term, when feedback is not considered during policy implementation.

The construction of the model that follows in chapter 5 reflects the establishment of the causality between the primary mining activities in the Manganese resources value chain and the sustainable development of the area around the mines. As it is reflected in the works of Fowler (2003), the simulation of the Manganese resource value chain and its causal relationship with the economic and sustainable development of the adjacent area may provide foresight into the future scenario rather than having to wait to see how the real system behaves

5. Construction of the system dynamics model

System dynamics models are characterised as predictive, aggregated and in many instances simplify reality for the sake of clarity (O'Regan *et al,* 2000:349). The system dynamics models described in this research focus on mine operations dynamics and their immediate environments. In developing the system dynamics performance model for the Manganese resources value chain. Manganese resources value chain, the research has focused on the production unit as the lowest level of breakdown for the simulation, since the production variations as well as dynamic impacts on revenue and cost can be determined at that level.

It is also argued in this research that, if a breakdown of a model parameter to the next level of detail does not change the dynamic behaviour of that parameter; such breakdown will not have a significant influence on the outcome of the system dynamics model simulation, if not modelled separately. All system dynamics models created in the Vensim software platform for this research are based on a Runga-Kuta (RK4) integration method, and a time step equal to 0.125 of a year, which implies that the results of the simulations are updated every half quarter of the year.

5.1. Structure of the model

The structure of the simulation model follows a two-staged approach. The first phase is based upon an evaluation of three Manganese resources value chain scenarios, out of which a preferred scenario is selected for the development of the socio-economic sustainability model in the second phase. The development of the socio-economic model is based on a selection of policies that support infrastructure growth and social development, to achieve sustainable development.

This design and construction the system dynamics models in this research adopts the principles and system dynamics methods developed through the works of Schumpeter (1962), Forrester (1969,1971),Graham *et al (1980),* Sterman (1984, 1989), Kleijnen (1993) , Barlas (1989, 1996) and more recently Davis *et al (2007),* Saeed (2010), (Meadows (2007,2010). The research also relies on principles and theories describing causality between infrastructure capacity and economic growth developed through the works of Hotlz-Eakin *et al (*1994), Esfahani *et al* (2003), Perkins (2005) and Fourie (2006). A multivariate analysis is achieved in the system dynamics model by varying input parameters listed in table 19 using a random triangular distribution within the Vensim software platform.

5.2. Construction of the system dynamics model of the Manganese resource value chain

At the core of the system dynamics model are the fundamental structures of a mining operation and the position of the mining industry in the South African economic structure. A system dynamics model of the capital growth with reinforcing and balancing loops from the work of Donella Meadows (, 2007), was used as a basis for developing the mine value chain system dynamics model in its research.

In Figure 38, Meadows (2007) describes a system dynamics model of an economic capital where the asset base, represented by the resource stock, is non- renewable. This implies that, as the capital stocks grows to meet the desired growth goal, the asset base becomes smaller and smaller and is then a constraint for growth. The Manganese mining value chain model has similar basis of growth dynamics to the model described in Meadows’ work.

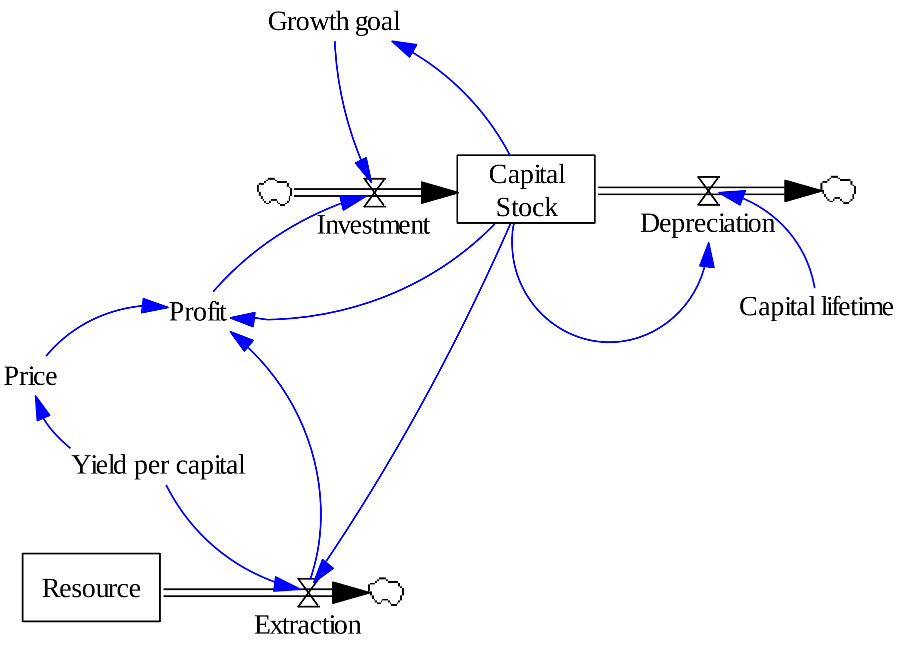


Figure 38: System dynamics model for an economic Capital Stock (Meadows, 2007:60)

<u>Manganese resource (Ore body)</u>

The Ore body described in Figure 38 represents the Manganese reserve based on the 2006 DME (SAMI, 2009) statement. The extraction rate is a variable that changes the level of the Ore body every year. The extraction rate is taken from the 2006-2010 data from the DME report (SAMI, 2011). The 2011-2016 forecasts are escalated by 5% annually from 2010 data. The Vensim diagram in Figure 38 shows the relationship between the stock level of the reserve and the extraction rate. The logic governing the depletion of a resource Ore body is determined by the rate of extraction of the minerals.

As indicated in Figure 40, the “Extraction rate” variable represents the rate at which mineral resources are processed through a mining activity. An auxiliary variable, “Ore input”, represents the feedback from the “upstream mining” stock, which is a true reflection of the rate at which the mineral reserve is depleted.

The “Ore body” stock has a definitive initial value, as it is required for a mine operation to have a specified level of confidence in the resource prior to commencing with mining operations. The depletion rate only represents the planned annual extraction of the mineral resource before adjustment for market demand. The value of this variable is linked to a declared life of mine in the reserve statement and is in essence a predetermined fraction of the “Manganese Resource’ stock. This is the rate that mines would present in their mine works plan to the Government, in terms of the South African legislative framework that governs mining activities (DME, 2004)

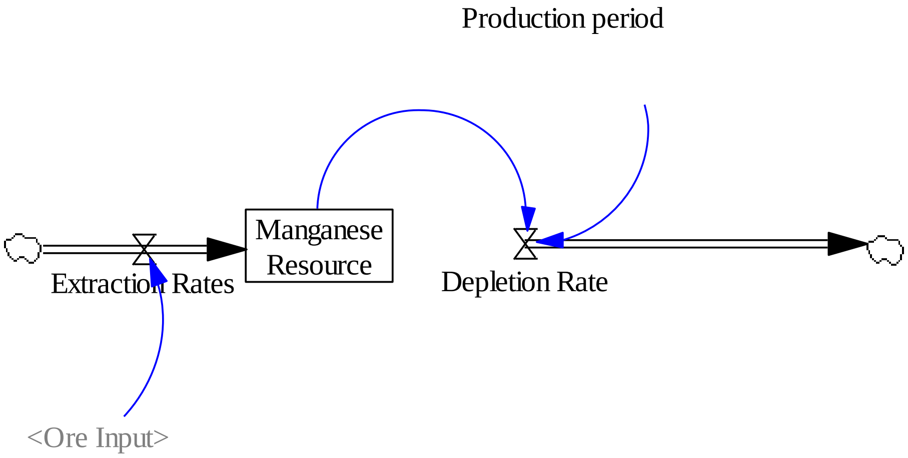


Figure 39: Stock flow diagram representing the basic Ore body depletion

Table 11: Table of parameters used in the model

Variable	Unit	Value(mean)	Source
Manganese Resource	Tons	4 billion	SAMI (2009)

Upstream Mining

The extraction of mineral resources from the Ore body is dependent on the production capability of the upstream mining operation and the performance of the Mangenese market. This operation is represented by the upstream mining stock flow logic in Figure 39. The basic logic for the upstream mining in Figure 36 is based on the mining business flow, which starts with the inflow of mineral resources from the ground (Inflow Rate) that are processed through a mining facility (Stock), to produce a product (Outflow Rate) that can then be sold. The logic in the “upstream mining” stock introduces a factor of 0.9 to represent the efficiency that is due to separation of product and waste in the mining process. The Inflow rate takes into consideration the feedback from the operating invironment (Balancing Feedback Upstream) and the External environment (Market Performance) to determine the optimal throughput.

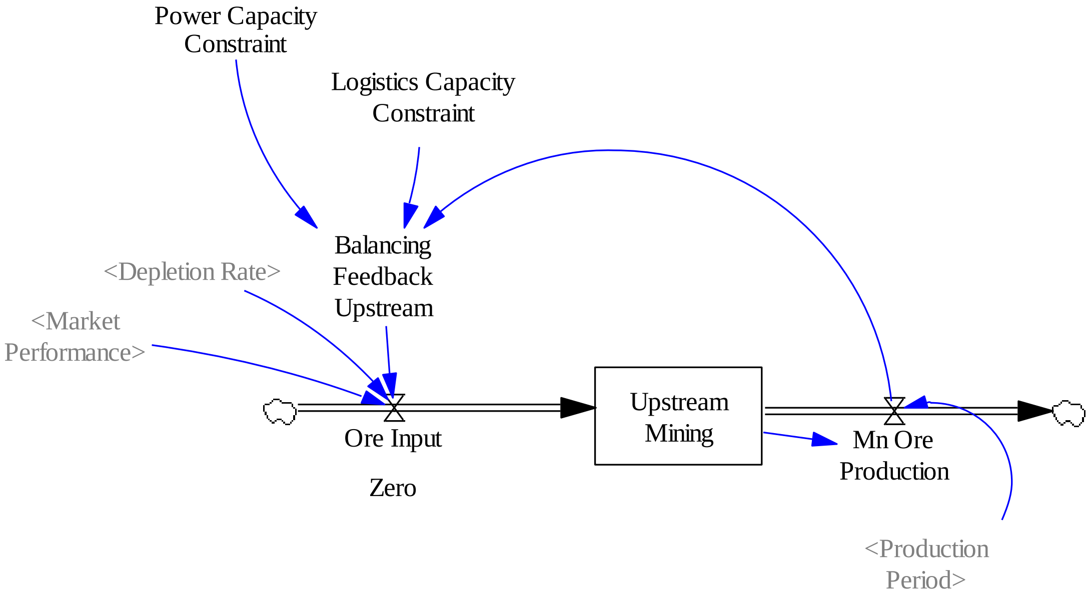


Figure 40: Stock flow diagram depicting the basic upstream mining logic

Table 10: List of parameters for the upstream mining model

Variable	Unit	Value(mean)	Source
Power Capacity Constraint	Tons/Year	40 million	NERSA (2012)
Logistics Capacity Constraint	Tons/Year	11 million	Transnet (2012)

The "Depletion Rate" variable represents the planned throughput before feedback, and is based on availability of the resource on the ground. The "Ore Input" rate is an auxillary variable determined by a logical result of the "depletion rate" variable against the "Balancing Feedback Upstream" variable. The "Balancing Feedback Upstream" variable represents the limits due to capacity constraint within the upstream mining operating environment. These constraints are the "logistics constraints", "power constraints" and "Ore Demand constraints". The "Mn Ore Production" is fed back to the integration equation of the "Mn Ore Input" at each step in influencing the rate of increase in the upstream mining.

The RK4 integration algorithm, and the feedback loop in the logic of the "Upstream Mining", provide the dynamic link between the Manganese mining operation and the impact of the market demands. This is at the core of the systems thinking approach, in that these variables are all considered in the integration equation to influence the pattern of performance for the scenario over a 10 year period. It is the essence of the model to take into consideration the feedback of the environment within which the business operates, to establish the future pattern of the business performance. The real impact of these dynamics is measured through the "Upstream Revenue" and "Capital Efficiency Upstream" variables.

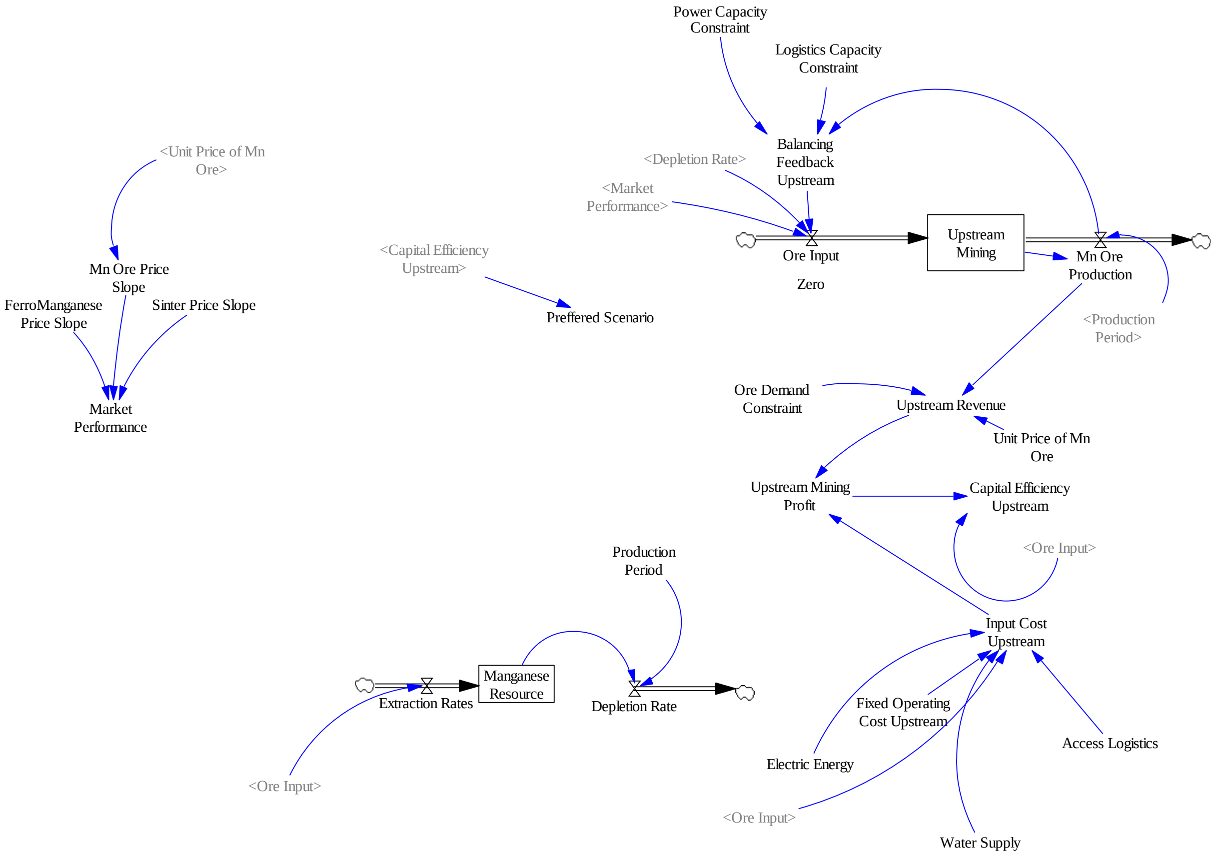


Figure 41: Stock flow diagram representing the complete Upstream Mining logic

The logic in Figure 41 represents the complete upstream mining logic, which includes the Manganese Resource stock flow logic described in Figure 39, and the components contributing to cost revenue and profit calculations. The cost and revenue calculations are performed as part of auxiliary variables and therefore are not affected by the integration logic. A list of practical parameters gained from field study and other sources which are used in the system dynamics model is represented in Table 12.

Table 12: List of parameters for the upstream mining system dynamics model

Variable	Unit	Value(mean)	Source
Electric Energy	Rand /Ton	65	NERSA (2012)
Water	Rand/Ton	1.2	Sedibeng (2012)
Access Logistics	Rand/Ton	350	Transnet (2012)
Unit Price of Mn Ore	Rand/Ton	1,300	CRU (2011)

The “Balancing Feedback Upstream” variable integrates the feedback from market product demands, and the constraints due to power and logistics capacity for the specific period. The logistics constraints reflect the limit due to access to the bulk loading and transportation facility on the Transnet freight rail system. The Power constraint represents the limit to the number of tons that can be produced with the current Eskom supply. The Ore demand constraint reflects the limitation that is due to the market’s ability to absorb the production. The detail of the logic is also described in Appendix B.

The causes tree diagrams in Figure 42 reflect the key parameters that influence the “Upstream Mining” stock variable. An important observation to make on the causes tree diagram is that the resultant value of the “Mn Ore Production” variable is considered as feedback on the input side of the stock variable. This feedback is cascaded down to the “Extraction Rate” variable, which means that, if the production exceeds the demand, or it exceeds the capacity of logistics and available power, the “Extraction rate” variable is affected.

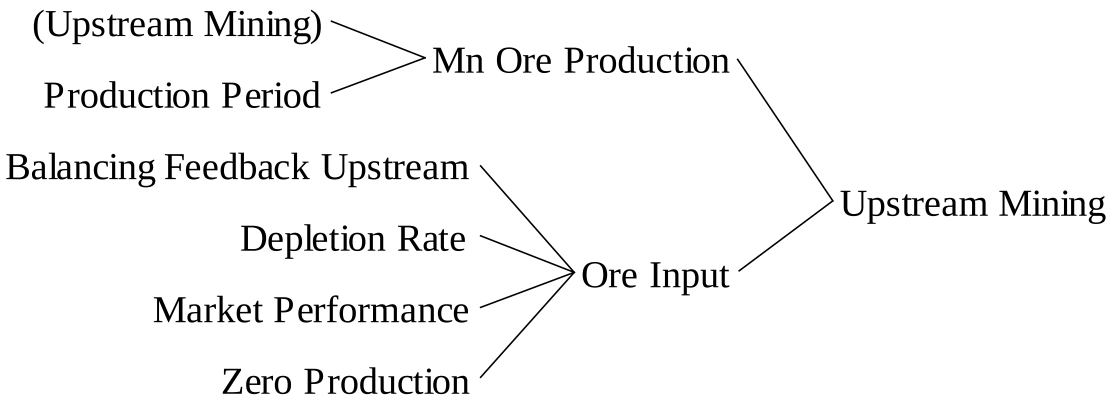


Figure 42: Upstream mining causes tree diagram

Primary beneficiation (Sintering)

The relationship between the upstream mining and the sintering stage is mutually inclusive. The output of the upstream mining process determines the rate of the input variable to the “Primary Beneficiation” stage of the Manganese mining value chain. The tonnage reduction from this process is 20% of the value the “Mn Ore In” variable represented in the upstream mining model. The structure of the primary beneficiation stock flow logic is similar to the upstream mining stock flow logic.

The difference is that the performance of the upstream mining scenario is independent of the outcome of the primary beneficiation scenario, whereas the primary beneficiation scenario is influenced by the changes in some variables of the upstream scenario. The “Capital Efficiency Sintering” and “Input Cost Sintering” variables depend on the “Ore Input” and “Input Cost Upstream” variables respectively both of the upstream mining scenarios.

Figure 43 represents the combination of the upstream mining and the primary beneficiation scenarios. The primary beneficiation scenario is the first value addition stage of the Manganese mining process, where the grade and unit price of the Manganese product is increased from a (36%-38%) Mn range to the (46%-48%) Mn.

The lists of parameters used in the primary beneficiation model that are not described in the previous sections of this report, are listed in Table 13.

Table 13: List of parameters for the primary beneficiation model

Variable	Unit	Value(mean)	Source
Electric Energy Sinter	Rand/Ton	22	NERSA (2012)
Solid Fuel	Rand/Ton	125	CRU (2011)
Sinter Demand Constant	Ton/Year	12.6 million	CRU (2011)
Unit Price of Sinter	Rand/Ton	2530	CRU (2011)

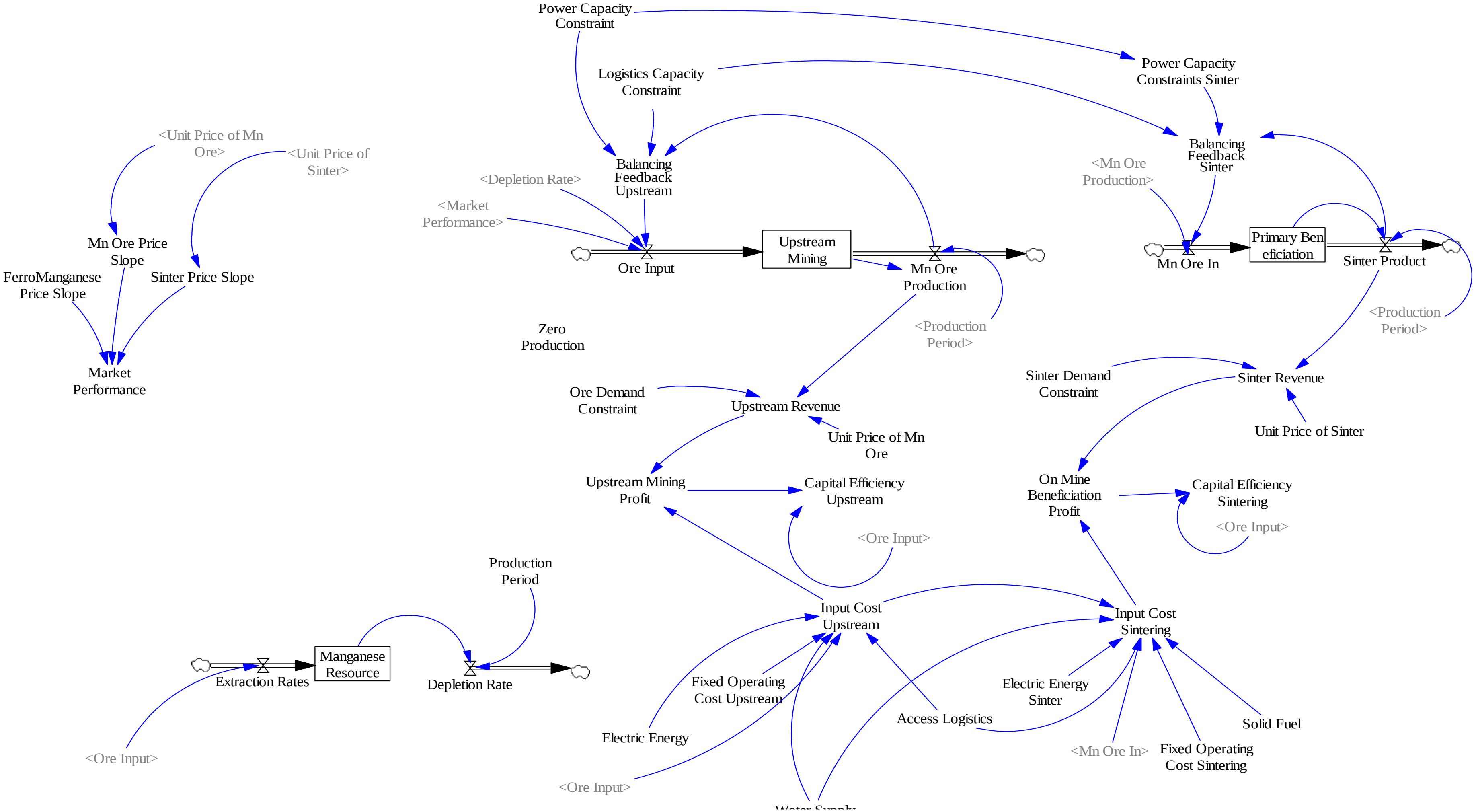


Figure 43: Stock flow diagram representing primary beneficiation logic

The system dynamics causes tree diagram in Figure 44 describes the causal relationship between the primary beneficiation stock variable and all other variables. This includes the feedback system through the “Balancing Feedback Sinter” and the “Primary Beneficiation” variables.

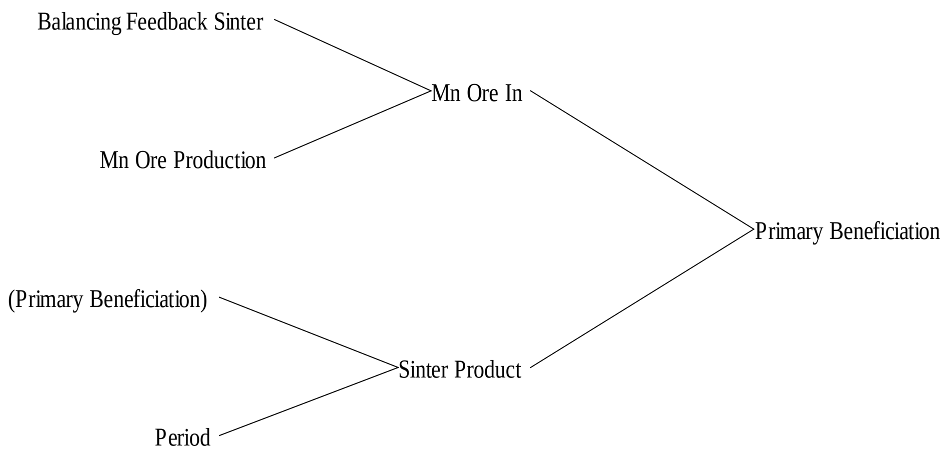


Figure 44: Primary beneficiation activity causes tree diagram

The integrated Manganese resources value chain model

Figure 45 shows an integrated Manganese resources value chain model with all three scenarios. The “Secondary Beneficiation” represents the second stage of the beneficiation process and is fed from the primary beneficiation outflows. The “Sinter Feed’ variable on the inflow of the “Secondary Beneficiation” stock determines its value from the “Sinter Product” variable in the outflow of the primary beneficiation logic. The feedback and constraint logic calculated through the “Balancing Feedback Smelter” is based on similar equations used for calculating the “Balancing Feedback Sinter”.

The notable difference in the logic between primary and secondary beneficiation is the efficiency factor. The metallurgical process in the secondary beneficiation reduces the outflow from the primary beneficiation scenario by a factor of 0.5. The stock-flow diagram in Figure 45 represents the biggest change of Ore grade in the Manganese mineral value chain. The Manganese grade is improved from (36%-38%) Mn to (78%-84%) Mn. The tonnage reduction of 50% is significant at this stage, whilst the unit price increases. The negative impact on production cost is equally high compared with the two previous scenarios. The reduction means that only half of Manganese Ore tons mined from the ground leaves the mining region. The impact on logistics infrastructure is positive, since a reduced volume of material is pushed through rail and road transportation infrastructures.

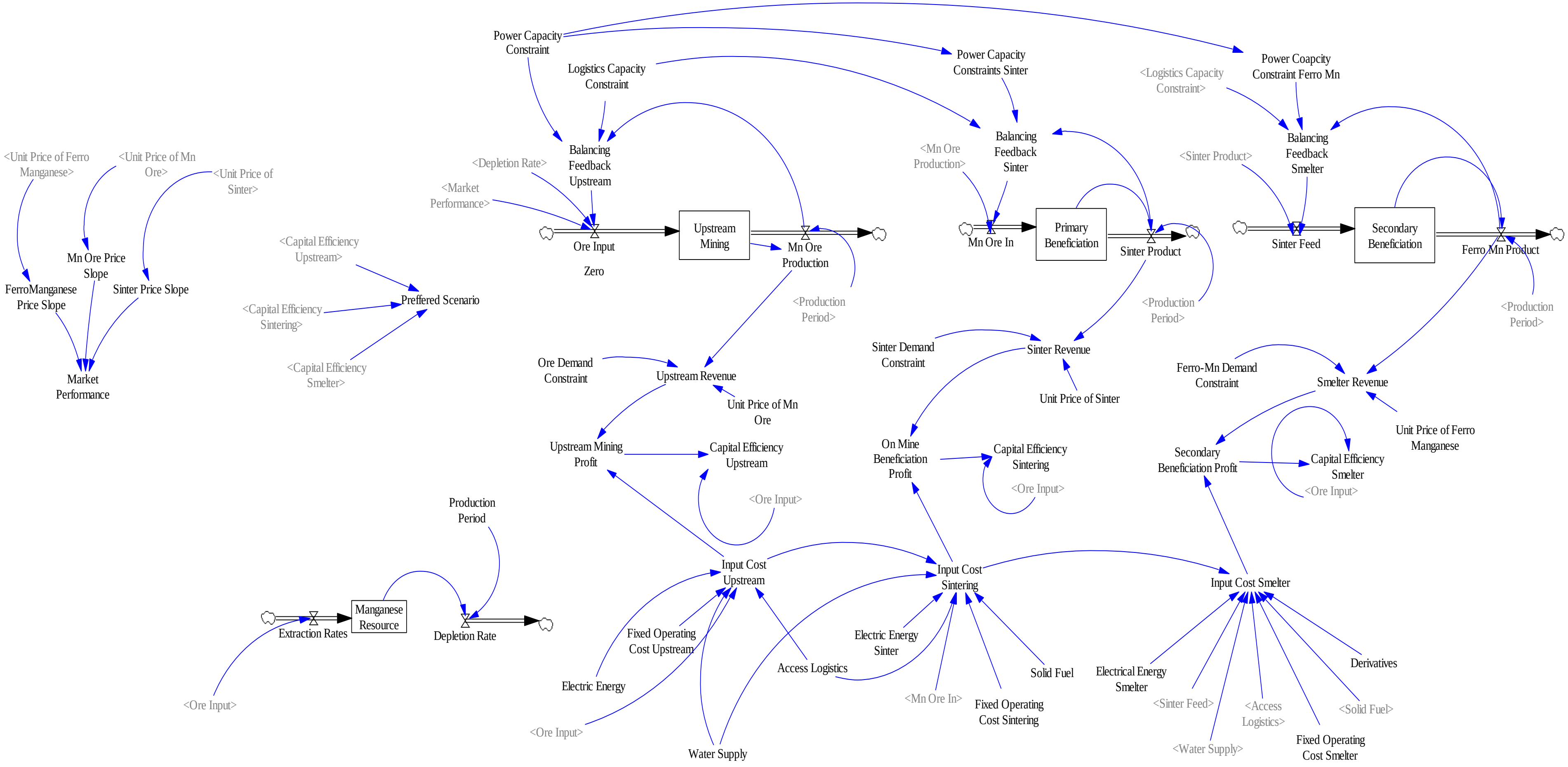


Figure 45: Stock flow diagram representing Secondary Beneficiation logic

The lists of parameters used in the system dynamics model that have not already been described in the previous tables are listed in Table 14.

Table 14: List of parameters used in the secondary beneficiation model

Variable	Unit	Value(Mean/Range)	Source
Electrical Energy Smelter	Rand/Ton	1800	NERSA (2012)
Ferro Mn Demand Constraint	Ton/Year	7,5 million	CRU (2012)
Unit Price of Ferro Manganese	Rand/Ton	13,000	CRU (2011)

The causes tree diagram in Figure 46 describes the causal relationship between the "Secondary Beneficiation" stock and other variables in the stock flow logic. The causes tree focuses on variables influencing the logical result of the stock variable. As is the case with the previous scenarios, the important observation is the feedback from market and input constraints, which determine the throughput levels in the primary beneficiation scenario.

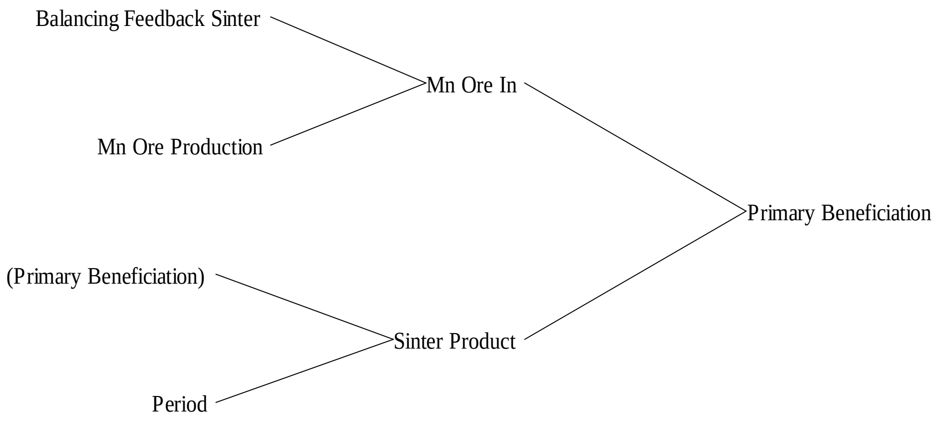


Figure 46: Secondary beneficiation activity causes tree diagram

Capital Efficiency

One of the most important indicators of performance of the three scenarios is the "Capital Efficiency" variable. This variable is used in the research to quantify and demonstrate the financial performance of each Manganese value chain scenario against the impact of changes in input cost and other variables affecting the performance of the Manganese value chain. The relationship between the "capital efficiency" variable and the "Ore Input", "Revenue" and "Input Cost " variables is described as follows:

$$Capital\ Efficiency = \frac{Revenue - Input\ Cost}{Ore\ Input}$$

The "Input Cost " variable encompasses the total cost (fixed +variable) of producing the given volume of Manganese Ore, whereas the "Ore Input" variables in the equation represents the total volume of Manganese Ore produced. The "Revenue" variable represents the total revenue earned for the given volume of Manganese Ore produced and sold. The calculation of this variable is based on the same equations for all three scenarios. The causes tree diagram in Figure 47 describes the causal relationships between the "Capital Efficiency" variable and other variables in the model. The pattern of performance of each scenario over the simulation period is determined by the outcome of this logic.

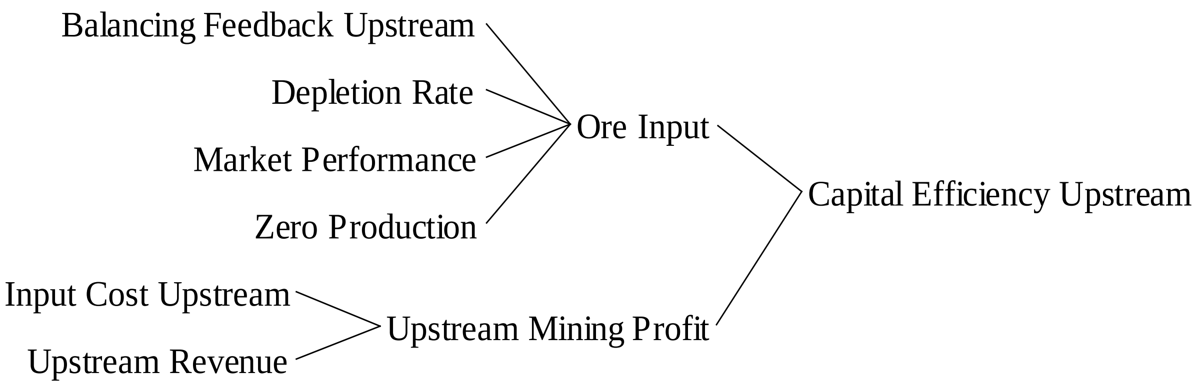


Figure 47: Causes tree for the calculation of the capital efficiency per ton of Ore mined

General Notes on Flows

The cost and variability of the input flows are modelled on an annual basis.

Power

In the simulation model, power cost is allocated based on Eskom rates converted to a kWh/ton. An investigation and practical research into active operations in the Manganese industry established that a benchmark grid load of 5 MW power is used for every million tons of non-beneficiated Ore. Similarly it was established that for a million Tons of Ore treated per annum, a power consumption benchmark of 16 MW is used for sintering process and 173 MW is used for a Smelter process. The cost measure in the model is based on the cost per metric ton of production. Actual cost from Eskom per kWh is used for the years 2006 to 2010. The price escalations for the Eskom power from 2011 to 2016 are based on NERSA approved increases (NERSA, 2012) and the industry forecast beyond 2013

Logistics

The logistics cost is based on the Transnet Freight Rail (TFR) line allocation cost per metric ton of Manganese transported from Hotazel in the Northern Cape to the port of Coega at Port Elizabeth in the Eastern Cape province, South Africa. Historical TFR rates are used for the period 2006 to 2010. The costs are escalated based on the industry forecast for the 5 years from 2011 to 2016, to complete the 10 year cost period.

Solid Fuel (Coke)

This input is only relevant for Sinter and Smelter operations. An average coke price from industry is used. The benchmark consumption of Coke used is 5% of the total Manganese Ore treated by weight for the sintering process, and 15% for the High Carbon Ferro-Manganese Smelter Process. Historical spot prices in Q1 of each year from 2006 to 2010 were used. CRU price estimates (CRU, 2012) were used for the period from 2011 to 2016

Fixed cost

A benchmark fixed operation cost for each scenario of the Manganese mining value chains are taken from industry averages. This information is detailed in Appendix F of this thesis.

Revenue per Ton

All revenues per metric ton of Manganese Ore, Sinter and High Carbon Ferro-Manganese are taken as averages per annum for the past years from 2006 to 2010, and forecast by the industry for the period 2011 to 2016.

Other input variables affecting the mine operation

Whilst energy and logistics are critical in the sustainable production of Manganese minerals in South Africa, water is also a critical variable. A joint effort between the water boards in the Northern Cape has sought to establish a scheme sufficient to supply all the mines in the region in the long term. This scheme comes at a significant cost, but, once completed, will guarantee the security of water for current and future players in the region. Skilled labour is another variable affecting the sustainability of the industry. However, the region has been able to attract skills from other parts of the country, albeit at a premium.

5.3. Construction of the system dynamics model of the socio-economic development

The system dynamics model for economic development adopts the principles developed from a number of studies in system dynamics and economic development. The first principles to be adopted came from the works of Forrester (1969) and Schumpeter (1962) in “Urban Dynamics” and “Capitalism, Socialism and Democracy” respectively. The concept of economic development, creative destruction and urban dynamics, from the works of Professor Khalid Saeed (2010), was considered in creating the logic used to develop the system dynamics model.

The conclusion from Perkins *et al* (2005) in their analysis of the South African economy, that there is causality between infrastructure capacity and economic growth is taken on board in developing the system dynamics model. Hotlz-Eakin *et al (*1994:6)'s conclusion that public capital injection is the source of intensive economic growth provided there is presence of private capital supports Perkins *et al* (2005) view.

Manganese Beneficiation

The secondary beneficiation scenario is carried forward from the Manganese resources value chain system dynamics model. In the social-economic system dynamics model, the "Manganese Beneficiation" stock that is described in Figure 48 represents the primary driver of the economic development, whereas the works of Forrester, Schumpeter and Saeed look at business in general. This research focuses on mineral beneficiation and the infrastructure development (including housing development) as key drivers of the socio-economic development. For this reason, the system dynamics model relies on the outcome of the Manganese resources value chain simulation conducted in the initial phase of this research, to describe the performance parameters of the Manganese industry as a primary input to the rest of the system dynamics model.

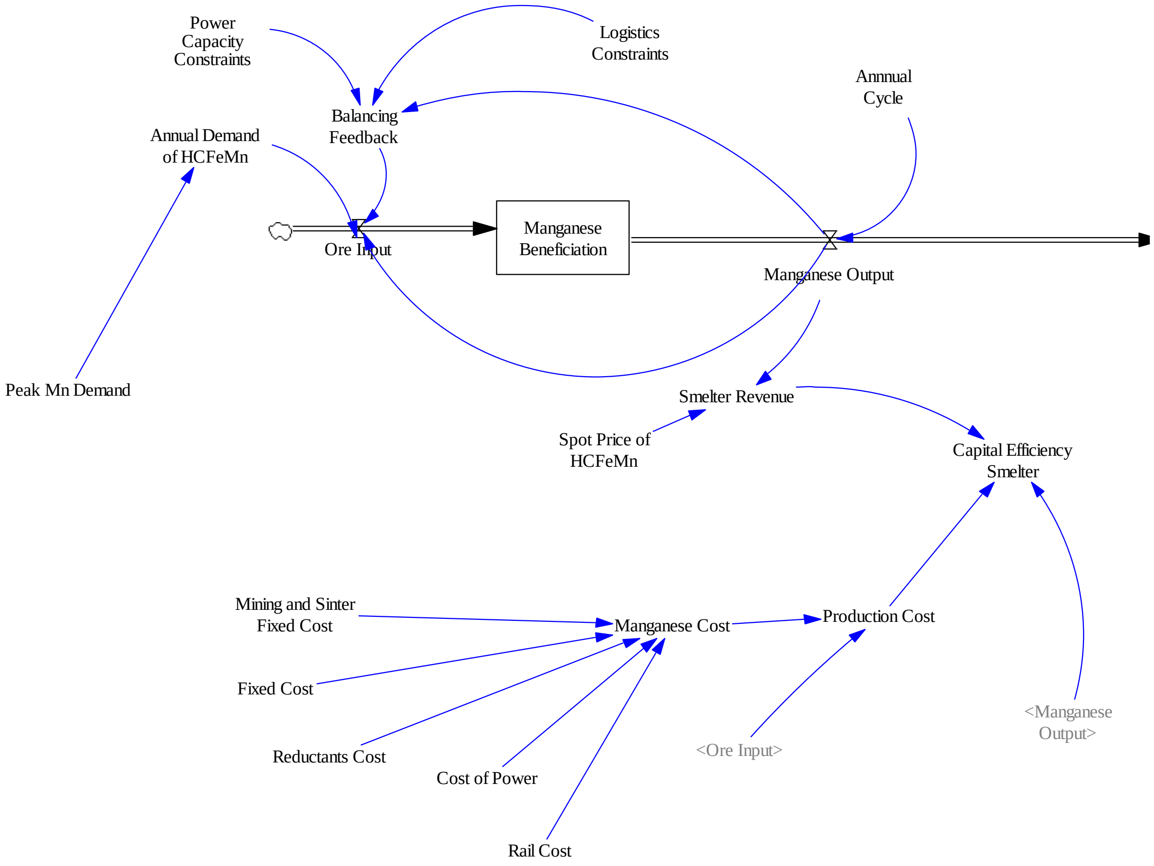


Figure 48: Manganese beneficiation stock flow logic

The logic of the system dynamics model for the "Manganese Beneficiation" stock is as described earlier for the "Secondary Beneficiation" scenario in the Manganese resources value chain system dynamics model. Additional variables included here are the "Production Cost" variables which are used to calculate the "Capital Efficiency" variable. Table 15 contains only those variables used in the logic that were not listed in previous tables.

Table 15: List of parameters used in the Manganese beneficiation model

Variable	Unit	Value (mean)	Source
Cost of Power	Rand/Ton	1800	NERSA (2012)
Reductants Cost	Rand/Ton	1800	CRU (2012)

The Human Development Model

The human development model describes the skills development within the three municipal areas surrounding the Kalahari basin, where 80% of the Manganese mining activity takes place. The key assumption made in developing this model is that skills development takes place when people are employed in key sectors of the economy in general and in manufacturing, retail and mining sectors in particular. Key labour force statistics used were determined by the 2011 census and published by Statistics South Africa (SSA, 2012). The labour intensity in the mining, manufacturing and retail sectors determined by the Statistics South Africa (SSA, 2012) is used to determine the non-mining and mining jobs ratios in the system dynamics model.

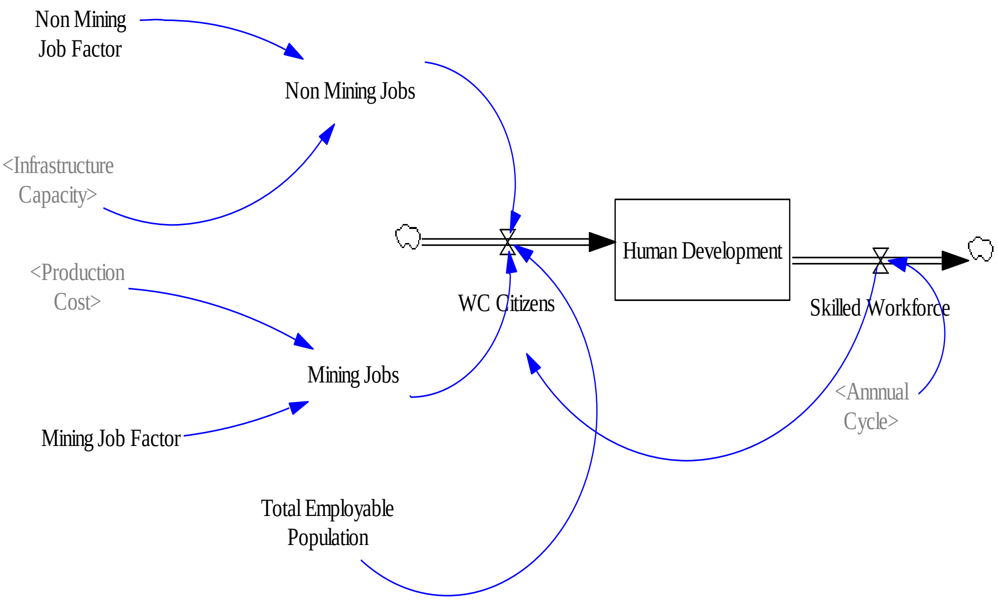


Figure 49: Human development stock flow logic

In the System dynamics model for human development, the "WC Citizens" variable measures the rate at which new jobs are created in the system, which includes both the mining and the non-mining sectors of the economy. This takes into consideration the rate of increase in new skills trained every year, through social and labour plans (SLP) and other training interventions, based on historical trends from data collected. The level of the "Human Development" stock represents the development of the society and how it is best positioned to drive infrastructure development and economic growth. The “Skilled Workforce” variable is an outflow from the “Human development” stock, which is also used as a feedback loop, to compare the number of skilled people in the area, against the “Total Employable Population”. The magnitude of the “Skilled Workforce” variable gives an indication of the capability of the population to support economic growth initiatives.

The causes tree diagram in Figure 50 shows the causal relationship between the human development stock and the other variables. It also shows the feedback loop from the outflow variable, which is the “The Skilled Workforce”

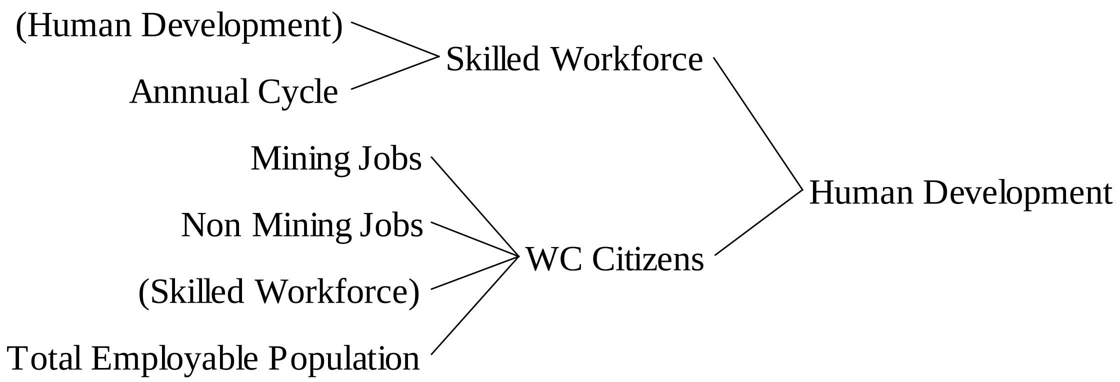


Figure 50: Causes tree diagram for the human development model.

Table 16: List of parameters used in the human development model

Variable	Unit	Value (Mean)	Source
Total Employable population	Persons	15,300	SSA (2012)
Mining Jobs Factor	Persons/Rand	0.013	SSA (2012)
Non Mining Jobs Factor	Persons/Rand	0.047	SSA (2012)

The creative destruction and change in composition of industry from urban dynamics.

In his review of urban dynamics and Schumpeter's work on creative destruction, Saeed (2010) developed a system dynamic model that shows how allowing the demolition of ageing infrastructure can create space for new infrastructure and attract professional employees. Figure 51 shows the enterprise development and demolition model from Saeed (2010). The system dynamics model in Figure 51 shows that, through the demolition of ageing industries, construction of new enterprises may become possible. Saeed (2010), Forrester (1969) and Schumpeter (1962) did indicate that more professional and management jobs are created during construction of infrastructure than at any other stage of the industry's life cycle.

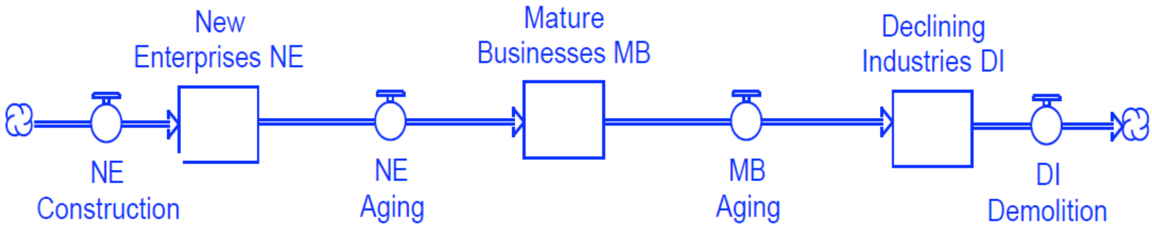


Figure 51: Infrastructure development model from Urban Dynamics (Saeed, 2010)

The result of Saeed's infrastructure system dynamics model in Figure 51 shows the dynamic changes in industry composition due to policies that encourage destruction of ageing infrastructure in a land constraint environment. One point in the graph (point 260 on the x- axis of the graph) in Figure 52, marks a critical intersection where the policy to demolish ageing infrastructure, due to declining industry, starts showing a positive impact in the development of new enterprises. At the same point, some of the new enterprises inevitably mature into established businesses. The result shows that the feedback of policy changes has a time lag and has no direct proportionality to the desired result in magnitude. This model is also influenced by the fraction of developed land that is available to attract new enterprise development.

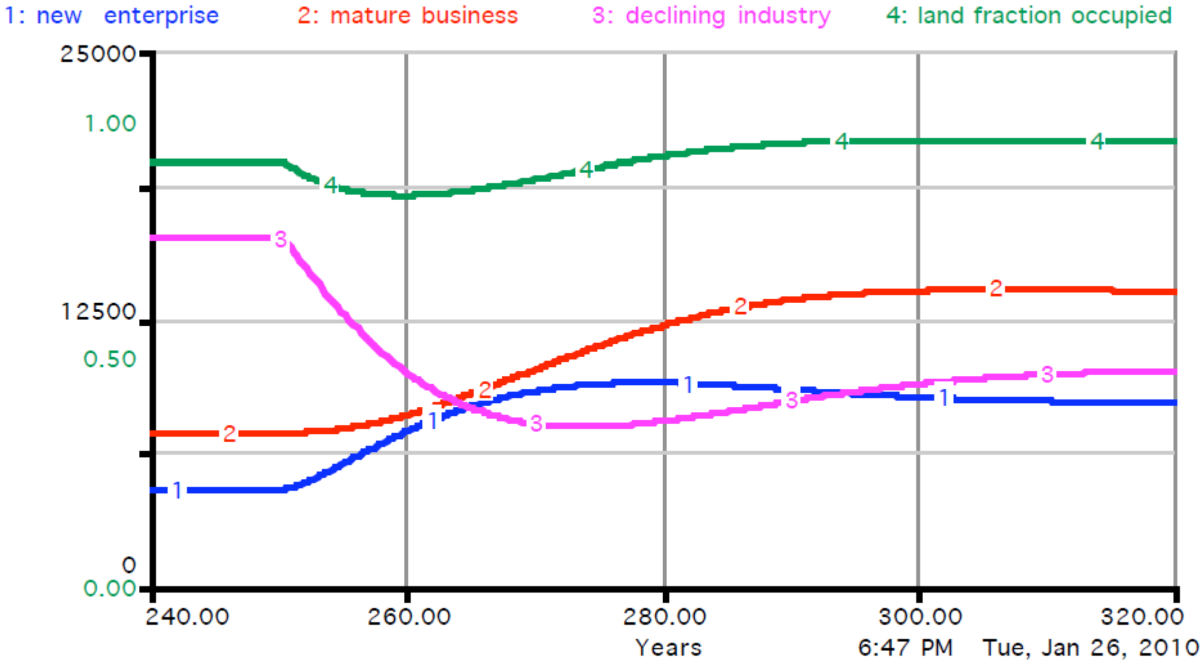


Figure 52: Change in composition of industry due to policies that clear aging infrastructure and encourage new enterprises (Saeed, 2010)

The models further indicate the impact of the composition in industry composition on labour force dynamics in Figure 53. At points 256 and 272 in the graph in Figure 53, Saeed shows that, with the emergence of new enterprises, comes an increase in the attraction of professional and management categories of the labour force. Under-employment also reduces most in the same period which implies that during the construction and start-up phases of new enterprises more jobs are most likely to be created.

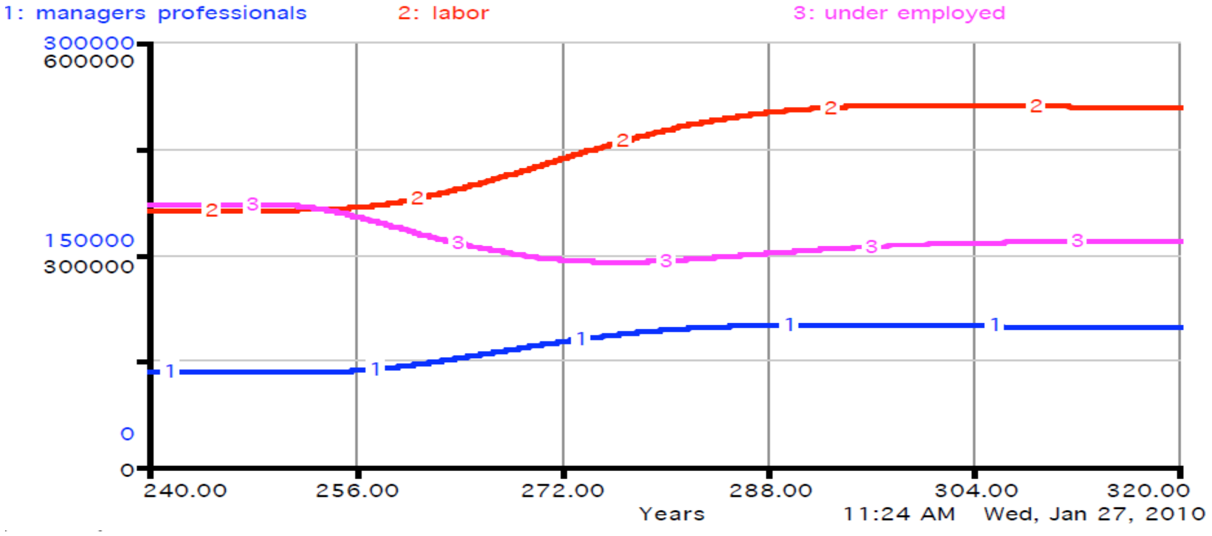


Figure 53: Change in workforce composition created by policies that clear aging infrastructure and encourage development of new enterprises.

The current research agrees with such thinking and adds that, with the attraction of high-end professionals comes the ability to buy and maintain new housing and related infrastructure. The attraction of new professional and management labour force may, in turn, drive the demand for construction of new housing and support facilities. This combination would result in a general socio-economic growth of an area. Schumpeter (1972) also concludes that the new composition of the economy, which is dominated by new infrastructure development and demolition of old buildings, is characterised by a high proportion of professionals and managers with both the capability to drive new enterprises and to purchase new housing.

The adjustment between the works of Forrester (1969), Schumpeter (1972) and Saeed (2010) and the system dynamics model described in this research is that the Northern Cape’s John Taolo Gaetsewe region, under focus, has a relatively young infrastructure and therefore does not offer enough in ageing and matured infrastructure. What is common in the system dynamics models is the potential to attract new affording professionals who, in turn, drive further demand for infrastructure development.

The Housing Development model

The system dynamic model in Figure 54 shows the housing development logic forms part of the integrated sustainable development model. As is the case in any urbanised economic environment, the demand for new housing in the mining area of the Northern Cape's John Taolo Gaetsewe region comes from all levels of income groups, ranging from professional managers through workers and the under-employed. In the model, the input side of the "Housing development" stock is driven by demand for new housing.

The "Housing demand" variable determines the rate for the inflow variable "WC Housing demand". The housing demand is determined by factoring a percentage of newly employed working class as those requiring housing. The factor used considers that not all employed personnel will acquire new housing, as some may already be settled in other parts of the country and, such being the case would prefer lease options. The "Housing per worker %" brings the factor into the number of "Skilled Workforce" to determine the auxiliary variable "Housing Demand".

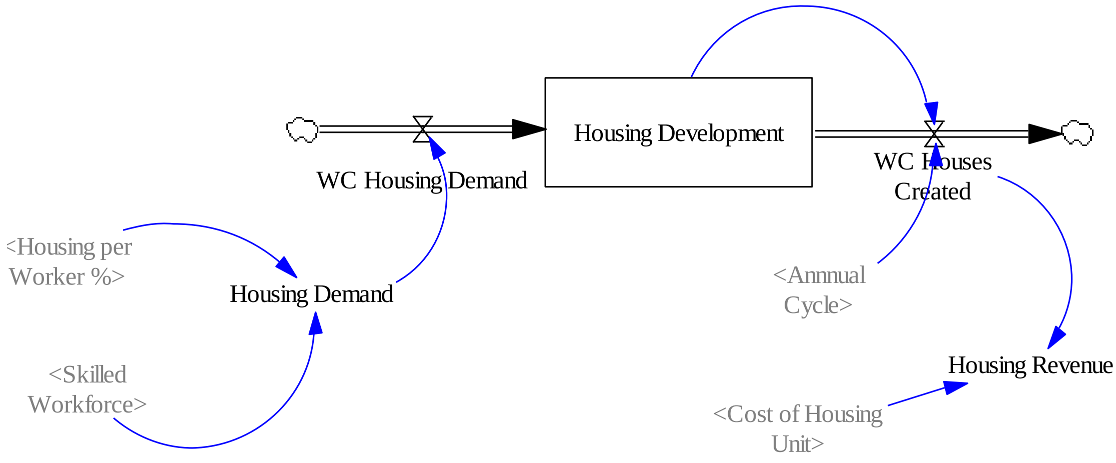


Figure 54: Housing development stock flow diagram

Table 17: List of parameters used in the housing development model

Variable	Unit	Value (mean)	Source
Housing Demand	House/Year	4,560	SSA (2012)
Cost of Housing Unit	Rands	900,000	NCED (2012

Area’s Attractiveness

A very crucial variable in the construction of the socio-economic system dynamics model is the Area’s Attractiveness index. As graphically described in figure 55 and Figure 56, the Area’s attractiveness is an evaluation of the balance between housing development represented by the “WC Houses Created” variable and “Total Housing Capacity” and in the same way, the level of employment represented by the “Skilled Workforce” variable against the “Total Employable Population”. The index manipulation in the model follows the logic that says “if more skilled people are available among the employable population, the area would be attractive for business development in the same way that the availability of balance between housing capacity and number of houses build will affect the attractiveness of an area for high end skilled workforce such as professionals and business in the same way.

In a similar evaluation of relative attractiveness of Ireland as mining location, O’Regan (2000:339) finds that the attractiveness is not only dependent upon the geology but other international markets and marketing strategies employed by competing countries. The construct of the system dynamics model takes this point into consideration however limits the variables determining the “Area’s Attractiveness” to housing land capacity and employment capacity. The reason for this position is that employment and human settlement (housing) is considered sufficient to give an indication of attractiveness of the area to business and critical skills in South Africa. A detail modelling of Area’s Attractiveness would require an inclusion of more variables in the equation however this is beyond the scope of this thesis.

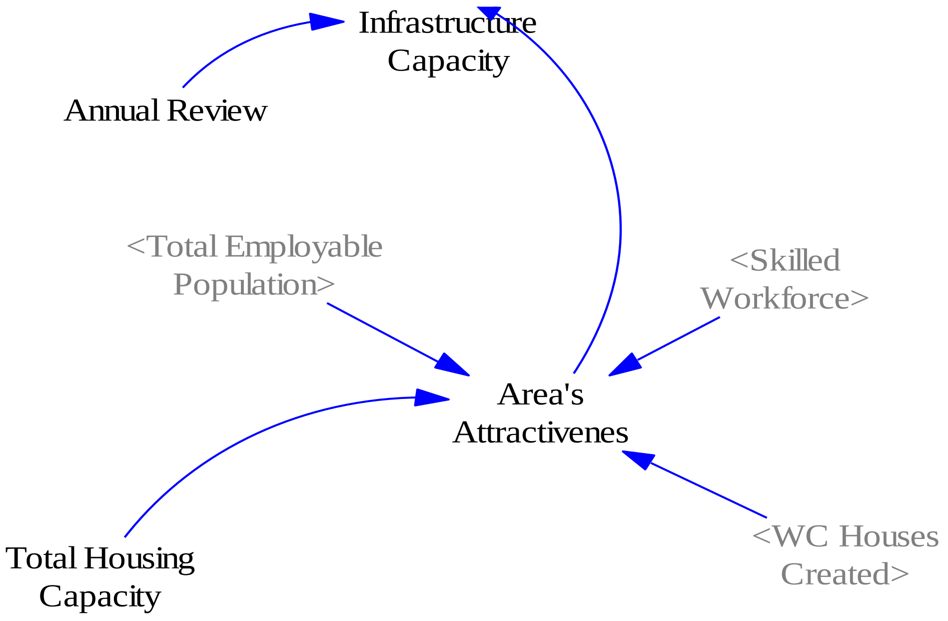


Figure 55: Stock flow logic for area’s attractiveness

The cause’s tree in Figure 56 shows how the human and housing development stocks and the outcome of the logic within those stocks, influence the outcome of the “Area’s Attractiveness” variable in the system dynamics model. The detail of the logic is described in Appendix D of this thesis.

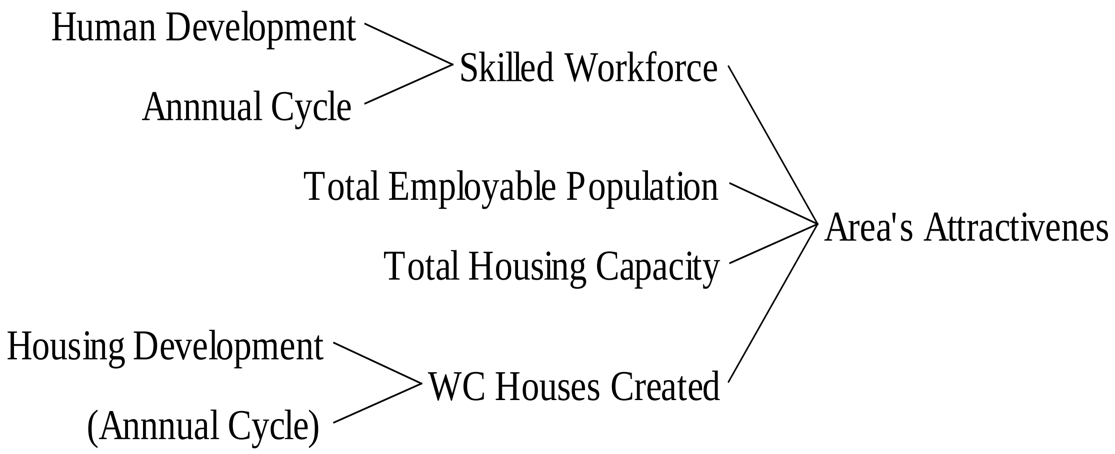


Figure 56: Causes tree diagram describing the area’s attractiveness

<u>Infrastructure Capacity Development</u>

The system dynamics model for infrastructure development depicted in Figure 57 expresses the logic in support of the principle which states that, infrastructure development aids economic growth. (Perkins *et al* 2005) The primary inflow to the “infrastructure development” stock is the cost associated with Manganese Beneficiation activities. However, the logic also takes into consideration the input from housing development revenue and Manganese revenue through corporate social investment (CSI), and social and labour plans (SLP). Both CSI and SLP are legislative requirements for corporations in general and mining operations in particular.

The “Infrastructure Development” stock factors the value of Manganese Beneficiation activities to reflect the value of mining revenue that can be used for further infrastructure development. The outflow variable in the infrastructure development model is the “Infrastructure Capacity”. This variable is influenced by the value of the “Area’s Attractiveness” variable. The system dynamics model uses the relative attractiveness of the area as a moderator of Infrastructure development, by acknowledging that infrastructure growth requires other factors, such as availability of suitable land and skilled workforce.

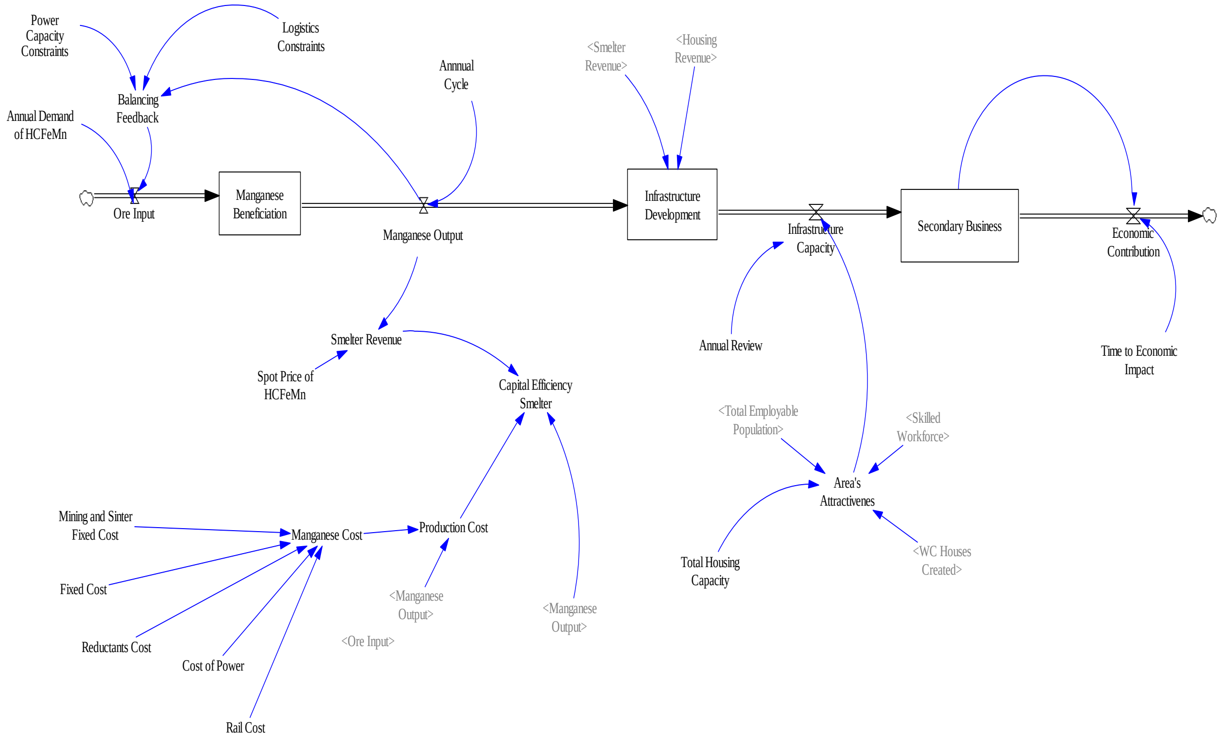


Figure 57: Stock flow logic for Infrastructure Development

The causes tree diagram in Figure 58 shows all the variables that influence the "Infrastructure Development" stock as considered in the system dynamics model. The observation that can be made in the causes tree is the three loops that include "Housing Revenue", Manganese Output and Feedback Loops that act on the "Infrastructure Development" stocks, thereby integrating the performance of all three system dynamics models. An integrated socio-economic system dynamics model is shown in Figure 59.

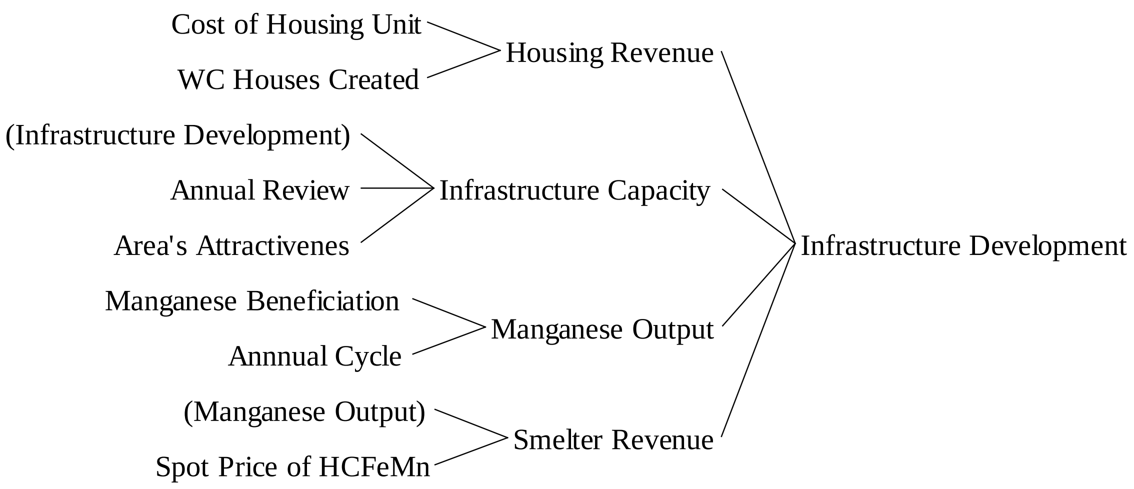


Figure 58: Causes tree diagram describing the Infrastructure Development

Table 18: List of parameters used in the Infrastructure Development model

Variable	Unit	Value (mean)	Source
Spot Price of HCFeMn	Rand/Ton	12,850	Ryan’s Notes (2012)
Annual Demand of HCFeMn	Ton	8,400	SSA (2012)
Total Housing Capacity	House	6,500	NCED (2012)

The socio-economic system dynamic model

The relationship between economic infrastructure and economic growth appears to run in both directions. Inadequate investment in infrastructure could create bottlenecks, and opportunities for promoting economic growth could be missed (Perkins, 2005). This relationship can also be likened to that of the chicken and the egg in that massive capital injection and demand guarantees are required for government to invest in infrastructure, whilst, at the same time, business also requires certainty on availability of infrastructure in order to invest in mining.

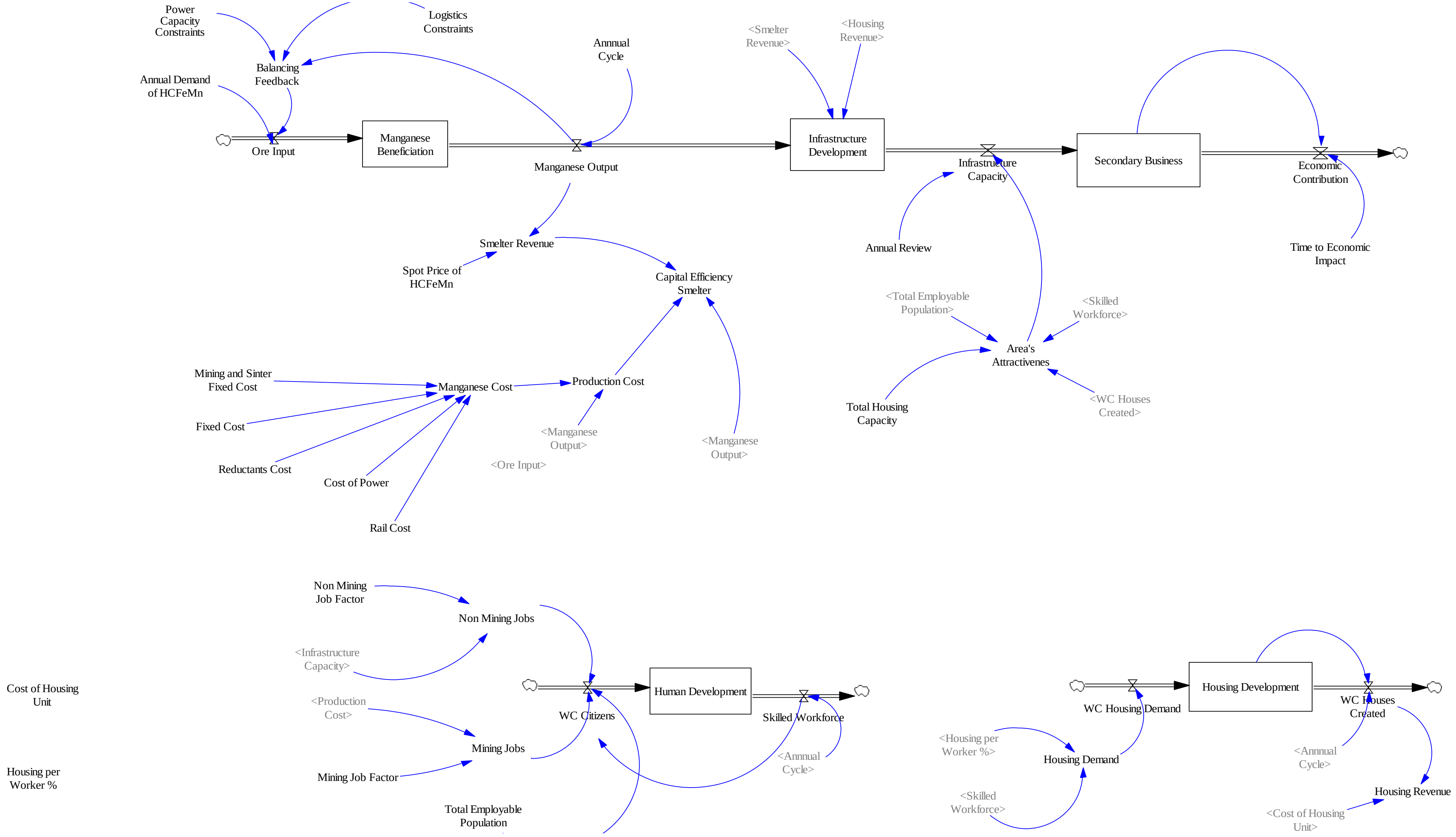


Figure 59: Stock flow logic for the socio-economic model

5.4. Conclusion of the model construct

The system dynamics model simulation was concerned with establishing the dynamic behaviours of the Manganese industry and economic development patterns around it. It is important to emphasize that the scope of the system dynamics model simulation was to establish patterns and indicators of mine performance, based on averaged industry economic figures.

The development of the system dynamics models described in this report relied on data gathered through practical research from varied sources which included, IMnI (2011, 2012, the DMR'S SAMI (2009, 2010, 2011), and statistical data mostly from Statistics South Africa (SSA, 2009, 2010, 2011). Specific information on input power and logistics cost forecast and movements were sourced from Eskom (2012) and Transnet Freight Rail (TFR, 2012). Forecast information on Manganese prices was sourced through CRU (2011, 2012) and Ryan's Notes (2012), as described in Chapter 4 of this report. This information was used to establish boundaries and mean values where random functions were used in the model.

The initial hypothesis upon which the construction of the system dynamics model was formulated is summarised as being:

- that beneficiation of minerals resources within the Manganese value chain will create more value and increase employment opportunities (DMR, 2004)
- that the relationship between infrastructure development and economic growth goes in both directions (Perkins *et al*, 2005)
- that the maintenance and expansion of infrastructure are important dimensions of supporting economic activity in a growing economy (Perkins *et al*, 2005)

The variables used to measure the sustainability aspects of the Manganese mining value chain in the simulation are: the revenue generated from mined Manganese Ore, the input cost of Mining operations, and the capital efficiencies per ton of Manganese Ore mined. Whilst the revenue and the input cost variables are self-explanatory, the capital efficiency should be seen as the measure of profitability of the operation for every ton of Manganese Ore that is mined from the ground. If looked at differently, positive capital efficiency represents a potential for a percentage of profits made to be re-invested into improvement of support infrastructure, or made available by the operation for Corporate Social Investment (CSI).

The simulation was based on a varied annual production of between 7 and 15 million tons of Manganese Ore over the 10 year period between 2006 and 2016. Historical production data from industry was used as the benchmark for the period between 2006 and 2011, whilst a forecast production profile was used for the period from 2012 to 2016. The benchmark data was used to set up parameters for the random function in the simulation software for the period from 2006 to 2016. While production throughput is kept within a range of simulated figures for the purpose of the simulation, all input and revenue numbers are based on hard data collected from respective industry sources.

An investigation into the geological formation of the Manganese resources in the Kalahari basin known as the Mamatwan type shows that, for every given quantity of Manganese Ore tons produced from upstream mining, only 80% of the said quantity can be produced as Sinter, and 50% of the Sinter as Ferro-Manganese product. These output numbers have a direct impact on the logistics capacity and cost impact in the system dynamics model simulation. It is also considered that logistic costs are proportional to the volume of exports; therefore, the higher the volume of materials exported, the more the logistics costs become an influence on the competitiveness of the operations cost. A bulk cost of logistics through Transnet Freight Rail (TFR) was used instead of road freight costs (Transnet, 2012).

Power Input cost

Power consumption in the three Manganese resources value chain scenarios is measured as a Rand per ton of Manganese produced. The amount of power in Kilowatt –hours (kWh) required for producing a ton of Manganese product in each scenario, determines the Rand per ton value of each scenario. The power consumption in kWh for each scenario reflects the efficiency of operations whilst, on the other hand, the cost per kWh changes in line with Eskom's tariff changes. The power cost trends for the three scenarios are depicted in Figures 60, 61 and 62. The cost of power (price/kWh) used on the graphs is based on Eskom's historical electricity tariffs for heavy industry converted to price per ton by multiplying the number of kWh consumed per ton of production by the price of electricity per kWh. The 2012 to 2016 prices are forecasts based on the National Energy Regulator of South Africa (NERSA)'s recommended tariffs.

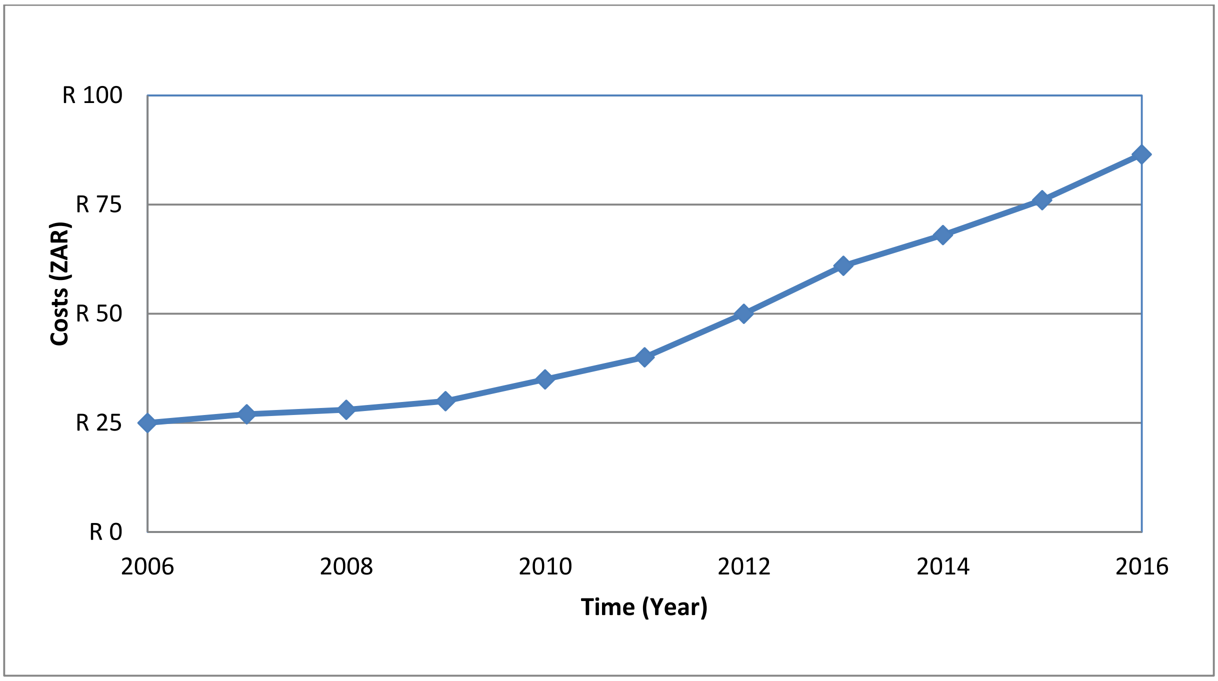


Figure 60: Upstream mining electric energy cost per ton for period from 2006 to 2016

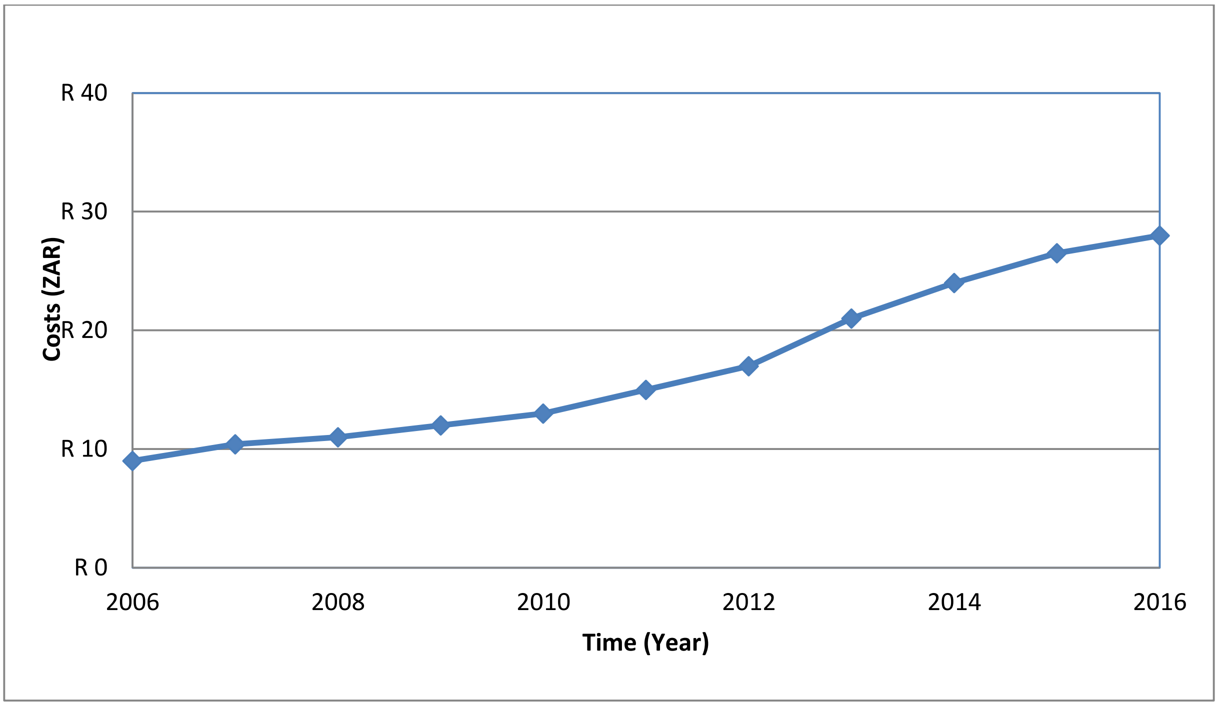


Figure 61: Sinter production electric energy cost per ton for period from 2006 to 2016

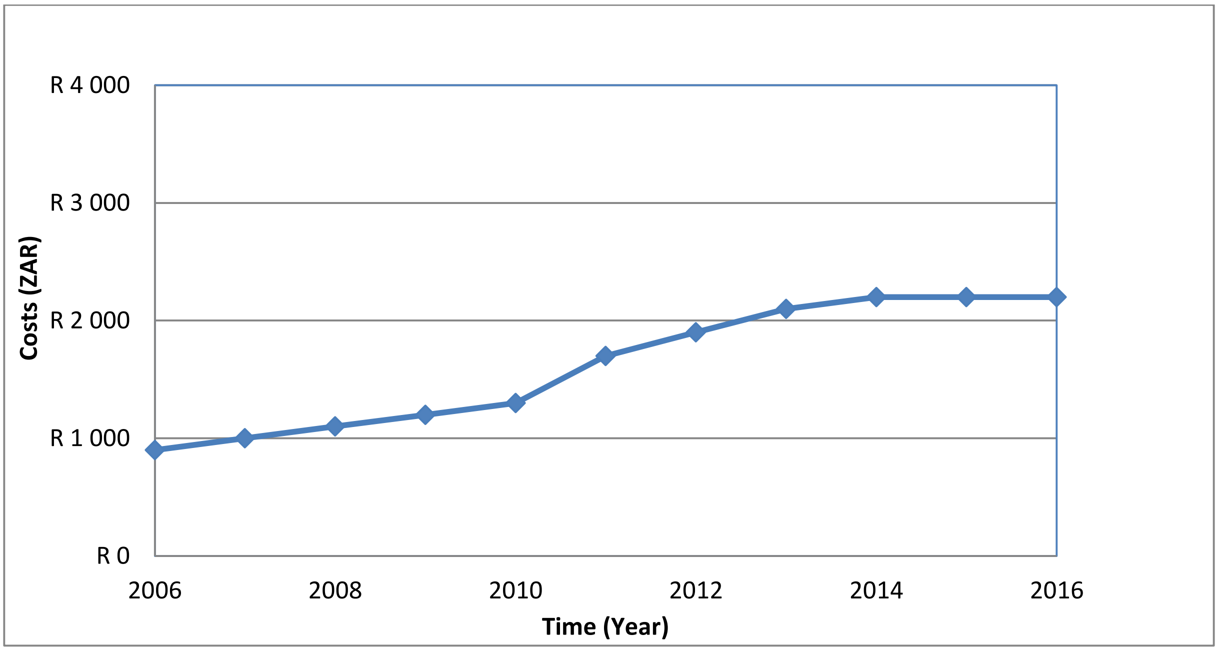


Figure 62: Smelter operations electric energy cost per ton treated for the period from 2006 to 2016

The significant difference in the three scenarios as indicated in the three graphs in Figures 60, 61 and 62, is that the power consumption per ton of Manganese Ore through the Smelter is significantly higher, followed by the per-ton power cost of sintering. Upstream mining power cost is the lowest.

The analysis of the modelling result that follows in the next chapter (chapter 6) is based on the concept of sustainability and economic development that was established through the literature review, and seeks to address the aspects of causality between infrastructure development, economic growth and sustainable development, as described in the summary of the initial hypotheses of this thesis.

6. Results presentation and analysis

The results of the Manganese mineral resource value chain system dynamics simulations are discussed first in Section 6.1 based on key variables affecting the industry, its ability to influence economic growth as well as attract more business to the Northern Cape's John Taolo Gaetsewe (JTG) region. The second portion of the analysis discussed in Section 6.2, is seen as a logical follow through step to the Manganese resources value chain simulation, in that it further analyses the impact of the beneficiation decision on regional socio-economic development.

Whilst the results that are described for the Manganese value chain scenario in section 6.1 focus a lot on comparison of the three scenarios in terms of magnitude, the socio-economic development model results analysis in section 6.2 will emphasise test of pattern prediction (Barlas, 1989:60). The system dynamics simulation modelled the usage of revenue from the Manganese secondary beneficiation value chain scenario, as a primary driver of infrastructure development, and as an impetus to skills development in the region.

6.1. Mine value chain model result analysis

The system dynamics model simulation in the research focused on the sensitivity of the Manganese business to the dynamic movements on the cost of the input variables and the price changes on the output side. The logic for which the results are presented is described for the three value chain scenarios in chapter 5 of this thesis. While the analysis of the results presented in this chapter largely focuses on the interplay between multiple variables, the sensitivity of the value chain scenarios to individual variable variations was also tested. This was done to draw inference to the dominance of certain variables within a multi-variate analysis, and to identify the possible existence of special case variables.

Due to the complexity of the dynamic relationships between the acting variables and the mine system in the mine value chain scenario, the univariate analysis falls short of describing the system. The final analysis for each scenario is therefore based on multi-variate analysis, due to the combined impact of power cost, logistics cost and price of the Manganese product. Whereas, in the past, the computations required for multi-variate analysis were overwhelming without the usage of software, the computational power of the Vensim software model combined with the current system dynamics model for Manganese resource value chain makes it possible to perform the multi-variate analysis within very reasonable time limits.

The presentation of the Revenue, Profit and Capital efficiency graph reflect the daily fluctuations in the spot price of Manganese since they are directly affected by price. However the Input cost graph do not show the same pattern as the Revenue, Profit and Capital Efficiency graphs since the cost parameters simulated using constant values. Fluctuation of the three Manganese products (Ore, Sinter and Ferro-Manganese) unit prices were simulated through a “Random Triangular” function in the simulation software to reflect the market fluctuations in the spot price of the three products. The results obtained in the system dynamics model simulation were based on annual mining production of Manganese resources of a range from 7 to 15 million tons. The timeline of the system dynamics model simulation covers a 10 year period, from 2006 to 2016

6.1.1. Cost and revenue performance comparison

The results of the system dynamics model simulation described in section 6.1.1.2 and section 6.1.1.3 of this thesis, broadly demonstrate congruence with the initial hypothesis of the research described in chapter 4 of the thesis. The initial hypothesis was described in chapter 4 based on three concepts as follows:

> The *first* concept regarding the Manganese resources value chain about sustainable development is that beneficiation of the minerals will create more value and increase employment opportunities (DMR, 2004)
>
> The *second* concept is that, the relationship between infrastructure development and economic growth goes in both directions (Perkins *et al*, 2005).
>
> The *third* concept is that the maintenance and expansion of infrastructure are important dimensions of supporting economic activity in a growing economy, provided that individual projects are chosen on the basis of appropriate cost-benefit analyses (Perkins *et al*, 2005).

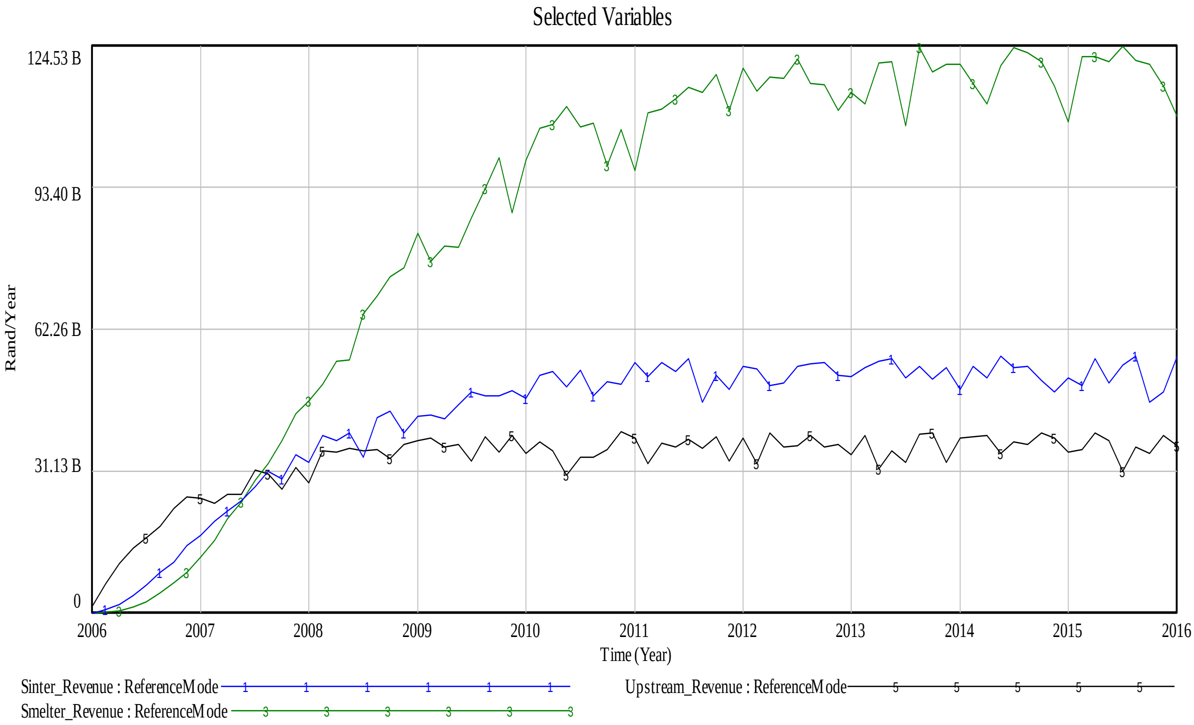
The simulation results show that, in the very short term, investment in the upstream mining activities of the mine value chain presents a lower risk and positive capital efficiencies for every ton of Manganese Ore mined. However, in comparison to the primary beneficiation and secondary beneficiation scenario, the upstream scenario has lower revenue and cost base, which implies that more tons of Ore need to be mined annually to support any significant spending in the area.

The results also show that more revenue is created with secondary beneficiation of Manganese into Ferro-Manganese, compared with the sale of non-beneficiated Manganese Ore, over the 10 year simulation period. Sintering makes some improvement in revenue generated from Ore production only, but falls far short in comparison with the secondary beneficiation.

6.1.1.1. Revenue Comparison

The revenue comparison depicted in Figure 63 indicates that there is more revenue earned through beneficiation scenarios with the secondary beneficiation scenario showing the highest cumulative revenue over the simulation period. In the first year of the simulation, there is no revenue indicated for the beneficiation scenarios and this is the case because the system dynamic model simulation links the product (output) of the upstream scenario to the input of the primary and secondary beneficiation scenarios hence the delay in revenue income to the latter.

From 2006 to 2007 as indicated in graph 63 data table, the annual revenue of the upstream scenario is superior when compared to both primary and secondary beneficiation scenarios. However, in 2008 as highlighted in the same data table, the revenue contribution from the primary and the secondary beneficiation scenarios surpasses that of the upstream scenario. It should be noted however that the early revenue from the upstream mining scenario that is depicted in Figure 63 presents a low risk for the investment in such scenario, when looked at from a payback period point of view.



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Cumulative
Upstream Revenue (ZAR)	1.61E+09	2.52E+10	2.85E+10	3.77E+10	3.49E+10	3.83E+10	3.83E+10	3.47E+10	3.85E+10	3.52E+10	3.68E+10	2.6951E+12
Sinter Revenue (ZAR)	0	1.71E+10	3.3E+10	4.3E+10	4.7E+10	5.5E+10	5.41E+10	5.19E+10	4.9E+10	5.15E+10	5.63E+10	3.49189E+12
Smelter Revenue (ZAR)	0	1.23E+10	4.64E+10	8.34E+10	9.95E+10	9.7E+10	1.19E+11	1.14E+11	1.21E+11	1.08E+11	1.09E+11	7.03924E+12

Figure 63: Mine value chain revenue comparison

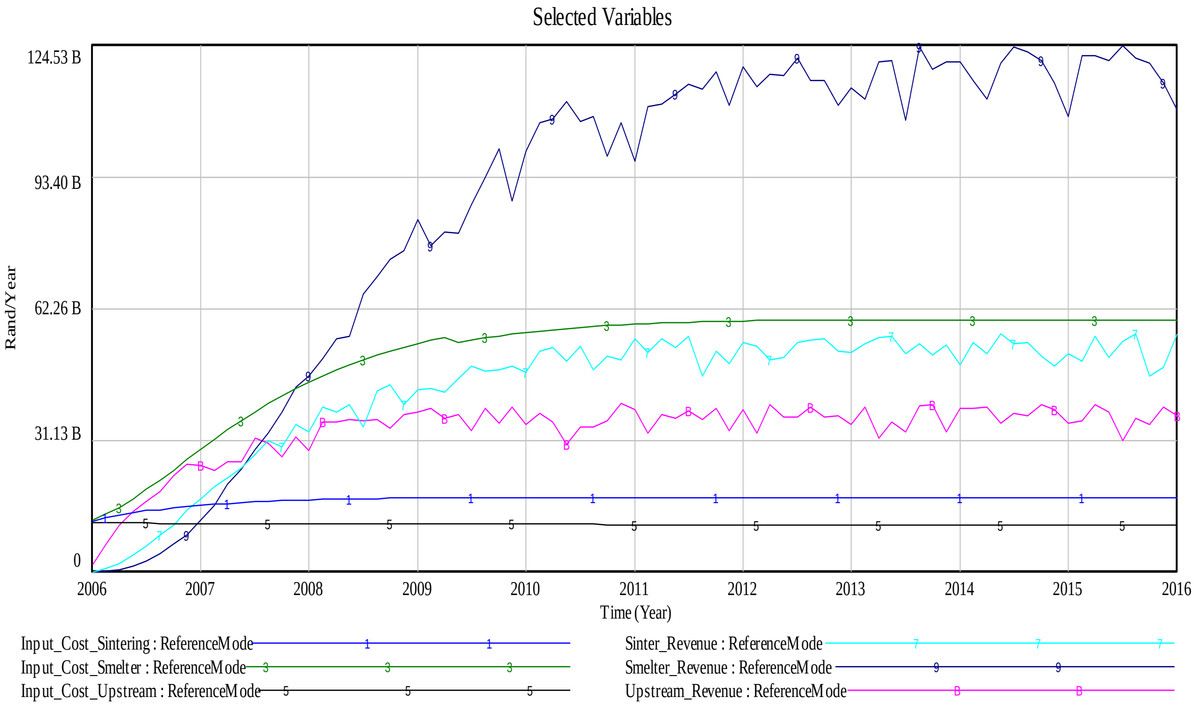
The secondary beneficiation scenario presents the highest revenue of the three scenarios and remains high for the rest of the simulation period. A comparison of peak revenues highlighted in the data table in figure 63 shows that the upstream mining and secondary beneficiation scenarios peak in 2014 whilst the primary beneficiation scenario peaks in 2016. The peak values confirm a pattern of revenue superiority by the secondary beneficiation scenario followed by the primary beneficiation scenario. It should be noted that the high revenue earned through the secondary beneficiation is due to the superior Rand price per ton of Ferro-Manganese product when compared with sintered Manganese and non-beneficiated Manganese Ore.

The fluctuations in revenue values throughout the simulation period are generated using the “Random Triangular” function to reflect the variations in prices. However, a contribution due to production adjustments is noted in 2010 which is due to feedback related to power and logistics capacity constraints shown in table 10. In the model, when production exceeds the power or logistics capacity limit, there is an automatic downward adjustment of production. To put context to the comparison made on revenue, a cost element is added to the comparison in the next section.

6.1.1.2. Cost comparison

In modelling the three Manganese resources value chain scenarios, the costs of electricity, water and logistics, the values of which were extracted from table 10 were considered key variables to the input cost. The difference in cost amongst the three scenarios is dependent on the individual scenario consumption of the inputs, mentioned above.

When analysed from a break-even point of view, the data from the graph in Figure 64, show that upstream scenario reaches break even in the first year whereas, the primary beneficiation (Sinter) and the secondary beneficiation (Smelter) would run at a loss for the first year and the two years respectively as highlighted in the data table.



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Cumulative
Input Cost Upstream (ZAR)	1.15E+10	1.13E+10	1.12E+10	1.12E+10	1.12E+10	1.11E+10	1.11E+10	1.11E+10	1.106E+10	1.1E+10	1.1000E+10	9.04172E+11
Input Cost Sintering (ZAR)	1.19E+10	1.56E+10	1.69E+10	1.74E+10	1.76E+10	1.76E+10	1.76E+10	1.75E+10	1.748E+10	1.74E+10	1.7387E+10	1.37728E+12
Input Cost Smelter (ZAR)	1.22E+10	2.89E+10	4.49E+10	5.4E+10	5.65E+10	5.85E+10	5.93E+10	5.95E+10	5.956E+10	5.95E+10	5.9344E+10	4.1712E+12
Base												
Upstream Revenue (ZAR)	1.61E+09	2.52E+10	2.85E+10	3.77E+10	3.49E+10	3.83E+10	3.83E+10	3.47E+10	3.85E+10	3.52E+10	3.6822E+10	2.6951E+12
Sinter Revenue (ZAR)	0	1.71E+10	3.3E+10	4.3E+10	4.7E+10	5.5E+10	5.41E+10	5.19E+10	4.9E+10	5.15E+10	5.6336E+10	3.49189E+12
Smelter Revenue (ZAR)	0	1.23E+10	4.64E+10	8.34E+10	9.95E+10	9.7E+10	1.19E+11	1.14E+11	1.205E+11	1.08E+11	1.0901E+11	7.03924E+12

Figure 64: Input Cost comparison

The shaded cells on the bottom half of the table in Figure 64 between the years 2014 and 2016 highlight the revenue points with peak annual profits for each scenario. When expressed in Rand terms, the profitability (difference between Revenue and Input Cost) of the secondary beneficiation (Smelter) is higher at (ZAR 6.1 billion) in 2014 than the primary beneficiation at (ZAR 3.9 billion) in 2016 and the upstream mining (ZAR 2.7 billion) in 2014. The detail logic for profit calculation is described in appendix B of this thesis.

The input costs of the upstream mining and primary beneficiation seem relatively close, as depicted in Figure 64. A mathematical average of the 10 input cost data points represented in the top half of the table in Figure 64 show that at ZAR 11 billion over the 10 year period the average upstream mining input cost is the lowest of the three scenarios. The secondary beneficiation input cost is the highest at an average of ZAR 51.49 billion.

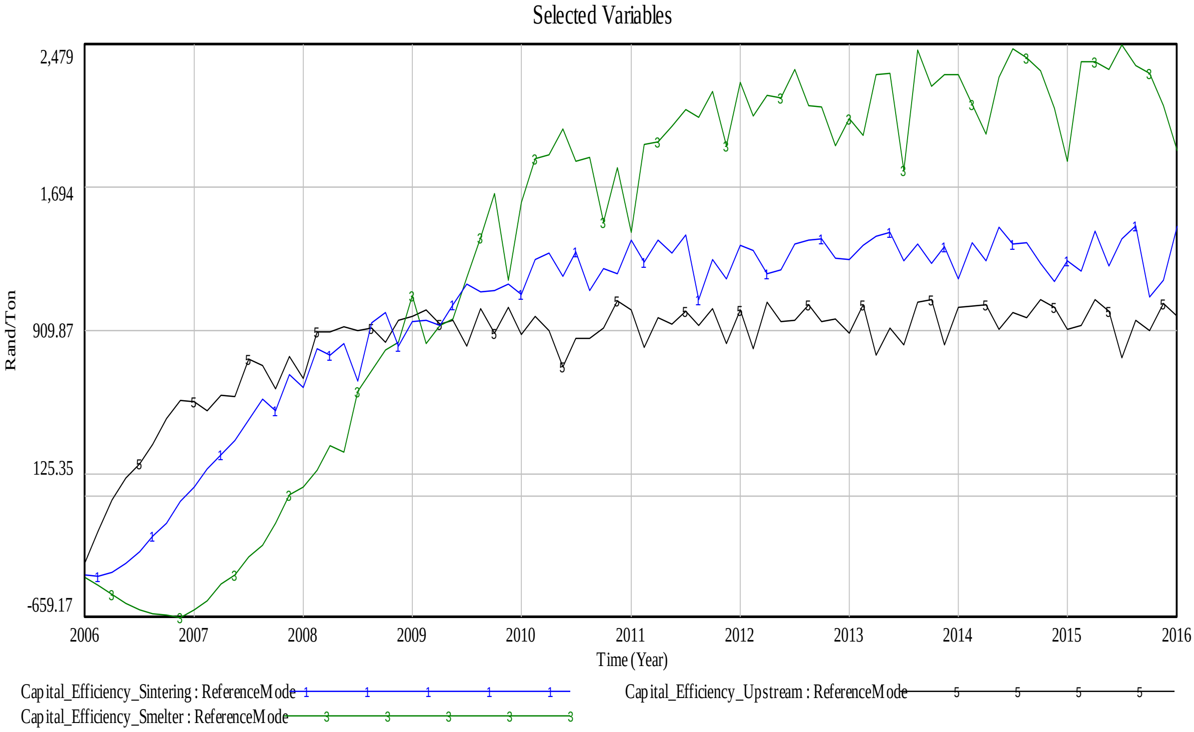
The cost of upstream mining is incorporated in the cost of primary beneficiation scenario simulation, with only the “logistics input cost” excluded, as it is accounted for in the primary beneficiation scenario’s input cost. The production output of the upstream mining activities is not shipped or sold to a secondary processing stage, but is handled within the same facility. The assumption made in the system dynamics model for the secondary beneficiation is that, the operator owns all stages of the Manganese mineral value chain.

Whilst the high cost of operating the secondary beneficiation facility may be seen as high cash flow risk by some investors, the same cost may also translate into opportunities for more localised spending and by implication more job opportunities. This scenario also represents a significant opportunity for skills development and employment within the technology and engineering support industry.

6.1.1.3. Capital efficiency comparison

Capital efficiency is used in the system dynamic model to indicate the profitability of each scenario under comparison in broader terms. This term is used to focus profitability towards the mineral resource volumes; hence it measures returns per ton of Manganese Ore mined. The capital efficiency graphs are depicted in Figure 65.

As indicated on the data table in Figure 65, the cumulative value of the capital efficiency for the upstream mining scenario is better in the first few years between 2006 and 2009 when compared to that of the primary beneficiation (Sinter) scenario. In the first 4 years to 2010, the primary beneficiation scenario could be looked at as less favourable return on investment however over the simulation period the view could change based on the overall performance. Whilst the average capital efficiency value of the upstream mining scenario is lower compared to the primary beneficiation and the secondary beneficiation, the early positive return in the upstream mining scenario may lower the perception of risk of returns on the investment and by implication, the ability of the business to re-invest in alternative economic activities.



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Capital Efficiency Upstream (ZAR)	-360.73	517.07	645.30	990.77	890.86	1021.93	1025.60	893.88	1040.53	918.34	984.33
Capital Efficiency Sintering (ZAR)	-432.05	53.35	597.76	958.63	1105.10	1407.73	1376.97	1300.37	1195.28	1294.28	1484.73
Capital Efficiency Smelter (ZAR)	-443.68	-619.15	55.59	1100.00	1611.69	1447.73	2269.74	2073.52	2311.06	1835.34	1893.20

Figure 65: Capital efficiency comparison

As highlighted in the data table of the graph in Figure 65, the capital efficiency of the secondary beneficiation scenario is negative for the first two years to 2007 which implies a negative return for every ton of Manganese Ore mined. The data on the shaded cells on the table in Figure 65 for the year 2009 show that, the returns from the secondary beneficiation scenario at ZAR 1100 surpass those of the upstream mining at ZAR 990 whilst the primary beneficiation scenario remains below the upstream mining capital efficiency in the same year. The shaded cells on the table in Figure 65 for the year 2010 show a new pattern of returns with the secondary beneficiation returning higher capital efficiency of ZAR 1611 followed by primary beneficiation capital efficiency at ZAR 1105 and upstream mining capital efficiency trailing the two for the remainder of the simulation period.

6.1.2. Results of univariate analysis

The system dynamics model simulation also focused on the impact of individual variables on the outcome of the simulation. The logistics and power cost variables were selected as focus variables for the univariate analysis as they constitute a significant proportion of the direct cost of mining. The sensitivity analysis of these variables was limited to variance in their values as this is deemed to be what determines the difference in their impact on selected output variables.

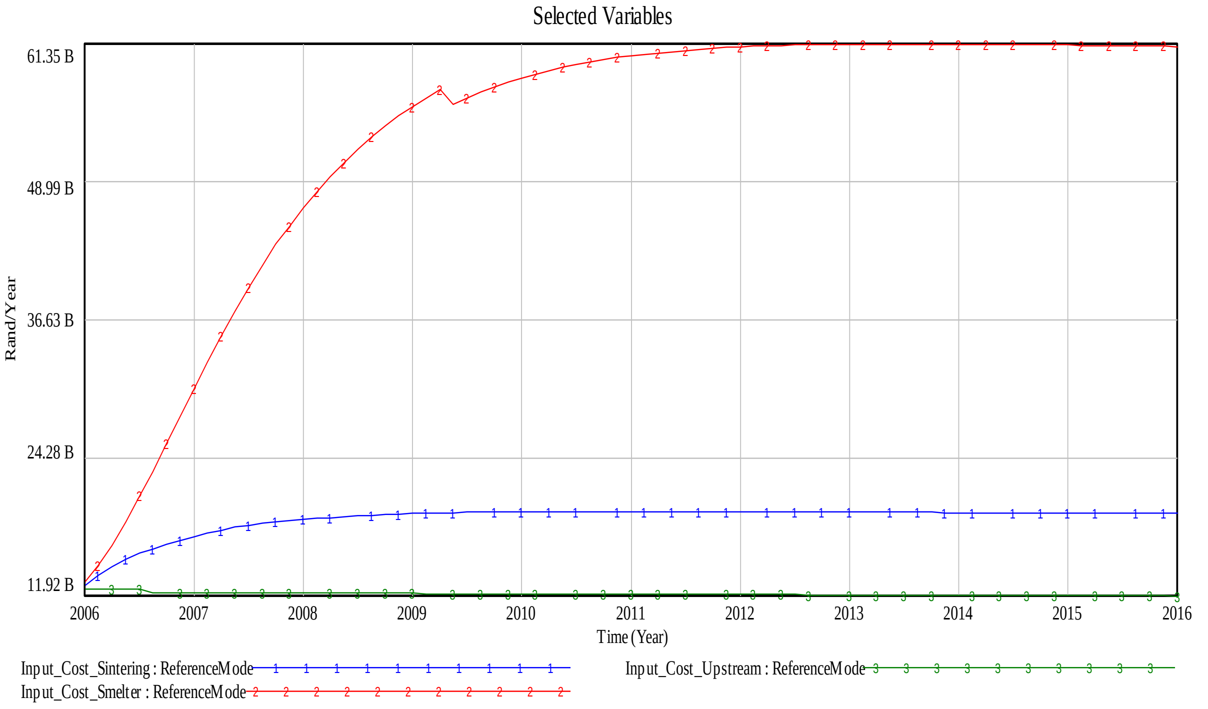
The analyses in this section are made by comparing the break even points of the base scenario (i.e. without change in variables) to the outcome of the changes input cost variable. The top half of the data table in each graph represent the after (result of a change) whilst the bottom half represents the base scenario. The graph itself shows the after change scenario.

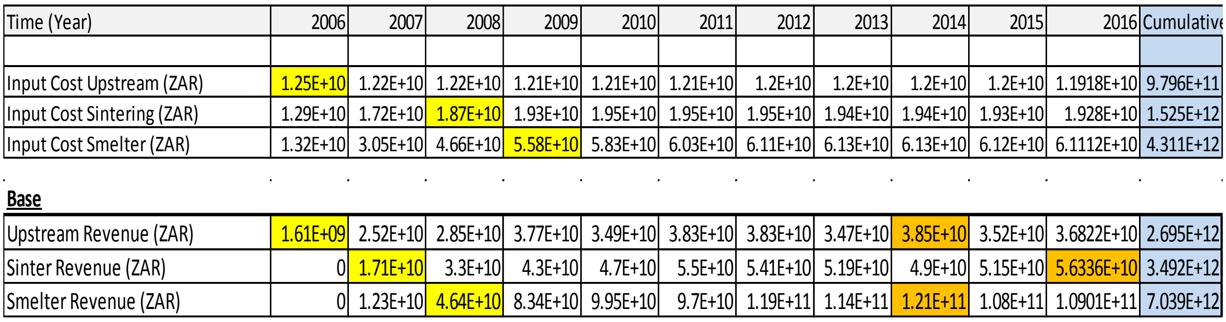
6.1.2.1. Sensitivity to logistics cost variations

The ratio of volume reduction from non-beneficiated Manganese Ore to Sinter product is 1: 0.8 due to losses in ignition, whereas the ratio from Manganese Ore to Ferro-Manganese is 1:0.4. Therefore the change in logistics cost is expected to have more influence in the cost of the upstream mining when compared to the Sinter and Smelter scenarios. The comparison displayed in the graphs and statistical data tables in the following sections focuses on the mean values before and after the variations in logistics cost. The cost pattern for all three scenarios does not change due to logistics cost variations, only the quanta are affected.

Impact of logistics cost increase on input cost

As indicated in Figure 66, an increase in the cost per ton of Manganese Ore transported, whether it is through rail or road, has a negative impact on input cost. To assess the impact of increased logistics cost, a comparison of the break-even point is used based on a 10 % increase in logistics cost.





Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Cumulative
Input Cost Upstream (ZAR)	1.25E+10	1.22E+10	1.22E+10	1.21E+10	1.21E+10	1.21E+10	1.2E+10	1.2E+10	1.2E+10	1.2E+10	1.1918E+10	9.796E+11
Input Cost Sintering (ZAR)	1.29E+10	1.72E+10	1.87E+10	1.93E+10	1.95E+10	1.95E+10	1.95E+10	1.94E+10	1.94E+10	1.93E+10	1.928E+10	1.525E+12
Input Cost Smelter (ZAR)	1.32E+10	3.05E+10	4.66E+10	5.58E+10	5.83E+10	6.03E+10	6.11E+10	6.13E+10	6.13E+10	6.12E+10	6.1112E+10	4.311E+12

Base

Upstream Revenue (ZAR)	1.61E+09	2.52E+10	2.85E+10	3.77E+10	3.49E+10	3.83E+10	3.83E+10	3.47E+10	3.85E+10	3.52E+10	3.6822E+10	2.695E+12
Sinter Revenue (ZAR)	0	1.71E+10	3.3E+10	4.3E+10	4.7E+10	5.5E+10	5.41E+10	5.19E+10	4.9E+10	5.15E+10	5.6336E+10	3.492E+12
Smelter Revenue (ZAR)	0	1.23E+10	4.64E+10	8.34E+10	9.95E+10	9.7E+10	1.19E+11	1.14E+11	1.21E+11	1.08E+11	1.0901E+11	7.039E+12

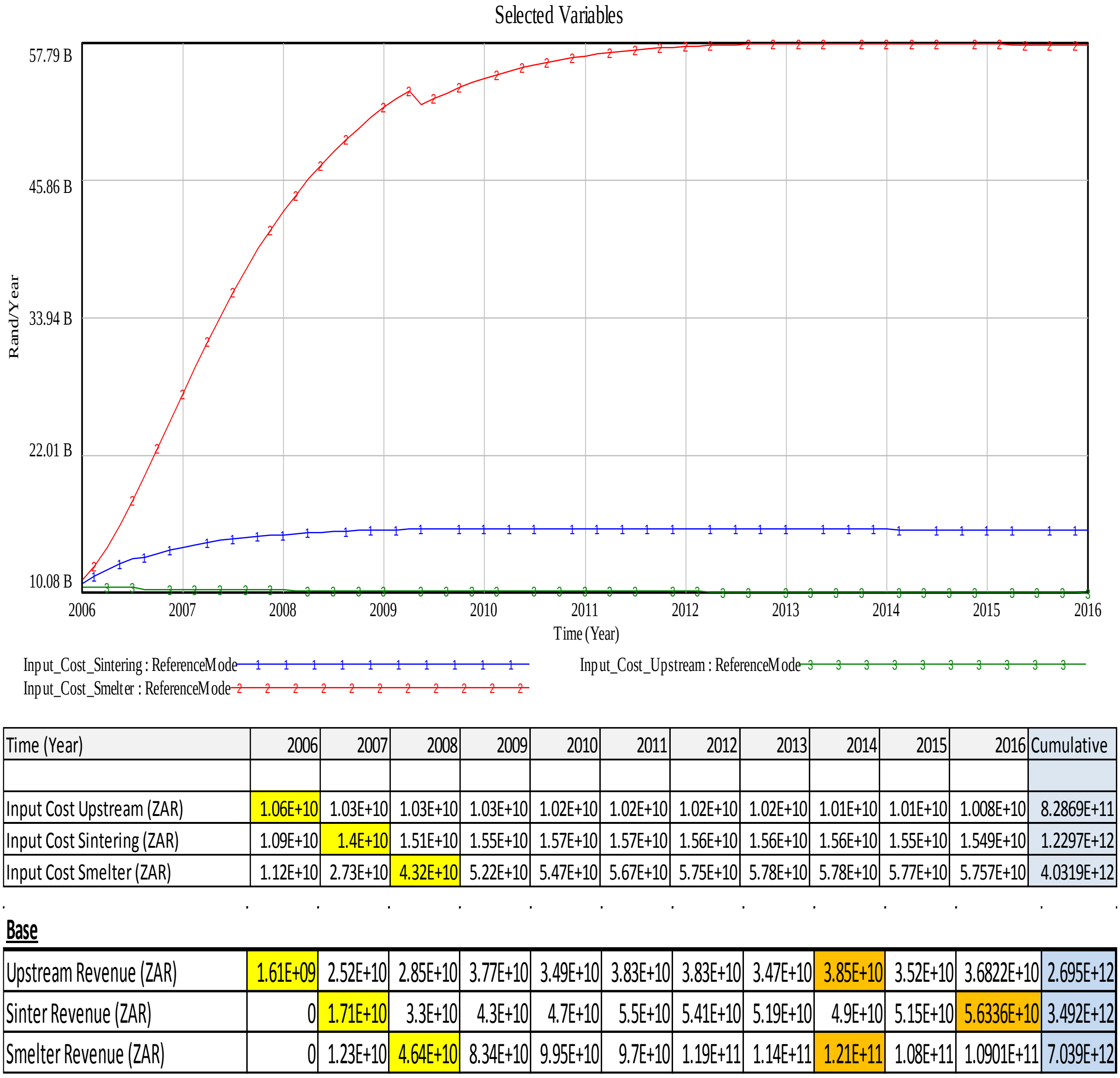
Figure 66: Input cost performance under increased logistics cost

The shaded cells on the bottom half of the table represent the break-even points with base logistics cost whilst the top half of the table show the new input cost and break even points as highlighted in the shaded cells due to increased logistics cost. The shaded cells on the data table in Figure 66 show that, the beneficiation scenarios have a shift of the break-even point by one year each when compared to the base on the bottom half of the data table. The primary beneficiation scenario has a beak-even point at 2008 under increased logistics cost which is a shift from 2007 before the increase was introduced. A similar impact is noted on the secondary beneficiation scenario where the break-even point moves from 2008 to 2009.

The impact of logistics on input cost may be even bigger when road transportation is used. In the survey conducted by the CSIR (2007) which was based on tonnages per kilometres and rand per ton per kilometre, it was confirmed that the cost of road transport was higher by 67% (CSIR, 2007:20) when compared with rail bulk transportation costs.

Impact of logistics cost decrease on input cost

As indicated in Figure 67, a decrease in the cost per ton of Manganese Ore transported shows a positive impact on input cost. The impact of a 10% decrease in logistics cost introduced in the system dynamics model is represented through an assessment of the break-even points highlighted by the shaded cells with bases case on the bottom half of the table and the new break-even points shown in the shaded cells on the top half of the data table in Figure 67.



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Cumulative
Input Cost Upstream (ZAR)	1.06E+10	1.03E+10	1.03E+10	1.03E+10	1.02E+10	1.02E+10	1.02E+10	1.02E+10	1.01E+10	1.01E+10	1.008E+10	8.2869E+11
Input Cost Sintering (ZAR)	1.09E+10	1.4E+10	1.51E+10	1.55E+10	1.57E+10	1.57E+10	1.56E+10	1.56E+10	1.56E+10	1.55E+10	1.549E+10	1.2297E+12
Input Cost Smelter (ZAR)	1.12E+10	2.73E+10	4.32E+10	5.22E+10	5.47E+10	5.67E+10	5.75E+10	5.78E+10	5.78E+10	5.77E+10	5.757E+10	4.0319E+12

Base

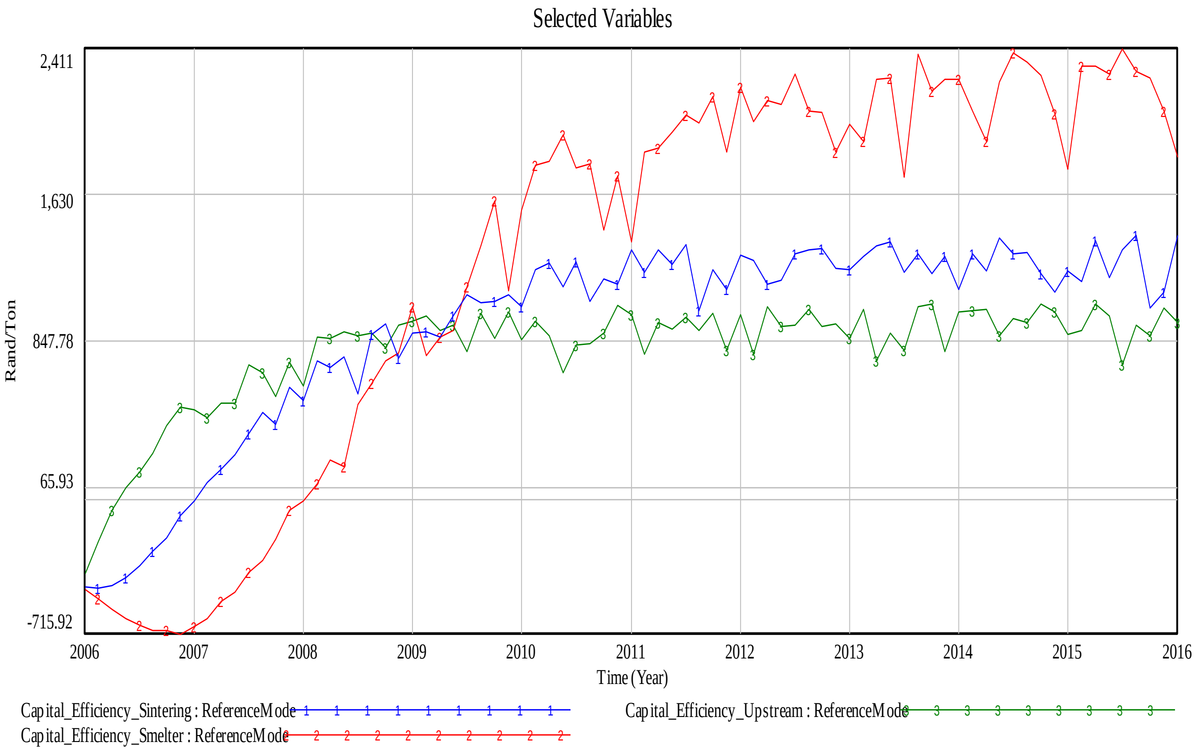
Upstream Revenue (ZAR)	1.61E+09	2.52E+10	2.85E+10	3.77E+10	3.49E+10	3.83E+10	3.83E+10	3.47E+10	3.85E+10	3.52E+10	3.6822E+10	2.695E+12
Sinter Revenue (ZAR)	0	1.71E+10	3.3E+10	4.3E+10	4.7E+10	5.5E+10	5.41E+10	5.19E+10	4.9E+10	5.15E+10	5.6336E+10	3.492E+12
Smelter Revenue (ZAR)	0	1.23E+10	4.64E+10	8.34E+10	9.95E+10	9.7E+10	1.19E+11	1.14E+11	1.21E+11	1.08E+11	1.0901E+11	7.039E+12

Figure 67: Input cost performance under decreased logistics cost

As highlighted in the shaded cells of the data table, the decrease in the cost of logistics does not impact the break-even point of any of the scenarios from a time point of view. However, the change in the cost of logistics from ZAR 350 per ton to ZAR 315 per ton translates into a decrease in the "Input Cost" of similar quantum for all three scenarios, as does the increase in logistics cost. The detail of these calculations and the system dynamics logic are described in Appendix B in this thesis.

Impact of logistics increase on capital efficiency

The increase in logistics cost has a varied impact on capital efficiency for the three scenarios. The extent of the change in the capital efficiencies of the three scenarios can be read on the data tables of the graph in Figure 68 where the top half of the table depicts the capital efficiency values after the increase and the lower part of the table depicting the base values of the capital efficiencies. The movement of the capital efficiency values from the base to the new values after the logistics cost increase is consistent with the movements in the values of the input cost for al scenarios observed in Figure 66.



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Capital Efficiency Upstream (ZAR)	-395.73	482.07	610.30	955.77	855.86	986.93	990.60	858.88	1005.53	883.34	949.33
Capital Efficiency Sintering (ZAR)	-468.57	-6.34	530.39	888.25	1033.60	1335.82	1304.92	1228.26	1123.14	1222.14	1412.58
Capital Efficiency Smelter (ZAR)	-480.21	-677.41	-8.72	1033.65	1544.50	1380.36	2202.32	2006.10	2243.63	1767.91	1825.78

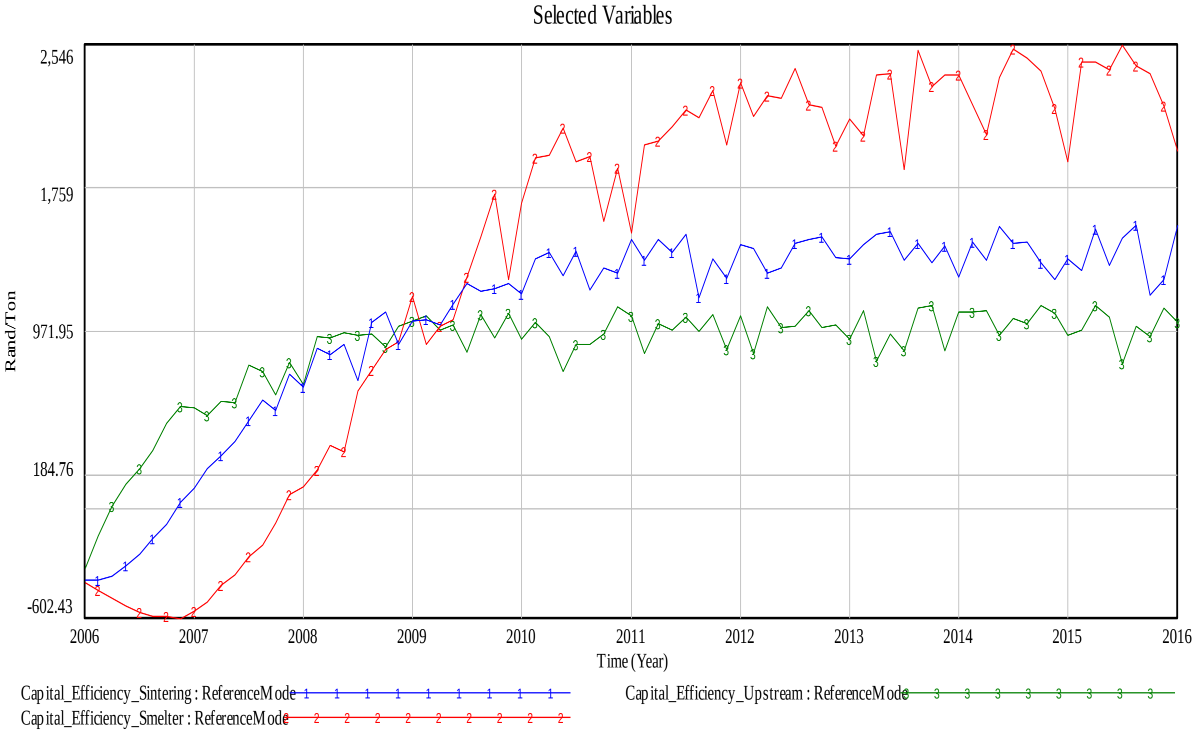
Base											
Capital Efficiency Upstream (ZAR)	-360.73	517.07	645.30	990.77	890.86	1021.93	1025.60	893.88	1040.53	918.34	984.33
Capital Efficiency Sintering (ZAR)	-432.05	53.35	597.76	958.63	1105.10	1407.73	1376.97	1300.37	1195.28	1294.28	1484.73
Capital Efficiency Smelter (ZAR)	-443.68	-619.15	55.59	1100.00	1611.69	1447.73	2269.74	2073.52	2311.06	1835.34	1893.20

Figure 68: Capital efficiency performance under increased logistics cost

An assessment of the “upstream capital efficiency” values in the shaded cells on both halves of the data table in Figure 68 show a reduction in the values from base to values after the increase in logistics cost. The reduction indicated by the shaded cells is from a base value of ZAR 990.77 per ton in year 2009 where the cost of logistics is fixed at ZAR 350 to a new value of ZAR 955.77 per ton on the top half of the data table highlighted in the shaded area of the top half of the data table in the same year when logistics cost is increased to ZAR 385 per ton of Manganese product transported. A similar pattern is observed for the primary beneficiation and secondary beneficiation “capital efficiency “values.

Impact of decreased logistics cost on Capital Efficiency

From Figure 69, the impact of decreased logistics costs on capital efficiency depicts a similar but positive trend for all three scenarios as it did for the increase in logistics cost. Comparing the performance of the three scenarios against the base values on the bottom half of the data table in 2009, an observation can be made that, the primary beneficiation “capital efficiency” value is higher than the upstream mining “capital efficiency” as shown in shaded cell on the top half of the data table in Figure 69, which was not the case with the base scenario on the bottom half of the table in the same year. This highlights that the movement in the cost of logistics has more impact on the primary beneficiation (Sintering) that it does so on the other two scenarios



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Capital Efficiency Upstream (ZAR)	-325.73	552.07	680.30	1025.77	925.86	1056.93	1060.60	928.88	1075.53	953.34	1019.33
Capital Efficiency Sintering (ZAR)	-395.52	113.04	665.13	1029.01	1176.59	1479.63	1449.03	1372.48	1267.41	1366.41	1556.87
Capital Efficiency Smelter (ZAR)	-407.16	-560.89	119.89	1166.36	1678.87	1515.10	2337.15	2140.95	2378.49	1902.76	1960.63

Base

Capital Efficiency Upstream (ZAR)	-360.73	517.07	645.30	990.77	890.86	1021.93	1025.60	893.88	1040.53	918.34	984.33
Capital Efficiency Sintering (ZAR)	-432.05	53.35	597.76	958.63	1105.10	1407.73	1376.97	1300.37	1195.28	1294.28	1484.73
Capital Efficiency Smelter (ZAR)	-443.68	-619.15	55.59	1100.00	1611.69	1447.73	2269.74	2073.52	2311.06	1835.34	1893.20

Figure 69: Capital efficiency performance under decreased logistics cost

6.1.2.2. Sensitivity to power cost variations

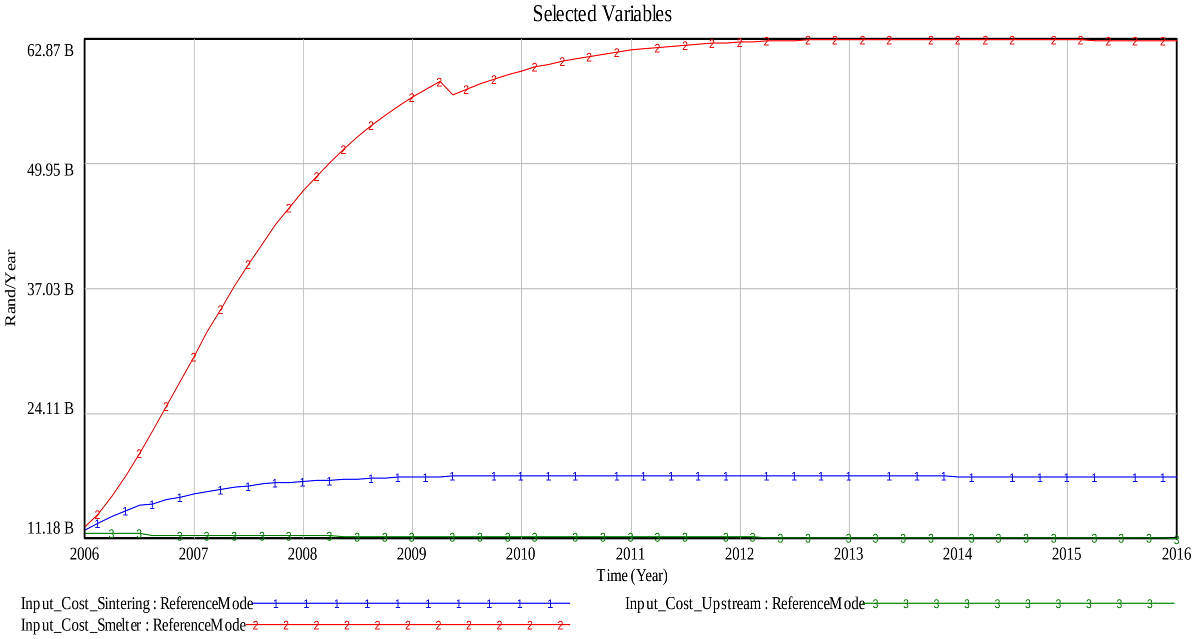
The data collected from the industry show that the cost of electricity in South Africa was the single most direct contributor to the high cost of secondary beneficiation. The actual cost of electricity measured in kWh has been on a steep increase since 2008 when NERSA (2012) started announcing approvals of multi-year price determinations (MYPD). The capital efficiency graphs in Figure 72 and 73 also show a dip in the graph during 2010 which reflects the correction in production of the high carbon Ferro-Manganese (HCFeMn) due to power constraints. A similar pattern is evident in the input cost graphs for the secondary beneficiation scenario in Figures 70 and 71.

Sensitivity to power cost increase

The cost of electricity was varied by 10% for all three scenarios, whilst all the other variables were kept at forecast estimates from the data collected.

Impact of power cost increase on input cost

The shaded cells on the data table of the graph in figure 66 demonstrates a shift in the break-even point of the secondary beneficiation (Smelter) scenario by one year from that which was achieved with base power cost. Whereas a break-even point is achieved in 2008 for the base power cost scenario with revenues of ZAR 46.4 billion, such revenues are not sufficient in the 10% power increase scenario where the input cost is ZAR 47.1 billion. The break-even points of the upstream mining and the primary beneficiation (Sinter) scenario remain in the same years that they were with the base power cost scenario albeit with increases in input cost due to increased power cost.



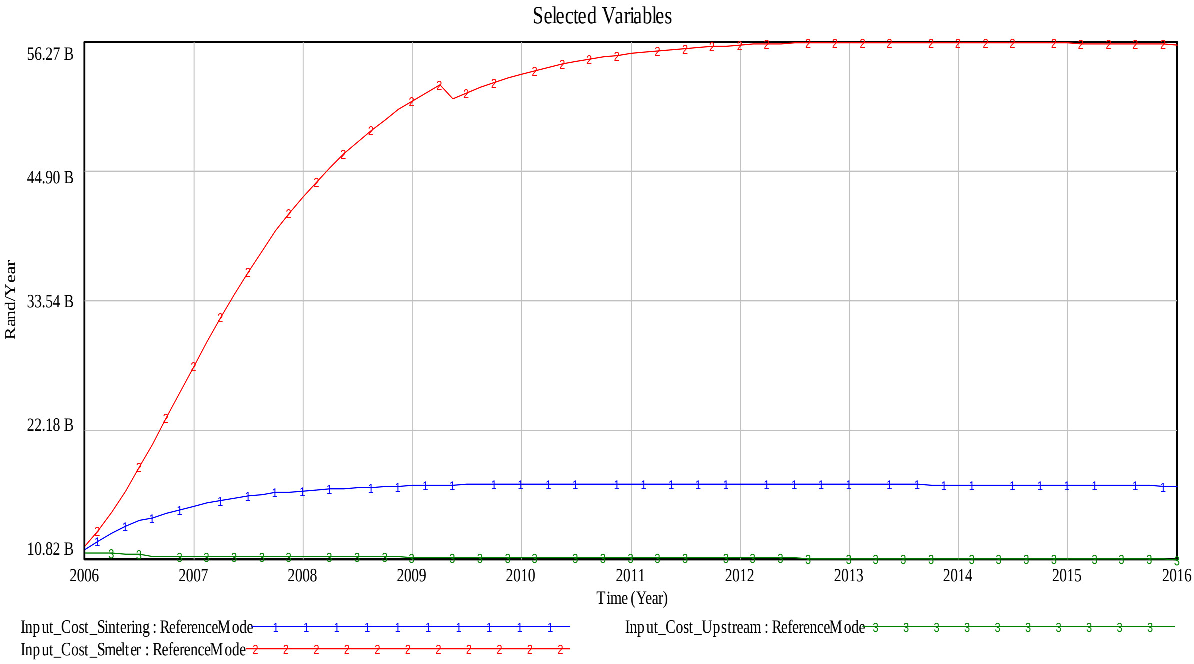
Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2014.875	2016	Cumulative
Input Cost Upstream (ZAR)	1.17E+10	1.14E+10	1.14E+10	1.14E+10	1.14E+10	1.13E+10	1.13E+10	1.13E+10	1.12E+10	1.12E+10	1.1171E+10	9.182E+11
Input Cost Sintering (ZAR)	1.21E+10	1.58E+10	1.71E+10	1.75E+10	1.77E+10	1.77E+10	1.77E+10	1.76E+10	1.76E+10	1.76E+10	1.7507E+10	1.388E+12
Input Cost Smelter (ZAR)	1.24E+10	3E+10	4.71E+10	5.69E+10	5.96E+10	6.17E+10	6.26E+10	6.28E+10	6.29E+10	6.28E+10	6.2644E+10	4.393E+12

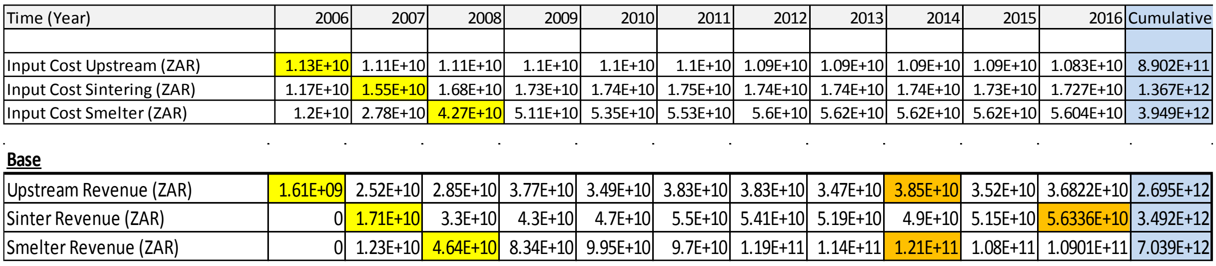
Base

Upstream Revenue (ZAR)	1.61E+09	2.52E+10	2.85E+10	3.77E+10	3.49E+10	3.83E+10	3.83E+10	3.47E+10	3.85E+10	3.52E+10	3.6822E+10	2.695E+12
Sinter Revenue (ZAR)	0	1.71E+10	3.3E+10	4.3E+10	4.7E+10	5.5E+10	5.41E+10	5.19E+10	4.9E+10	5.15E+10	5.6336E+10	3.492E+12
Smelter Revenue (ZAR)	0	1.23E+10	4.64E+10	8.34E+10	9.95E+10	9.7E+10	1.19E+11	1.14E+11	1.21E+11	1.08E+11	1.0901E+11	7.039E+12

Figure 70: Input cost performance under increased power cost

With average power utilisations of 3100 kWh/ton for the secondary beneficiation, 90kWh/ton for the upstream mining and 32 kWh/ton for the primary beneficiation scenario, it is no surprise that the secondary beneficiation scenario is more sensitive to the cost of electrical energy than the other two scenarios.





Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Cumulative
Input Cost Upstream (ZAR)	1.13E+10	1.11E+10	1.11E+10	1.1E+10	1.1E+10	1.1E+10	1.09E+10	1.09E+10	1.09E+10	1.09E+10	1.083E+10	8.902E+11
Input Cost Sintering (ZAR)	1.17E+10	1.55E+10	1.68E+10	1.73E+10	1.74E+10	1.75E+10	1.74E+10	1.74E+10	1.74E+10	1.73E+10	1.727E+10	1.367E+12
Input Cost Smelter (ZAR)	1.2E+10	2.78E+10	4.27E+10	5.11E+10	5.35E+10	5.53E+10	5.6E+10	5.62E+10	5.62E+10	5.62E+10	5.604E+10	3.949E+12

Base

Upstream Revenue (ZAR)	1.61E+09	2.52E+10	2.85E+10	3.77E+10	3.49E+10	3.83E+10	3.83E+10	3.47E+10	3.85E+10	3.52E+10	3.6822E+10	2.695E+12
Sinter Revenue (ZAR)	0	1.71E+10	3.3E+10	4.3E+10	4.7E+10	5.5E+10	5.41E+10	5.19E+10	4.9E+10	5.15E+10	5.6336E+10	3.492E+12
Smelter Revenue (ZAR)	0	1.23E+10	4.64E+10	8.34E+10	9.95E+10	9.7E+10	1.19E+11	1.14E+11	1.21E+11	1.08E+11	1.0901E+11	7.039E+12

Figure 71: Input cost performance under decreased power cost sensitivities

Impact of power decrease on input cost

A low power-cost scenario favours the secondary beneficiation scenario, due to the known input cost structure compared with the upstream mining and primary beneficiation scenarios. The input cost for the Smelter highlighted in the shaded area on the top half of the table in 2008 shows that at ZAR 42.7 billion, the break-even point is ZAR 4.4 billon lower compared to where it was (ZAR 47.1 billion) when power cost was increased by the same percentage as indicated in Figure 66.

An observation can also be made from the data in the shaded area that break-even is achieved a year earlier for the Smelter operation in this scenario compared to the scenario in Figure 70. In contrast to the primary beneficiation scenario in the same year, the change in the primary beneficiation input cost is ZAR 300 million (difference between ZAR 17.1 billion in Figure 67 and ZAR 16.8 billion in Figure 70) however, the timing of break-even remains unchanged in 2007.

The upstream mining scenario is also impacted by the changes in the power cost however the magnitude of the impact is lower compared to the secondary beneficiation scenario. What is notable in both graphs in Figure 70 and Figure 71 is that the break-even points of the upstream mining and primary beneficiation scenarios are not affected by the 10% change in power cost. The results in Figure 71 demonstrate that the secondary beneficiation scenario is more sensitive to the variations in the cost of power than the other value chain scenarios.

Impact of power cost increase on Capital Efficiency

The two data tables in Figure 72 compare the result of the simulation with 10% increase in power cost and the results of the simulation with no change to power cost. The table on top displays the data points in the graph for each year of the simulation period. From the results indicated in the data tables, an observation can be made that, at year 2009 the comparison between the base power cost scenario (the second table) and the 10% power cost increase scenario shows a significant reduction in the rand value of the secondary beneficiation's capital efficiency from ZAR 1,100 to ZAR 991. Whilst this represents a reduction of ZAR 109, the reduction on the primary beneficiation is just over ZAR 4 in the same year.

Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2014.875	2016
Capital Efficiency Upstream (ZAR)	-367.23	510.57	638.80	984.27	884.36	1015.43	1019.10	887.38	1034.03	1029.52	977.83
Capital Efficiency Sintering (ZAR)	-438.47	48.14	592.96	953.99	1100.51	1403.16	1372.42	1295.81	1190.72	1177.47	1480.17
Capital Efficiency Smelter (ZAR)	-450.10	-661.11	-28.00	991.75	1496.34	1326.53	2145.88	1948.51	2185.55	2004.58	1767.40

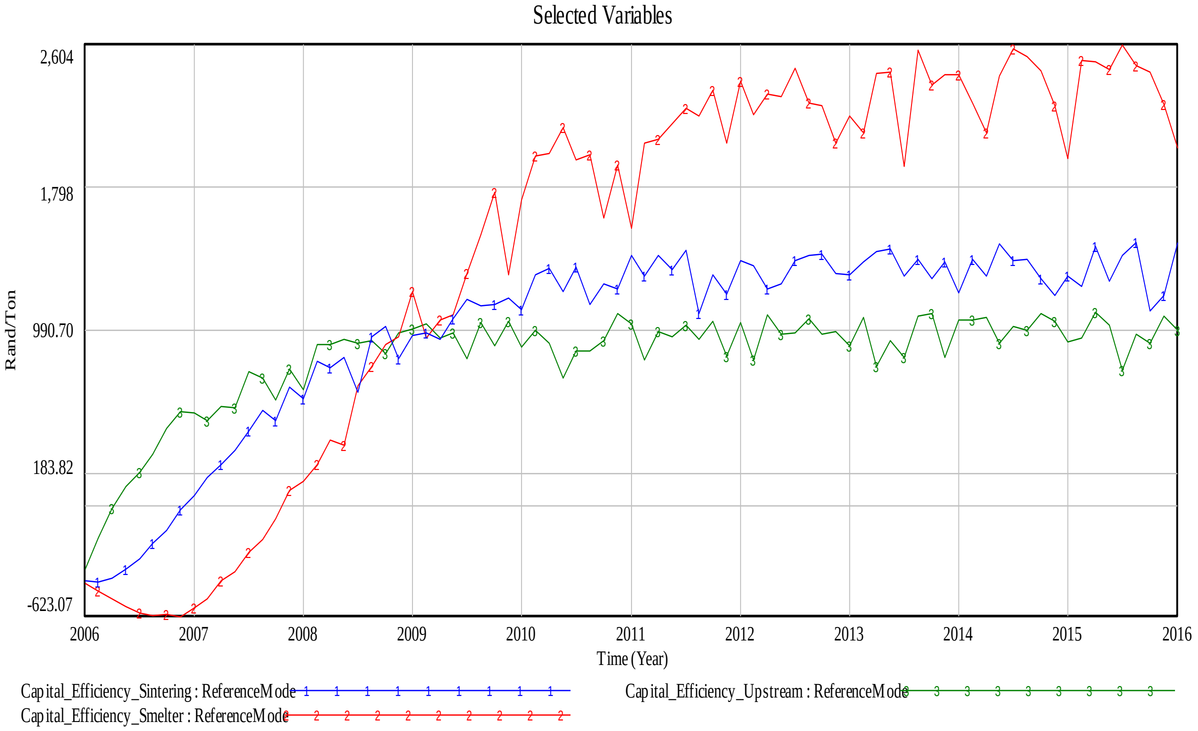
Base

Capital Efficiency Upstream (ZAR)	-360.73	517.07	645.30	990.77	890.86	1021.93	1025.60	893.88	1040.53	918.34	984.33
Capital Efficiency Sintering (ZAR)	-432.05	53.35	597.76	958.63	1105.10	1407.73	1376.97	1300.37	1195.28	1294.28	1484.73
Capital Efficiency Smelter (ZAR)	-443.68	-619.15	55.59	1100.00	1611.69	1447.73	2269.74	2073.52	2311.06	1835.34	1893.20

Figure 72: Impact of power cost increase on capital efficiency

Impact of power decrease on capital efficiency

Figure 73 indicates that the impact of a decrease in the cost of power has a positive impact on the capital efficiencies of all three scenarios. However, as is the case with increased power costs, the secondary beneficiation scenario shows more sensitivity to this change. The pattern of the results is similar to those indicated in Figure 72 albeit on the upside in the case of a decreased power cost scenario. The results observed in Figure 72 and 73 emphasize the sensitivity patterns of the three Manganese value chain scenarios towards power cost variations.



Time (Year)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Capital Efficiency Upstream (ZAR)	-354.23	523.57	651.80	997.27	897.36	1028.43	1032.10	900.38	1047.03	924.84	990.83
Capital Efficiency Sintering (ZAR)	-425.63	58.55	602.57	963.28	1109.68	1412.29	1381.53	1304.92	1199.83	1298.83	1489.28
Capital Efficiency Smelter (ZAR)	-437.26	-577.19	139.17	1208.26	1727.03	1568.94	2393.59	2198.54	2436.57	1961.06	2019.01

Base											
Capital Efficiency Upstream (ZAR)	-360.73	517.07	645.30	990.77	890.86	1021.93	1025.60	893.88	1040.53	918.34	984.33
Capital Efficiency Sintering (ZAR)	-432.05	53.35	597.76	958.63	1105.10	1407.73	1376.97	1300.37	1195.28	1294.28	1484.73
Capital Efficiency Smelter (ZAR)	-443.68	-619.15	55.59	1100.00	1611.69	1447.73	2269.74	2073.52	2311.06	1835.34	1893.20

Figure 73: Impact of decreased power cost on capital efficiency

6.1.3. Results of multi-variate analysis

In a real operating environment, several input cost and price variables are likely to change simultaneously. For that reason, the system dynamics model was used to perform a random variation of the input logistics, input power cost and market price of produced Manganese products, to determine the sensitivity of each scenario under such conditions. The Monte Carlo simulations were performed with a Random triangular distribution function using the data in table 19.

The parameters for the random triangular function in the sensitivity analysis are designed to give a tent like distribution (Vensim, 2010). The distribution starts with the

"Start" parameter which is the first value in the distribution and ends with the last value specified as the "Stop" parameter. The "tent like" or the triangle distribution that is required is achieved by mixing the values of "Min", "Peak" and "Max" parameters (Vensim, 2010). The minimum and maximum parameters of the variables in table 19 are determined from the historical data described in chapter 4 of this thesis.

Table 19: List of variables used for the Monte Carlo simulation

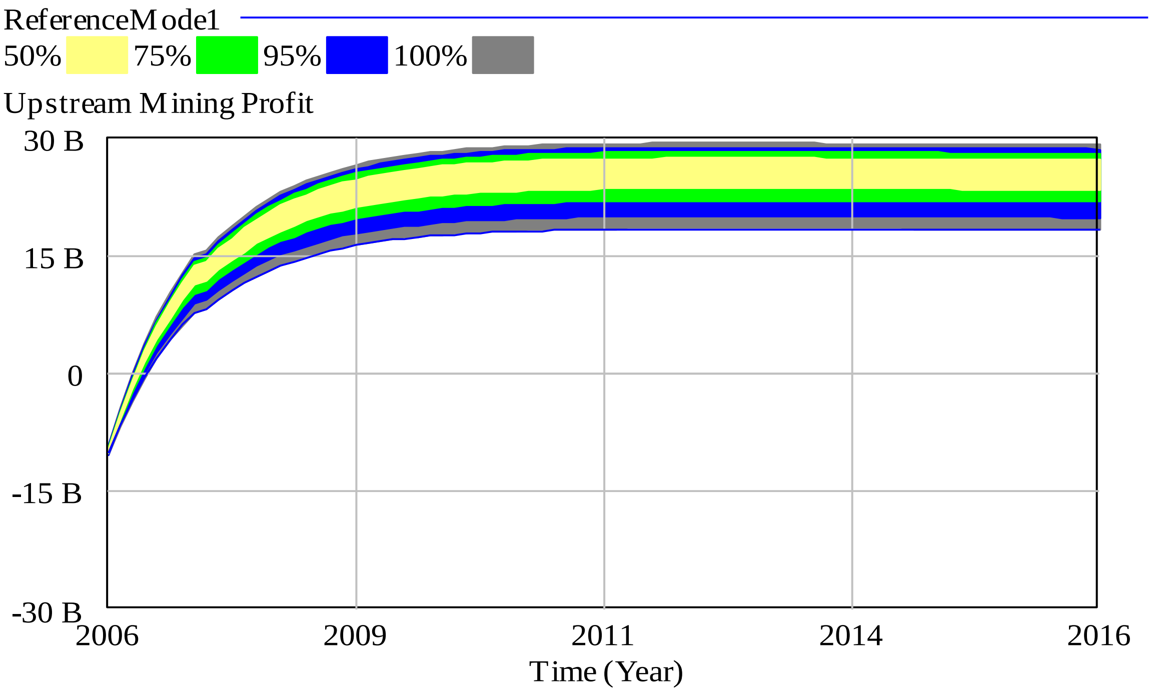
Variable	Units	Min	Max	Start	Peak	Stop
Power Cost Mn	Rand/Ton	45	80	51	65	55
Power Cost Sinter	Rand/Ton	20	35	22	30	28
Power Cost Smelter	Rand/Ton	1600	2000	1620	1800	1650
Logistics Cost	Rand/Ton	280	450	330	400	350
Price of Mn	Rand/Ton	1200	2400	1300	2000	1600
Price of Mn Sinter	Rand/Ton	1800	4000	2520	3500	3000
Price of HCFeMn	Rand/Ton	9000	18000	12500	15500	14500
Fixed Cost of Smelter	Rand/Ton	120	200	125	170	150

The output variables selected for observation of impact due to variations in the variables mentioned here, are: Profit, Capital Efficiency and Revenue. As indicated earlier, the analysis was performed to determine the performance patterns of the three scenarios. The outcome of the analysis is discussed in the sections below as follows:

6.1.3.1. Impact on Profit

The impact on the upstream mining scenario

To assess the profit performance of the upstream mining scenario under concurrent variation of input cost variables, the result of the Monte Carlo sensitivity was selected for 5 different periods of 12 months each to give a view of the impact on the mean value and standard deviation for each scenario. The "norm" parameter displays the normalised standard deviation, which is a standard deviation divided by the mean value of the variable monitored. The results shown on the data tables in Figure 74 represent the variations at each year on the curve.



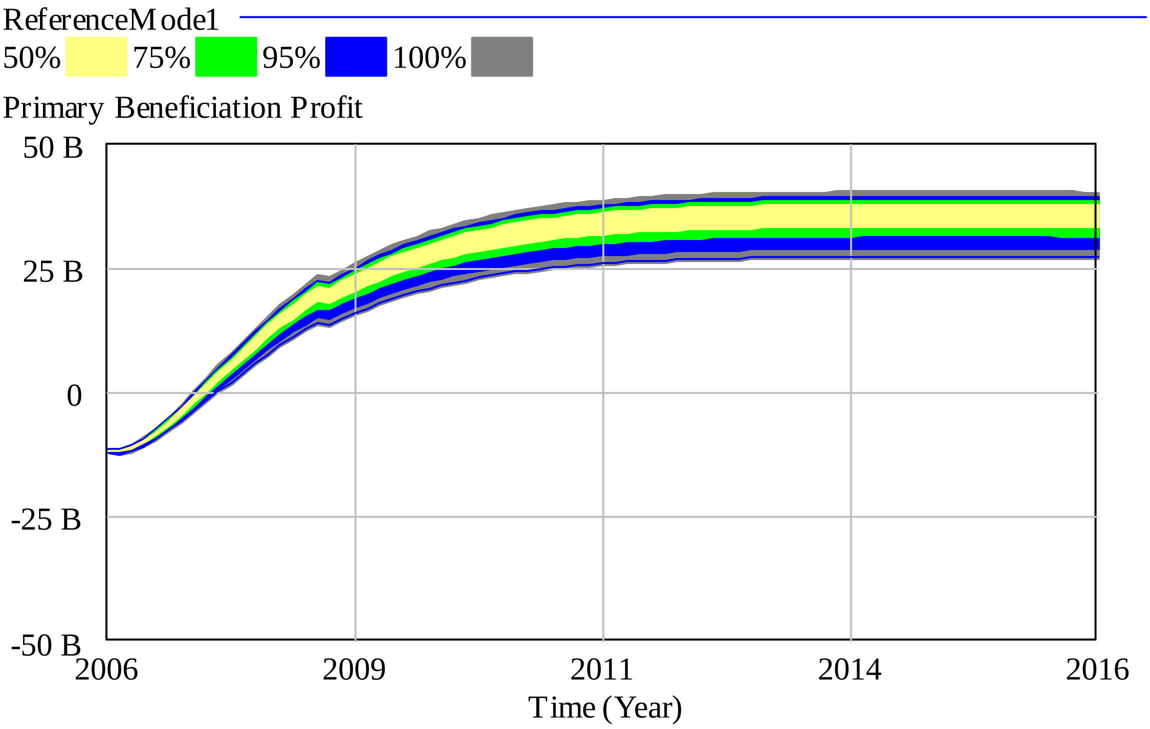
Variable	Min	Max	Mean	Median	StDev	(Norm)
Upstream Mining Profit sensitivity results at time 2006 Runs:	-1.03E+10	-9.12E+09	-9.8E+09	-9.9E+09	2.56E+08	-0.02605
Upstream Mining Profit sensitivity results at time 2008 Runs:	1.594E+10	2.442E+10	2.09E+10	2.15E+10	2.22E+09	0.106179
Upstream Mining Profit sensitivity results at time 2009 Runs:	1.842E+10	2.761E+10	2.38E+10	2.45E+10	2.41E+09	0.101519
Upstream Mining Profit sensitivity results at time 2011 Runs:	1.958E+10	2.91E+10	2.52E+10	2.59E+10	2.5E+09	0.099587
Upstream Mining Profit sensitivity results at time 2014 Runs:	1.961E+10	2.911E+10	2.52E+10	2.59E+10	2.5E+09	0.09932

Figure 74: Impact of cost and price variations on upstream mining profit

In 2006 as shown in Figure 74, the standard deviation is smaller in value when compared to the standard deviations in 2008, 2009, 2011 and 2014 however it should be noted that in 2006, production is ramping up and much less revenue is created compared to other years. Although the standard deviations in the years after 2006 are higher, the values show that the range of the performance volatility of ±ZAR 2.5 billion of this scenario can be predicted within 10% of the individual annual averages at ZAR 25.2 billion.

The impact on the primary beneficiation scenario

The values in the shaded cells on the data table in Figure 75 show that, the standard deviation and the normalised standard deviation change quite significantly between 2008 and 2010. This confirms the pattern of the graph which shows a small dip in 2009 before it continues ramping up in 2010 and stabilising thereafter. This highlights the impact of variations in logistics and power cost in the initial years of operation for the primary beneficiation scenario. The standard deviation and the normalised standard deviations from 2010 to 2014 are narrower at 10% which highlight more predictability of the profits despite variations in logistics and power cost. All this imply that the first years of operating the primary beneficiated scenario is more sensitive to changes in input cost and anyone investing in this scenario need to plan carefully for such variations.



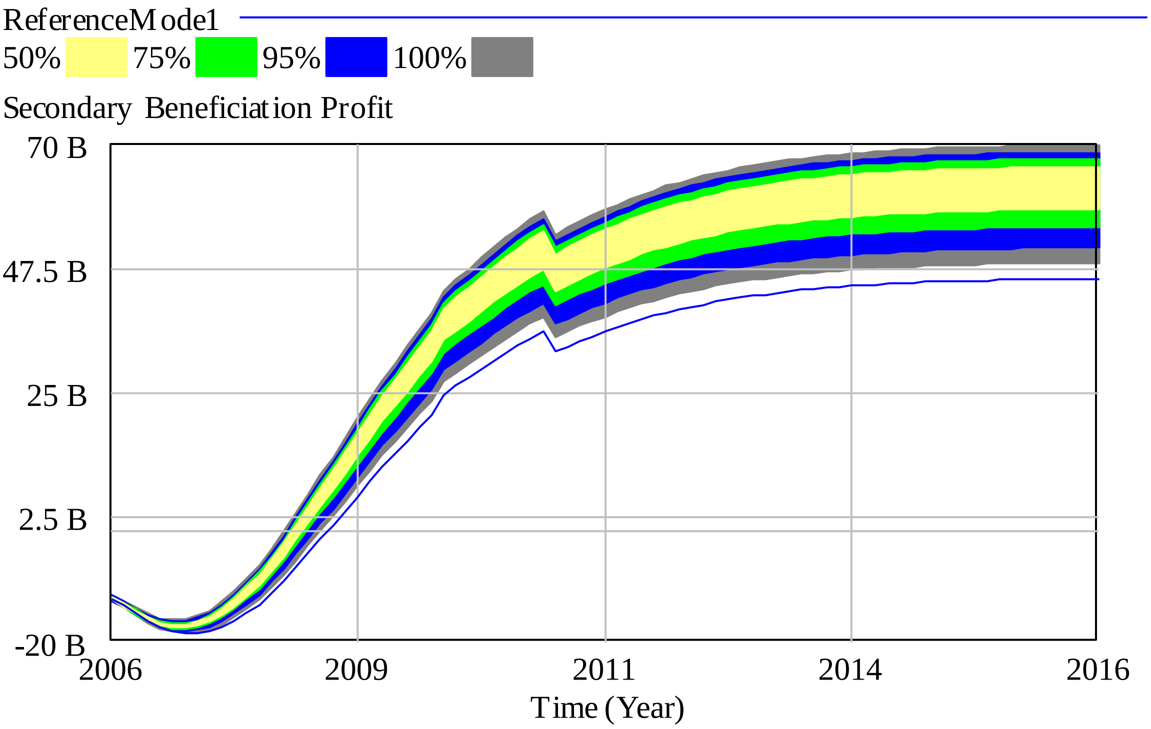
Variable	Min	Max	Mean	Median	StDev	(Norm)
Primary Beneficiation Profit sensitivity results at time 2006 Runs:	-1.22E+10	-1.11E+10	-1.2E+10	-1.2E+10	2.47E+08	-0.02094
Primary Beneficiation Profit sensitivity results at time 2008 Runs:	1.232E+10	2.133E+10	1.79E+10	1.83E+10	2.08E+09	0.116277
Primary Beneficiation Profit sensitivity results at time 2010 Runs:	2.354E+10	3.57E+10	3.11E+10	3.17E+10	2.87E+09	0.092292
Primary Beneficiation Profit sensitivity results at time 2014 Runs:	2.697E+10	4E+10	3.51E+10	3.58E+10	3.09E+09	0.08815

Figure 75: Impact of variations to logistics and power cost on Sinter Profit

The impact on the secondary beneficiation scenario

The shaded cells in the data table in Figure 76 highlight the extent of the standard deviation in the formative years of operating the secondary beneficiation scenario. The deference in the standard deviation from 2006 to 2008 is almost 10 fold when compared to the difference in standard deviation from 2010 to 2012. This signifies the extent of the uncertainty in profit performance when logistics and power cost are varied simultaneously with price during the early operation of the secondary beneficiation business.

What is notable in the graph is that in the year 2010, the profit curve shows a downward correction before rising into stability by 2015. The correction is mainly due to the correction in the production levels due to power and logistics constraint feedback designed into the system dynamics model which ensures that production gets reduced gradually when the logistics and/or power capacity are exceeded.



Variable	Min	Max	Mean	Median	StDev	(Norm)
Smelter Profit sensitivity results at time 2006 Runs:	-1.25E+10	-1.14E+10	-1.2E+10	-1.2E+10	2.47E+08	-0.02038
Smelter Profit sensitivity results at time 2008 Runs:	-1.45E+09	6.656E+09	2.9E+09	3.1E+09	1.83E+09	0.629509
Smelter Profit sensitivity results at time 2010 Runs:	3.661E+10	5.305E+10	4.61E+10	4.66E+10	3.9E+09	0.084624
Smelter Profit sensitivity results at time 2011 Runs:	4.07E+10	5.818E+10	5.08E+10	5.13E+10	4.16E+09	0.081748
Smelter Profit sensitivity results at time 2015 Runs:	5.034E+10	6.959E+10	6.16E+10	6.21E+10	4.6E+09	0.07476

Figure 76: Impact of cost and price variations on Smelter profit

The data observed in Figure 76 indicate that the secondary beneficiation scenario has a better percentage standard deviation in the years 2008, 2010, 2011 and 2015 when compared to the other two scenarios as shown in Figures 74 and 75 previously however this trend is more consistent from year 2011 to 2015. As an example, in year

2015 the standard deviation from the mean is ZAR 4.6 billion against a mean profit value of ZAR 61.6 billion, making the deviation 7.5%. However the Rand value of the standard deviation in the secondary beneficiation scenario is still higher than what it was in the upstream mining and the primary beneficiation scenarios.

The major contribution to these variations comes from energy consumption in the electric furnaces, where power costs contribute significantly to the cost per ton of Manganese treated. These observations indicate that the secondary beneficiation scenario favours a more stable logistics and power cost environment however as a percentage of revenue and profits, the selected variations are small.

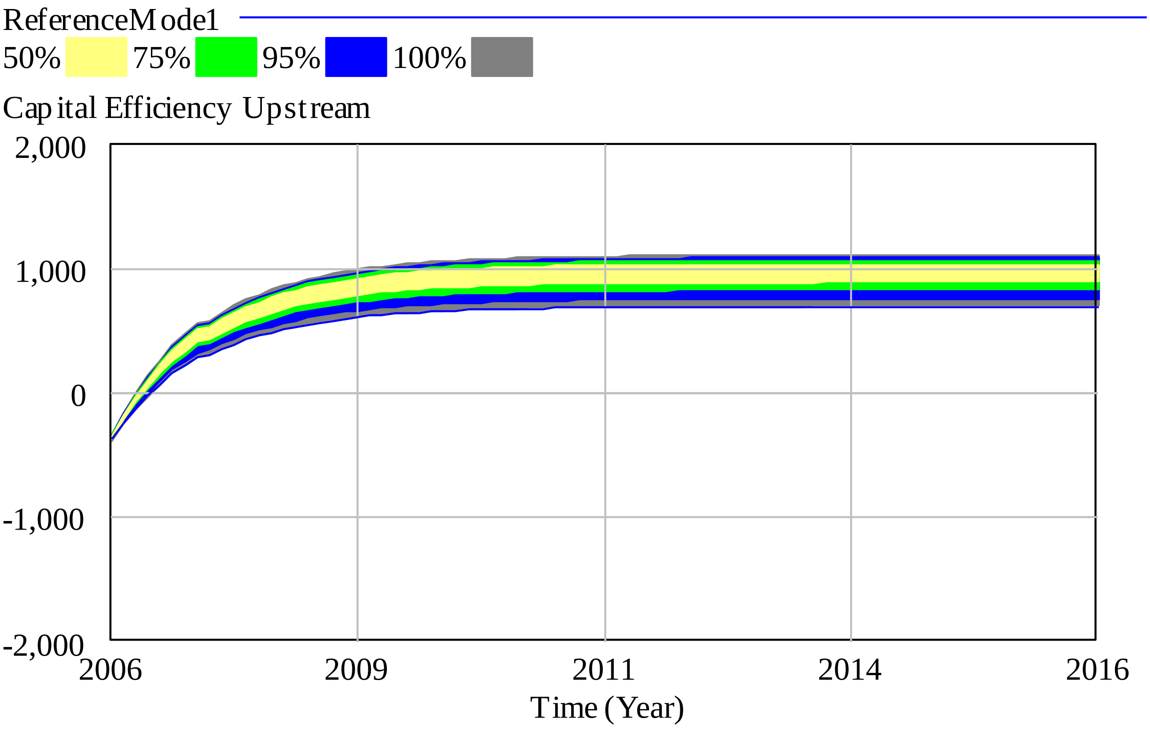
6.1.3.2. Impact on Capital Efficiency

The capital efficiency performance was measured on 4 or 5 selected years in the simulation to observe the relationship between the standard deviations in each selected year and the mean value in that year. The mean and the standard deviations are calculated through the Monte Carlo sensitivity function using the parameters listed in table 19 and the logic defined in chapter 5 of the thesis. The statistical observations are summarised for each scenario in this section.

The impact on the upstream mining scenario

The results depicted in Figure 77 show that the impact of variations in price of Manganese Ore and input cost. The shaded cells on the data table in Figure 77 show that the standard deviation from the mean changed significantly from ZAR 9.31 in 2006 to ZAR 82.7 in 2008 when compared to the 2 year periods between 2010- 2012 and 2012-2014. This shows that the Capital efficiency is most affected by variations in price and cost inputs in the formative year of the upstream mining operation but become predictable with normalised standard deviations fairly consistent at ±10% from the mean during three of the selected years i.e. 2008, 2010 and 2014.

The standard deviation and the mean value from the 2006 simulation year can be considered an outlier and not fully representative of the performance of the upstream mining scenario in a long term. The same assessment can be made for the primary and secondary beneficiation scenario performances since they are all linked to the production efficiencies of the upstream mining scenario in the system dynamics model simulation.

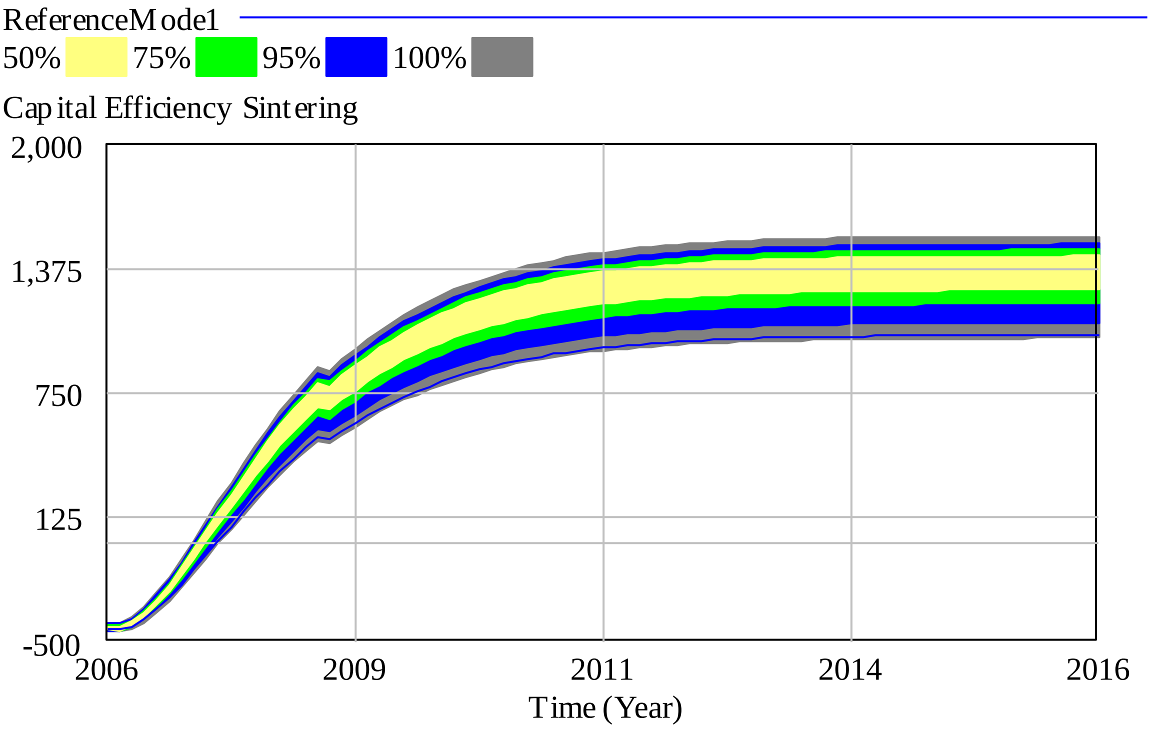


Variable	Min	Max	Mean	Median	StDev	(Norm)
Capital Efficiency Upstream sensitivity results at time 2006 Runs:	-374.55	-331.683	-357.285	-358.732	9.30797	-0.02605
Capital Efficiency Upstream sensitivity results at time 2008 Runs:	594.817	910.8612	778.6674	802.8181	82.6783	0.106179
Capital Efficiency Upstream sensitivity results at time 2010 Runs:	723.6701	1077.908	930.8771	957.2946	93.1659	0.100084
Capital Efficiency Upstream sensitivity results at time 2014 Runs:	743.5267	1103.7	954.3751	981.143	94.7881	0.09932

Figure 77: Impact of cost and market price variations on upstream mining capital efficiency.

<u>The impact on the primary beneficiation scenario</u>

The variations on input cost and market price have a similar impact on the primary beneficiation capital efficiency as it does on the upstream mining capital efficiency albeit with slight difference in 2010 where the upstream mining capital efficiency has a standard deviation above 10%. The shaded cells also show a significant jump in the standard deviation from ZAR 8.97 in 2006 to ZAR 77.66 in 2008. This shows the same pattern as the “capital efficiency” predictability seen on the upstream mining scenario in Figure 77. The notable difference in standard deviation patterns between these scenarios as seen on the data table in Figure 78 the standard deviation continues change by bigger margins of just below ZAR 20 for periods 2008-2010 and 2010-2012 however stabilises between 2012 and 2014 with a small change of ±ZAR 2.



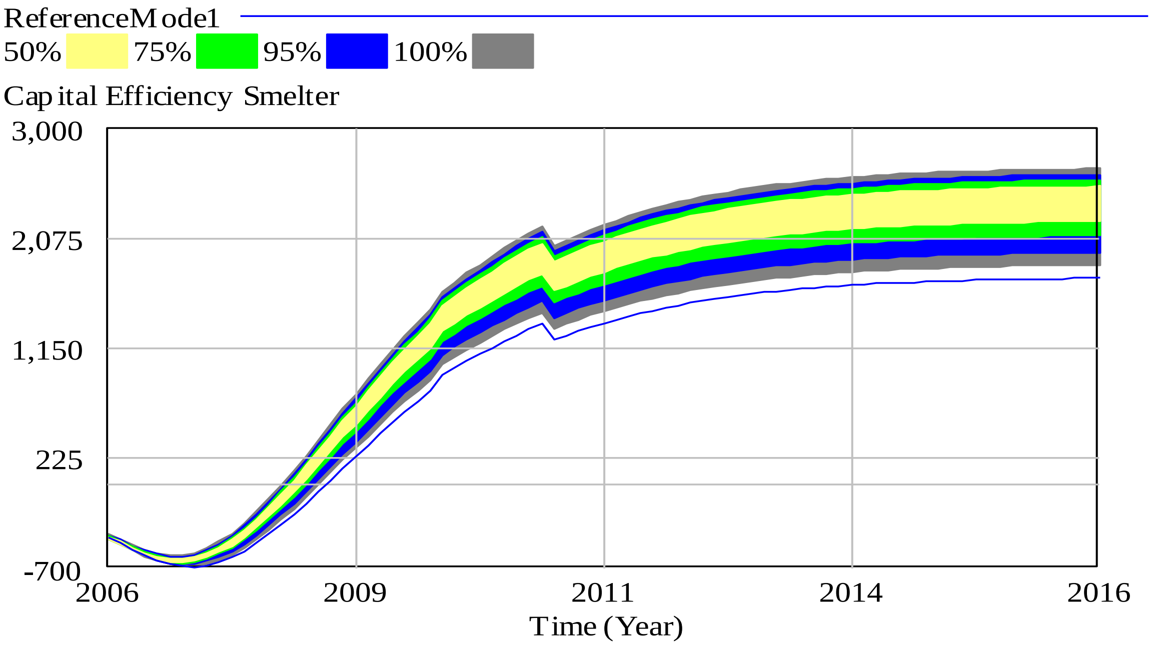
Variable	Min	Max	Mean	Median	StDev	(Norm)
Capital Efficiency Sintering sensitivity results at time 2006 Runs:	-442.172	-404.669	-428.332	-429.975	8.96869	-0.02094
Capital Efficiency Sintering sensitivity results at time 2008 Runs:	459.7236	795.7047	667.8674	684.1671	77.6576	0.116277
Capital Efficiency Sintering sensitivity results at time 2010 Runs:	716.6221	1126.78	971.7798	993.8762	96.1524	0.098945
Capital Efficiency Sintering sensitivity results at time 2012 Runs:	999.8119	1487.702	1304.41	1330.225	115.785	0.088764
Capital Efficiency Sintering sensitivity results at time 2014 Runs:	1022.7	1516.736	1331.214	1357.531	117.346	0.08815

Figure 78: Impact of variations in input cost and market prices on Sinter capital efficiency

From the selected simulation years, it is also evident that the normalised standard deviation is consistently below 10% for the 2010, 2012 and 2014 simulation years. The notable difference between the values observed in 2006 and 2008 confirm the erratic and slow performance of a primary beneficiation operation’s start-up period where production ramps up from low base with revenue income lagging input cost.

<u>The impact on the secondary beneficiation scenario</u>

Figure 79 shows that, when only the Rand value of standard deviations are observed, it would appear as if the secondary beneficiation scenario is the most impacted by variations in input costs and market prices, compared with the other two scenarios. As depicted in the statistical data in graph 79, between the year 2008 and 2014 the standard deviation of the secondary beneficiation's capital efficiency from the mean is higher than it is observed in the upstream mining and primary beneficiation scenarios. As a percentage of the mean, the secondary beneficiation shows a better variation as it can be seen in the shaded cells on the data table in the year 2014 where the standard deviation is only 7.5% compared to the upstream mining and the primary beneficiation scenarios which were both showing standard deviations of ±9% in the same period.



Variable	Min	Max	Mean	Median	StDev	(Norm)
Capital Efficiency Smelter sensitivity results at time 2006 Runs:	-453.808	-416.305	-439.968	-441.611	8.96869	-0.02038
Capital Efficiency Smelter sensitivity results at time 2007 Runs:	-645.119	-529.932	-589.455	-590.594	22.2768	-0.03779
Capital Efficiency Smelter sensitivity results at time 2008 Runs:	759.515	1256.38	1041.049	1057.948	116.263	0.111679
Capital Efficiency Smelter sensitivity results at time 2011 Runs:	1530.842	2188.169	1912.011	1931.134	156.304	0.081748
Capital Efficiency Smelter sensitivity results at time 2014 Runs:	1887.808	2614.73	2312.399	2332.768	173.832	0.075174

Figure 79: Impact of variations in input cost and market prices on Smelter capital efficiency

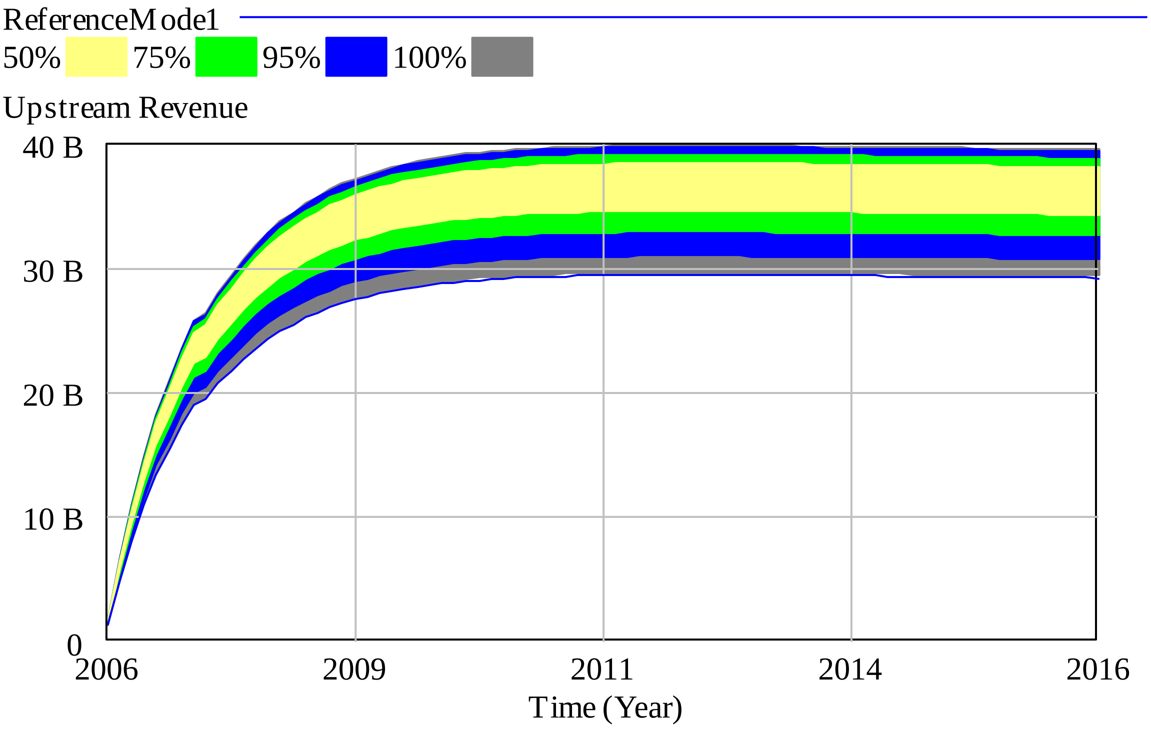
A notable observation from the data displayed in Figure 79 is that the secondary beneficiation scenario returns negative values for the first two simulation years in 2006 and 2007 however the increase in mean values from 2008 to 2011 and 2014 is much more significant compared to the primary beneficiation and the upstream mining scenario. As indicated in the thesis already, the negative correction in 2010 on the graph in Figure 79 reflects the adjustment of production due to the feedback from logistics and power capacity constraints configured into the system dynamics model and as such have no relationship to the Monte Carlo sensitivity simulation.

6.1.3.3. Impact on Revenue

The revenue generated in all three scenarios is mainly impacted by the market prices and the ability of the producers to get the respective Manganese products to the markets and as such, the capacity constraints in both logistics and power have a direct effect on revenue.

The impact on upstream mining scenario

The upstream mining scenario shows a stable pattern of revenue variance over the simulation period, albeit with a slight increase on the Rand value of the standard deviation from 2010 to 2014. This implies that the volume and price of Manganese Ore can be used to predict much of the revenue performance of this scenario in a long term.



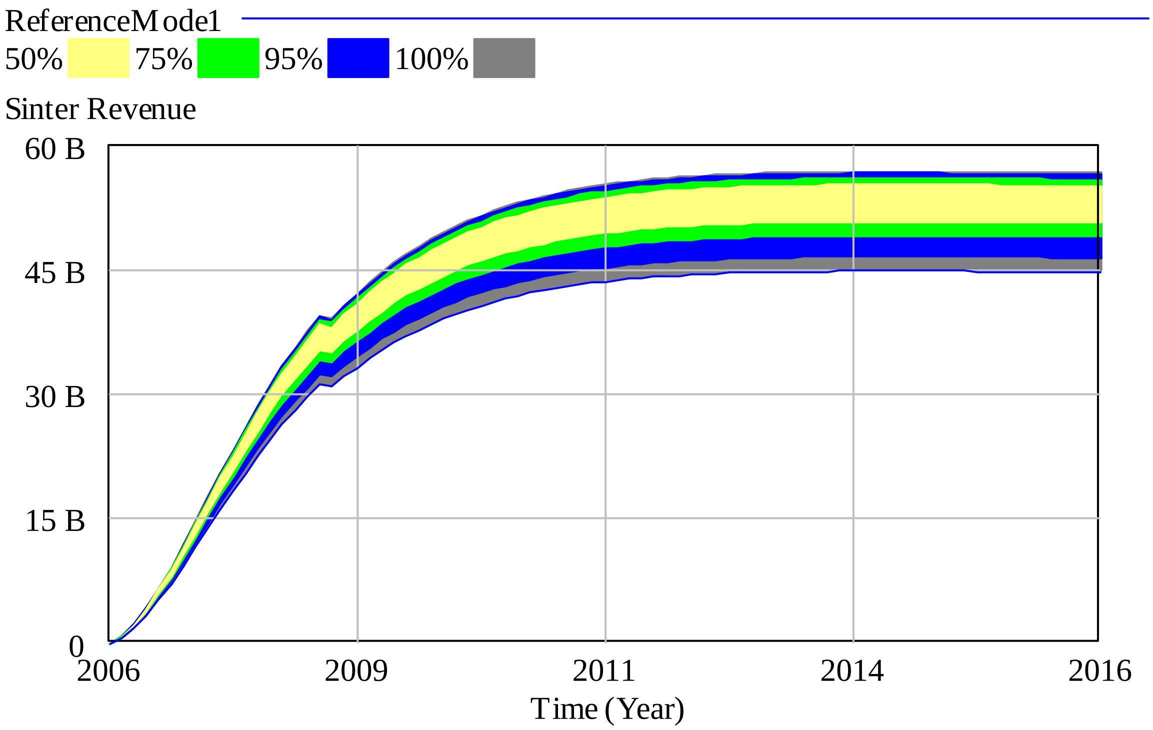
Variable	Min	Max	Mean	Median	StDev	(Norm)
Upstream Revenue sensitivity results at time 2006 Runs:	1.35E+09	1.76E+09	1.6E+09	1.63E+09	1.11E+08	0.069227
Upstream Revenue sensitivity results at time 2007 Runs:	2.03E+10	2.64E+10	2.4E+10	2.44E+10	1.66E+09	0.069227
Upstream Revenue sensitivity results at time 2010 Runs:	3.03E+10	3.95E+10	3.59E+10	3.66E+10	2.48E+09	0.069227
Upstream Revenue sensitivity results at time 2014 Runs:	3.05E+10	3.97E+10	3.61E+10	3.68E+10	2.5E+09	0.069227

Figure 80: Impact of market price on Upstream Revenue

Although the quanta of the standard deviations for the individual or selected years in the data table in Figure 80 are different, the percentage deviations for each year are the same. This implies that although the variation in market price would have impact in revenue performance of the upstream mining, the risk exposure can be easily predicted and managed.

The impact on the primary beneficiation scenario

Similar to the upstream mining scenario, the primary beneficiation scenario displays a steady envelop of revenue performance throughout the simulation period. However the data in Figure 81 shows a steep increase in the Rand value of the standard deviation from 2007 to 2008. The gap is maintained throughout the remainder of the selected years. As a percentage of the mean values, the normalised standard deviations are fairly stable around 5.77% in all the selected years from 2007 to 2014.



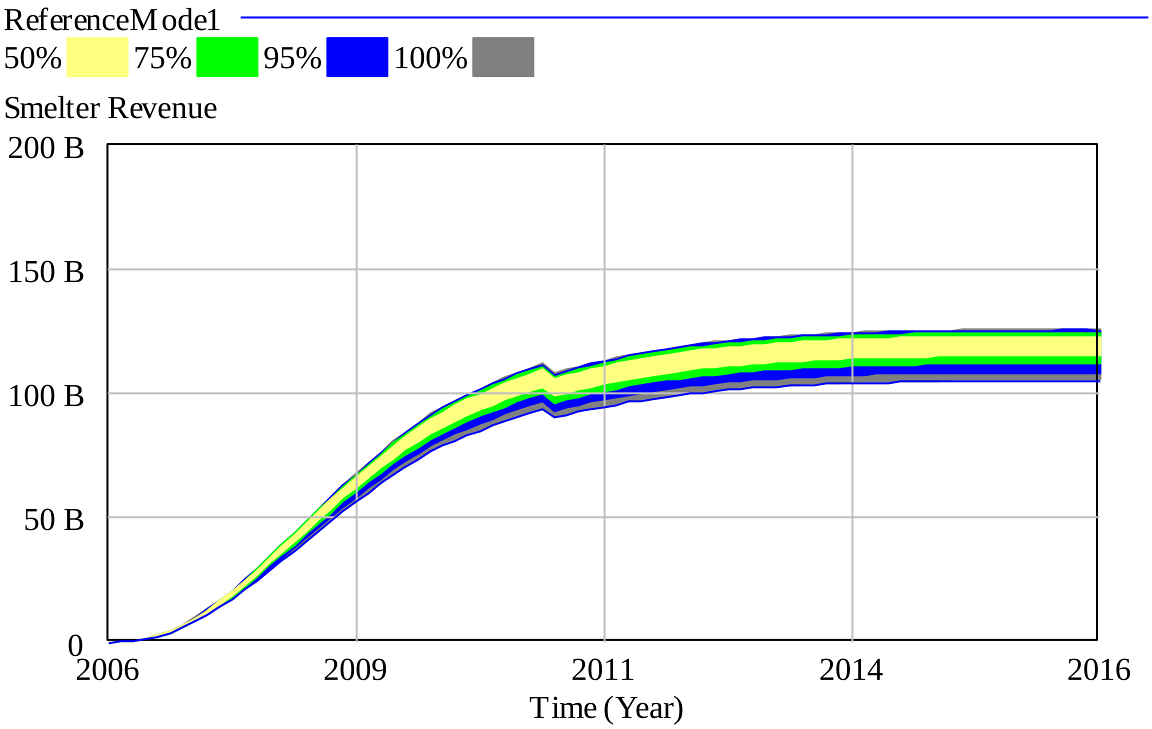
Variable	Min	Max	Mean	Median	StDev	(Norm)
Sinter Revenue sensitivity results at time 2007 Runs:	1.39E+10	1.76E+10	1.63E+10	1.64E+10	9.37E+08	0.05764
Sinter Revenue sensitivity results at time 2008 Runs:	2.98E+10	3.76E+10	3.48E+10	3.51E+10	2.00E+09	0.05764
Sinter Revenue sensitivity results at time 2010 Runs:	4.17E+10	5.26E+10	4.86E+10	4.91E+10	2.80E+09	0.05764
Sinter Revenue sensitivity results at time 2014 Runs:	4.50E+10	5.68E+10	5.25E+10	5.31E+10	3.03E+09	0.05764

Figure 81: Impact of input cost and market price variations on Sinter Revenue

In comparison to the upstream mining scenario, the primary beneficiation is a better performer in terms of revenue risk. This relationship is useful for the investor who wants dynamic stability and predictability, based on the input costs and market price of sintered Manganese product.

The impact on the secondary beneficiation scenario

The standard deviations and mean values resulting from a Monte Carlo simulation are used to assess the statistical variations of the revenue from the mean on an annual basis. 5 different years from 2007 were selected for the purpose of analysis using the data displayed in Figure 82. The secondary beneficiation scenario has high revenues compared to both the upstream mining and primary beneficiation scenarios. The variations in revenue of the secondary beneficiation scenario in Rand terms are much higher compared to the upstream mining and primary beneficiation scenarios.



Variable	Min	Max	Mean	Median	StDev	(Norm)
Smelter Revenue sensitivity results at time 2007 Runs:	1.11E+10	1.29E+10	1.22E+10	1.22E+10	4.73E+08	0.03866
Smelter Revenue sensitivity results at time 2008 Runs:	4.18E+10	4.88E+10	4.61E+10	4.62E+10	1.78E+09	0.03866
Smelter Revenue sensitivity results at time 2010 Runs:	9.09E+10	1.06E+11	1.00E+11	1.00E+11	3.88E+09	0.03866
Smelter Revenue sensitivity results at time 2014 Runs:	1.07E+11	1.25E+11	1.18E+11	1.18E+11	4.56E+09	0.03866
Smelter Revenue sensitivity results at time 2015 Runs:	1.07E+11	1.25E+11	1.19E+11	1.19E+11	4.58E+09	0.03866

Figure 82: Impact of input cost and market price variations on Smelter Revenue

A comparison of the three scenario for the simulation year 2014 in Figures 80, 81 and 82 show that the deviations from the mean values are ZAR 2.5 billion and ZAR 3.03 billion for the upstream mining and primary beneficiation scenarios respectively compared to ZAR 4.56 billion for the secondary beneficiation. However as percentage of the mean, the secondary beneficiation has a lowest normalised standard deviation at 3.8% compared to 6.8% and 5.77% for the upstream mining and primary beneficiation respectively. As is the case with the data presented in Figures 80 and 81 for the upstream scenario and primary beneficiation scenario, the normalised standard deviations are consistent on all selected years. This confirms that even in a Monte Carlo or multivariate sensitivity analysis the revenue performance remains predictable on all three scenarios.

6.1.4. The preferred scenario

The analysis of the results covered in Sections 6.1.1 to 6.1.4 describes the dynamic relationship between the three Manganese resources value chain scenarios and the key variables affecting the performance of the industry. The results demonstrate that the secondary beneficiation (Smelter) scenario generates more revenue in comparison with the primary beneficiation (Sinter) and upstream mining scenarios. The cost of production in the secondary beneficiation scenario is high compared with the Sinter and upstream mining scenarios.

The multi-variate sensitivity analysis performed and discussed in sections 6.1.1 to section 6.1.3 shows that there is more impact on the results of the scenario's capital efficiencies and profit when input cost particularly power and logistics cost varied. Although revenue is affected by market prices of products on all three value chain scenarios, the normalised standard deviations on all three scenarios are consistent and below 10%. The secondary beneficiation scenario sensitivity result in revenue has the lowest normalised standard deviation of just more than 3%.

From the results presented in the previous section, the secondary beneficiation scenario was preferred and chosen for further system dynamics model simulation of the socio-economic development model. The results of the socio-economic development model simulation are discussed in section 6.2 of this thesis.

6.2. Socio-economic development model results analysis

The system dynamics model, for which the results are detailed in the following sub-sections, is based on the fundamentals of a country's economy which is driven by three key sectors: the primary, secondary and tertiary sectors. Havenga (2012:7) describes these sectors as indicated in further detail in Figure 79, and draws linkages between primary sector (mineral extraction, agriculture), secondary sector (beneficiation, manufacturing) and the tertiary sector (consumer driven, housing, retail and financial services).

The system dynamics simulation has sought to describe the relationship between the three sectors by simulating the impact of mining production on secondary infrastructure development, whilst at the same time demonstrating how human development and housing development (tertiary economy sector) can be linked to production of High Carbon Ferro-Manganese (HCFeMn). As O'Regan *et al* (2000:349) correctly point out, system dynamics models are characterised as predictive and aggregated and the presentation of the results in this section is emphasizing this aspect more that the point of accuracy. The cost impact of logistics (which forms a part of the tertiary sector) is factored into the model, based on the outcome of the modelling of the Manganese resources value chain performed in Section 6.1 of this thesis.

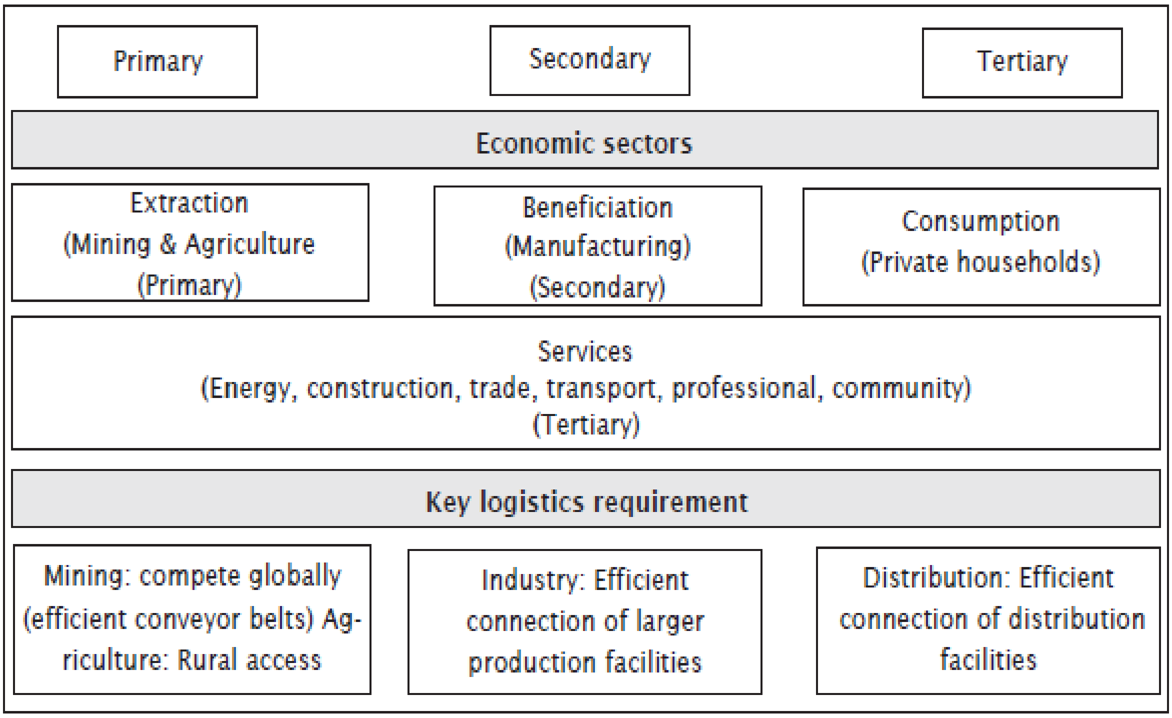


Figure 83: Basic economic structure and the resultant logistics requirements (Havenga, 2012:7)

6.2.1. Variables in the model for socio-economic development

In the system dynamics model simulation of the socio-economic development model described in Figure 59, section 5.2 of this thesis , five variables were identified that influence the model. These included variables that determine the viability of mining activity and beneficiation as well as those variables that influence the housing development activities. The five key variables that drive the system dynamics simulation model are listed and discussed as follows:

1. Annual Demand for High Carbon Ferro-Manganese (HCFeMn)
2. Price of HCFeMn
3. HCFeMn production cost
4. Cost of housing units
5. Housing demand

Annual demand of HCFeMn

The demand for Manganese alloys has been growing since the turn of the century, albeit with fluctuating demands during some years. The 10 year history and forecast from 2006 to 2016 shows a stable-to-general increase in demand for HCFeMn, making Manganese a strategic mineral for South Africa going forward. The demand is forecast to grow, partly due to the forecast decline in high metallurgical grade Manganese Ores from competing countries such as China, India and Australia.

South Africa continues to maintain a share of the world's known reserves that are above 80%. Figure 84 depicts the annual demand volumes used in the system dynamics model. In creating the system dynamics model, the "Annual demand for HCFeMn' variable was varied through a random selection of figures between the lower limit (7.516 million tons) and the upper limit (10.2 million tons) of the data collected as indicated in Figure 84.

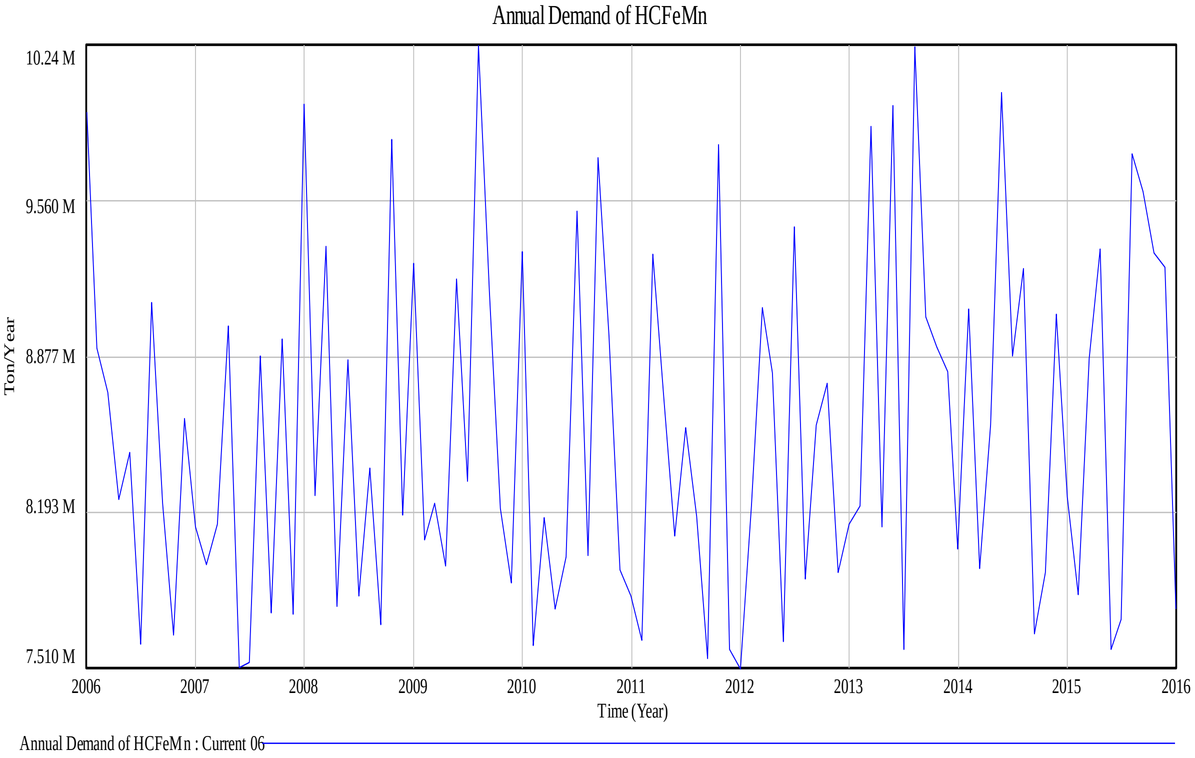


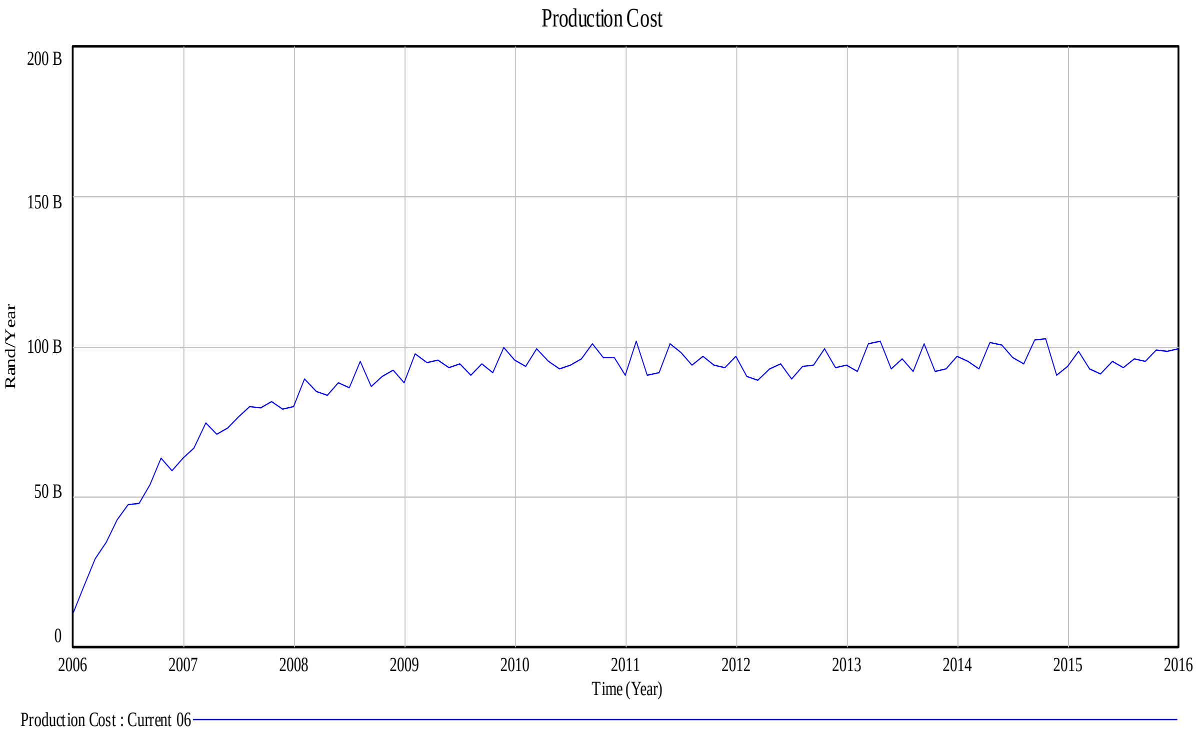
Figure 84: Annual demand for HCFeMn from 2006 to 2016

Price of HCFeMn

The price of HCFeMn is determined on a spot price basis and has seen the highs in 2010 and 2011, after a crash in 2009. The price is influenced by the rise in steel production demand around the world, against production levels. The actual trading takes the form of bid-offer between producers and customers the majority of who are in Asia and China in particular. CRU (2012), a United Kingdom based firm is among the few companies that publish the spot prices based on their analysis of the market dynamics which are used as guideline for trading. For the purpose of the system dynamics model simulation, an average price was used for the simulation period.

Production cost

The "Production cost" values depicted on the table in Figure 85 show a result of a simulated variable in the system dynamics model and reflect the annual Manganese production cost. The detail of the logic is described in Appendix D of this thesis. The variable is driven by the production tonnage profile of the system over the simulation period. Figure 85 depicts this critical parameter for the system dynamics model, based on the historical average cost per ton of HCFeMn alloy produced. At peak values of ZAR 100 billion as indicated in Figure 85, the "Production cost" variable also represents the amount of money that can be circulated in the area where mining and beneficiation activities take place. This level of activities in production also reflects the potential for job creation in the area.



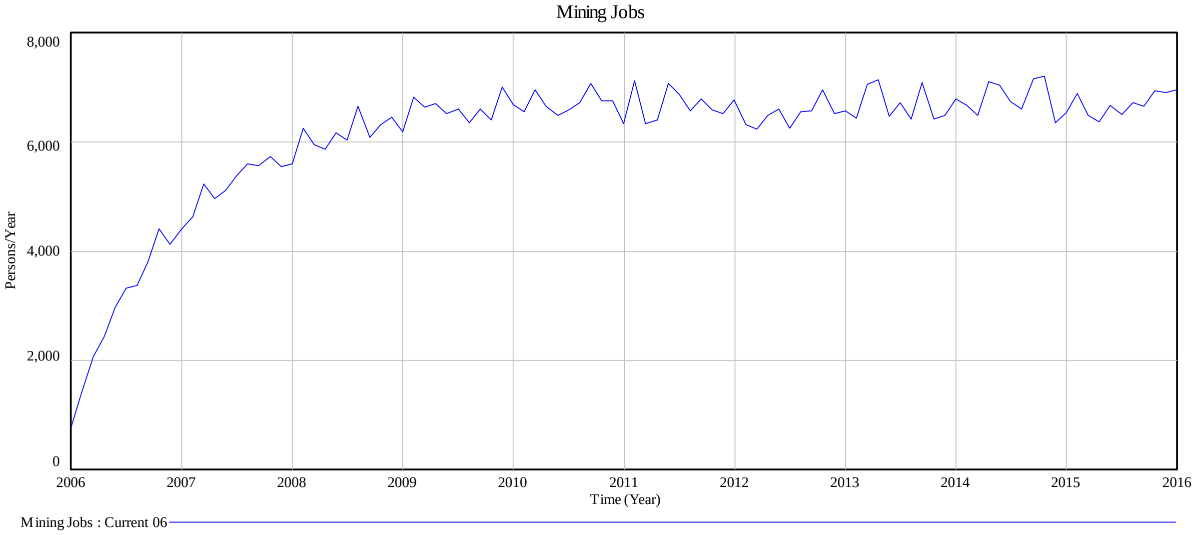
Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Production Cost	1.14E+10	6.61E+10	8.93E+10	9.75E+10	9.37E+10	1.02E+11	9.03E+10	9.20E+10	9.52E+10	9.84E+10	9.93E+10

Figure 85: Annual production cost of HCFeMn

Mining jobs and labour intensity

A report from the Northern Cape Department of Economic Development department (NCDED, 2008:6) highlighted that, compared with tertiary industries; mining creates only 13 jobs for every ZAR 1 million of production cost, against 47 jobs created in tertiary industries. For the purpose of the system dynamics model simulation, all Manganese mining and beneficiation assume labour intensities equal to 13 jobs per ZAR 1 million spent in production costs and 47 jobs per ZAR 1 million spent in housing construction and retail business activities.

These ratios were used in the model simulation as a factor to demonstrate the job creation potential that comes with each investment decision. These ratios are important in the model because they demonstrate also how the development of infrastructure attracts secondary and tertiary business can impact on jobs created in ways more effective than primary mining activities can be.



Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Mining Jobs	7.99E+02	4.63E+03	6.25E+03	6.82E+03	6.56E+03	7.12E+03	6.32E+03	6.44E+03	6.66E+03	6.89E+03	6.95E+03

Figure 86: Number of direct mining jobs created over the simulation period.

Figure 86 indicates that mining and beneficiation jobs growth per annum peaks at 7120 jobs in 2011 at an annual average of 6200 jobs created over the simulation period. This is again calculated in the model using the labour intensity of 13 jobs per ZAR 1 million production cost. From the results discussed in previous sections of this thesis, an observation is made that the input cost of secondary is 4 times the input cost of upstream mining, therefore a conclusion can be made that the absence of beneficiation activities may result in only about 25% direct job opportunities created compared to potential job creation scenario where beneficiation activities exist.

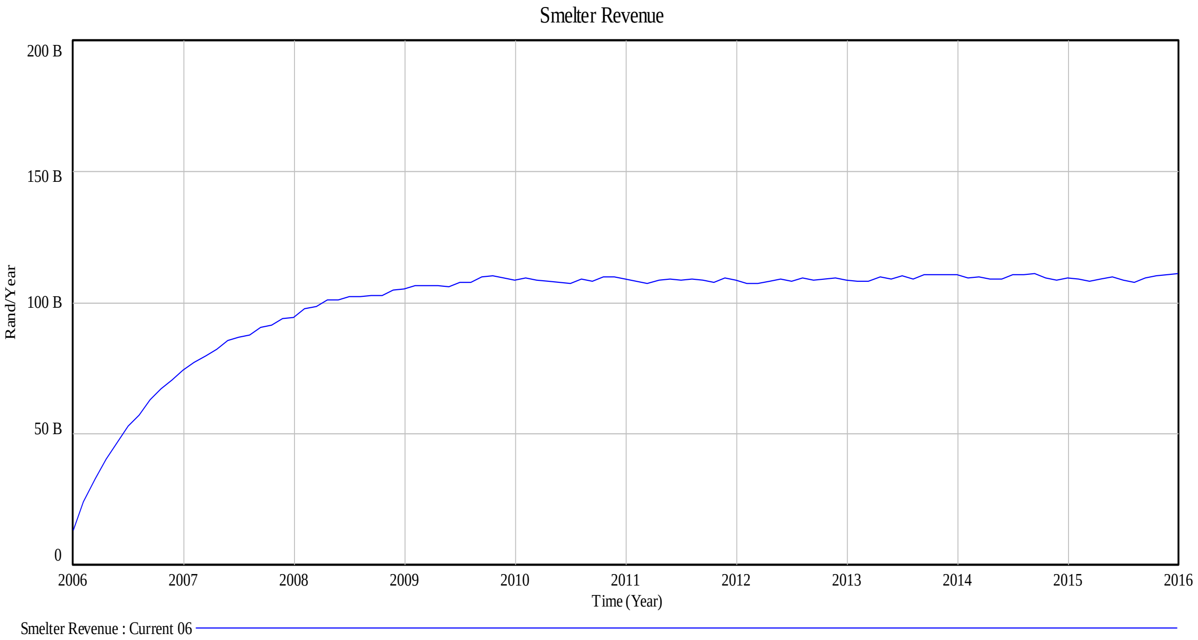
The number of jobs only reflects potential direct mining jobs and excludes jobs that are created by the infrastructure development and secondary support industries, based on the ratios of production cost to labour, described by the Northern Cape Department Economic Development known as NCDED(2008:6).

6.2.2. Results of the socio-economic development model simulation

The results discussed in this section build on the discussion of the socio-economic development model described in section 6.2.1 of this thesis. The logic for all the results described in this section is graphically detailed in Appendix C with related syntax and comments described in detail in Appendix D. The simulation is based on the manipulation of the 5 variables discussed in section 6.2.1 within the system dynamic model structure described in Figure 59, Chapter 5 of this thesis. The results describe the dynamic pattern of a mining-driven economic development in a Northern Cape's John Taolo Gaetsewe region along the Manganese rich Kalahari basin.

Mining and mineral beneficiation revenue

Mining revenue represented in Figure 87 is based on the annual sales of Ferro-Manganese products. This represents a preferred scenario from the Manganese value chain simulation results discussed in section 6.1 of this thesis, where all the Manganese Ores mined in South Africa are beneficiated through a Smelter operation. This radical approach forms a case for a true beneficiation led economic development, and is a step forward in creating an opportunity for more spending in the John Taolo Gaetsewe (JTG) region.



Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Smelter Revenue	1.30E+10	7.73E+10	9.78E+10	1.07E+11	1.10E+11	1.08E+11	1.07E+11	1.08E+11	1.09E+11	1.09E+11	1.11E+11

Figure 87: Revenue generated from mining and mineral beneficiation operations

With annual revenues above ZAR 100 billion for the most part of the simulation period and annual peaks at ± ZAR 111 billion in 2010 as indicated on the data table, this revenue stream would contribute considerably towards the economic activities in the mineral resources industry, and the Northern Cape Province in particular.

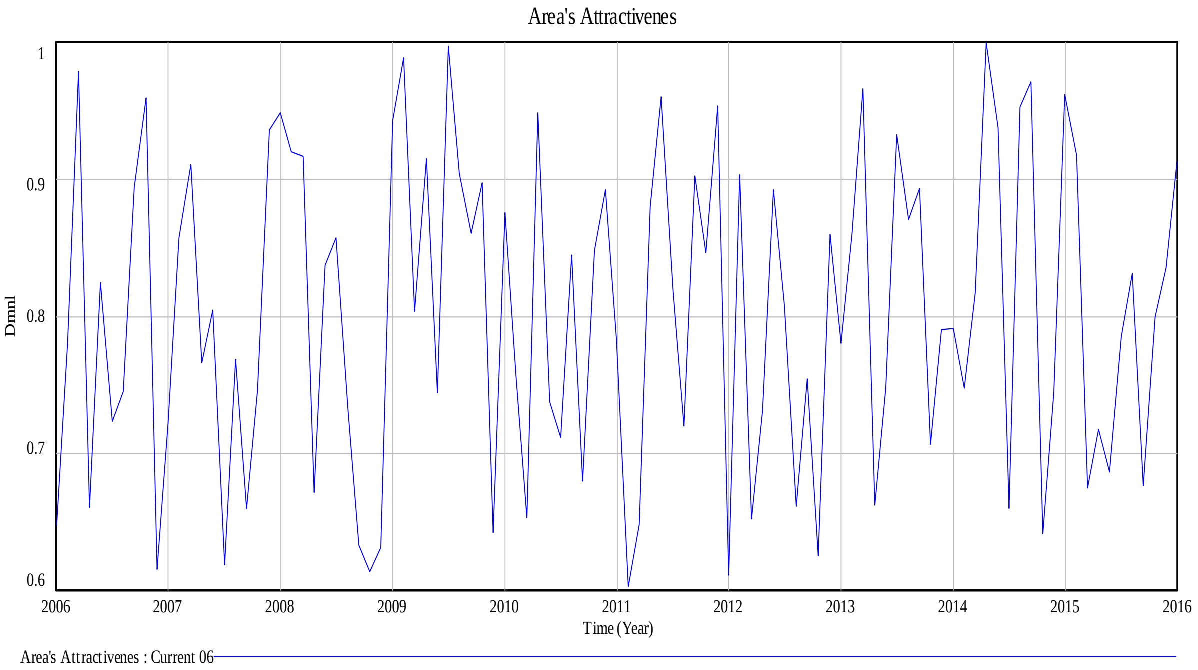
<u>Area's attractiveness</u>

The area's attractiveness, as described in the urban dynamics model (Forrester, 1969) and later described by Saeed (2010) , varies due to the number of economic and social capabilities of the area. In the system dynamics model, four aspects were assessed to determine the area's attractiveness, as follows:

- "Skilled workforce",
- "WC Skilled workforce ",
- "Total housing development capacity" and
- "WC houses created".

The resultant index from the system dynamics logic described graphically in Appendix C with syntax and comments in Appendix D, determines the ability of the area to attract and take advantage of potential infrastructure and economic growth. This variable plays a vital role in the model and is at the heart of the argument for the beneficiation policy as a vehicle for sustainable development. In the system dynamics model for the socio economic development, the value of the area's attractiveness is used as a multiplier to available revenue assigned for infrastructure development, to determine the potential for infrastructure development, by Rand value, without specifying the type of infrastructure.

As highlighted in Figure 88, the area's attractive index fluctuates between 1 and 0.65 for the duration of the simulation period. The index reflects the attractiveness of the area only in terms of available housing development space, and the rate of development, as well as the employment levels against availability of skilled workforce in the area. The logic within which this variable is calculated is described in Appendix D of this thesis.



Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Area's Attractivenes	6.47E-01	8.58E-01	9.20E-01	9.89E-01	7.57E-01	6.03E-01	9.03E-01	8.60E-01	7.48E-01	9.17E-01	9.13E-01

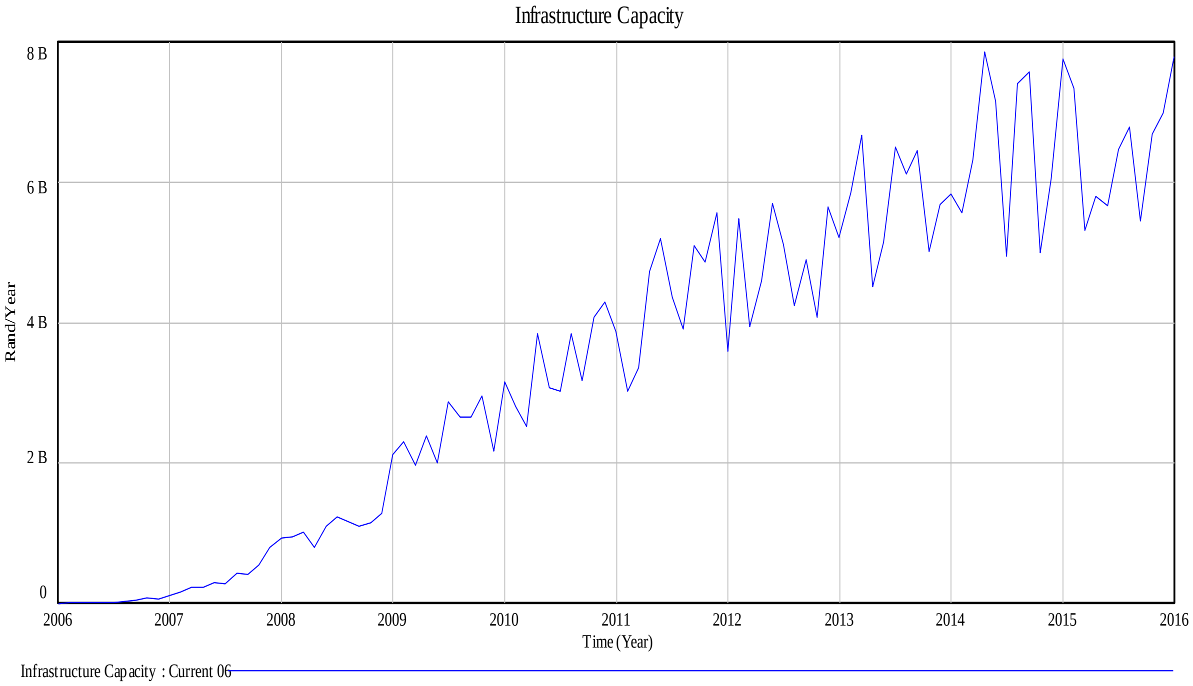
Figure 88: Area's attractiveness over the simulation period

Infrastructure Capacity Development

The infrastructure capacity describes the extent to which the area can be viewed as suitable for new business investment. The Rand value of “Infrastructure Capacity “ variable depicted on the graph in Figure 89 is used in the system dynamics model in Figure 59 demonstrate the potential for creation of business infrastructure and points to the capability of the area’s economy to attract more comercial growth.

The studies conducted by Fedderke *et al*. and cited by Kularatne (2011:11), point to the relationship between infrastructure investment and economic growth, which concludes that this relationship runs in both directions. They specifically find a forcing relationship running from infrastructure fixed capital stock to gross domestic product (GDP), suggesting that the infrastructure leads growth, though they also find evidence of potential simultaneity between infrastructure and output (GDP and locomotives, GDP and goods stock, goods vehicles and GDP, GDP and electricity).

Figure 89 indicates a steady increase in the ability of the economy to create the business infrastructure. This can be looked at as a growing return on the percentage of mining revenue generated over the simulation period. The data represented in Figure 85 only reflects a percentage of the mining costs and revenue that can potentially be spent in the area. An average of ZAR 3,53 billion per annum with peak annual flows at ZAR 7.79 billion in 2016 would make a significant difference in the economic growth of the Northern Cape region of John Taolo Gaetsewe by creating and sustaining employemnent opportunities.



Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Infrastructure Capacity	0.00E+00	1.60E+08	9.43E+08	2.30E+09	2.80E+09	3.02E+09	5.48E+09	5.84E+09	5.57E+09	7.34E+09	7.79E+09

Figure 89: Value of infrastructure capacity created over the simulation period

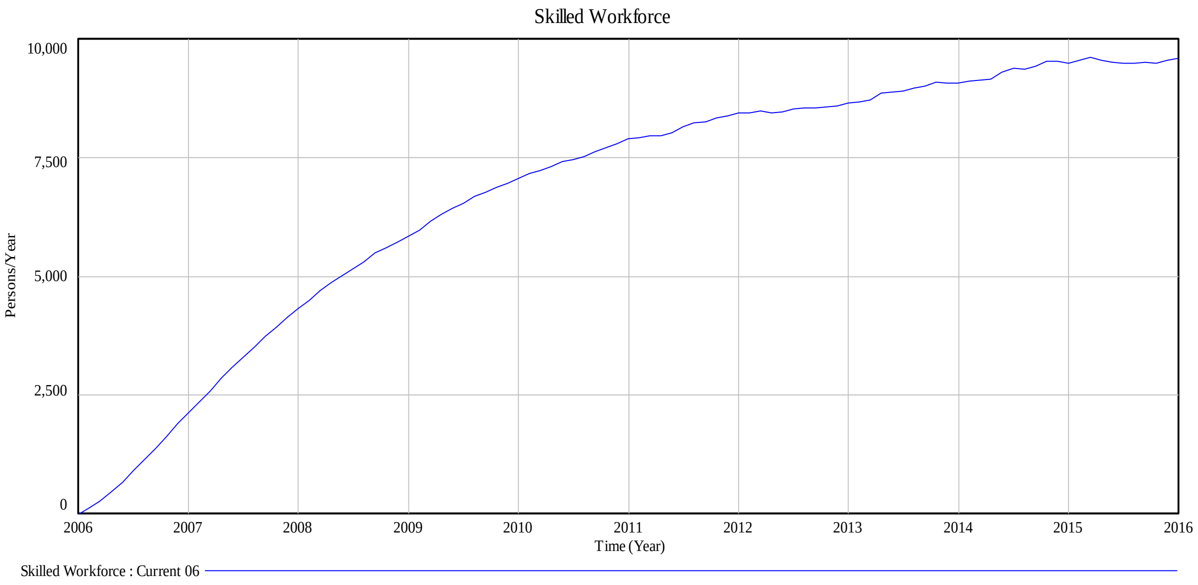
A similar reference in describing the relationship between mining and infrastructure development can be made from the gold rush in Johannesburg in the late 19th century. The discovery of gold in the Witwatersrand in 1886 had a marked effect on the railways, amongst other infrastructure development, as it generated both demand for transport services and the revenue with which to finance them (Perkins, 2005:216). Although it is not quantified in this study, the extent of the infrastructure rollout in the late 1800s would have created a significant hype of economic activities and optimism in the job creation market at the time.

Perkins points out in his work that within 10 years of the gold discovery, Johannesburg was connected by rail to Cape Town, Port Elizabeth, East London and Durban. Today, these lines are used to carry in excess of 2.2 million passengers daily, in six metros across the country (Walters, 2008:104). This represents an average of 10.4% of the personal income of these users for transport to work, against an average of 12.3% of personal income used for transport across all modes (Walters, 2008:102).

The infrastructure capacity graph in Figure 89 shows that just as it happened in the gold era of Johannesburg's development, an increase in mining and beneficiation activity demands a development of infrastructure such as rail to move goods and materials as well as social support infrastructure such as housing to accommodate the workforce within a reasonable distance from work.

Skilled workforce

The system dynamics model simulation described in Figure 59 also measures the potential for new skills development through minng and beneficiation actvities. The results of the simulation represented in Figure 90, show the extent to which new jobs and new skills are created due to the mining and beneficiation activities. It represents a pool of skilled workforce that can be used in alternative business activities other than direct mining activities. The results are also influenced by the impact of inward and outward migration of skilled resources due to natural attrition.



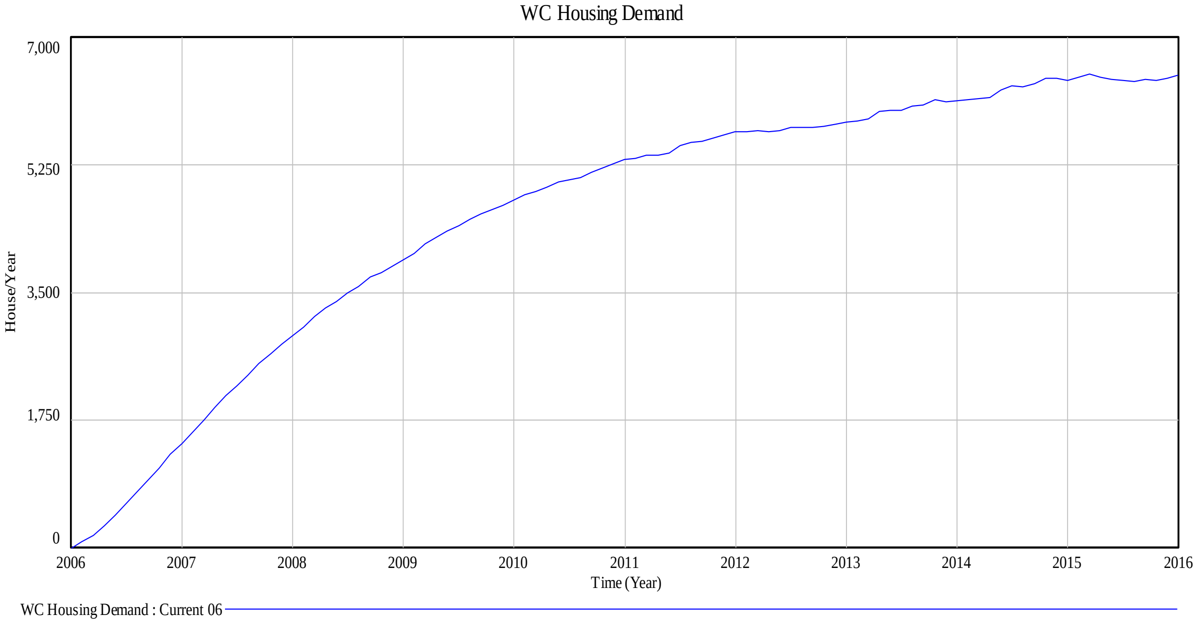
Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Skilled Workforce	0.00E+00	2.36E+03	4.48E+03	5.98E+03	7.17E+03	7.91E+03	8.44E+03	8.68E+03	9.11E+03	9.55E+03	9.60E+03

Figure 90: Number of skilled workforce created from mining related employment

WC Housing Demand

The “WC Housing Demand” variable describes the level of demand for new housing development that is driven by affordability. Based on data collected through interviews and focused industry groups sumarised in table 9 in chapter 4 of this thesis, an asumption was made that about 67% percent of the skilled workforce that is permantly employed by the mining industry are likely to require housing, which means that for every 3 employees permanently employed by the mine, two housing units would be required. This number focuses only on mining employees and is seen as conservative, but it is sufficient for the demonstration of the dynamic patterns and relationships described in the system dynamics model.

The result in Figure 91 shows that an average of 5,070 housing units per annum can be developed over the 10 years of the simulation period. What is of significance with this number, is that these are houses that are owned by employed citizens who,in theory, can afford to pay for municipal services rendered to them. This is an important element for sustainability of an area, based on the principle of relative attractiveness of such an area (Saeed, 2010).

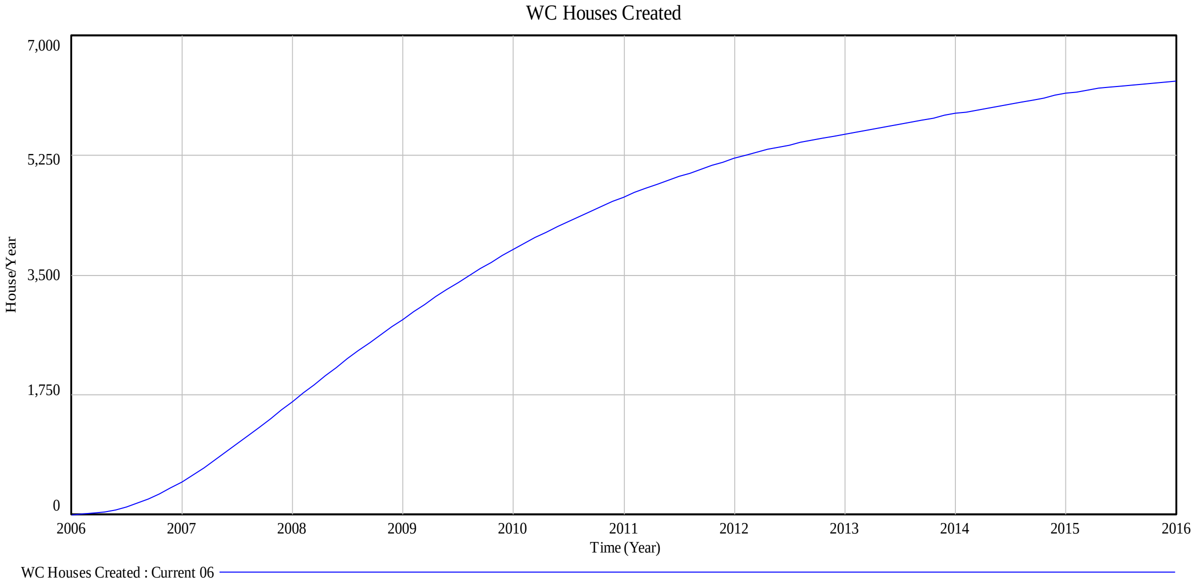


Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Housing Demand	0.00E+00	1.77E+03	3.36E+03	4.49E+03	5.37E+03	5.93E+03	6.33E+03	6.51E+03	6.83E+03	7.16E+03	7.20E+03

Figure 91: Working-class housing demand

WC Housing Created

Figure 88 shows the resulting number of houses created over the same period. The number in Figure 92 reflects the delay in the actual delivery of houses. The number of new houses created in Figure 92 could be looked at as a measure of increase in the consumer economic growth, also classified in this research as the tertiary economy. What is important is that, for any service type business to be attracted to the region, the consumer confidence and economic growth are the indicators that are used to determine the affordability, or the potential buying power, that is required for the business outlet to work.



Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
WC Houses Created	0.00E+00	5.81E+02	1.78E+03	2.96E+03	3.96E+03	4.71E+03	5.25E+03	5.58E+03	5.88E+03	6.18E+03	6.33E+03

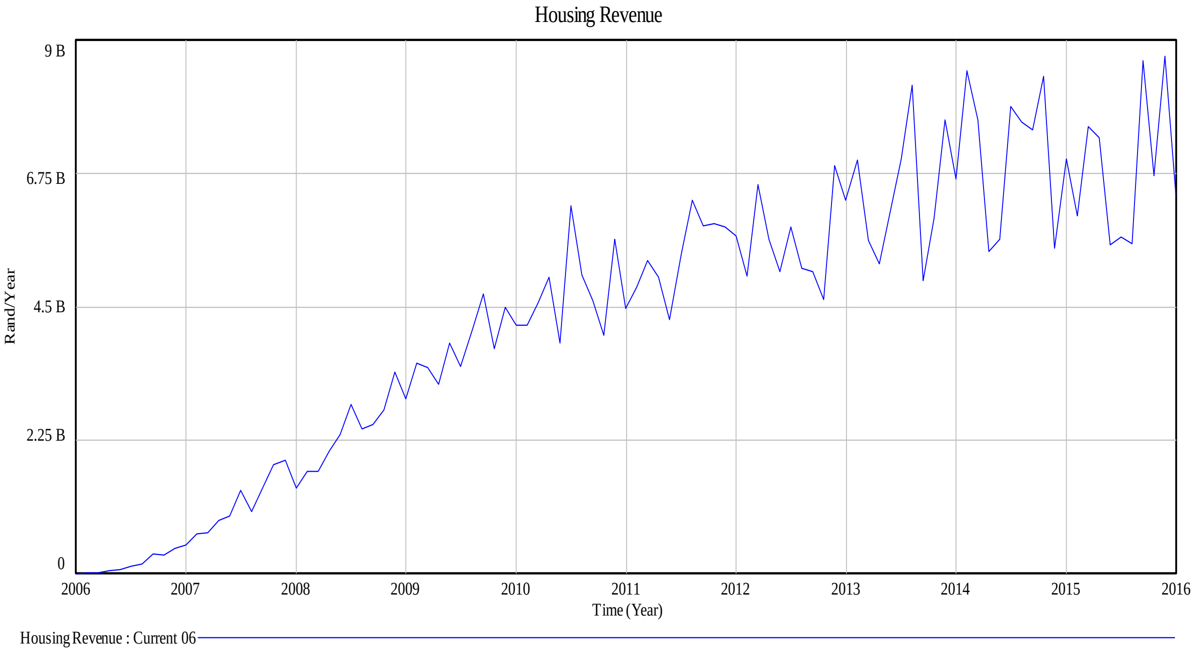
Figure 92: Working class houses created over the simulation period.

The system dynamics model simulation emphasizes “houses created” for a number of employed people, because the affordability level is predictable for this class.

Contribution of the Housing Revenue

Figure 93 depicts the revenue created from the housing development over the simulation period. This is based on houses directly linked to the number of skilled workforce employed in the primary Manganese mining and beneficiation sector of the Northern Cape economy, and does not account for other housing demands from the rest of the society. The objective of this approach is to demonstrate the direct and dynamic impact of the Manganese beneficiation approach on the steady and predictable development of a secondary, and perhaps tertiary, economy over a longer period of sustainability. It is also important to emphasize that this contribution does not reflect the contribution of other primary sectors, such as Agriculture and non-Manganese mining sectors.

Although the housing market crashed in 2008, during the recession, the average cost of building did not drop significantly during that rescession in South Africa. The average cost of ZAR 1 million reflects the mean cost of housing in the region around the three towns of Hotazel, Kuruman and Kathu, between 2006 and 2012, and this figure has been used to calculate the revenue from housing development.



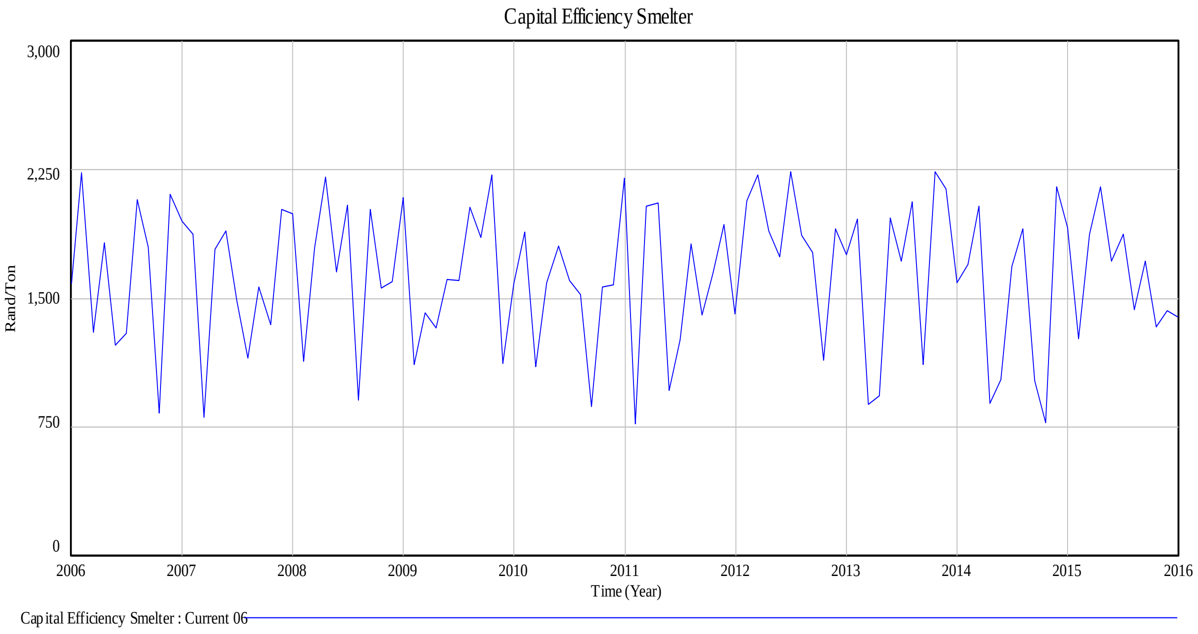
Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Housing Revenue	0.00E+00	6.72E+08	1.71E+09	3.55E+09	4.19E+09	4.83E+09	5.02E+09	6.98E+09	8.49E+09	6.03E+09	6.39E+09

Figure 93: Housing revenue created over the simulation period.

The most important measure of this revenue curve for housing is its support of the consumer market and accessories that follow. The revenue reflected on the graph in Figure 93 represents the minimum contribution of the housing development to the economy, simply because the consequential spending that follows cannot be predicted without further research and modelling of the related property market dynamics.

Contribution of Mining Capital Efficiency

Figure 94 depicts the contribution of the mining re-investment potential based on the capital efficiency in the Northern Cape JTG region's economic growth. The positive value of the mining capital efficiency is an indication of the potential for re-investment into secondary business in the area where mining takes place. The simulated data in Figure 94 however shows the impact of fluctuations in both market demand and spot price of the Managnese alloy products on the capital efficiency over the simuation period.

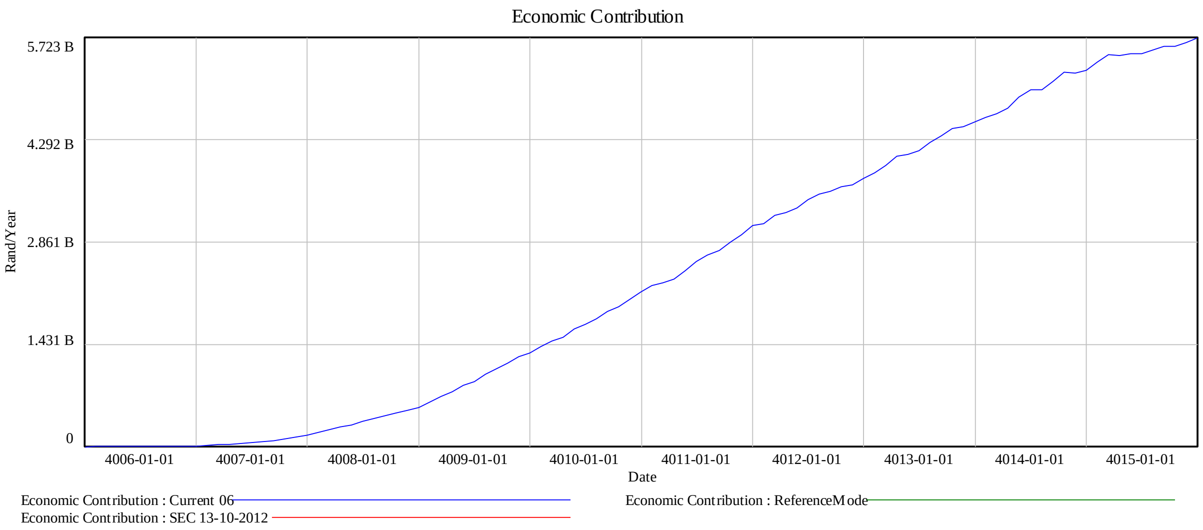


Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Capital Efficiency Smelter	1.58E+03	1.87E+03	1.13E+03	1.11E+03	1.89E+03	7.67E+02	2.07E+03	1.96E+03	1.70E+03	1.26E+03	1.39E+03

Figure 94: Capital efficiency of Smelter beneficiation activities

Value of Economic Contribution

The outcome of the uncertain relationship between growth in mining and beneficiation output and the development of a secondary and tertiary economy, based on the policy of beneficiation and reinvestment in the local economy, is measured through the “Value of Economic Contribution”.



Date	2006/01/01	2007/02/06	2008/02/06	2009/02/06	2010/02/06	2011/02/06	2012/02/06	2013/02/06	2014/02/06	2015/02/06	2016/02/06
Economic Contribution	0.00E+00	1.77E+07	2.04E+08	6.25E+08	1.40E+09	2.25E+09	3.12E+09	3.83E+09	4.60E+09	5.39E+09	5.72E+09

Figure 95: Value of Economic contribution from beneficiation and secondary business

The result in Figure 95 shows that an increase in economic contribution is steady until 2015, when growth slows. This is a combined contribution of mining, housing and infrastructure development over the simulation period. The spin-offs of mining economies have been seen in major centres in the country, where the secondary and tertiary economies help to sustain the economy, well outside of immediate mining activities.

Confirming in some sense the simulated trend displayed in Figure 95 is Johannesburg and the Gauteng province in general, described in a study of the Gauteng economy by sector, conducted by Stats SA in 2009 and cited in the Gauteng Department of Economic Development (GDED, 2010:22). The GDED (2012) study shows that while real growth in mining has slowed by more than 22% between the years 2000 and 2008, secondary and tertiary sectors have seen growth ranging between 36%

(Manufacturing) and 123% (Construction). Wholesale and food retail has grown by 40% while the transport and finance sectors have seen growth of 60% and 75 % respectively (GDED, 2010:22).

6.2.3. Results of multi-variate or Monte Carlo analysis

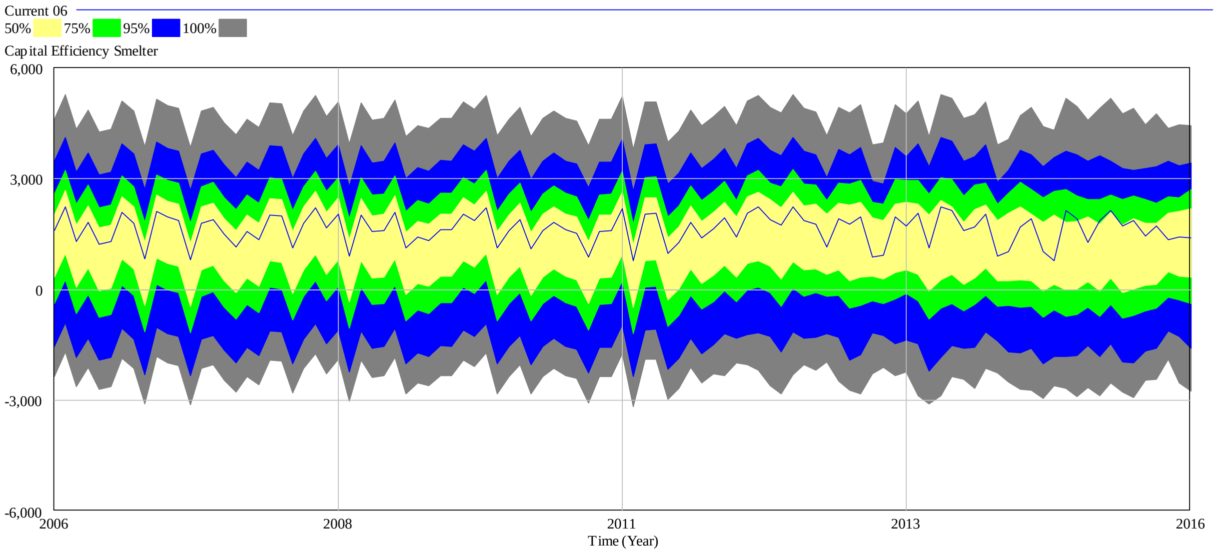
A Monte Carlo analysis was performed to test the volatility/stability of the key output variables against variability in a combination of input variables. The economic structure of the John Taolo Gaetsewe region and the role of mining beneficiation are complex and such being the case, a univariate analysis (not a feature of system dynamics) of variance in any individual variable will fall short of indicating the patterns of behaviour on the subject. The variances in power and logistics costs in their natural inter-play, will give a better impact on the dynamic behaviours of the system being simulated according to the system dynamics model logic described in Figure 59. A summary of variables used in the Monte Carlo simulation is listed in Table 19.

The output variables measured in the analysis include the mining and beneficiation revenue, housing revenue, infrastructure capacity and value of impact to economic activity in the region. These are evaluated against variations in input variables including, rail cost, power and fixed operating costs. The results of the Monte Carlo analysis are represented in the following section.

6.2.3.1. Impact on Mining Capital Efficiency

The graph in Figure 96 shows a consistent variability of the capital efficiency throughout the simulation period. The notable difference between the graph in Figure 93 and the graph displayed in Figure 79 in section 6.1.3 is the lag in the production of the Smelter scenario in the Manganese Value Chain model. This is the case because the Manganese Value Chain model is configured to reflect the transfer of Manganese Ore from the upstream mining stage through the Sinter stage to the Smelter stage in a series like arrangement. This implies that the Capital Efficiency performance of the Smelter depicted in Figure 79 returns negative values during the ramp up period. The socio-economic development model is different for the Capital Efficiency because there is no lag hence the return is positive from the first year of simulation.

The standard deviations and the mean values displayed on the data table in Figure 96 are calculated through the Monte Carlo sensitivity using a random triangular function on “logistics cost”, “power cost” and “Manganese price” parameters.



Variable	Min	Max	Mean	Median	StDev	(Norm)
Capital Efficiency Smelter sensitivity results at time 2006 Runs	-2.35E+03	4.61E+03	1.15E+03	1.22E+03	1.26E+03	1.09E+00
Capital Efficiency Smelter sensitivity results at time 2008 Runs	-1.94E+03	5.02E+03	1.56E+03	1.63E+03	1.26E+03	8.06E-01
Capital Efficiency Smelter sensitivity results at time 2010 Runs	-2.35E+03	4.61E+03	1.15E+03	1.22E+03	1.26E+03	1.09E+00
Capital Efficiency Smelter sensitivity results at time 2014 Runs	-2.44E+03	4.62E+03	9.89E+02	1.02E+03	1.30E+03	1.31E+00

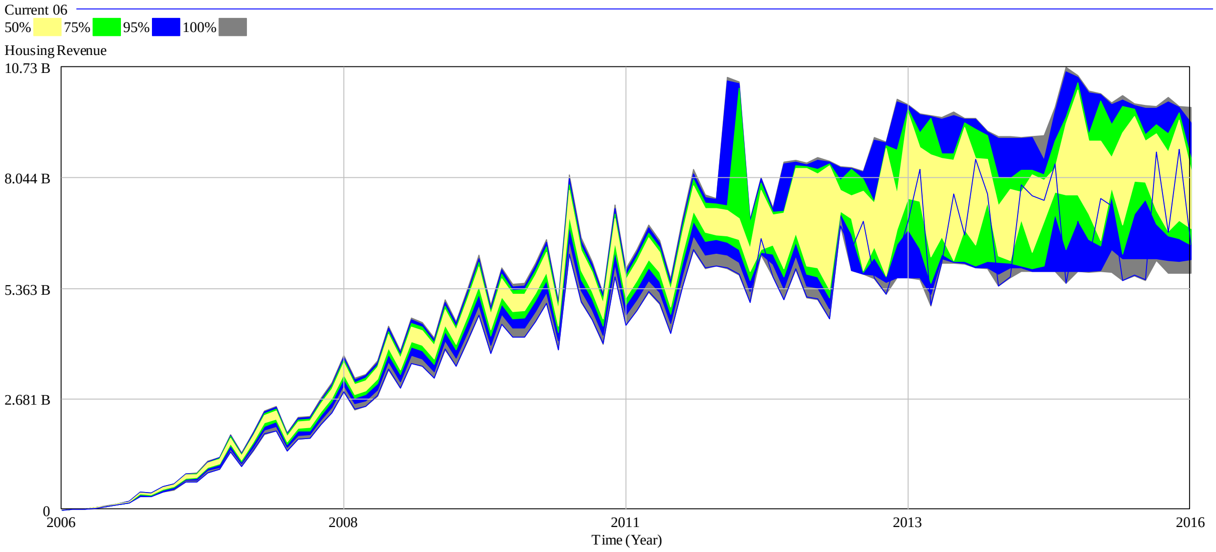
Figure 96: Impact of input cost and market price variations on capital efficiency

The result of the variations in input costs and market prices on the secondary beneficiation (Smelter) capital efficiency is depicted in Figure 96. The standard deviations from the mean values are consistent throughout the simulation and this is observed from the selected annual sensitivities depicted on the data table in Figure 96. At standard deviation value of ZAR 1260, the variations in 2006, 2010 and 2014 are higher than the average values with 2008 being the only exception of the selected simulation years.

This observation implies that on an annual basis there is as much risk of major losses as there is potential for good returns. The sensitivity is uniform throughout the simulation period, indicating that the impact of the variations can be predicted and managed by understanding the interplay of the input variables.

6.2.3.2. Impact on Housing Revenue

The housing revenue is dependent on spending from revenues earned in the mining beneficiation activities either through company spending or employees own income expenditure. Apart from housing the revenue being a smaller percentage of the mining beneficiation income, it has a lagging relationship with variations to the mining input cost and Manganese prices. The highlighted section of the data table in Figure 97 shows that housing revenue is only earned from 2007-2008 due to its dependence on the outcome of the mining beneficiation revenue. The system dynamic model of the socio-economic development assume zero (0) initial values for the housing development stock however the housing revenue and other variables in this stock are updated with new values at the end of the first simulation period. What can also be observed from the simulated data is that the mean values in Rand terms are much lower in 2008 compared to values in 2010 and 2014.



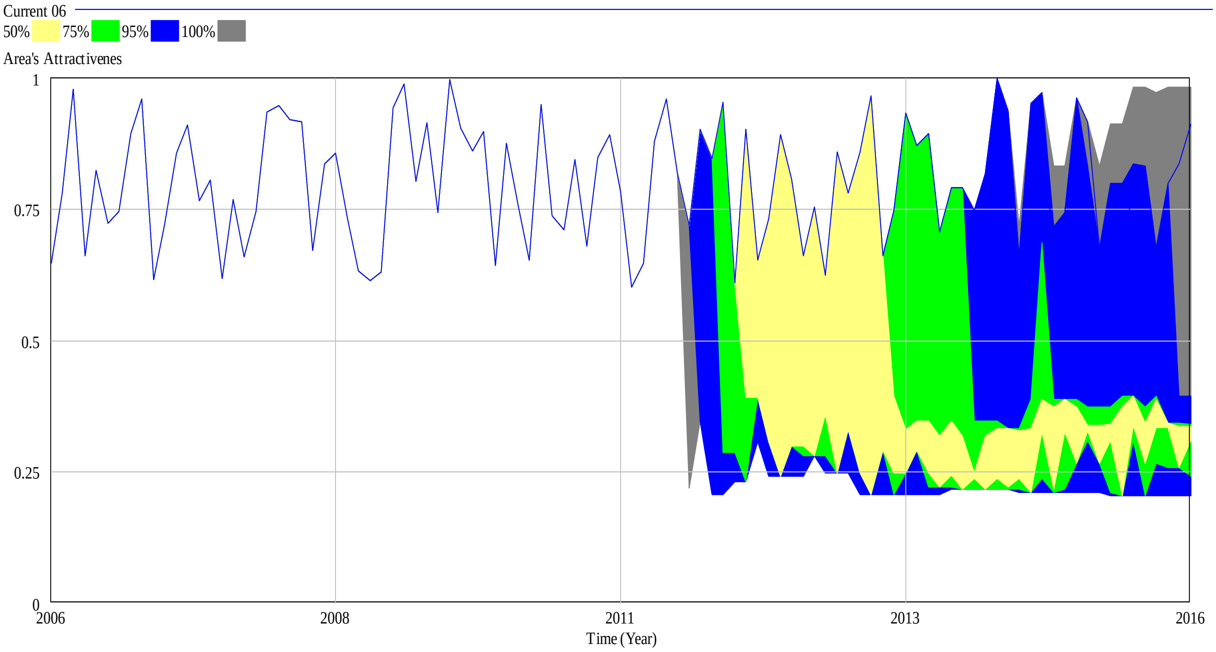
Variable	Min	Max	Mean	Median	StDev	(Norm)
Housing Revenue sensitivity results at time 2006 Runs:	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Housing Revenue sensitivity results at time 2008 Runs:	1.43E+09	1.87E+09	1.71E+09	1.73E+09	9.37E+07	5.48E-02
Housing Revenue sensitivity results at time 2010 Runs:	4.17E+09	5.47E+09	5.00E+09	5.04E+09	2.75E+08	5.50E-02
Housing Revenue sensitivity results at time 2014 Runs:	5.95E+09	9.48E+09	7.88E+09	8.05E+09	1.22E+09	1.55E-01

Figure 97: Impact of input cost and market price variations on housing revue

The graph in Figures 97 show that, though not directly affected by the variation in power and rail costs, the uncertainties in those costs may trickle down to the secondary and tertiary sectors in mine-driven economies. This view is supported by the observation that can be made from the graph in Figure 97 which shows that, the standard deviations from the mean increases substantially from 2008 to 2010 and from 2010 to 2014.

6.2.3.3. Impact on area’s attractiveness

The area’s attractiveness index is influenced by the activities in the housing and human development area and this relationship is programmed in the system dynamics logic in Figure 55, chapter 5. The results displayed in Figure 98 show that there are no deviations from the annual mean values of this index in the years 2006 to 2011 however this situation changes in 2011 and the subsequent years.



Variable	Min	Max	Mean	Median	StDev	(Norm)
Area's Attractivenes sensitivity results at time 2006 Runs:	6.47E-01	6.47E-01	6.47E-01	6.47E-01	0.00E+00	0.00E+00
Area's Attractivenes sensitivity results at time 2008 Runs:	9.48E-01	9.48E-01	9.48E-01	9.48E-01	0.00E+00	0.00E+00
Area's Attractivenes sensitivity results at time 2010 Runs:	8.76E-01	8.76E-01	8.76E-01	8.76E-01	0.00E+00	0.00E+00
Area's Attractivenes sensitivity results at time 2012 Runs:	2.31E-01	6.11E-01	5.33E-01	6.11E-01	1.46E-01	2.73E-01
Area's Attractivenes sensitivity results at time 2014 Runs:	2.17E-01	7.91E-01	3.17E-01	2.38E-01	1.87E-01	5.90E-01
Area's Attractivenes sensitivity results at time 2015 Runs:	2.11E-01	9.62E-01	3.55E-01	3.35E-01	1.48E-01	4.16E-01

Figure 98: Impact of input cost and market price variations on area’s attractiveness

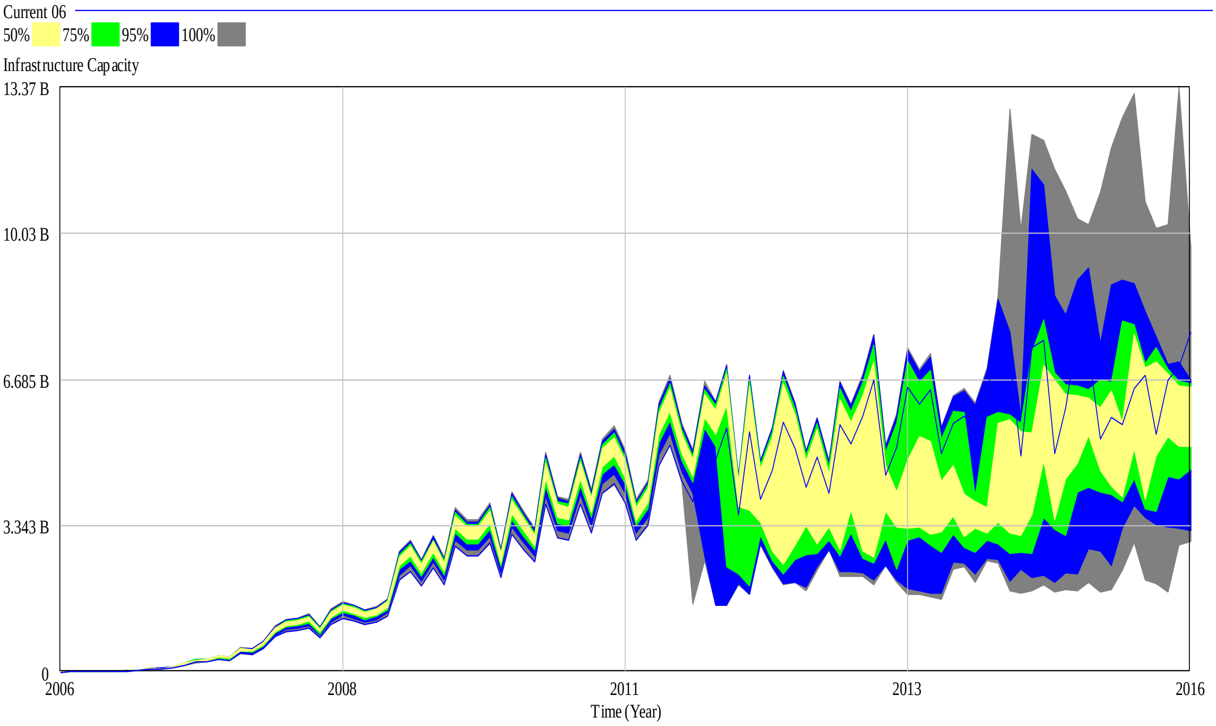
The area's attractiveness is an evaluation of the balance between housing development represented by the "WC Houses Created" variable and "Total Housing Capacity" and in the same way, the level of employment represented by the "Skilled Workforce" variable against the "Total Employable Population". The index manipulation in the model follows the logic that says "if more skilled people are available among the employable population, the area would be attractive for business development in the same way that availability positive net balance between housing capacity and number of houses build will affect the attractiveness of an area for high end skilled workforce such as professionals and business in the same way.

The graph in Figure 98 is a good example of early indication of growth that may reach a level where reversal of gains becomes imminent. The transition in the graph marked by the shaded area in 2012 reflects a view that is also supported by Graham *et al* (1980:287)'s finding that when the number of unemployed skilled workforce becomes so small that firms compete for these limited resources, the cost of labour becomes so high that labour become no more attractive than capital leading to the replacement by the later. This is a point in the period of development that may highlight the reversal of gains achieved during the early years of economic growth and attraction of skilled workforce in the area.

The stability of this index in the first 5 years of the simulation period from 2006 to 2011 as indicated in Figure 98 reflects a period where an evaluation of the four variables described above using the "IF THEN ELSE "logic in the system dynamics model yields more variations on the logical result of the index than they do in the first 5 years to 2011.This fluctuation in the area's attractiveness indicated by the shaded portion of the graph from 2012 shows the approach to limits on the housing capacity and due to uncontrolled housing development.

6.2.3.4. Impact on Infrastructure capacity

Due to their direct link to mining performance, the sensitivity of the housing revenues and infrastructure capacity are similar. The Monte Carlo results depicted in Figure 99 show that the development of infrastructure capacity, based on beneficiation economy is certain to grow rapidly in the beginning (as is the case from 2006 to 2011). However, over time it becomes less robust and sensitive (as indicated by the variations from 2011 to 2016) to variation in input costs and market prices as would housing revenue as shown in Figure 97.



Variable	Min	Max	Mean	Median	StDev	(Norm)
Infrastructure Capacity sensitivity results at time 2006 Runs:	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Infrastructure Capacity sensitivity results at time 2008 Runs:	9.18E+08	1.20E+09	1.10E+09	1.11E+09	6.03E+07	5.49E-02
Infrastructure Capacity sensitivity results at time 2010 Runs:	3.15E+09	4.12E+09	3.77E+09	3.80E+09	2.07E+08	5.49E-02
Infrastructure Capacity sensitivity results at time 2012 Runs:	2.01E+09	4.48E+09	3.74E+09	4.14E+09	8.62E+08	2.30E-01
Infrastructure Capacity sensitivity results at time 2014 Runs:	2.40E+09	6.47E+09	3.76E+09	3.45E+09	1.08E+09	2.87E-01

Figure 99: Impact of input cost and market price variations on infrastructure capacity

The standard deviation and mean values highlighted in 2008 and 2010 show a significant increase from 2006 and 2008 respectively. The infrastructure development logic in the system dynamics model depends on the area's attractiveness index and as it can be observed from the results presented in Figure 98, the attractiveness index shows more volatility from 2012 onwards compared to the preceding years. The certainty of infrastructure development reflects this variability from 2010 to 2014 in the data table in Figure 99.

6.3. Contrasting simulation results against problem statements

The observations made in the results presented in section 1 are contrasted with problem statement and question raised in chapter 1 of this thesis. The questions raised in section 1.2 of the thesis are contrasted as follows:

- *What are the key drivers of sustainable economic development in a Manganese mining context?*

The results of the simulation in section 6.1 have shown that power and logistics costs are major cost drivers for all three Manganese value chains. However, the secondary beneficiation scenario is most affected by the variability in the cost of power. In the presentation of the results of the socio economic model in section 6.2, labour intensity ratios were used to simulate the impact of beneficiation activities and infrastructure development on skills development. The results show some causality between increased production, human development and housing revenue generated. The results further show causality between growth in production levels and infrastructure capacity which in turn influences economic contribution.

- *What are the key systems challenges that prevent sustainable economic development in the South African Manganese mining industry*?

The results of the sensitivity analysis on the “Area’s Attractiveness” presented in Figure 59 demonstrate that the attractiveness of the area will change over time due to saturation in occupied land and skills availability. Policies that are required to encourage industrial growth can sometimes be compromised by the need to deal with social pressures to provide land for housing for instance. Although the utilisation of prime land has not been the hindrance in the development of the business infrastructure in the Kalahari Manganese basin, within the John Taolo Gaetsewe region, mining companies have often incurred massive costs of moving communities that are already placed in areas above mineral resource deposit. The 2013 annual report of an Iron Ore mine in the region demonstrate a significant cost of moving communities (Kumba, 2014)

- *Is there a balance in approach between short-term policy interventions and long-term sustainability of the Manganese minerals industry?*

The results presented in section 6.1 and particularly the data presented in Figure 59 and 61 demonstrate that the current approach by Manganese mining operators may be influenced by short term targets. The healthy bottom line performance of the upstream mining scenario which shows quick revenue generation and positive capital efficiency is generally preferred. However the secondary beneficiation scenario shows delayed revenue with significant short term losses albeit with superior performance in the long term.

- *Is there a case for a systems-thinking approach in dealing with the sustainable economic development challenge in South Africa?*

The results of the system dynamics model simulations presented in this chapter the details of which are described in Appendices A-D, point to a feedback relationship in the mine and socio economic systems that demonstrate non linearity and unpredictability to the extent that without integrating all key variables into a logical equation, the long term outcome of a policy intervention cannot be predicted. In the comparison of the capital efficiency performances of the 3 manganese value chains in section 6.1 of this thesis, the upstream mining scenario demonstrate results that in the short term seem superior to the other two scenarios. When considered over the longer term, it appeared through the results that the secondary beneficiation scenario has a superior long term performance.

The feedback system in the structure of the model has also demonstrated significant corrective feedback that changes the trajectory of performance of the secondary beneficiation value chain due to limitations in power and logistics inputs that may otherwise not be easily predicted using conventional production forecasting methods. This observation would suggest that systems thinking approach is necessary when making policy decision such as selecting the value chain scenario however, more simulation work would be required to generate confidence in the policy decision.

- *What influences the development and performance of the Manganese resources value chain in the South African economy?*

The system dynamics model simulation did not explore all the possible elements of the Manganese value chain business due to the research limitations. However, the results presented in this section demonstrate that power and logistics cost are key input variables in the performance of the Manganese value chain. On the other hand, the price of Manganese product has absolute influence on the revenue. The volumes of Manganese product sold only serve as a multiplier. The generation capacity and cost of power on the one hand is a limitation for beneficiation scenario however, producing non-beneficiated Manganese Ore results in high volumes of exports which is also met with logistics capacity challenges particularly due to availability of rail capacity.

- *Is there any causality between infrastructural developments and sustainable economic development through mining?*

The question on causality between infrastructure growth and economic development was adopted from the work of Perkins (Perkins *et al*, 2005) who concluded that there is a causal relationship between the two. The results presented in section 6.2 of this thesis show that the contribution to economic growth in the John Taolo Gaetsewe region is primarily propelled by mining and beneficiation revenue. However as the mining and beneficiation production stabilizes, the delayed revenue from housing development keeps the graph on a positive growth trend albeit lower than the initial mining and beneficiation contribution does. As demonstrated in the results in Figure 87, 89 and 95, one would not expect the growth in capital stock, whether public or private capital in one year to be correlated with growth in output in the same year (Munnell, 1992:193) Figure 87, 89 and 95 also demonstrate the relationship between mining, infrastructure development and economic contribution in the area.

6.4. Verification and Validation of the system dynamics model

In his presentation to the international system dynamics conference in 1994 , Yarman Barlas (1994:2) highlighted that validity in system dynamics means validity in the internal structure of the model and not the validity of its output behaviour. Barlas (1994:2) described the principle of “the right behaviour for the right reason” which is premised on the fact that system dynamics is based on causality of variables and concluded that a connection should exists between scientific justification of theories and validation of system dynamics models. Referencing Forrester (1961), Barlas (1996:184) emphasises the relationship between the model’s scientific validity and validity due to the usefulness of its purpose. This implies that the validity of the model has to consider the structural validity and the usefulness of the model based on the questions raised and similarity to other systems

The system dynamics model for the Manganese resources value chain and its associated socio-economic model represent an integrated form of resource beneficiation that has never been implemented in the Manganese industry in South Africa. The verification of the model was achieved by comparing the model structure to the structure of the Chrome mineral resource value chain, implemented by Outokumpu, a company based in Tornio, Finland. The validation of the system dynamics model is achieved by comparing the behaviour of the system dynamics model to the following:

- the economic performance from the South African Reserve Bank (SARB, 2012), and
- causal link between infrastructure development and economic development. work done by Perkins *et al* (2005)

- the urban dynamics and transportation model work of Professor Forrester (1969) later reviewed by Professor Saeed (2010).

The following section focuses on the verification of the two system dynamics models described in section 5.1 and section 5.2 of this thesis.

6.4.1. Verification of the system dynamics model

Verification test are largely concerned with structure verification, parameter verification and dimensional consistency tests (Barlas: 1994:4). The verification of the system dynamics model in this thesis follows this approach. A Chromium-based beneficiation facility is used for the purpose of verification of a Manganese resources value chain model in this research, because the two metaliferrous minerals find common use in the manufacturing of steel (albeit different in types) and have similar value chain dynamics. The Outokumpu beneficiation facility in Tornio, Finland, has demonstrated success in the development of the value chain from upstream mining to downstream steel manufacturing as an integrated (4 in 1) Chrome mining and beneficiation business. The data collected from a benchmarking visit to this facility was used for verification purposes against the results of the system dynamics model described in Chapter 5 of this thesis.

6.4.1.1. Key structural and performance data

The structural components of the Outokumpu facility in Tornio, Finland are compared to the selected model structure for this research to demonstrate similarities of value chain patterns between the two. The magnitude of the facilities and the quantum of production and income are not the same. This difference is not considered to be of material significance since this comparison is only to demonstrate pattern of value chain flow as a way of verifying the structure of the model selected.

Although the value chain structure and data of the model in this research is based on Manganese and not Chrome, the two minerals have similar downstream application and so is their demand and supply pattern. For this reason, the comparison of the two minerals based on performance pattern and value chain structure is considered appropriate.

<u>The structure of the Outokumpu 4 in 1 Chrome value chain integrated facility in Tornio, Finland</u>

The structure of the Outokumpu facility in Tornio, Finland is described in terms of a number of variables and levels of beneficiation of Chrome minerals as indicated in table 21.

Table 21: Parameters within the structure of the Outokumpu 4 in 1 facility

Parameter	Units	Mine	Sinter Plant	Smelter Plant	Steel Plant
Annual throughput	Ton	1,200,000	900,000	265,000	2,350,000
Total Permanent Employment	Person	600	1200	1000	800

<u>Structure of this research's system dynamics model of a beneficiation system</u>

Similar to the Outokumpu facility in Tornio, the structure of the Manganese value chain is described in terms of a number of variables and levels of beneficiation of the value chain however it excludes the downstream beneficiation through steel manufacturing. The data is depicted in table 22.

Table 22: Parameters within the Manganese beneficiation scenario in the Northern Cape

<u>Parameter</u>	<u>Units</u>	<u>Mine</u>	<u>Sinter Plant</u>	<u>Smelter</u>	<u>Steel Plant</u>
Annual throughput	Ton	23,5 million	18,5 million	8,5 million	<u>N/A</u>
Total permanent employment	Person	6000	3000	6000	<u>N/A</u>

6.4.1.2. Key success element of the Outokumpu facility

Energy usage

The beneficiation facilities in Tornio and the mine get power from a hydro-power plant in Kemi. This takes advantage of the excessive amount of water flowing through the Kemi river for the greater part of the year. However, the Carbon monoxide (CO) emissions from the Sinter and Smelter process in the Outokumpu plant are utilised in the co-generation plant to supplement the power from the Kemi Power plant. The CO is, however, first utilised in the smelting process for pre-heating the material that is going to be fed into the blast furnace. By doing this, the CO gets recycled into the process, making the process a closed-loop system. The second advantage is that, by pre-heating the material, the energy consumption of the furnace is reduced by up to 30% (Outokumpu, 2012)

Carbon Footprint

Of the 4-in-1 components, the mine is the furthest component at 30km distance from the rest of the facility. The transportation of Chrome from the mine to the facility represents what could be potential air pollution, due to emissions of Sulphur Dioxide (SO_2) from trucks used in hauling Chrome Ore. It is not in the scope of this research to quantify the exact impact of emissions of greenhouse gases (GhG) associated with the choice of a Manganese resources value chain scenario. It is, however, worth pointing out that, at a high level, the scenario comparison where Ore is trucked over 1000km from the Kalahari basin, in non-beneficiated form will certainly present a higher impact of SO_2 and other GhG emissions than the example of the arrangement in the Tornio and Kemi 4-in-1 Chrome to steel production facility.

6.4.1.3. What can be concluded from the Outokumpu facility

Outokumpu, through partnership with a technology company, Outotec GmBH, in 1968, developed the 4-in-1 solution into what has become the biggest and most efficient upstream integrated steel manufacturing facility in the Eurozone (Outokumpu, 2012). The key benchmark aspect of these facilities is the sustainability that is achieved through power and logistics cost savings. These are uniquely attributable to the setup of the facility and its proximity to the Chrome mine in Kemi. The facility integrates the side stream beneficiation aspect, using the slag and Carbon monoxide (CO) by-products in such an efficient way that the facility creates very little closure cost liability due to its operation.

The three components of the integrated facility occupy a relatively smaller footprint in Tornio, and this gives the operations leverage in transport logistics between the three beneficiation stages. By comparison with the South African Manganese setup, Manganese Ore has to be transported over a 1000 km to the ports (Coega and Saldanha) in volumes that are more than double what could be transported if the Ores were beneficiated into Ferro-alloys. The impact of the South African scenario is that the overall greenhouse gas (GhG) emissions are higher, irrespective of whether the Ore is transported by rail or road, although the latter represents the worst case scenario.

The proximity of the Smelter to the steel plant in the Tornio facility allows the operator to transfer Ferrochrome in liquid uncooled form directly to the melt shop of the steel mill. This results in the reduced pre-heating requirement in the melt shop of the steel mill, thereby saving on electricity consumption at this stage of the steel manufacturing process.

The benefits that have been highlighted in the case study were not achieved in one step of the operation, but through a systematic integration of the value chain from upstream mining to the final steel making process. The ability to influence input costs for a stainless steel business, makes the Tornio facility in Outokumpu more efficient than most of its competing plants in Europe and abroad. However, this business case was not obvious at the beginning, and required integrated planning with a systems thinking view to the business. This is the view that the Manganese mining industry is grappling with in South Africa today.

The logistics limitation on the Coega and Port Elizabeth line from Hotazel, and the shortage of power in the Kalahari basin, are viewed by the industry as a key constraint for production growth in Manganese, and by implication the Northern Cape region. This is notwithstanding the inefficiencies highlighted above in terms of the industry structure and the timing of Eskom's generation and power distribution infrastructure in the country. This view negates any benefit in investing in a power distribution network in the area, as well as the establishment of solar power projects in the area, which have a potential of making the region a net exporter of power in the next 5 years (Eskom, 2012).

The observations made in the Tornio facility and the Kemi Chrome mine, when contrasted against the Manganese industry setup in South Africa, leads one to the conclusion that the Tornio setup is more sustainable, both in terms of economic benefits to the area and minimizing the impact on the environment. The South African Manganese industry can benefit from a similar arrangement, considering the power costs and rail limitation challenges that the industry is facing in the short to medium term.

6.4.2. Validation of the system dynamics model

In describing the sequence of validating a system dynamics model, Barlas (1994:4) emphasises that the structure and behaviour test are important in validating the models. The behaviour patterns tests are essential in the validation process and they follow the successful direct theoretical and empirical structure and behaviour tests. Barlas (1996:184) also argues that it is philosophical untenable to ask for models in the socio-economic discipline to be an entirely formal/objective process. The validation process in this thesis focused on behaviour pattern test of the system dynamics model based on similar results from other researches.

6.4.2.1. Comparing model behaviour with South African economic development indicators

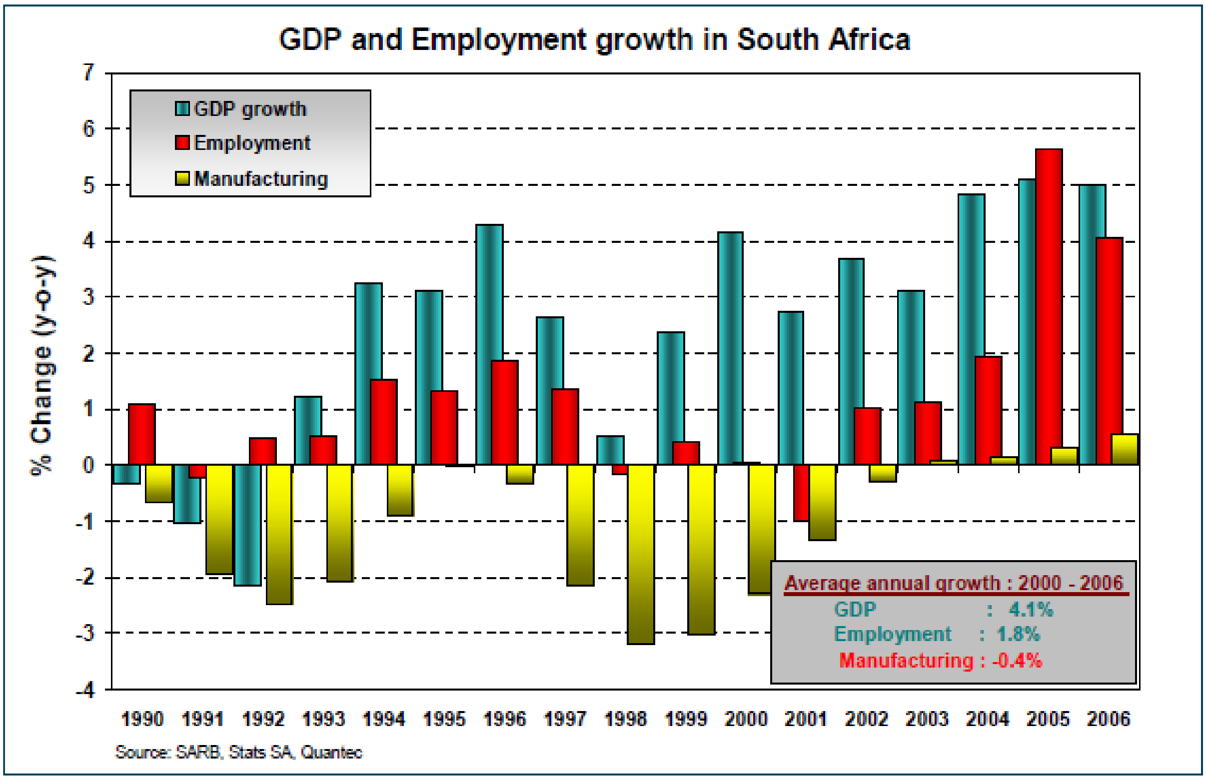
The results of the system dynamics model simulation in section 6.2 highlights a closer link between infrastructure growth, increased economic activity and increased employment opportunities. Although studies have shown that the public investment and private capital investment can act as opposing forces, further analysis through estimates equations (Munnell, 1992) have shown that public investment can stimulate private investment. The results of the system dynamics model simulation also show a causal link between the "area's relative attractiveness" and the infrastructure growth, albeit with the area's attractiveness as a moderator of infrastructure growth. Because time series of simulated output does not occur in the same time series of real data output described in Figure 98 and Figure 99, the focus of the thesis is to show that the outcome of the model reflects the phenomenon of the phenomenon of interest (Kleijnen, 1993:8) rather than the point prediction of the values in the time series.

These patterns of causality are compared with the results reported by the Industrial Development Corporation IDC in their 2007 economic report (IDC, 2007) depicted in Figure 100. Although the IDC results contrast economic growth with manufacturing and employment levels, the system dynamics model broadly describes economic activity that is secondary to mining activities to infrastructure development. The emphasis is on behaviour pattern prediction such as frequencies, trends and amplitudes rather than precise point prediction (Barlas: 1994:4)

<u>Impact on employment</u>

The IDC (2007) points to an important relationship between manufacturing and acceleration in employment in the graph, wherein, despite positive growth recorded between 1997 and 2001, the average employment was almost zero. The notable difference between this period and the period between 2002 and 2006, when GDP growth resulted in better than average employment, is that in the period between 1997 and 2001, there was constant contraction in manufacturing, whereas the period between 2002 and 2006 had a positive average growth in manufacturing. As Barlas

(1996:186), the expectation of performance from a system dynamics model is "producing the right output behaviour for the right reasons". This IDC (2007) results were chosen to demonstrate the similarity between the model and the IDC study on the impact of infrastructure development (through manufacturing) and the growth in GDP and employment.



Source: SARB, Stats SA, Quantec

Figure 100: GDP and Employment growth in south Africa- adopted from IDC (2007)

The graphs in Figure 101 show the result of the socio economic model and the number of jobs created in the mining-driven economy simulated in the system dynamics model for this research. What becomes a clear pattern in the two graphs is that mining jobs are realised almost immediately when investment is made. However, the picture is different for jobs created due to infrastructure investment.

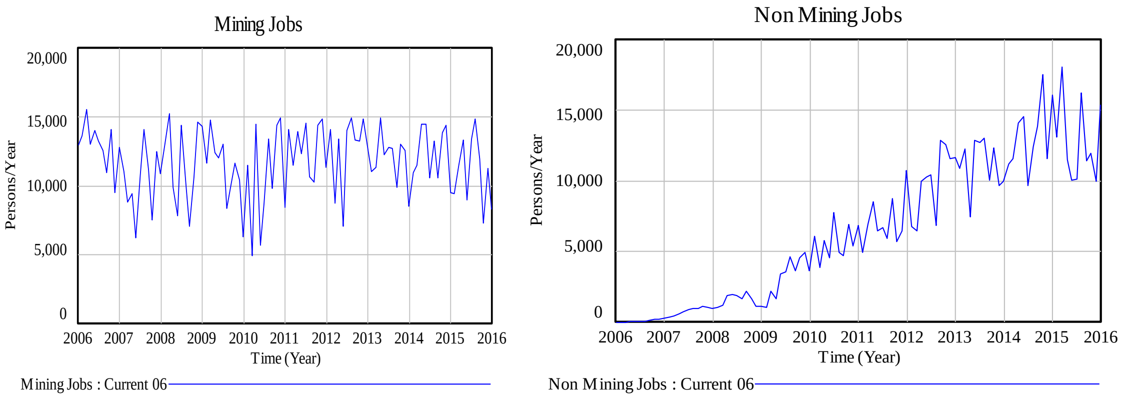


Figure 101: Number of direct mining and non-mining jobs created over the simulation period

The two graphs in Figure 101 indicate a pattern of jobs created through mining activities and secondary business activities. The second graph shows that jobs in the non-mining sector only start growing following a lag, when compared with direct mining jobs. In the model, all mining-related jobs, including Smelter created jobs, are classified as mining jobs, and whereas jobs created through infrastructure development and housing development are classified as non-mining jobs. Contrasting this with the IDC (2007) result, a causality of manufacturing (secondary business) shows that real impact of economic growth on employment is only realised when some level of manufacturing (secondary business) is taking place.

6.4.2.2. Causal link between infrastructure investments and economic activity

When assessing the impact of infrastructure on economic growth, it is necessary to separate regional vs. provincial and countries because as Chandra *et al* (2000:471), the impact of a highway construction may have a positive impact on the region through which the highway crosses and a negative or no impact on the regions isolated from the traffic due to the highway construction. The span of the system dynamics result discussed here is reduced to the region where mining and beneficiation activities occur. The result of the system dynamics model simulation shows causality between infrastructure investments and economic development.

This causality is depicted by the two graphs in Figure 102. The “Economic Contribution” graph shows a correlation between activity infrastructure capacity development and contribution towards the economy of the area. The model demonstrate that although expenditure in infrastructure contributes to the economy of the area, this contribution will only be a fraction of the expenditure as some of the material and labour is sourced outside the area of concern.

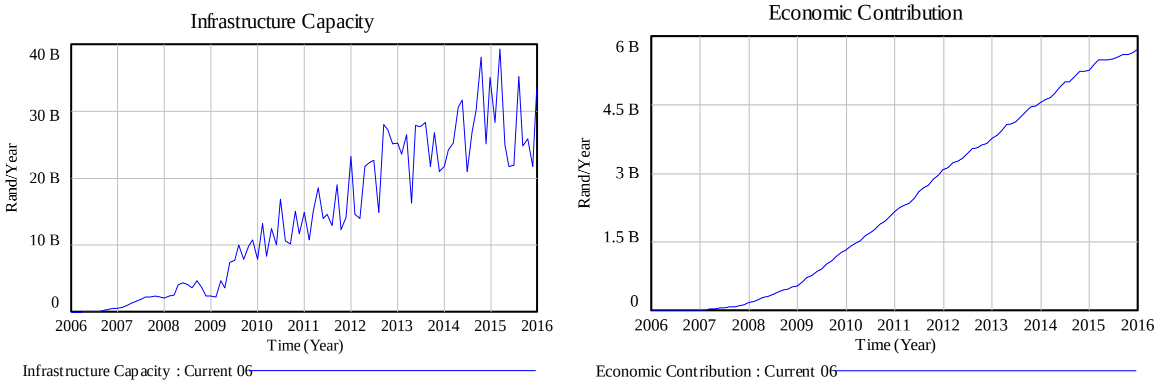


Figure 102: Infrastructure capacity and its impact on economic activity

When contrasted against the results presented by Perkins *et al* (2005), the pattern of behaviour displayed in the results of the system dynamics model simulation does indicate appropriate behaviour. Figure 102 depicts the pattern of causality between investment in infrastructure, fixed capital stock and real GDP in the South African economy over 40 years (Perkins *et al*, 2005). In their result, they show two distinct features in the response of the GDP growth to infrastructure development that are not distinctly clear in the system dynamics model results:

- The impact of infrastructure is not the sole contributor to economic growth; however, it has the most influence.
- The impact of infrastructure investment only shows impact on GDP after 10 years. This may be indicative of the reality in terms of the time it takes before the improvement of infrastructure in a country or region may translate into new business activities.

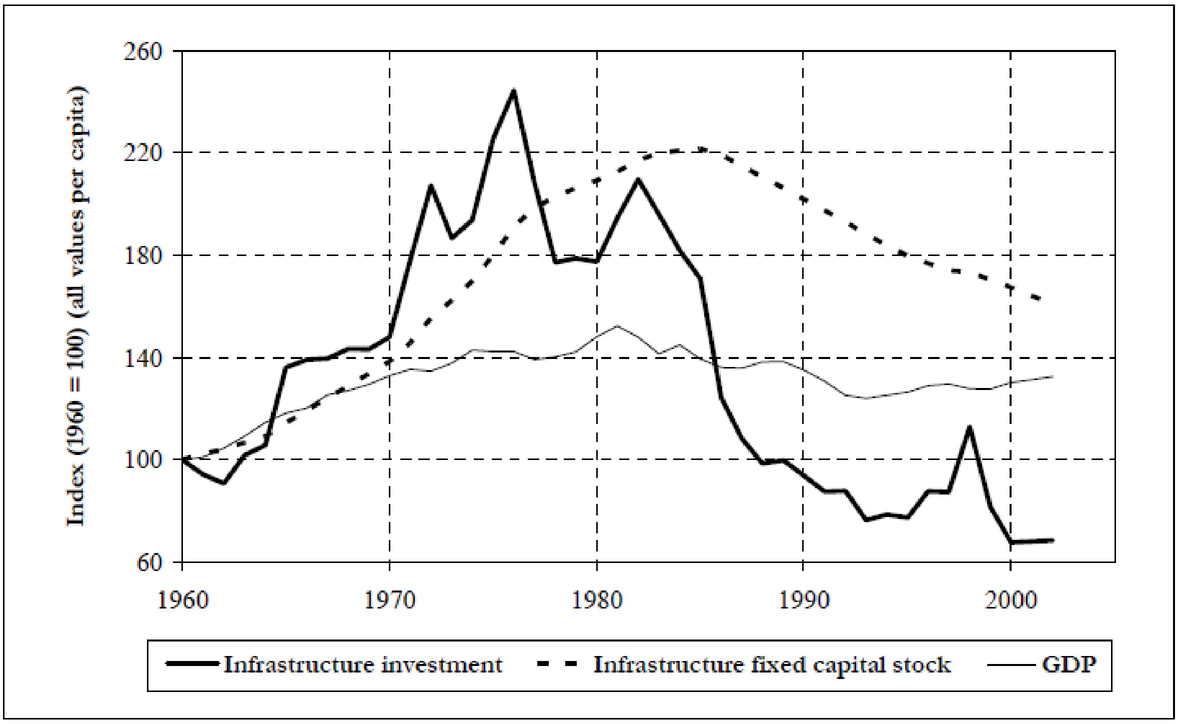


Figure 103: Impact of infrastructure investment on Real GDP in South Africa (Perkins et al, 2005)

The data in Table 20 is also used to highlight the impact of rail infrastructure on mobility of passengers and goods, and, by implication, increased business activities.

The data highlights the growth in rail and rail usage over almost a century, and the correlation between rail infrastructure development, usage and real GDP growth.

Commuter rail is the essential mode of public transport for many South Africans, and it mainly serves people at lower income levels because of its affordability (Erero *et al*, ca 2010). As indicated in Table 20, there was a significant decline in the investment in rail infrastructure during the period from 1980 to 2002, which was also followed by a serious decline in passenger train usage, especially for long distance travel. According to Erero *et al* (2010), the average real GDP growth also slowed to almost a third of the average growth seen in the period from 1930 to 1980.

The Northern Cape, despite being endowed with Manganese and Iron Ore minerals, is unable to beneficiate these minerals due to a shortage of power, which is limited by the lack of electricity transmission infrastructure from Mpumalanga and Limpopo provinces, where the bulk of the power is generated (Eskom, 2012).

Table 20: Average annual growth rates for rail infrastructure, traffic and real GDP from 1911 to 2002 (Erero, 2010)

	1911-1930	**1930-1980**	**1980-2002**
Railway lines	2.2	0.2	0.1
Locomotives	2.4	1.6	-1.8
Coaching stock	2.7	2.2	-2.2
Goods stock	2.6	3.3	-2.2
Carrying capacity (goods)	4.0	4.3	-0.5
Passenger journeys	4.2	4.4	-1.7
Goods freight	3.8	4.4	0.0
Real GDP	2.0	4.6	1.7

The results of the SARB (2012) research in Figure 104 indicate a continual increase in international prices of Iron Ore, over the 6 selected commodities, since 2009. The demand and pricing of Iron Ore gives an indication of the demand for Manganese mineral resource, since its final use is in steel production, wherein it is used to supplement Iron Ore to achieve the required strength of steel.

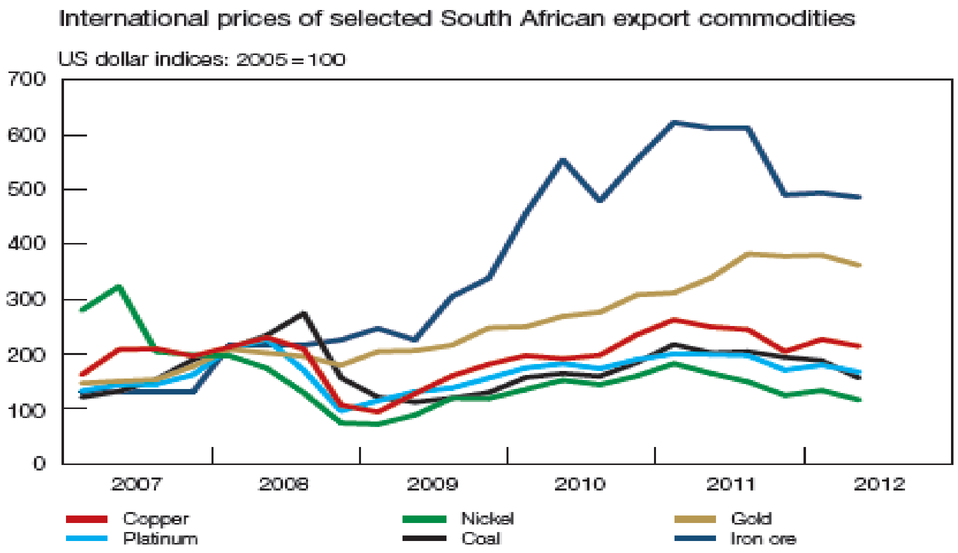


Figure 104: International prices of South African commodities (SARB, 2012)

6.4.2.3. Validation against the creative destruction and industry composition model

The behaviours observed from the system dynamics model simulation were also validated against the work of Professor Saeed (2010). Whilst the graphs in Figure 105 show a correlation between the growth in non-mining jobs and the rate of infrastructure development, Saeed indicates in Figure 106 that, when new enterprise infrastructure is developed to replace ageing infrastructure, a generally professional and skilled workforce is attracted to the area. At points 256 and 272 in the graph in Figure 104, Saeed shows that, with the emergence of new enterprises, comes an increase in the attraction of the professional and management categories of the labour force. Under-employment also reduces most in the same period, which implies that, during the construction and start-up phases of a new enterprise; most jobs are most likely to be created.

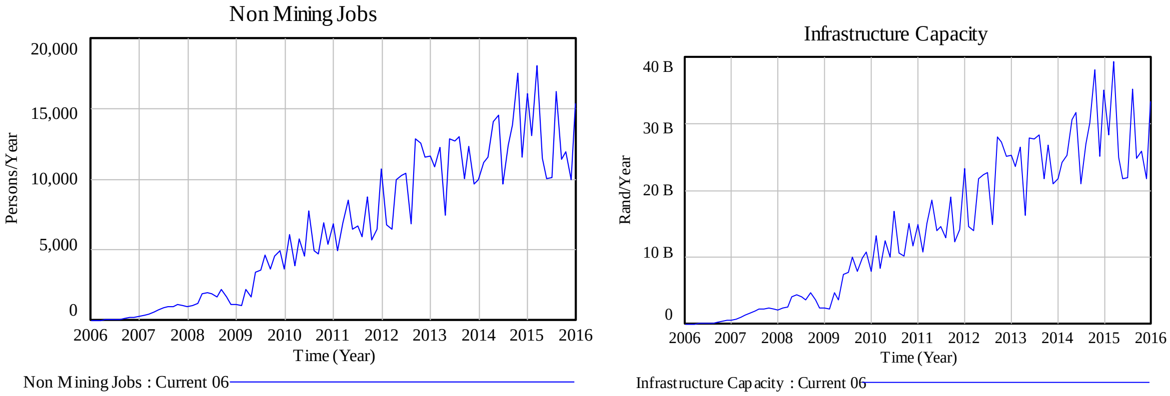


Figure 105: Non-mining jobs and infrastructure development comparison

With the attraction of high-end professionals comes the ability to buy and maintain new housing and related infrastructure. The attraction of new professional and management labour force may, in turn, drive the demand for construction of new housing and support facilities. This combination would result in a general socio-economic growth of an area. Schumpeter (1972) also concludes that the new composition of the economy that is dominated by new infrastructure development and demolition of old buildings is characterised by a high proportion of professionals and managers with both the capability to drive new enterprises and to purchase new housing.

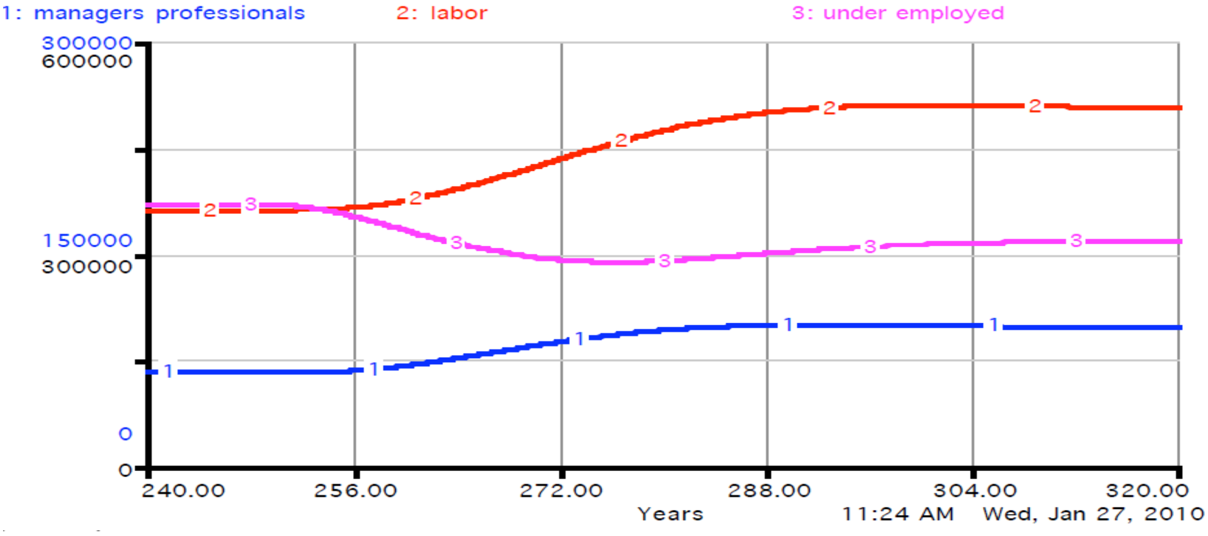


Figure 106: Change in workforce composition created by policies that clear aging infrastructure and encourage development of new enterprises.

The adjustment between the works of Forrester (1969), Schumpeter (1972) and Saeed (2010) and the system dynamics model described in this research is that the Northern Cape's John Taolo Gaetsewe region under focus has a relatively young infrastructure and therefore does not offer enough in ageing and matured infrastructure. What is common in the system dynamics models is the potential to attract new affording professionals, who in turn drive further demands for infrastructure development.

6.5. Conclusion of the results presentation and analysis

The results of the modelling exercise broadly demonstrate congruence with the initial hypothesis of the research as described in section 4.2.2 of this thesis. The modelling results suggest that a long-term investment should be made to create a sustainable environment in the Manganese sector. Mining of the Manganese Ore at higher volumes depletes the resource base much quicker, shortens the life of the mine and negatively impacts on economic activities in the area. The employment numbers achieved through non-beneficiated mining are much lower when compared with beneficiated scenarios. Whilst the system dynamics model for socio-economic system included the outcome of the model was determined by the internal stock flow relationships within the model. This agrees with the argument put forward by Barlas *et al* (2014:2) that, the systemic perspective or world view held by system dynamics seeks to endogenously incorporate all variables that are relevant to the simulated problem.

Historically, Manganese Ores have been beneficiated in Europe and the Americas, and now in China and other Asian countries. In both cases, as demonstrated in the system dynamics simulation results in Section 6.1, these other countries have an advantage over South Africa in technology, skills and overall input cost. The advantages that the Asian players have over their South African counter parts, are attributed to the efficient use and cost of technology and infrastructure capacity that exist in Asia.

The biggest limitation in South Africa is the scarcity of power and the necessary logistics. The simulation result in Section 6.2 shows that infrastructure capacity can be developed over time when higher revenues are generated in the area. What the system dynamics simulation results in Sections 6.1 and 6.2 have demonstrated, is that high capital investments are required in a beneficiation scenario, and should be made upfront in order to stimulate meaningful growth in infrastructure and secondary business activities.

6.5.1. Opportunities

The socio economic development system dynamic model has demonstrated that infrastructure that is created to support mining and beneficiation activities can assist in stimulating growth in other industries within the area. This research does not suggest that private infrastructure investment becomes a substitute for public infrastructure investment by the government authorities. However, this is a chicken and egg scenario that requires long-term decision making. Munnell (1992:192) in analysing the relationship between public and private investment found that on the balance, public capital investment stimulate private investment. In comparison, of the total volumes transported by rail from the Kalahari basin in the Northern Cape to Port Elizabeth for export to the overseas markets, only 40% of equivalent volumes of Ferro-Manganese would be transported for the same mining target in a scenario where secondary beneficiation is done in the Kalahari basin.

With both Manganese and Iron deposits predominantly found in the same area in the Northern Cape's John Taolo Gaetsewe region, an opportunity exists to maximise the potential for integrated upstream to downstream and indeed side-stream beneficiation. A similar set up has already been tried and proved to be successful in the case of the Outokumpu 4-in-1 integrated facilities in Finland albeit at smaller scale. Integrated facilities such as the 4-in-1 Chrome to steel Outokumpu facility in Tornio, Finland, give the operator more control over the cost and direct optimisation of the entire Manganese resources value chain.

Independent Power Producers and Solar Power

By 2012, Eskom had approved 99 independent power production proposals for the Northern Cape (Eskom, 2012), that would make the province a Net Producer of power by 2015. The majority of these projects are based on solar power farms across the province. According to Nakedi (2011), the province has the highest sun energy index in the world ranging from a 4.5 kWh/m^2 to 6.5 kWh/m^2 daily for more than 2 700 hours per year. The demand for power that comes with beneficiation plants at an estimated 3200 kWh/ton treated could serve as immediate consumers of solar generated power to ease the load on the Eskom grid. This, together with technology enhancement in co-generation in the Smelter plants using CO gases, would reduce the reliance of Smelter operations on Eskom power, and eventually make the input cost of beneficiation, related to power smaller.

Human development

Lessons from the system dynamics models in the urban dynamics work done by Forrester (1969) in Boston, Massachusetts, and later reviewed by Saeed (2010), point to advantages that come with making hard decisions on human development by prioritizing industry development over short-term social solutions. The current simulation results show that secondary beneficiation in the Northern Cape is likely to support a significant growth in the engineering support industry, an area that requires practical technical skills that can be developed through the mines and other vocational training interventions.

For a province with the lowest population number in South Africa (SSA, 2011) and vast deposits of natural resources (SAMI, 2009), development of skills in heavy industry could propel more growth in other sectors, such as energy and manufacturing. The majority of the studies conducted by both the private and public sectors in South Africa, point to lack of hard skills at artisan level as a key constraint to growth. This is despite the strong history of excellence in this area in the 20th century that led to the massive industrialisation in logistics. The skills development in the hard engineering sectors was led by the growth in mining, energy and rail infrastructure development. This acclamation is supported by the outcome of the simulation results presented in section 6.2.

Sustainable housing and social development

Housing is considered a basic right in the South African constitution, along with access to services such as water, sanitation and energy. The implementation of the RDP policy, referred to in this research, demonstrates that, providing low cost housing without the ability to provide the associated services creates a problem. This has been demonstrated through the constant service delivery protests by communities against municipalities, ranging from clean water, waste removal to health services. Although there are problems with the competency of officials and corruption within the municipal structures, the biggest constraint is the inability of municipalities to fund service delivery, due to non-payment for the services by the same communities that expect the services to be improved.

The researcher makes this case here because the communities that are under-serviced are geographically placed adjacent and very close to established areas that are well serviced by the same government structures. The significant difference lies in the rates and taxes that the government is able to collect from the affluent areas and the right that those residents feel they have to demand the services. While this research is not making any inference on whether or not it is justified for Government to provide service to areas based on their ability to pay, the research highlights that the households are placed in a position to pay for any services required to keep a certain standard. The system dynamics simulation results link the development of housing to the level of employment, and estimate the ability of each household to support the development of the services industry, from retail to health and other convenient services.

6.5.2. Evaluation of the three Manganese resources value chain scenarios

In the simulation of Manganese resources value chain scenarios, the upstream mining scenario presents a low cost, low risk and quick returns scenario. This scenario is more predictable and most investors prefer this option when a shorter term horizon is taken. This scenario, however, makes more revenue through higher volumes in production, and vice versa. By implication, the profitability of this scenario is inversely proportional to the cost of transportation and logistics, due to the volume needed to drive revenue generation. The capital efficiency of the upstream mining scenario is good; however, it does not demonstrate a proportional gain with increased volume.

This scenario requires very minimal processing of Manganese Ore and, as such, requires minimal use of technology, which by implication means a lesser number of skilled resources required to operate successfully. This does not bode well for general human skills development in the impoverished areas like the John Taolo Gaetsewe region of the Northern Cape Province. With labour intensities of 13 jobs per ZAR 1 million of direct production cost, this scenario presents a lost opportunity for jobs from secondary sectors that have the potential to create up to 47 jobs for every ZAR 1 million of direct production cost spent.

The system dynamics simulation results presented in section 6.1 and 6.2, have demonstrated good dynamic patterns and feedback between various scenario inputs, and some known variables of the Manganese mineral business. The benefit of the system dynamics simulation has been the long-term feedback indicating the reversal of some of the early gains that come with low risk on the upstream scenario, and the real benefit of the beneficiation scenario on economic contribution.

Another way of looking at the relationship is by expressing the revenue gap between the upstream mining and secondary beneficiation (Smelter) as potential income lost to the region. This view represents the reversal of the attractiveness of the upstream mining scenario compared with the secondary beneficiation scenario. The simulation confirms that doing very little beneficiation has very little cost risk in the short term, but also indicates a very narrow profit margin that is sensitive to volume of Manganese Ore mined. The business activities and expenditure levels are low compared with the other scenarios. This level of business activity is not sufficient to support development of alternative industries or any significant support of corporate social investments (CSI) initiatives.

Because of the technology intensity that is associated with the beneficiation scenario, investment in manufacturing, engineering, fabrication workshops and foundries in the area becomes possible and would support development of alternative industries in the area. The proximity of a support industry could reduce the cost of operations throughout the value chain, but the other benefit is the development of critical technical and commercial skills for the region. This can extend beyond mining business however this may be a question to be considered in further research on the subject in future.

Opportunities for re-investment in power and alternative technological solutions become possible in a beneficiation scenario in the medium-to-long term for the Northern Cape. Sometimes a stimulus for technology innovation in one part of an industrial value chain occurs when other industrial value chains find uses for the by-products of the first value chain (Betz, 1993). The Northern Cape Province is blessed with higher than average sun energy throughout the year. South Africa receives more than 2 700 hours of sunshine per year with average solar radiation levels that range between 4.5 and 6.5 kWh/m^2 daily (Nakedi,2011).

6.5.3. Evaluation of the integrated beneficiation and economic development

The simulation results from Section 6.2 demonstrate how the revenue required to reinvest in infrastructure can be generated through the Manganese beneficiation scenario. The simulation focuses only on revenue generated through mining, and spill-overs from mining, and does not take into account the contribution of government spending on social infrastructure. Also missing in the simulation is the massive rail and power infrastructure spending by government and may be subject of future research about the region's economic dynamics. Section 6.2.2 demonstrates how the housing development policy can also stimulate further spending in infrastructure, provided that this is done based on demand, driven by affording individuals, as opposed to low cost housing that is built for unemployed individuals.

Whilst every household based on an employed individual has the potential to utilize any municipality service and retain the consumer business in the area, it is not the case with housing development based on RDP policies. The concept of attractiveness of an area, described in the urban dynamics model of Jay Forrester (1971), suggests that, by making an area attractive to uncontrolled immigrants, the very attractiveness of the area becomes diluted. In the logic to describe attractiveness index in the system dynamics simulation in section 5.2 of this thesis, a point is made that, by attracting the right skills, the potential for more infrastructure and alternative business growth is enhanced.

Feedback, non-linearity and hidden delays in systems defeat most conventional policies (Etienne *et al*, 2010). Eventually there should be a shift in paradigm away from traditional analytical methods to the urban dynamics viewpoint to conserve what already exists, and reinforce the preferred counter balances (Forrester, 1971). Client involvement in modelling is expected to change mental models, and thereby foster implementation of conclusions (Etienne, *et al*. 2010)

The human development measure, in the simulation, seeks to create a pattern of skills development that is driven by corporate social investments (CSI) and other social and labour plans (SLP) related interventions by the mine operators, as a measure of the ability of the region to turn the rand equivalent of infrastructure investment potential into infrastructure capacity of the area. In this manner the attractiveness of the area for business and highly skilled immigrants can be maintained, or even further improved, by attracting more businesses to the area.

The results of the system dynamics model simulation, and the sensitivity analysis, have highlighted some aspects of the Manganese resource value chain performance, and the sustainable development dynamics in a mining-led economy, which are summarised in detail in Chapter 7, as part of case building for the application of system dynamics modelling in mining development projects.

7. A case for systems thinking and system dynamics modelling based approach

This research has relied on the systems thinking approach to define the relationship between the various elements of the mining-led socio-economic system. As Barile (2011:24) points out, in a holistic vision, time and space unite in a single whole evading the perceptions of human beings. Because systems thinking supposes that the social construction of the world is systemic, which suggest the emergent property of the interrelated whole (Flood, 2010). Having constructed the concept of the John Taolo Gaetsewe's mining driven socio-economic system based on the systems thinking parading through causal loops, only then was a system dynamics model constructed. Systems thinking was therefore used as a conceptual framework within the interrelatedness of the system was described prior to implementing the model with feedback loops using system dynamics.

This chapter sets out an argument which suggests that system dynamics modelling, as used in the research, presents a good opportunity, not only to simulate, but to create better appreciation of the complex problem of sustainable development in a Manganese mining led economy. The current research has established an argument that system dynamics modelling can serve as an ideal interface between hard core mathematical modelling using differential equations required to solve complex systems problems, and graphical systems thinking representation of real life challenges and problems. As Davis *et al* (2007:481) points out, in a research such as this one (on mineral beneficiation in South Africa) where empirical data is challenging to obtain simulation is a useful sweet spot between empirical methods and theory testing using statistical analysis.

Whilst it is necessary for the modelling team to understand the mathematics behind the system dynamics model, the graphical interface can be used to capture imaginative participative input of a broader team in creating real life scenarios using the systems thinking approach. Complex systems refer to a high order, multi-loop and non-linear feedback structure class, to which all social systems belong (Forrester, 1969:107). The management and interface structure of a business system also belong to this class of complex systems, considering the number of feedback loops that exist between the business and all other business support and regulatory systems.

The system dynamics model created and analysed in this research for socio economic development has demonstrated patterns that may allow inference of relationship between mineral beneficiation variables and economic development variables through analysis of the simulation results in a similar way that empirical analysis from real life observations would do (Harrison *et al* 2007:1231)

Mineral deposit tend to be located in areas with large sparsely populated areas with little integration to political economic and political system (Bunker, 1994:438) .Whilst it can be argued that the challenges of the Manganese mining industry's economic growth, and the information used in this research, are known and not unique, it is argued in the research that availability of information is not the barrier to finding sustainable growth solutions but how the existing information is used to find these solutions. The barrier to understanding the industry (complex system) dynamics is due to the lack of willingness and ability to organise the information that already exists into a structure that represents the dynamic formation of the actual system, and therefore has an opportunity to behave as the real system would (Forrester, 1969:114).

A single mining operation may have feedback loops linked to support industries, customers, regulatory bodies, unions and local communities, all of which are complex entities in their own right. The results of the Monte Carlo analysis on the "Area's Attractiveness" have demonstrated that, similar to Graham *et al* (1980:287)'s finding, variables that make an area attractive at the beginning such as high rates of employment and housing developments leading to eventual replacement of labour with capital.

The capability that the current system dynamics modelling brings in simplifying complex relationships between sub-systems in a complex economics setup, achieved through a targeted observation of patterns of behaviour, would make it possible to achieve maximum participation by all stakeholders in a policy formulation environment.

In the sub-sections that follow, the advantages of the current system dynamics modelling approach are described, while carefully outlining the limitations of this approach and suggesting measures that can be applied to counter the limitations.

7.1. Sustainability models- some background

Todorov *et al* (2009) found that the analysis of models used to describe sustainable development is also related to the proposed new area of research, namely: sustainometrics. These are described in five major categories of models, namely quantitative models (including mathematical, statistical, data-based, econometric and computer simulation), pictorial visualisation (including the Vensim diagram, graphic representation, pictures and drawings), conceptual models (representing particular concepts and theories), standardising models (including indicators, benchmark values and targets) and physical models (a smaller or larger physical version of the object/system that allow visualisation and further investigation) (Todorov *et al* 2009:1217). Todorov *et al* argue that sometimes a combination of the afore-described categories can be used to analyse and solve a specific phenomenon of sustainable development, depending on the level of abstraction and audience.

Giddings *et al* (2002:188) found that there are different views on sustainable developments from sectors of society such as the Ecologist. This being the case the impact of sustainable development in creating the relationship between socio-economic and environmental aspects of life has gained the concepts wider acceptance (Giddings *et al*, 2002:188). Quantitative models are deemed appropriate for policy-making perspectives according to Todorov *et al* (2009: 1218), and, among the six types of quantitative models described, are system dynamics models, which have been used in the current research. Based on the theory of systems thinking, system dynamics focuses on creating the structures and relationships that exist between elements of systems. Systems thinking is the discipline of seeing the “structures” that underlie complex situations, and for discerning high from low leverage to change (Senge, 1990:69).

The single criticism of the quantitative models has generally been that they tend to be dominated by the discipline from which they originate. This assertion by Todorov *et al* (2009) suggests that system dynamics would be dominated by engineering, since it originates from the electrical engineering field of engineering. However, as it has been demonstrated in this research, just as the founding father of system dynamics, Professor Jay Forrester, has demonstrated in Urban Dynamics (1969) and World Dynamics (1971), system dynamics can be used successfully to solve problems in the socio-economic space including the Manganese mining environment.

7.2. More about the use of system dynamics in the model

Complexity can easily undermine confidence and responsibility, as in the frequent refrain, "It's all too complex for me", or "There's nothing I can do, it's a system" (Senge, 1990:69). System dynamics models bridge this gap by providing a combination of pictorial, computer simulation, and a trial and error approach to dealing with complex systems of a higher order and multi-loop feedback nature. The four central characteristics that make system dynamics models especially well-suited for learning about, and designing effective policies, according to Ghaffarzadegan (2010), are: feedback approach, aggregate approach, simulation approach and small size models.

The research conducted, and the results analysis presented in Chapter 6 of this report, indicate alignment of focus, on the research method, to the views of Ghaffarzadegan *et al* (2010) in looking at the characteristic elements of the system. The method used in this research integrated the dynamic behaviours of the Manganese mine value chain, based on a two-stage beneficiation process of Manganese to Ferro-alloys, over a 10 year simulation period. The production of Ferro-Manganese alloys require a mixture of Manganese Ores, reductants or a carbon form and calcium oxide (CaO) to be smelted at 1200 degree Celsius to enable a reductive reaction and alloy formation (Zhang,2007:139) The cost of reductants and electrical energy are critical cost drivers in the process. The simulation feedback indicates that, although there are high risks associated with the cost of beneficiation due to costs of energy and reductants, creating this scenario in the value chain can stimulate infrastructure growth, due to high requirements for support industry and logistics.

Although the research was not focused on the study of mineral economics or a detailed financial analysis of mining projects, cost and revenue patterns were used to establish feedback loops between mining, as a primary industry, and three other socio-economic sectors around mining, that have an impact on the growth or decline of a mining-driven economy. The Vensim (2010) simulation and modelling platform provides a graphical and interactive interface to simulate the dynamics among the key sub-systems (mining value chain, infrastructure development, housing development and human development) of the mining-based economic development, to test the sustainability aspect of the system beyond active mining.

7.2.1. Important characteristics of a system

An analysis of the modelling process followed in this research highlighted some aspects of the four characteristics of a system, described by Ghaffarzadegan *et al* (2010), and briefly discussed in the paragraphs that follow.

Feedback approach

The modelling took into consideration the dynamic impact of various inputs on the viability of each one of the Manganese resources value chain scenarios. Whilst this may seem obvious when studied individually, the collective sensitivity of electricity cost, logistics and skills levels in an economic system, such as the Manganese mineral industry, can be confusing. The size of cost and revenue movements involved in the mining industry is very high, and making practical observations of these dynamic changes in the variables highlighted above, before making a correct decision in a real economic system, may prove to be a costly exercise.

Aggregate approach

Unlike a normal feasibility study for a specific investment, the research, and the simulation conducted, focused on the aggregate cost and revenue performance of each Manganese resources value chain scenario. As an example, fixed cost of a particular Manganese operation size is treated as a single number. For instance, there is no split between labour fixed cost and general maintenance cost. The focus of the simulation is more on patterns of growth, equilibrium and feedback, and this can be achieved without accuracies of numeric values. The system dynamics modelling approach seeks to form the pattern or direction of performance without committing too many resources, or too much time, into studying an individual dynamics of a cost element.

The simulation approach

The work conducted in this research demonstrated that the dynamic behaviour of a system can be described visually and logically at presentation level without using complex mathematical equations in an analytical approach. However the development of the system dynamics model requires understanding of basic concepts of differentiation and mathematical modelling.

The modelling conducted in this research combines, in one simulation, the dynamics of the mine value chain, the housing industry, human development and infrastructure development, with its impact on the capacity of the economy to support growth. This allows performance feedback on each of the four industries to influence, simultaneously, the behaviour of the economy, as is the case in real life.

Small size model

The simulation conducted in this research assumes a few variables, considering all the cost and revenue variables involved in the Manganese resources value chain, and the associated industry in the economic development. Although it is undeniable that some significant changes in some of the variables, not explicitly simulated, may influence the performance of the system at unit level, the performance of the system can be profiled with reasonable accuracy to inform a policy decision at a higher level.

The use of a small model may have a down side, if it is used as an absolute tool to make those significant policy decisions, because, as is the case in the simulation conducted for the research, detailed parameters of the Manganese resources value chain, as a main driver, may require a further detailed sensitivity analysis, to ascertain specific aspects of the system that are not explicitly modelled. These can include tax provisions, foreign exchanges and import technology. Small models should therefore be used to enable strategic direction only, at policy level, and not as substitution for feasibility and engineering studies required before an investment decision is made.

7.2.2. System dynamics and strategic socio-economic planning

Companies must be flexible to respond rapidly to competitive and market changes. They must benchmark continuously to achieve the best practice (Burgelman *et al*, 2004:113). The simulation in Sections 6.1 and 6.2 have shown that the performance of the Manganese resources value chain system can change under different market conditions. The simulation focused on changes in single variables to illustrate the contribution of those selected variables. The real world can introduce drastic changes in more than one of the simulated variables simultaneously, making it impossible for any business strategy to withstand the dynamic changes.

In his work on the relative attractiveness of investment in mineral exploration, O'Regan *et al* (2003:75) finds that a number of micro level determinants (such as per unit cost) and macro level determinates act as reinforcing loops in a causal loop that describe the dynamic behaviour of a single mine system The complexity of a socio-economic system is of the highest order, and, as such, it is extremely difficult for a group of individuals to predict without using tools that can deal with the mathematics of multiple feedback loops. Like any other software algorithm, configuring the model and quality of information used to develop the model is important, because the integrity of the results will depend on the dependability of the information used in developing the model. What the current system dynamics model will assist the user with the ability to integrate the most crucial feedback aspect of the system performance, to give an indication of the medium-to-long term performance under the specific policy intervention.

7.3. Proposed framework for integrated Manganese beneficiation in SA

The structure of Manganese business is well established in the upstream mining. However, the downstream business still remains largely uncharted for the South African environment. With very few greenfields Manganese secondary beneficiation facilities in the country, the last of which was built more than 20 years ago, it is a cause for concern for the employment and growth in this sector of the economy. The developing trend, since the turn of the century, shows that new operators focus only on the upstream mining to minimise capital expenditure before production. The argument that follows this approach is that, doing so, allows the operators to control the cost variables in the business. However, it limits the revenue potential for the mine operators. Whist prices of Sinter and Ferro-Manganese represent 20% and 40% improvement on that of Manganese Ores due to enhanced Manganese content through these two processes (Pienaar *et al*: 1992:131), the cost of sintering and Ferro-Manganese production is equally high, and discourages many investors from making investments in those ventures.

The steel industry, which is considered the final beneficiation destination for Manganese, is dominated by a single multinational in South Africa. South Africa still imports a lot of steel products, due to uncompetitive prices from the local suppliers. This is a sad story, considering the fact that all the required material ingredients for steel production are available in South Africa. As with other high energy manufacturing and metallurgical operations, the availability and cost of power are amongst the leading constraints to steel manufacturing in South Africa, and the Northern Cape region in particular.

The constraints may be valid, but the outcome of the current simulation research and the results presented in Section 6.2 of this report, indicate that there is potentially a more sustainable profit opportunity that may lead to more employment and overall socio-economic development, if the beneficiation scenarios are pursued over a long term, based on a model similar to what has been a success story at Outokumpu (2012) in Tornio Finland.

The simulation results show that the benefits of pursuing the beneficiation scenario may not be realised in the short term, and may even require a lot of capital expenditure and high working capital before gains are realised. The impact of the beneficiation scenario on human and housing development, demonstrated in Section 5.2.2, answers the question that is always raised by both business and government, on the enablers of industrialisation and job growth in South Africa.

7.3.1. Basis for the framework

There are a number of definitions of the word framework in various literatures and other sources. In most cases the context within which it is defined may determine its acceptance for a particular discussion or a topic. A definition of a physical framework will differ from that of framework of a written concept. The definition adopted for this research is taken from “TheFreeDictionary (2014)” which defines a framework as a set of concepts, assumptions, values and practices that constitute a way of viewing reality.

The framework proposed by this research incorporates the lessons learned from the current Manganese mining industry structure, the result of the system dynamics simulation conducted during the research, the benchmarking lessons from the urban dynamics work of Forrester (1969) and the world dynamics work of professor Jay Forrester (1971), benchmarking of the Cassora (2005)’s OMPHILOS model, and the Outokumpu (2012) 4-in-1 beneficiation structure. The proposed framework also takes into consideration the input constraints to the South African mining environment described in chapter 5 of this thesis.

7.3.2. Linking the framework to the system dynamics modelling results

The results of the system dynamics revealed a number of dynamic elements that exist in a mining and beneficiation driven economy. The result presented in section 6.1.3 and the discussion in 6.1.4 of the thesis demonstrated that the secondary beneficiary (Smelter) scenario is preferred because of its high cost and revenue impact. The low normalised standard deviations on its revenue performance under changing environment as demonstrated through the result in section 6.1 would confirm the basis upon which this framework is anchored on mineral economic value as one of the frameworks key elements.

In Section 6.2 of this thesis, the results of the system dynamics model simulation of the socio-economic model demonstrated that as significant contribution can be made towards infrastructure can be made due to the high capital intensity of secondary beneficiation. The input cost portion of the secondary beneficiation is high and if localised to the area can impact on development of secondary industries in the area. This aspect is captured under the business impact element of the Framework.

In his work on modelling the collapse of complex societies Bueno (2011) finds that in an expansion phase, an increase in the cost of socio-political integration combine to lower the margins of return leading to those societies becoming vulnerable to collapse. The system dynamics model also demonstrates that the attractiveness of an area is driven by elements that can change over time. In Figure 95, the result of the Monte Carlo sensitivity analysis demonstrated the elements that drive attractiveness of an area for economic growth such as land capacity and availability of skilled workforce can quickly reach saturation points beyond which attractiveness is compromised. The framework incorporates this aspect by identifying key system elements for each stage of development.

The results presented in Figure 87 through 91 highlighted that although the mining and beneficiation activities have the ability to impact of development of infrastructure and impact economic growth through secondary and tertiary industries such as manufacturing and retail, this does not happen in the same years during which mining and beneficiation revenues are created however there is a lag in time. The framework emphasises the timing of the impact in the same way.

The framework also accommodates the short comings of the secondary beneficiations due to the volatility of its profit and capital efficiency in the formative years of operation by proposing that the development of the upstream mining activities, the primary and secondary beneficiation be sequence to enable stability of each stage before the next stage is brought on line.

7.3.3. The key elements of the framework

The framework comprises five key focus elements as follows: Mineral economic value, Business activity, Areas of business impact, Challenges/Opportunities and Key business drivers. The elements are intended to provide a structure with which any group of stakeholders, looking at an evaluation of the sustainability of the Manganese resources value chain opportunity, can work. The elements are aimed at stimulating an inclusive and integrated evaluation of the key dynamics of the Manganese mining value chain, when looking at an investment or any policy decision in the business.

The framework seeks to focus both investors and policy makers on the total value of the mineral reserves. This view does not negate the established importance of using the mineral evaluation method to prevent risk of investment on unproven minerals, but seeks to draw attention to what is probable in the long term. This view is informed by the extent to which more investment in new technology, over a longer period, can make non-mineable resources viable in the long term; hence the planning of the sustainable Manganese industry should consider this as a real potential.

Business Activity

The business activity element builds on the results of the modelling work performed in Section 6, and the outcome of the analysis. The framework encourages policy makers to perform scenario and sensitivity modelling when making decisions on value chain investment, to ensure that the dynamic pattern of input and surrounding environmental influence are understood over a longer period.

Areas of business impact

As part of the MPRDA (DME, 2004), mining businesses are expected to contribute to community upliftment, and this is enforced through corporate social investment and social labour plans, as a percentage of profits earned from mining proceeds. Often, mining companies make a financial contribution to comply with this legislative requirement, but the impact is not realised. The framework also seeks to encourage decision makers to place efforts in studying areas where the impact can be realised more optimally, and can benefit sustainable development of the area. The areas of business impact are economic and social activities that the mining activity can support, directly or indirectly, without being the sole driver. These is different from one geographical area to another, due to the demographics of the area, and, such being the case, decision makers need to have a deeper understanding of the dynamics of these areas to predict the business behaviour over a long term.

Key economic drivers

Challenges and opportunities exist in every business endeavour, and at times are not clearly visible to the decision makers. Key system elements that drive business success are as important to identify and understand as the business opportunities themselves. As has been demonstrated in the principle of attraction referenced in the urban dynamics model by Forrester (1969) and more recently later in the work of Saeed (2010) and Graham *et al* (1980:287), what may seem like an opportunity in the short term could create or turn into challenges in the long term. The framework seeks to encourage decision makers to evaluate the opportunities presented at the time of deciding on the Manganese mining value chain. This was to establish feedback over a long term due to decisions taken from information around the challenges and opportunities.

From infrastructure to skills levels, this aspect of the framework is vital as it may change for better or worse over a long period. The causal link between infrastructure and business or economic growth is often likened to that of the chicken and egg scenario (Perkins, 2005). This is the element that should be modelled and simulated more before major decisions on the Manganese mining value chain are taken. The diagram in Figure 105 describes the proposed framework.

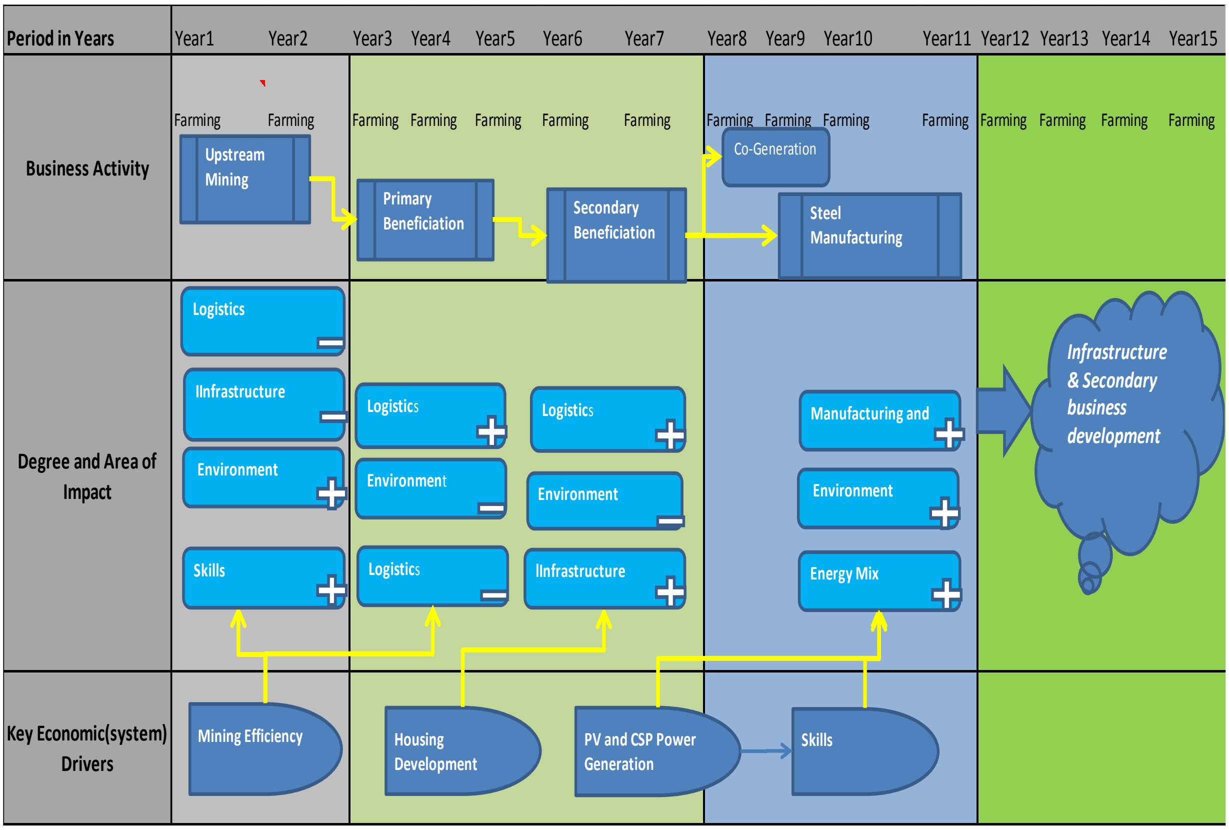


Figure 107: Framework for sustainable Manganese mining

7.3.4. Description of the Framework

The framework described in Figure 107 emphasises the staged approach to looking at decision making within the Manganese mining value chain in order to foster sustainable development in the areas where mining activities take place. The framework recognises that different decisions may be required on the same issue, depending on the life cycle phase of a mining development.

The framework proposes a staged beneficiation approach for the Manganese mining industry. The process proposed in the framework assumes four phases of sustainable mining development into sustainability. Though not specifically modelled in this thesis, the importance of farming in the areas where the mineral exploration and mining takes place is acknowledged in the description of the framework. In South Africa, and the Northern Cape in particular, mining comes at a cost of reduced farming capability. However, mines should bring infrastructure that may also benefit the farming business.

This is the reason why the trade-off should be done to assess the practicality of the benefits to farming.

The main business activities, proposed by the framework, centre on Manganese mineral exploitation throughout the Manganese mining value chain, starting with the upstream mining, through beneficiation stages, to creation of a sustainable economy over a long period. The mining value chain activities are sequential in nature, in order to allow feedback and review of capability on skills and infrastructure. The process acknowledges the cost of downstream beneficiation, and proposes a reinvestment of proceeds from upstream mining into beneficiation activities over an extended period. This approach allows a steady development of required skills and infrastructure to support beneficiation activities.

Impact of business activities

The framework encourages decision makers to measure the degree of impact of each business activity on a number of areas, i.e. Revenue generated, skills development index, jobs to skills ratio, logistics, infrastructure, environment, housing development and energy mix. Implementers of this process can add variables that they wish to measure, based on the structure and nature of the economic challenges they face. Impact on power and logistics is particularly crucial for the industry development and economic development in general. The simulation results in Section 6.1 ad 6.2 demonstrate that there is an inverse proportional relationship between power and logistics across the Manganese resources value chain. In the upstream scenario simulated, the cost of logistics is high and the power cost is low. However, this relationship reverses itself in the two beneficiation scenarios. The structure of the framework suggests that these trades-offs, between input elements, need to be cleared at the beginning of the investment period.

Element of progress to be monitored

During the analysis of the performance of the Manganese mining value chain, key variables that drive sustainable development should be monitored prior to progression to the next stage. Todorov *et al* (2009:1225) highlight the challenge of modelling sustainable development due to the contested nature of the concept and suggest a development of tools to measure what he terms sustainometrics instead. Todorov *et al* (2009's argument emphasise the need to continuous measure the sustainable development element in an integrated manner to accommodate all elements of socio-economic and environmental progress made by the industry and human kind in general These variables can be evaluated, through the system dynamics simulation process, to predetermine the sensitivities of certain decisions regarding the success of the investment decision. The impact on environment and social development should be monitored closely, and integrated into business performance.

Limitations and Risks

The frameworks should be applied with constant consideration for prevailing political, economic, social and technological environments, and should be in compliance with legislative framework provided by the country. The framework is not a substitute for the engineering and economic evaluation process to which new mining and expansion investment should be subjected. The framework assumes that, by investing more proceeds of mining into infrastructure and retaining circulation of money in the area, new skills are developed, making the area attractive and viable for new business investment. This may not always be the case where the scale of the investment is smaller.

7.3.5. Recommendations for the new framework

The biggest lesson gained through experience of the current system dynamics modelling and the benefits realised in understanding the dynamics of the Manganese resources value chain, is the need to look at a system as a whole, using a systems thinking approach when making strategic decision acknowledging complexity of such decisions (Mingers *et al*, 2010:1153). Client involvement in modelling is expected to change mental models and thereby foster implementation of conclusions (Ettiene *et al*, 2010). This should be done earlier in the objective setting for green fields mining project development. However, the simulation of the sensitivities of key variables should be conducted on a more regular basis. The system dynamics simulation work conducted in the research established that long-term feedback, indicating the reversal of some of the early gains that come with low risk decisions on the upstream scenario, compared with the real benefit of the beneficiation scenario, could change the way in which critical investment decisions are made in the industry.

The cost of high energy beneficiation requires sufficient infrastructure investment to support the activities which in turn would support economic growth in the area. This view is reflected in Esfahani *et al* (2002:471), who conclude that the impact of infrastructure on GDP growth can be substantial. (Munnell, 1992:193) argues however that the impact of infrastructure investment on economic growth may not be seen in the same that the investment is made. The results of simulation in section 6.2 of the thesis demonstrate this delayed effect between beneficiation activities, infrastructure capacity development and contribution to economic growth.

By looking specifically and critically at the areas of business impact, as indicated in the proposed framework, decision makers may find that opportunities for reinvestment in power, and alternative technological solutions, become possible in a beneficiation scenario in the medium-to-long term for the Northern Cape. As Betz *et al* (1993) pointed out in their work on technology innovation, a stimulus for technology innovation in one part of an industrial value chain occurs when other industrial value chains find uses for the by-products of the first value chain.

Secondary beneficiation of the Manganese mineral has not happened in the Northern Cape over the past 50 years, in part due to lack of power, amongst other infrastructure requirements. This is despite the fact that the province is blessed with higher than average sunlight throughout the year. South Africa receives more than 2 700 hours of sunshine per year, with the average solar radiation levels that range between 4.5 and 6.5 KWh/m^2 daily (Nakedi, 2011). By reinvesting in projects such as solar, for its employees and the surrounding communities, the load on the local Eskom grid, supplying the mine, can be eased in the long term, creating more space for alternative business expansions.

The simulation results analysis, in Section 6.1, confirms that doing only the minimum upstream mining has very little financial risk in the short term, but also indicates a very narrow profit margin that is sensitive to volume of Manganese mined. The business activities and local expenditure levels are very low and, as such, they do not support the development of support and alternative industry, nor give any significant support to corporate social investment (CSI) initiatives. The beneficiation scenario presents a better option for a developing industry and a sustainable development environment, due to high revenue potential in the long term, albeit with high cost requirements in the beginning.

Because of the technology intensity that is associated with the beneficiation scenario, investment in manufacturing, engineering, fabrication workshops and foundries in the area become possible, and would support development of alternative industry in the area. The proximity of a support industry could reduce the cost of operations throughout the value chain, but the other benefit is the development of critical technical and commercial skills for the region, that extend beyond mining business.

The framework challenges business and other stakeholders in the Manganese industry to look at their business, and the community around the business, as a whole and take a unified approach to problem management (Jackson, 2001:236) The framework is not a substitute for the engineering and financial feasibility study processes that have been used to determine viability of new or extension projects. The framework is, however, aimed at providing a complementary tool to the existing study and business case processes, to ensure long-term sustainability of the Manganese mining investments.

The proposed framework may be useful in determining future dynamics in the Manganese resource value chain and the economic region within which mining activities are undertaken however, more research may be required to capture the impact of other industries not studied in this research. The next chapter summarises the contributions and the limitations of this research.

Chapter 8 of this thesis summarises the process undertaken in this research, the interpretation of the system dynamics modelling results and the contribution of the systems thinking approach into describing and understanding Manganese value chain dynamics. The new understanding of the dynamic behaviour of the Manganese value chain system against varying input cost element, its short comings and the new questions raised as a result of this understating are discussed in more detail.

8. Conclusion of the research

Corporate systems, military systems, ecological systems, economic systems, living organisms are arranged in hierarchies. It is no accident that that is so. If subsystems can largely take care of themselves, regulate themselves , maintain themselves, and yet serve the needs of the larger systems, while the larger systems coordinates and enhances the functioning of the subsystems, a stable ,resilient , and efficient structure results **----** (Meadow,2007:73)

The objective of this research was stated, in Chapter 1 of this thesis, as being "to define a systems level relationship between economic infrastructure, mining activities and community social development in relation to sustainable development in a mining driven economy". The sustainability of development in a mining-led economy has many aspects that influence it. However, the research focused on the mineral resources beneficiation in a Manganese industry as the primary driver and the basis for the system dynamics modelling used in the research. In acknowledging the complex nature of the world today Repenning (2003:326) highlights that the social system has become more interconnected, fragile and complex than it ever was. Repenning (2003:327) moves to conclude that system dynamics is uniquely suited into tying all the non-linear elements of the social system together into an empowering social system.

In responding to the objective, and in acknowledgement of the complexity of the subject, a systems thinking approach was taken to define the problem for the system dynamics model, with more emphasis on established patterns of causality between the sub-systems of sustainable development (i.e. Manganese resources value chain, infrastructure development and human development), rather than on a micro level of details of specific variables.

A complex systems theory, systems thinking, operations research and system dynamics are concepts that always get mentioned when an alternative approach to solving socio-economic problems are sought. This research investigated the literature background to these concepts, and has applied the valuable lessons learned in other applications, where these concepts have been successfully applied collectively or individually. The use of simulation models in system dynamics has helped in validating and verifying the theories and concepts developed through this research. Harrison *et al* (2007:1232) point out in their work that simulation models provide logical consistency that is useful in theory development. The use of system dynamics simulation in this research has helped in performing complex multi-variate sensitivity analyses with increased consistency

Extensive reference was made to the works of Forrester (1956, 1969 and 1971), Schumpeter (1962), Sterman (1984, 1989), Meadows (2007, 2010) and Saeed (2010) in system dynamics. Reference was also made to the object-oriented model for predicting human activities of learning organisation systems (OMPHALOS). This approach to modelling was developed in the 1990's for modelling complex technical, social and economic systems, and was based on system dynamics theory (Cassora, 2005:1).

8.1. Contributions of this research

8.1.1. Predicting future performance of the Manganese resources value chain

One of the contributions of this research is the indication that the dynamic performance of the Manganese resources value chain system as well as the sustainability of the economic system around the value chain can be predicted based on system dynamics model simulation. The presentation of a predicted future scenario can therefore provide foresight rather than having to wait and see how the real system actually behaves (Fowler, 2003:143).

The results presented in chapter 6 of this thesis have demonstrated that the benefits of secondary beneficiation can be missed if a decision to invest is based on short term performance and limited understanding of input cost and price dynamics. The multi-variate sensitivity analysis highlights the long term stability of the secondary beneficiation scenario and its contribution to the development of infrastructure that would not be easily predicted without undertaking this kind of simulation. The system dynamics simulation provides a platform for a multivariate sensitivity analysis which in its own assists in assessing different scenarios for the future that would otherwise be expensive to experiment without dynamic simulation.

Built on the strength of mathematical modelling through Differential Equations, the system dynamics model in the Vensim platform can be used to create an interface that is user friendly for a broader stakeholder group. More useful models can be created in Vensim a lot quicker than it will take to solve mathematical analytical equations for the same problem because these equations are inherently coded in the Vensim software; however an appreciation of the Differential Equations is essential for successful use of the software.

8.1.2. Feedback system in evaluating mining value chain performance

The research introduces the ability to integrate the feedback loop system when simulating the potential performance of a Manganese resources value chain stage. As Sterman (1989:338) points out in his work in modelling managerial behaviour, the efficacy and decision strategies lies crucially in the action between decisions and changes in the environment which condition future decisions. The feedback mechanism that system dynamics provide in the Vensim tool makes the tool relevant for the simulation of policy intervention in the Manganese mineral beneficiation scenario analysis and the same could be applied in other mineral commodities.

The challenge as Sterman (1989:321) correctly points out, lies in the cognitive and informational limitations in human beings, which affects their rationality. The system dynamics model has demonstrated, by using the “balance feedback” variable, the impact of power cost (Eskom, 2012) and logistics capacity cost (Transnet, 2012), constraints on the ability of the Manganese resource value chain to meet the targeted depletion rates, irrespective of market demand.

A second form of significant feedback, in the system dynamics model simulation for socio-economic development, is the impact of attractiveness of the area on business and economic activity. This feedback highlights the limitations that may exist in the sustainable development of an area, due to a number of factors, amongst which skilled labour and land availability (Graham *et al* 1980) play a part. The impact of input variables, as constraints to growth, was also identified in the works of Forrester (1969), Schumpeter (1962), Meadows (1998) and Saeed (2010), making this approach a common feature of system dynamics modelling. This research brings this approach to modelling the performance potential for mining-driven sustainable development.

The second important contribution of this research, and the application of the system dynamics approach to modelling, is the ability to integrate in the model the impact of multiple variables, and observe the impact of each variable using the integrated Monte Carlo function in the Vensim DSS (Vensim, 2010). The results of the system dynamics simulation have demonstrated that there are no obvious choices in so far as the Manganese mining and economic development decisions are concerned. There are also no easy predictions that can be made about external variables such as price of the product, demand for the product and cost of major-input cost drivers such as power and logistics. By establishing a pattern of performance in and sensitivity to, various elements of the business, investors can make bold and informed decisions at various stages of the Manganese resources value chain, and sustainable development planning.

8.1.3. Potential of reversal of benefits

The system dynamics modelling brings to light aspects of the Manganese resources value chain performance that may show reversal of benefit of performance over time, or when increased beyond specific limits. As O'Regan *et al* (2000: 342) stated much of the dynamics in complex systems arise from the delayed feedback between decision points in particular when such feedback crosses the system (organisational) boundary. This aspect is also demonstrated through the socio-economic model, where the policies that increase production without consideration for input capacity limits, may create uncontrolled growth, attracting more people into the area, only for the production to stagnate and lose the very job opportunities that attracted people to the area, leaving an even higher pool of unemployed people in the area.

The relative attractiveness of an area is also dependent on the balance between the total housing capacities of the area versus the demand for housing. The index drops when the size of the skilled workforce is very low compared with the total number of employable people in the area. Graham *et al* (1995:308) in their work on the long wave of innovation correctly conclude that when capital has accumulated to a point of maturity, adding more capital is no more attractive than adding labour. Graham *et al* *(*1995:308)'s conclusion would support the thesis conclusion that limitations may exist in a developing area, despite availability of financial resources and the willingness of authorities to invest.

8.2. Limitations of the research

The obvious limitation of the research is its boundary, which is limited to the John Taolo Gaetsewe region, and the Manganese resource value chain within the Kalahari basin. The system dynamics model simulation did not include other variables from the broad sectors of the John Taolo Gaetsewe region's economy, which include Iron Ore mining, agriculture and secondary and tertiary sectors, which in some way may influence the direction of sustainable development in the area, when considered. As Munnell (1992:196) highlighted, aggregate results alone, which the system dynamic model results are (O'Regan *et al* 2000:349), cannot be used to inform spending in investment without cost benefits analysis.

The John Taolo Gaetsewe region has a number of other industries that are mushrooming, which may also influence the dynamics in the housing and infrastructure business sector of that economy and, by implication, the human development index in that area (JTGD, 2013). Some of the aspects of the John Taolo Gaetsewe region that are not simulated in the system dynamics model in this research include the following:

The emerging renewable energy projects

The Northern Cape is experiencing a high level of interest in solar-renewable projects, due to its vast land and high average solar radiation (Nakedi, 2011). This may result in major industrial activities in the area, due to the expected rollout of the Integrated Resource Plan, which will see in excess of 300MW capacity being built from Solar power plants (DoE, 2011), the majority of which is implemented in the area of the John Taolo Gaetsewe region. The tariff system in South Africa was originally designed to ensure that Eskom, the state-owned power utility, is able to fund its operations and the necessary expansion at no profit or loss (Maroga, 2009). This approach has fallen behind the developmental needs on both the domestic and the industrial front; hence the introduction of alternative power production methods, and the introduction of Independent Power Producers (Eskom, 2012)

Rail Logistics infrastructure upgrades

The biggest challenge in South Africa, with the mining export economy, is the capacity of rail to carry all the exports to the ports. Both the Manganese and Iron Ore industries are affected by the bottleneck on the Transnet rail lines. Transnet Freight Rail has responded with a massive capital expenditure to upgrade rail capital stock in order to achieve increased rail capacity by 2018 (Transnet, 2012). Some of this work is carried out in the John Taolo Gaetsewe region, and will affect employment and industrial activities in the area.

8.3. Some new knowledge gained through the research

The principle of relative attractiveness, which was developed during the urban dynamics work (Forrester, 1969) and reviewed by professor Saeed (2010), was applied in the system dynamics model simulation of the beneficiation-led economic development. The principle of relative attractiveness also implies that all areas be it countries, provinces and regions have some elements of risk and potential for profit generation, the only difference is the degree of the risk (O'Regan, 2003:84). The conflict between providing access to developed and well-serviced prime land and impoverished communities, and reserving this area for self-sustaining business, is often difficult and requires long-term observation and feedback to see real impact of any policy decision in that sense.

The dynamic journey of a policy decision and feedback received, based on such a decision, demonstrate that time, as a factor, introduces potential for dynamic changes to the action, resulting from the decision and the feedback on its impact. The information, upon which the policy decisions are made, is also subject to time limits in terms of validity. This information may change between policy decision and action being completed, and, as such, there is a need for review of the feedback. The diagram in Figure 108 describes the dynamic process that a policy decision goes through in real life, and confirms how different the results of a policy decision can become, from what has been intended due to time delay and external feedback.

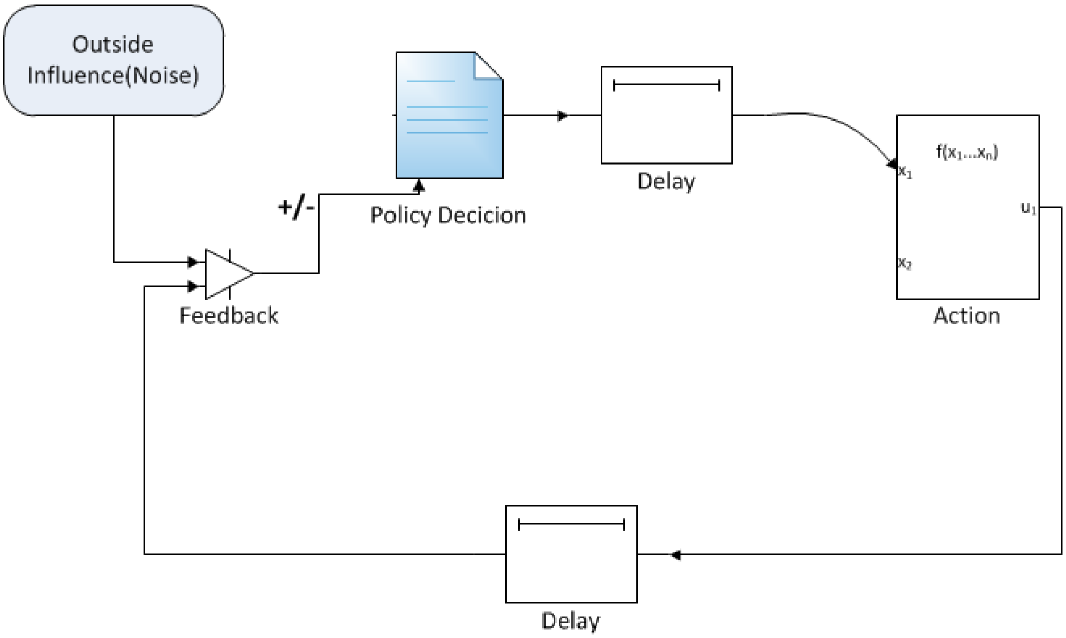


Figure 108: The description of a dynamic process of a single policy decision

The dynamic performance of mining businesses and, in particular, Manganese mining, cannot always be predicted with certainty. The cyclic nature of market conditions affecting the performance of the Manganese industry requires both a long-term view and filtering of feedback, in order to understand the underlying patterns of performance. The system dynamic simulations performed in this research have demonstrated how the performance of a Manganese resources value chain scenario could change over a 10 year simulation period. The delay in the causality of the input flow and the stock accumulation, allows the simulation model to reflect the real dynamics in a mining business system, and reaction to policy changes made in this business area.

The value attached to South African minerals indicates the extent of the potential that the industry has to impact GDP growth of the country in the next 2 to 3 decades, if managed properly. To achieve real growth, the mineral resources value should be used to create sustainability beyond the direct revenue of the minerals themselves. It means that the value of every ton of Manganese Ore extracted should be maximised, both in terms of Rand or Dollar value, and the leveraging that can be achieved on socio economic gains for the country. The simulations performed on the three Manganese mining value chain scenarios, as described in Sections 6.1 and 6.2, indicate that secondary beneficiation impacts on infrastructure and housing development more positively than upstream mining activities in the long term. However, this is not obvious in the short term.

This stems from the ability that the business operator has to generate more revenue in the secondary beneficiation business, when compared with the primary beneficiation and the upstream mining scenarios. The secondary beneficiation scenario also attracts higher cost of production per ton of Manganese alloy, produced through the furnaces, mainly due to higher energy and maintenance costs. The sensitivity analysis performed on the scenario simulations, also indicated more stability in the secondary beneficiation scenario over the long term. The dynamics of the Manganese mining value chain are complex and require the application of the software simulation system to analyse sufficiently. The system dynamics simulation used in this research provides a software platform, based on Vensim, which is relatively easy to configure when compared with traditional modelling methods, using analytical solutions.

The value of using system dynamics in studying the complex behaviour of a part of the minerals sector, i.e. The Manganese industry, has been the ability of the system dynamics simulation to establish the long-term benefits of pursuing a Manganese resources value chain policy that links upstream mining, secondary and downstream beneficiation with social infrastructure development, to achieve long-term sustainability of the industry. As is the case with developed economies, most communities could be developed from primary sector driven business activities into services and manufacturing-driven economies. This may only be possible if high technology, engineering and manufacturing skills are developed during the height of mining activities.

By linking housing and urban development to a pull effect on skilled employment, through extended Manganese mining and mineral value chain activities, the economy may stimulate the affordability of social services and consumer goods sales to residents in the area. Growing the capability for manufacturing and beneficiation in the region through investment in skills and infrastructure development, may attract more future investment from other countries with mineral resources and lower beneficiation and manufacturing capability, due to limited mineral resource volumes. This is the situation in Asia and Europe where, despite having a low mineral base, there is a high manufacturing and beneficiation capacity. It is in these countries where the beneficiation of most South African minerals takes place.

8.4. Some new questions for further research

The research did not study in detail the unique influence of the labour dynamics of the region. The, current and historical migration patterns, and to the extent that these affect skills attraction to the regions, have not been studied in detail. To the extent that the factors listed above may affect the attractiveness of the area to business and professional labour, this may require further research in future.

The integrated impact of developments in the solar power and rail development industries has not been incorporated in the model, due to the broad nature of the development. While the system dynamics model simulation has highlighted some critical patterns of sustainable development, based in Manganese resource value chain and its impact in the John Taolo Gaetsewe Region, future simulation work may be required to study the integrated impact of Iron Ore mining, agricultural, and broader infrastructure development work currently planned for the region.

The results of the simulation have not been subjected to time series decomposition and forecasting methods to ensure that elements of the data described as Trend (T), Cyclical , Seasonality and Irregular/Randomness are identified. Further research on the dynamics of mining value chain and its relationship to socio-economic develop may require the application of such statistical techniques as moving average and exponential smoothing forecasting models. The statistical techniques could be used to deal with effects of white noises and seasonality using smoothing and seasonality constants (Lee, 2014).

In further describing the association of variables in a mining value chain with elements of Areas attractiveness, regression techniques can be used to explain the impact of independent variables at a lower system hierarchy compared to the level 2-4 simulation covered in this research. Further analysis of associations at lower levels may enhance in-depth understanding of the statistical variance and endogenity of the system elements for more efficient policy decision making.

As Albert Einstein said, *“the problems that we have today cannot be solved at the same level of thinking that created them*”.

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10. Appendices

10.1. APENDIX A: Mining value chain stock flow diagram

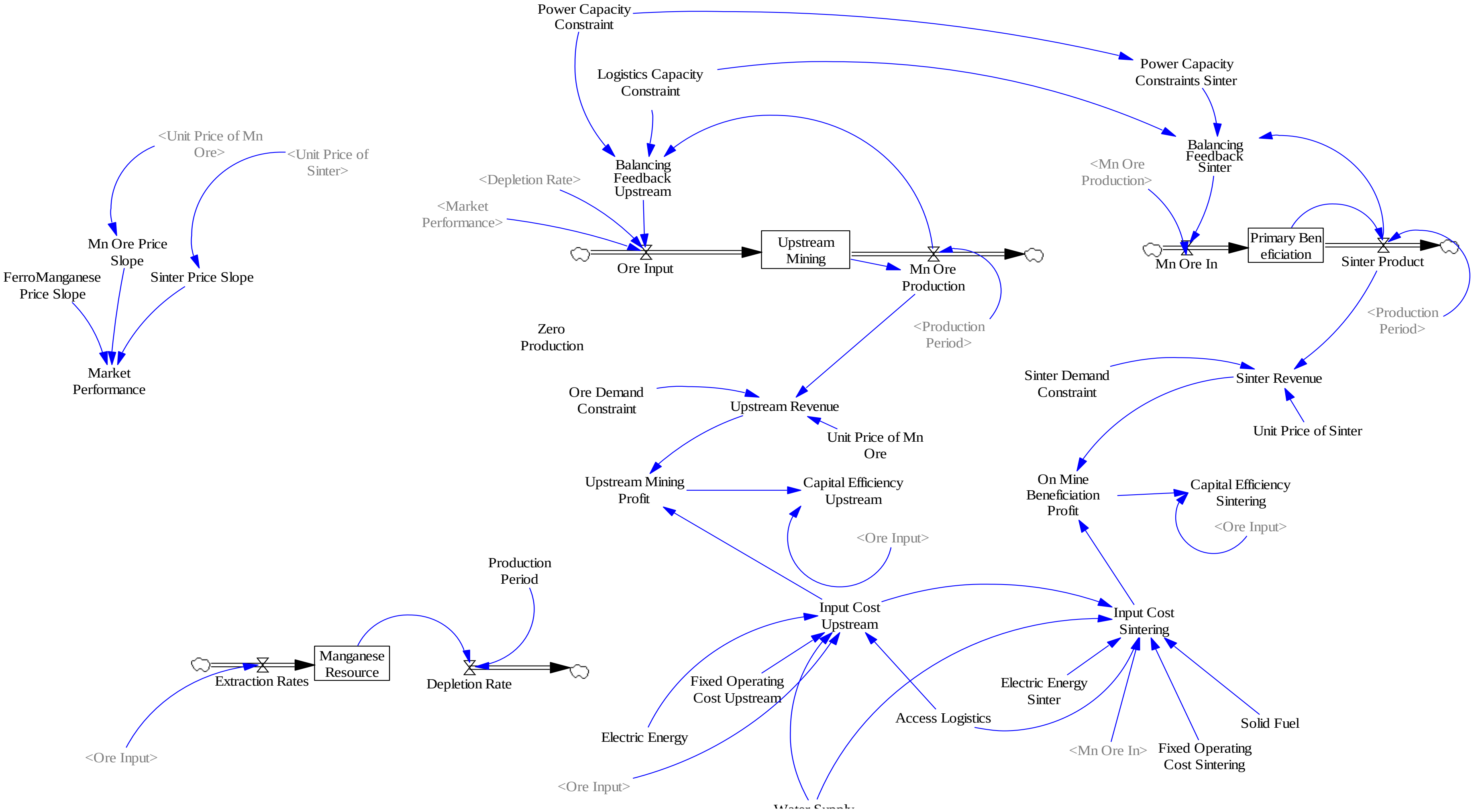


Figure 109: Manganese resources value chain model setup

10.2. APENDIX B: Mining value chain evaluation logic

The text below the start line is a copy of the system dynamics model code from Vensim including comments.

START:

```
Access Logistics=
            350
      Units: Rand/Ton
```

This variable measures the cost contribution from Rail Shipping which is required to get Manganese mineral out to the markets and from various sources in the region. Alternative transportation by road has a very different and significantly higher cost base compared to rail bulk however this has not been factored into the model.

```
Balancing Feedback Sinter=
      IF THEN ELSE (Sinter Product>Logistics Capacity Constraint, 0.98, IF
THEN ELSE
(Sinter Product>Power Capacity Constraints Sinter
       , 0.95, 1))
Units: Dmnl
```

The relationship between the “Primary Beneficiation" and the "Upstream Mining” scenario is a mutually inclusive one. Because the value of the throughput rate "Mn Ore Production" has already considered the feedback of power and logistics constraint (on the input side of the "Upstream Mining"). The "IF THEN ELSE" logic in this equation evaluates the throughput level per annum in this scenario and compares it with the limits in capacity of logistics (mainly Transnet freight rail) and Eskom power available to the Northern Cape region to balance production output. A 2% reduction in production targets is imposed for any limitations in logistics. A 5% reduction in production is imposed for power constraints. When both power and logistics are not a constraint, opportunity for restoration of production rates back to normal production are allowed to go through. A 5% reduction in production due to power constraints is brought about due to the fact that the mining industry does not have alternative power source to Eskom in sufficient capacity to compensate for the shortage in Eskom supply.

```
Balancing Feedback Smelter=
      IF THEN ELSE (Ferro Mn Product>Logistics Capacity Constraint, 0.98, IF
THEN ELSE
(Ferro Mn Product>Power Capacity Constraint Ferro Mn
       , 0.95, 1))
Units: Dmnl
```

The logic applied in this equation is similar to the logic described for "Balancing Feedback Sinter. The decision by the value of "Balancing Feedback Sinter" is to remove the double impact of logistics and Power constraints from the "Primary Beneficiation" scenario to the "Secondary Beneficiation (Smelter)" scenario. The relationship between the” Secondary Beneficiation" scenario and the other two scenarios is that all other two become a part this scenario in series arrangement. The "IF THEN ELSE" logic in this equation evaluates the throughput level per annum in this scenario and compares it with the limits in capacity of logistics (mainly Transnet Freight rail) and Eskom power available to the Northern Cape region to balance production output. A 2% reduction in production targets are imposed for any limitations in logistics. A 5% reduction in production is imposed for power constraints. When both power and logistics are not a constraint, opportunity for increase in production rates up to 5% of normal production are allowed to go through. A 5% reduction in production due to power constraints is brought about due to the fact that the mining industry does not have alternative power source to Eskom in sufficient capacity to compensate for the shortage in Eskom supply.

```
Balancing Feedback Upstream=
      IF THEN ELSE (Mn Ore Production>Logistics Capacity Constraint, 0.98,
IF THEN ELSE
(Mn Ore Production>Power Capacity Constraint
       , 0.95, 1))
Units: Dmnl
```

The balancing feedback logic checks the production levels per annum and compares this with the capacity available in both logistics (based on Transnet freight rail capacity) and power available to the region. A 2% reduction in production targets is introduced to indicate the impact of limitations in logistics. A 5% reduction in production is factored in for power constraints. When both power and logistics are not a constraint, normal production rates are allowed to go through. A 5% reduction due to power constraints is due to the fact that the industry does not have alternative power source to Eskom in sufficient capacity to compensate for the shortage in Eskom supply.

```
Capital Efficiency Sintering=
      Primary Beneficiation Profit/Ore Input
Units: Rand/Ton
```

Capital efficiency is calculated as a Rand value of earnings after operating cost per Ton of Manganese mine from the ground. This value indicates the potential for mining business to re-invest in growth infrastructure because unless business makes good returns on mining activities, the industry cannot be sustained.

```
Capital Efficiency Smelter=
      Secondary Beneficiation Profit/Ore Input
Units: Rand/Ton
```

Capital efficiency is calculated as a Rand value of earnings after operating cost per Ton of Manganese mine from the ground. This value indicates the potential for mining business to re-invest in growth infrastructure because unless business makes good returns on mining activities, the industry cannot be sustained.

```
Capital Efficiency Upstream=
      Upstream Mining Profit/Ore Input
Units: Rand/Ton
```

Capital efficiency is calculated as a Rand value of earnings after operating cost per Ton of Manganese mine from the ground. This value indicates the potential for mining business to re-invest in growth infrastructure because unless business makes good returns on mining activities, the industry cannot be sustained.

```
Depletion Rate=
      (Manganese Resource*0.0025+1.5e+007)/Period
Units: Ton/Year [1000,]
```

The depletion rate is determined by a combination of Market demand and a nominated rate of mining from the know reserve. This value takes into consideration the fact that only when there is a proven reserve can any mining occur.

Electric Energy=
    65
Units: Rand/Ton

The cost of power is based on Eskom rates (approved by the National Electricity Regulator of South Africa- Nersa) per kWh converted to cost per ton by multiplying the Eskom rate by the number of kWh required to treat a ton of production material. The power consumption is significantly different for Upstream Mining, Sintering and Smelter operations.

Electric Energy Sinter=
    22
Units: Rand/Ton

The cost of power is based on Eskom rates (approved by the National Electricity Regulator of South Africa- Nersa) per kWh converted to cost per ton of Manganese production by multiplying the Eskom rate by the number of Kwh required to treat a ton of production material. The power consumption is significantly different for upstream mining, Sintering and Smelter operations.

Electrical Energy Smelter=
    1800
Units: Rand/Ton

The cost of power is based on Eskom rates (approved by the National Electricity Regulator of South Africa- Nersa) per kWh converted to cost per ton by multiplying the Eskom rate by the number of kWh required to treat a ton of production material. The power consumption is significantly different for Upstream Mining, Sintering and Smelter operations.

Extraction Rates=
    Ore Input
Units: Ton/Year

This variable provides feedback from annual mining activities of the mine reserves in order to determine the volume and value of remaining reserve on the ground

Ferro Mn Product=
("Secondary Beneficiation (Smelter)")/Period
Units: Ton/Year

This represents a fully beneficiated form of Manganese with improved grade and value. In this form, the Manganese alloy can be used for further value add in the mild steel making process.

"Ferro-Mn Demand Constraint"=
7.5e+006
Units: Ton/Year

This represents a Market driven demand for Sinter Manganese product. For the purpose of the model and this study, this Figure is calculated as 50% of raw manganese. The reason for this assumption is that the ultimate driver of Manganese demand in whatever form is the steel manufacturing industry. The Smelter operator is limited to this Figure since producing more Sinter would only create inventory with significant storage costs

Ferro-Manganese Price Slope=
IF THEN ELSE (Unit Price of Ferro Manganese>12000, 1, IF THEN ELSE (Unit Price of Ferro Manganese
<9750,-1, 0))
Units: Dmnl

Fixed Operating Cost Sintering=
8.2e+007
Units: Rand/Year

This cost category covers the other costs which include labour and materials that are not directly linked to production volume. Also included in this Cost is the labour component which is calculated based on a StatSA determined constant rand per ton of production in Mining industry?

Fixed Operating Cost Smelter=
3.2e+008

Units: Rand/Year

This cost category covers the other costs which include labour and materials that are not directly linked to production volume. Also included in this Cost is the labour component which is calculated based on a StatSA determined constant rand per ton of production in Mining industry?

Fixed Operating Cost Upstream=
      8.2e+007
Units: Rand/Year [20, 5e+008, 2000]

This cost category covers the other costs which include labour and materials that are not directly linked to production volume. Also included in this Cost is the labour component which is calculated based on a StatSA determined constant rand per ton of production in Mining industry.

Input Cost Sintering=
      ABS ((Electric Energy Sinter+ Solid Fuel+ Water Supply-1.2*Access Logistics)*
Mn Ore In) +Input Cost Upstream+Fixed Operating Cost Sintering
Units: Rand/Year

Input cost summarizes direct and fixed cost associated with a Mining or beneficiation activity. This variable is used to determine profitability of a Manganese value chain activity as well as the capital efficiency of each activity.

Input Cost Smelter=
      ABS ((Electrical Energy Smelter+Solid Fuel+Reductants+Water Supply-0.2*Access Logistics
)*Sinter Feed) +Input Cost Sintering
      +Fixed Operating Cost Smelter
Units: Rand/Year

Input cost summarizes direct and fixed cost associated with a Mining or beneficiation activity. This variable is used to determine profitability of a Manganese value chain activity as well as the capital efficiency of each activity.

Input Cost Upstream=

ABS ((Access Logistics+Electric Energy+Water Supply)*Ore Input) +Fixed Operating Cost Upstream
Units: Rand/Year

Input cost summarizes direct and fixed cost associated with a Mining or beneficiation activity. This variable is used to determine profitability of a Manganese value chain activity as well as the capital efficiency of each activity.

Logistics Capacity Constraint=
1.1e+007
Units: Ton/Year

The capacity constraints due to Transnet line limitations are a real constraint. This limits bulk capacity on trains to 11 million tons of Manganese per annum that can be transported between the Northern Cape and the Port Elizabeth port of Coega. The model considers this as a limitation and reduces the production targets accordingly

Manganese Resource= INTEG (
(-Extraction Rates),
4e+009)
Units: Ton

This is the residual Manganese reserve on the ground. It should be noted that this reserves reduces with annul production. Exploration activities can result in addition to the reserve however this generally lags production and as such does not translate into direct replenishment of the extracted reserves.

Market Performance=
IF THEN ELSE (Ferro-Manganese Price Slope+Sinter Price Slope>=1: OR: Mn Ore Price Slope
+Ferro-Manganese Price Slope>1, 1.1, IF THEN ELSE (Ferro-Manganese Price Slope
: OR: Mn Ore Price Slope: OR: Sinter Price Slope=-1, 0.95, 1))
Units: Dmnl

Mn Ore In=
Mn Ore Production*Balancing Feedback Sinter

Units: Ton/Year [0, 1.05e+009, 10000]

"Mn Ore In" determines what the Sinter Plant can produce per annum based on dynamic feedback from previous performance and external conditions. The feedback on capacity of rail logistics and power supply is used to determine the annual production of Sintered Manganese. Small reduction of 10% of annual production is made every time there is a logistics bottleneck. This represents the limit in logistics that cannot be immediately compensated for through road transport. At the same time, an increase in production of 20% is made for conditions favorable in both logistics and power requirements.

Mn Ore Price Slope=
IF THEN ELSE (Unit Price of Mn Ore>1400, 1, IF THEN ELSE (Unit Price of Mn Ore
<1080,-1, 0))
Units: Dmnl

Mn Ore Production=
Upstream Mining/Period
Units: Ton/Year

This is the number of tons that is produced as non-beneficiated Lumpy Ore (raw Manganese) per annum

Ore Demand Constraint=
1.5e+007
Units: Ton/Year

This represents a Market driven demand for raw manganese. The mine operator is limited to this Figure since producing more would only create inventory with significant storage costs

Ore Input=
IF THEN ELSE (Depletion Rate>=Zero, Balancing Feedback Upstream*Depletion Rate
*Market Performance, 0)
Units: Ton/Year [0, 5e+008, 10000]

Ore Input determines what the mines can produce per annum based on dynamic feedback from previous performance and external conditions. The feedback on capacity of rail logistics and power supply is used to determine the annual production of Manganese. Small reduction of 10% of annual production is made every time there is a logistics bottleneck. This represents the limit in logistics that cannot be immediately compensated for through road transport. At the same time, an increase in production of 20% is made for conditions favorable in both logistics and power requirements.

```
Period=
      1
Units: Year
```

```
Power Capacity Constraint=
      4e+007
Units: Ton/Year
```

Power is the single biggest constraint to mining and mineral beneficiation in the Northern Cape. Alternatives to Eskom supply include cogeneration and diesel generators both of which have serious limitations and therefore not sufficient for production.

```
Power Capacity Constraints Sinter=
      Power Capacity Constraint/2
Units: Ton/Year
```

The consumption of power per ton of Ferro-Manganese in a Smelter operation is about twice compared to what is required to produce to produce and ship non-beneficiated Manganese Ore. In calculating the Power capacity constraints for a Smelter operational quotient of 2 per unit is used.

```
Power Capacity Constraint Ferro Mn=
      Power Capacity Constraint/6.5
Units: Ton/Year
```

The consumption of power per ton of Ferro-Manganese in a Smelter operation is about seven times that required to produce to produce and ship non-beneficiated Manganese Ore. In calculating the Power capacity constraints for a Smelter operational quotient of 7 per unit is used.

```
Preferred Scenario=
```

```
      IF THEN ELSE (Capital Efficiency Upstream>Capital Efficiency Sintering,
1,
 IF THEN ELSE (Capital Efficiency Upstream>Capital Efficiency Smelter, 1, 0
 ) )
Units: Dmnl
```

```
Primary Beneficiation= INTEG (
      (Mn Ore In*0.8-Sinter Product),
            0)
Units: Ton [0, 4e+009, 10000]
```

The primary beneficiation stock is an accumulation of Sintered Manganese tons sourced directly from the upstream mining activity. This stage of the value chain yields at 80%, which means that 20% of what has been produced in the upstream mining activity, is reduced to waste. This scenario has a mutually inclusive relationship to the "Upstream Mining Activity" stock

```
Primary Beneficiation Profit=
      Sinter Revenue-Input Cost Sintering
Units: Rand/Year
```

This is a basic gross profit calculation based on the difference between revenue generated and operating cost at any given period.

```
Reductants=
      500
Units: Rand/Ton
```

This is the cost of Anthracite, silica and other reductants

```
Secondary Beneficiation Profit=
      Smelter Revenue-Input Cost Smelter
Units: Rand/Year
```

This is a basic gross profit calculation based on the difference between revenue generated and operating cost at any given period.

```
"Secondary Beneficiation (Smelter)"= INTEG (
      (Sinter Feed*0.5-Ferro Mn Product),
            0)
```

```
Units: Ton [0, 8e+008, 10000]
```

The Smelter process represents the true beneficiation process of Manganese. A 50% reduction of the feed from the Sinter process is realized. This scenario depends on the "Upstream Mining Activity" and the "Primary Beneficiation" scenario's output. The product of this process is High Carbon Ferro-Manganese which is used as an alloy in steel making process whilst the other 50% is reduced to slag (waste).

```
Sinter Demand Constraint=
      1.26e+007
Units: Ton/Year
```

This represents a Market driven demand for Sinter Manganese product. For the purpose of the model and this study, this Figure is calculated as 80% of raw manganese demand. The mine operator is limited to this Figure since producing more Sinter would only create inventory with significant storage costs

```
Sinter Feed=
      Sinter Product*Balancing Feedback Smelter
Units: Ton/Year [0, 4e+009, 10000]
```

"Sinter Feed" determines what the smelter can produce per annum based on dynamic feedback from previous performance and external conditions. The feedback on capacity of rail logistics and power supply is used to determine the annual production of Ferro-Manganese. Small reduction of 10% of annual production is made every time there is a logistics bottleneck. This represents the limit in logistics that cannot be immediately compensated for through road transport. At the same time, an increase in production of 20% is made for conditions favorable in both logistics and power requirements.

```
Sinter Price Slope=
      IF THEN ELSE (Unit Price of Sinter>3000, 1, IF THEN ELSE (Unit Price
of Sinter
<2234, -1, 0))
Units: Dmnl
```

```
Sinter Product=
      (Primary Beneficiation)/Period
Units: Ton/Year [0, 3.05e+010]
```

This represents a Sinter product produced out of the raw material from the upstream mining activity. This product represents an improved grade and value of Manganese that is favorable to the Smelter operators due to its improved quality.

```
Sinter Revenue=
      IF THEN ELSE (Sinter Product>Sinter Demand Constraint, Sinter
Product*Unit Price of Sinter
*0.95, Sinter Product*Unit Price of Sinter
      )
Units: Rand/Year
```

The revenue is determine by alignment of production to market demand to represent reality. Where production exceeds market demand, only 80% of production revenue is factored into the equation.

```
Smelter Revenue=
      IF THEN ELSE (Ferro Mn Product>"Ferro-Mn Demand Constraint", Ferro Mn
Product
*Unit Price of Ferro Manganese*0.95, Ferro Mn Product
      *Unit Price of Ferro Manganese)
Units: Rand/Year
```

The revenue is determined by alignment of production to market demand to represent reality. Where production exceeds market demand, only 80% of production revenue is factored into the equation.

```
Solid Fuel=
      125
Units: Rand/Ton
```

This is a cost of coking coal and anthracite required for the Sintering and Smelter processes. The cost is based on spot price per ton of coke multiplied by the consumption of coke per ton of Manganese produced.

```
Unit Price of Ferro Manganese=
      12850
Units: Rand/Ton
```

Although the pricing of Manganese is determined by the market on a spot price basis, an average price is used in the model based on data collected from industry speculating agencies

Unit Price of Mn Ore=
1300
Units: Rand/Ton

Although the pricing of Manganese is determined by the market on a spot price basis, an average price is used in the model based on data collected from industry speculating agencies

Unit Price of Sinter=
2530
Units: Rand/Ton

Although the pricing of Manganese is determined by the market on a spot price basis, an average price is used in the model based on data collected from industry speculating agencies

Upstream Mining= INTEG (
(Ore Input*0.9-Mn Ore Production),
1e+006)
Units: Ton [0,4e+010,10000]

The upstream mining activity produces raw Manganese with yields as high as 90%. This means that only 10% of Ore from underground is discarded as waste.

Upstream Mining Profit=
Upstream Revenue-Input Cost Upstream
Units: Rand/Year

This is a basic gross profit calculation based on the difference between revenue generated and operating cost at any given period.

Upstream Revenue=
IF THEN ELSE (Mn Ore Production>Ore Demand Constraint, Mn Ore Production*Unit Price of Mn Ore
*0.95, Mn Ore Production*Unit Price of Mn Ore
)

```
Units: Rand/Year
```

The revenue is determine by alignment of production to market demand to represent reality. Where production exceeds market demand, only 80% of production revenue is factored into the equation.

```
Water Supply=
      1.2
Units: Rand/Ton
```

The consumption of water is measured as number of cubic meters of water consumed per ton of Manganese production and billed as such by the water supply boards. This cost, though not very significant is important to track in the model

```
Zero=
      0
Units: Ton/Year
```

Zero is a constant use for comparison in the logic. It is permanently set to zero and not manipulated by the program

END

10.3. APENDIX C: Socio -economic development model stock flow diagram

The stock flow diagram in the next page describes the logic for the socio-economic development system dynamics logic.

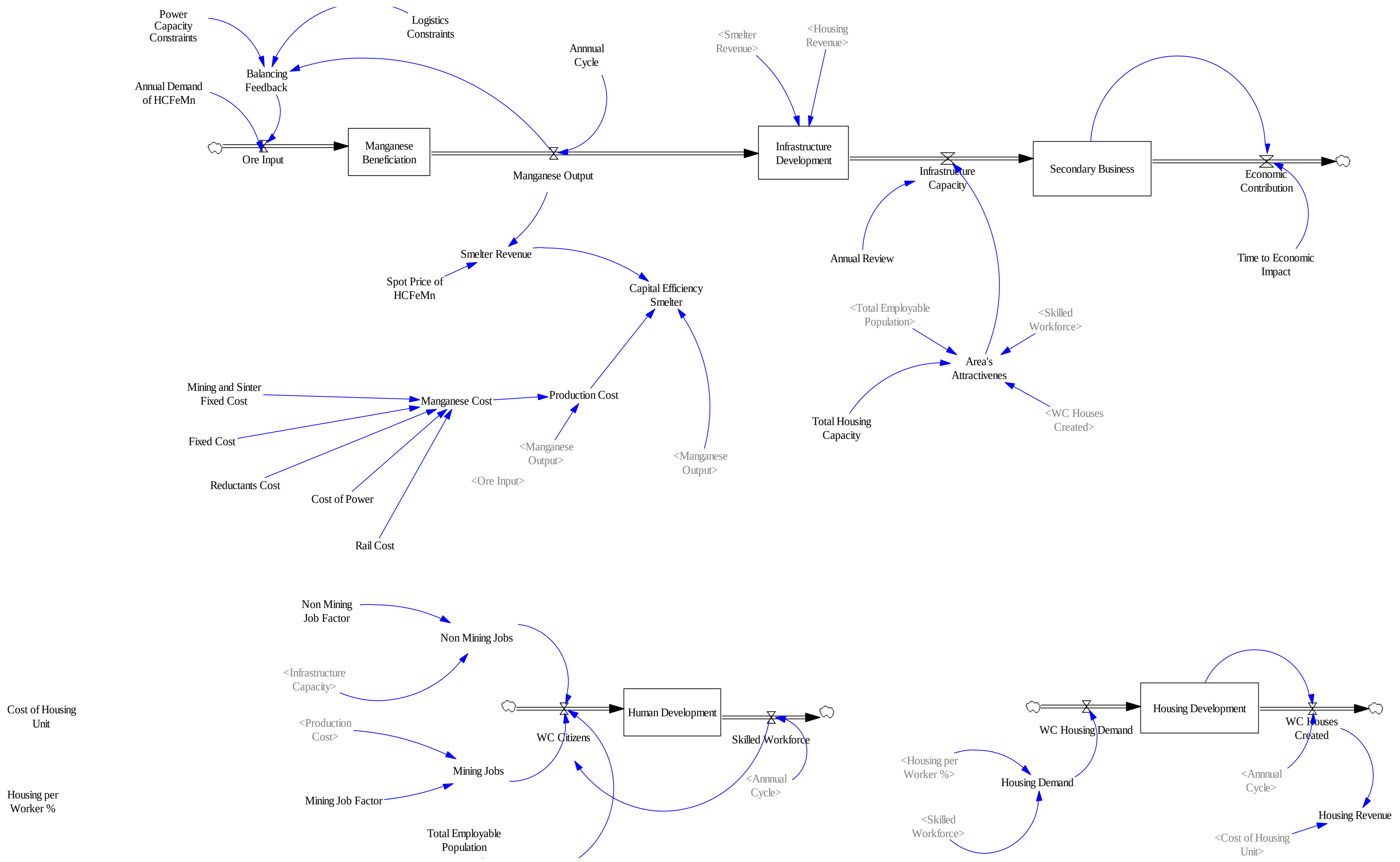


Figure 110: Socio-economic development model stock flow diagram

10.4. APENDIX D: Socio-economic development model logic

The text below the start line is a copy of the system dynamics model code from Vensim including comments.

START

```
Annual Cycle=
            1
      Units: Year

Annual Demand of HCFeMn=
      RANDOM TRIANGULAR (7.5e+006, 1.5e+007, 7e+006, 1.4e+006, 1.05e+007, 5)
Units: Ton/Year

The demand for Ferro-Manganese products is driven by the steel manufacturing
industry. Based on historical data, the envelop is determined for a random
fluctuation of demand for this model.

Annual Review=
      1
Units: Year

Area's Attractiveness=
      IF THEN ELSE (Skilled Workforce-Total Employable Population>0: OR:
Total Housing Capacity
-WC Houses Created>0, RANDOM NORMAL
      (0.6, 1, 0.8, 0.5, 0), IF THEN ELSE (Skilled Workforce-Total Employable
Population
<0: OR: Total Housing Capacity-WC Houses Created
      <0, RANDOM NORMAL (0.2, 0.4, 0.3, 0.5, 0), 0))
Units: Dmnl [0, 1]

Balancing Feedback=
      IF THEN ELSE (Manganese Output>=Power Capacity Constraints, 0.95, IF
THEN ELSE
(Manganese Output>=Logistics Constraints, 0.98, 1))
Units: Dmnl [0,]
```

The balancing feedback logic checks the production levels per annum and compares this with the capacity available in both logistics (based on Transnet freight rail capacity) and power available to the region. A 2% reduction in production targets is imposed for any limitations in logistics. A 5% reduction in production is imposed for power constraints. When both power and logistics are not a constraint, opportunity for increase in production rates are allowed to go through. A 5% reduction in production due to power constraints is brought about due to the fact that the mining industry does not have alternative power source to Eskom in sufficient capacity to compensate for the shortage in Eskom supply.

Capital Efficiency Smelter=
(Smelter Revenue-Production Cost)/Manganese Output
Units: Rand/Ton

Capital efficiency is calculated as a Rand value of earnings after operating cost per Ton of Manganese mine from the ground. This value indicates the potential for mining business to re-invest in growth infrastructure because unless business makes good returns on mining activities, the industry cannot be sustained.

Cost of Housing Unit=
RANDOM NORMAL (800000, 3.5e+006, 1.1e+006, 200000, 0)
Units: Rand/House

The true cost of housing development is determined by the size and area of development. In this model a range is used based on historical cost Figures from the Northern Cape towns of Kathu, Kuruman and Hotazel.

Cost of Power=
1800
Units: Rand/Ton

The cost of power is based on Eskom rates (approved by the National Electricity Regulator of South Africa- Nersa) per kWh converted to cost per ton by multiplying the Eskom rate by the number of Kwh required to treat a ton of production material. The power consumption is significantly different for upstream mining, sintering and smelting operations.

```
Economic Contribution=
      Secondary Business/Time to Economic Impact
Units: Rand/Year
```

The value of GDP impact indicates the ability of the regional economy to carry its burden of providing necessary jobs to its population.

```
Fixed Cost=
      134
Units: Rand/Ton
```

Input cost summarizes direct and fixed cost associated with a mining and sintering activities. This variable is used to determine profitability of a Manganese value chain activity as well as the capital efficiency of each activity.

```
Housing Demand=
      "Housing per Worker %"*Skilled Workforce
Units: House/Year

Housing Development= INTEG (
      WC Housing Demand-WC Houses Created,
            0)
Units: House

"Housing per Worker %"=
      0.75
Units: House/Persons
```

Due to mobility of some levels of resources, the model assumed that only 60% of the employed workforce will commit to purchase of housing units in the Area whilst the rest will rent in temporary accommodation some of which could be temporary structures. This is applicable to construction and other specialized workers who may service more than one operation at a time.

```
Housing Revenue=
      Cost of Housing Unit*WC Houses Created
Units: Rand/Year
```

This calculation is based on an average price of housing development in the Northern Cape area multiplied by the number of houses created for a period in question.

```
Human Development= INTEG (
      IF THEN ELSE (Skilled Workforce<>WC Citizens, WC Citizens-Skilled
Workforce
, 0),
            0)
Units: Persons
```

The cumulative social development of an area is determined by this stock variable

```
Infrastructure Capacity=
      Area's Attractiveness*Infrastructure Development/Annual Review
Units: Rand/Year
```

Infrastructure development is a result of investment in supporting facilities for both business and social development in the area that may in turn attract more business development. The Capacity of Infrastructure is a significant driver of development for an area however this also requires the presence of business development to support its growth. It is a chicken and egg relationship as it is unclear which one should be implement first.

```
Infrastructure Development= INTEG (
      IF THEN ELSE (Manganese Output>1.2e+007, Smelter Revenue*0.2-
Infrastructure Capacity
 , Housing Revenue-Infrastructure Capacity),
            0)
Units: Rand [0, 1.001e+013, 10000]
```

The infrastructure development stock measures the development of Infrastructure that is possible based on revenues generated in Mining and social infrastructure development over a given period.

```
Logistics Constraints=
      1.49e+007
Units: Ton/Year
```

The capacity constraints due to Transnet line's limitations are a real constraint. This limits bulk capacity on trains to 11 million tons of Manganese per annum that can be transported between the Northern Cape and the Port Elizabeth port of Coega. The model considers this as a limitation and reduces the production targets accordingly

```
Manganese Beneficiation= INTEG (
      (Ore Input*0.4 -Manganese Output),
            1e+006)
Units: Ton
```

The Smelter process represents the true beneficiation process of Manganese. A 50% reduction of the feed from the Sinter (or 60% of raw Manganese Ore) process is realized. The product of this process is High Carbon Ferro-Manganese which is used as an alloy in steel making process whilst the other 50% is reduced to slag (waste).

```
Manganese Cost=
      Cost of Power+Fixed Cost+Mining and Sinter Fixed Cost+Rail Cost+Reductants Cost
Units: Rand/Ton
```

Cost is the sum of 1. Direct cost Mining (210) + Sintering (200) + Smelter (4200) + Logistics (320 rail+80 port handling) and 2. Fixed Cost Mining and Sinter (34) and Smelter (100)

```
Manganese Output=
      Manganese Beneficiation/Annual Cycle
Units: Ton/Year
```

This represents a fully beneficiated form of Manganese with improved grade and value. In this form, the Manganese alloy can be used for further value add in the mild steel making process.

```
Mining and Sinter Fixed Cost=
      410
Units: Rand/Ton
```

This cost category covers the other costs which include labour and materials that are not directly linked to production volume. Also included in this Cost is the labour component which is calculated based on a StatSA determined constant rand per ton of produced in Mining industry.

```
Mining Job Factor=
      7e-007
Units: Persons/Rand
```

This is a factor that has been determined by statistics SA as representative of the capital intensity of mining industry in comparison to agriculture and Manufacturing industries in South Africa. This number is used in the model as a measure of employment potential due to cost of production in the South African mining economy.

```
Mining Jobs=
      (Production Cost*Mining Job Factor)*0.1
Units: Persons/Year
```

This variable indicates the number of direct jobs that can be created for every rand spend in the production of mining products. This indirectly also give an indication of new skills that can be created with more expenditure in production over the 10 year simulation period. Because people are not employed every year despite the fact that they come and go, the result of logic in the brackets is multiplied by 0.1 to bring the number to an annual accumulation over a 10 year period. The same logic is applied for the non-mining jobs calculation in the section that follows

```
Non Mining Job Factor=
      4.6e-006
Units: Persons/Rand
```

This is a factor that has been determined by statistics SA as representative of the capital intensity of Manufacturing industry and similar industries in the secondary economy in South Africa. This number is used in the model as a measure of potential employment potential due to cost of production in the secondary economy outside of agriculture and direct mining jobs

```
Non Mining Jobs=
      (Infrastructure Capacity*Non Mining Job Factor)*0.1
Units: Persons/Year
```

This variable indicates the number of direct jobs that can be created for every Rand spend in the manufacturing of goods outside of mining activities Over a 10 year period. These may however be products that are consumed by the mining industry. This also gives an indication of new skills that can be created with more expenditure in the secondary that may be influenced by the presence of mining activity in the area. This variable is also an indicator of maturity in the economy that is slowly growing independent of direct mining and agriculture.

```
Ore Input=
       (Balancing Feedback/0.4)*Annual Demand of HCFeMn
Units: Ton/Year [0, 1e+008, 10000]
```

Ore Input determines what the mines can produce per annum based on dynamic feedback from previous performance and external conditions. The feedback on capacity of rail logistics and power supply is used to determine the annual production of Manganese. Small reduction of 10% of annual production is made every time there is a logistics bottleneck. This represents the limit in logistics that cannot be immediately compensated for through road transport. At the same time, an increase in production of 20% is made for conditions favorable in both logistics and power requirements.

```
Power Capacity Constraints=
       8.4e+006
Units: Ton/Year
```

Power is the single biggest constraint to mining and mineral beneficiation in the Northern Cape. Alternatives to Eskom supply include cogeneration and diesel generators both of which have serious limitations and therefore not sufficient for production.

```
Production Cost=
       (Manganese Output/0.4)*Manganese Cost
Units: Rand/Year
```

Input cost summarizes direct and fixed cost associated with a Mining or beneficiation activity. This variable is used to determine profitability of a Manganese value chain activity as well as the capital efficiency of each activity.

```
Rail Cost=
      350
Units: Rand/Ton
```

This variable measures the cost contribution from Rail Shipping which is required to get Manganese mineral out to the markets and from various sources in the region. Alternative transportation by road has a very different and significantly higher cost base compared to rail bulk however this has not been factored into the model.

```
Reductants Cost=
      RANDOM NORMAL (1600, 2200, 1800, 350, 0)
Units: Rand/Ton
```

This is a cost of coking coal and anthracite required for the sintering and smelting processes. The cost is based on spot price per ton of coke multiplied by the consumption of coke per ton of Manganese produced.

```
Secondary Business= INTEG (
      (Infrastructure Capacity-Economic Contribution),
            0)
Units: Rand
```

The growth in demand for business and social services in an area is an indication of growth in the economy that is independent of the primary industry and therefore leading to sustainability of an area.

```
Skilled Workforce=
      Human Development/Annual Cycle
Units: Persons/Year
```

This variable gives an indication of new skills developed in the area per annum. This number also gives an indication of an increase or decrease in the affordability or buying power of the population in the region.

```
Smelter Revenue=
      Manganese Output*Spot Price of HCFeMn
Units: Rand/Year
```

The revenue is determined by alignment of production to market demand to represent reality. Where production exceeds market demand, only 80% of production revenue is factored into the equation.

Spot Price of HCFeMn=
      13000
Units: Rand/Ton

Although the pricing of Manganese is determined by the market on a spot price basis, an average price is used in the model based on data collected from industry speculating agencies

TIME STEP = 0.1
Units: Year [0, 0]

The time step for the simulation.

Time to Economic Impact=
      2
Units: Year

Total Employable Population=
      RANDOM TRIANGULAR (15000, 40000, 25000, 30000, 20000, 7)
Units: Persons/Year [2000, 1e+006]

The total employable population (ages between 15-64) of the area is 153 120 out of 224 000

Total Housing Capacity=
      6500
Units: House/Year

WC Citizens=
      IF THEN ELSE (Total Employable Population>Skilled Workforce, Mining Jobs+Non Mining Jobs
 , 0)
Units: Persons/Year [0, 0]

This number gives an indication of the number of the employable population in the region that is absorbed into the mainstream economy thereby indicating the skills development progress in the region

```
WC Houses Created=
      Housing Development/Annual Cycle
Units: House/Year [0, 100000]
```

This variable indicates as an average, the number of houses created over a period which impact on infrastructure development due to services demanded by the new household. These infrastructure requirements may range from access roads, shopping facilities, health facilities and entertainment. The model only measures houses created due to a number of employed population although in reality there will be informal settlements that develop on the periphery of the formal development however these are not considered in driving economic growth of the area since their true buying power is hard to measure.

```
WC Housing Demand=
      Housing Demand*0.9
Units: House/Year [?, 1e+006]
```

Working Class Housing demand determines the real demand of mid-range to expensive housing that is based on a number of employed people in the area. This, unlike RDP housing, gives an indication of buying power and affordability of the populous that can also maintain the services required to support housing development and maintain the relative attractiveness of the area.

10.5. APPENDIX E: Simulation results graphs

10.5.1. Mine value chain simulations results

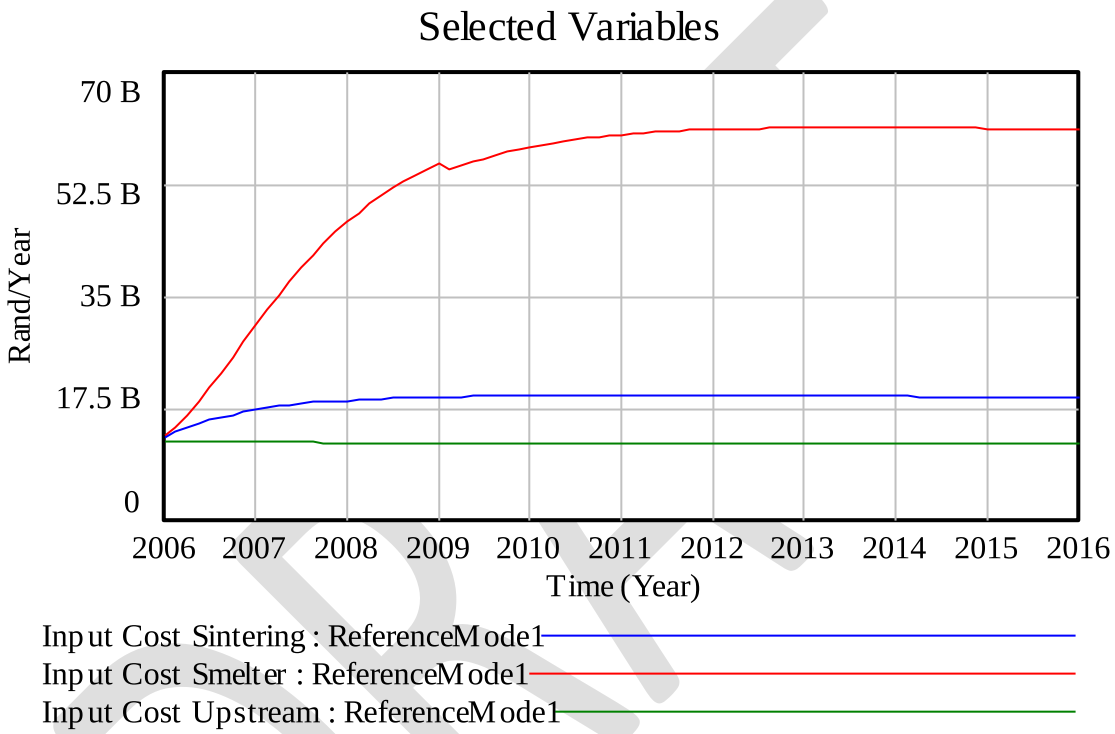


Figure 111: Input cost comparison for the three value chain scenarios

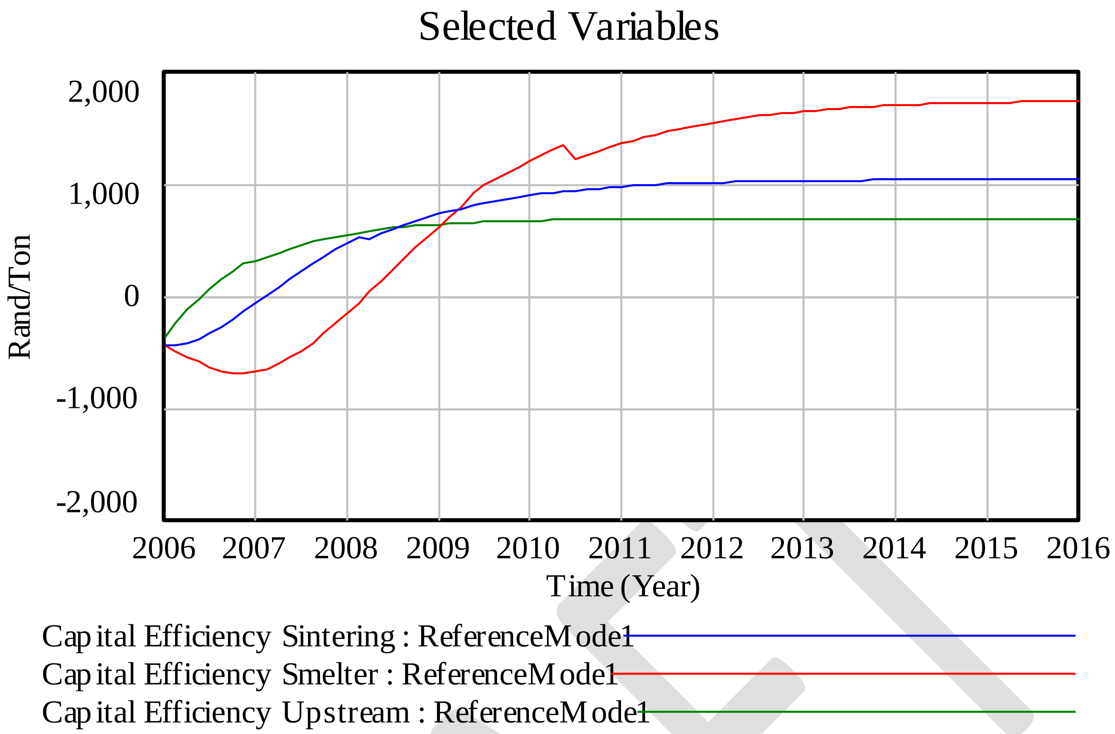


Figure 112: Capital efficiency comparison against common mining input

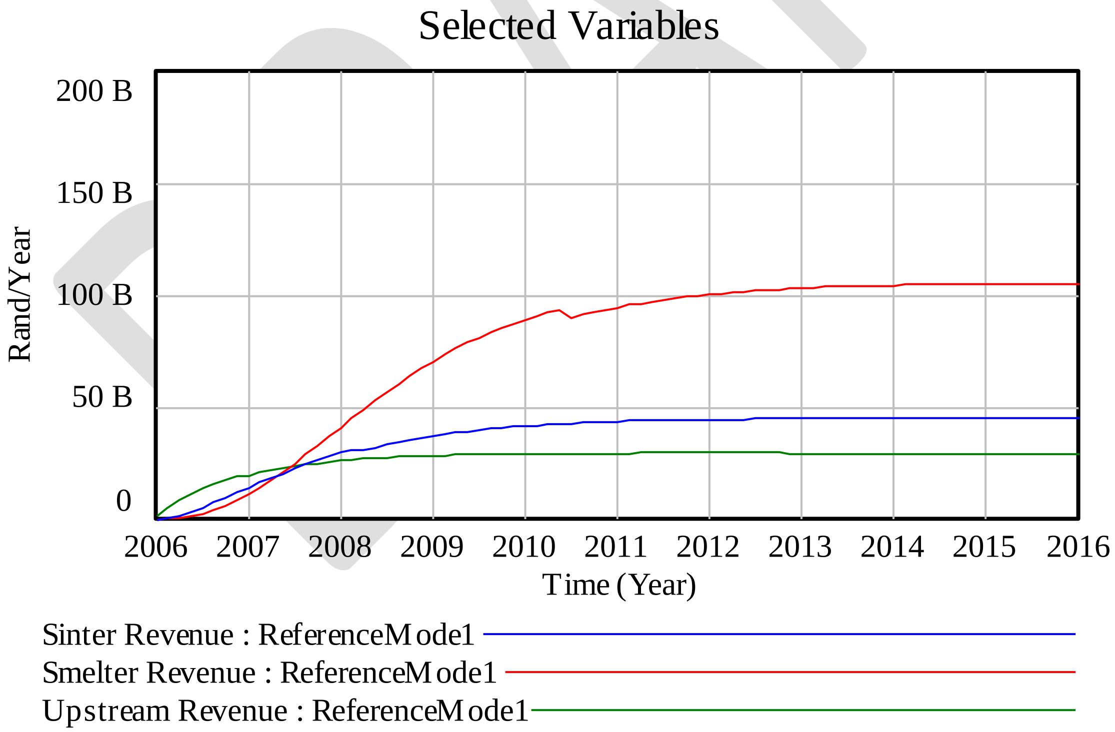
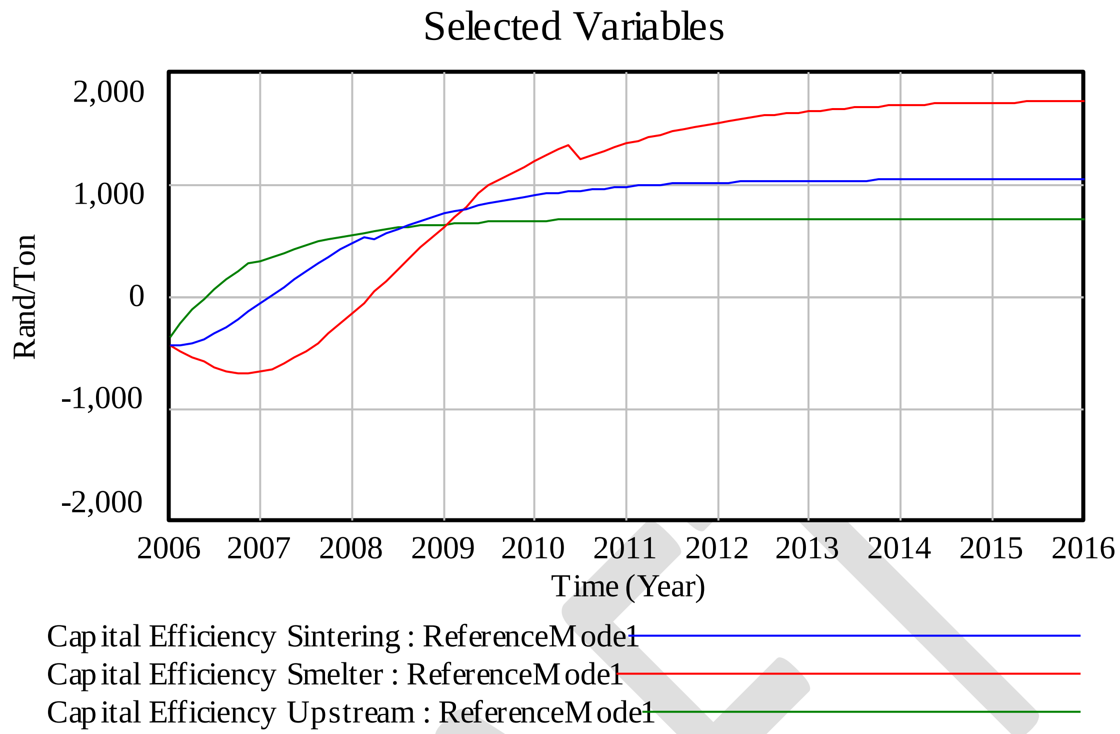


Figure 113: Revenue comparison for the three value chain scenarios on same Ore input



Variable	Count	Min	Max	Mean	Median	StDev	(Norm)
Selected Variables for Time (Year) from 2006 to 2016 Runs:	ReferenceMode1						
Capital Efficiency Sintering	81	-4.37E+02	1.04E+03	6.35E+02	7.46E+02	3.65E+02	5.74E-01
Capital Efficiency Smelter	81	-7.48E+02	1.65E+03	7.95E+02	1.21E+03	7.83E+02	9.84E-01
Capital Efficiency Upstream	81	-3.59E+02	9.66E+02	6.49E+02	6.92E+02	2.27E+02	3.50E-01

Figure 114: Capital efficiency comparison on reduced price (Rand per ton)

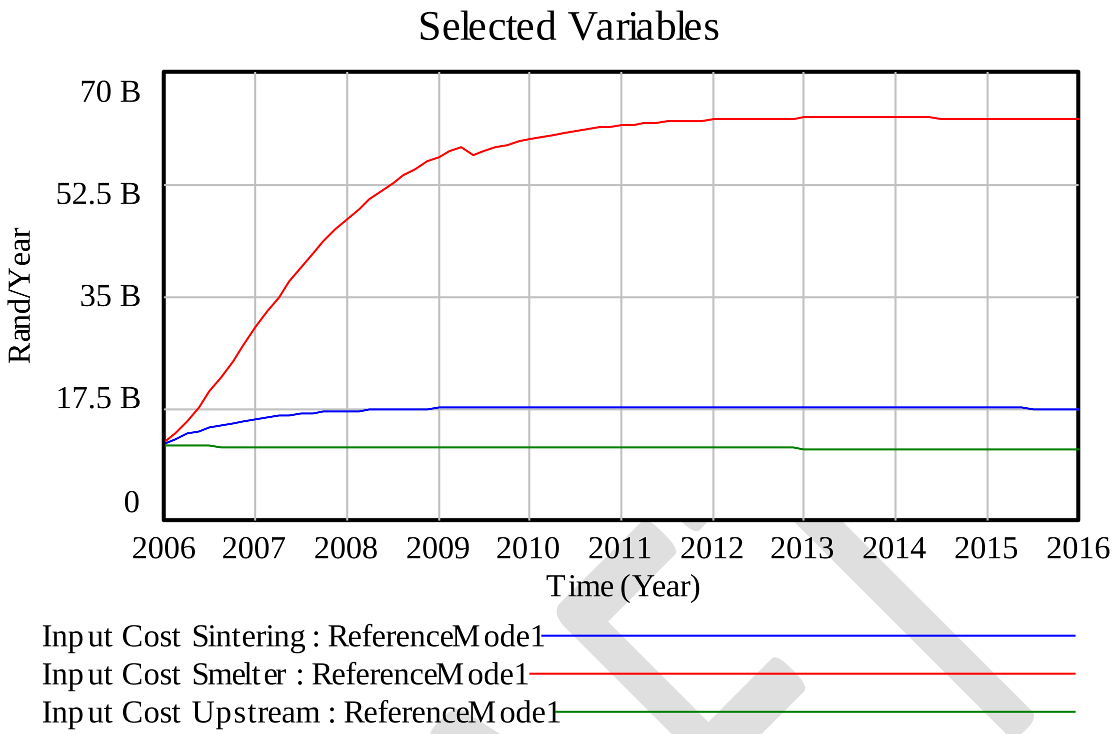


Figure 115: Effect of power cost increase on input cost compared

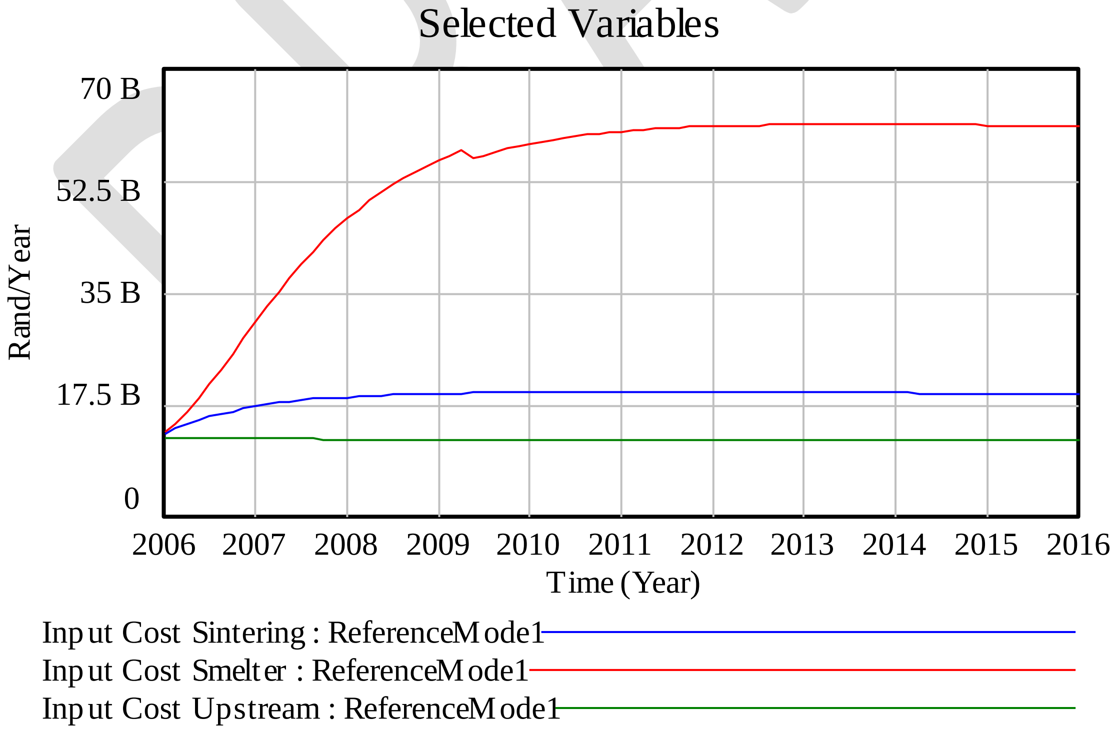


Figure 116: Effect of logistics cost decrease on input cost compared

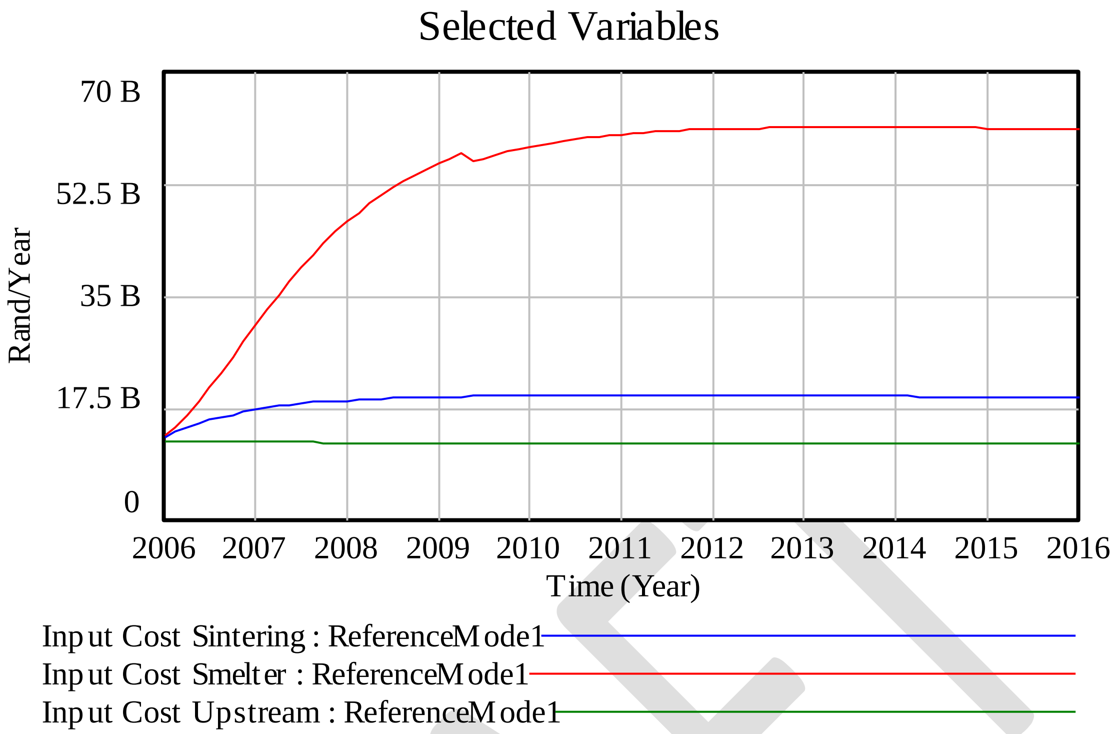


Figure 117: Effect of logistics cost increase on input cost compared

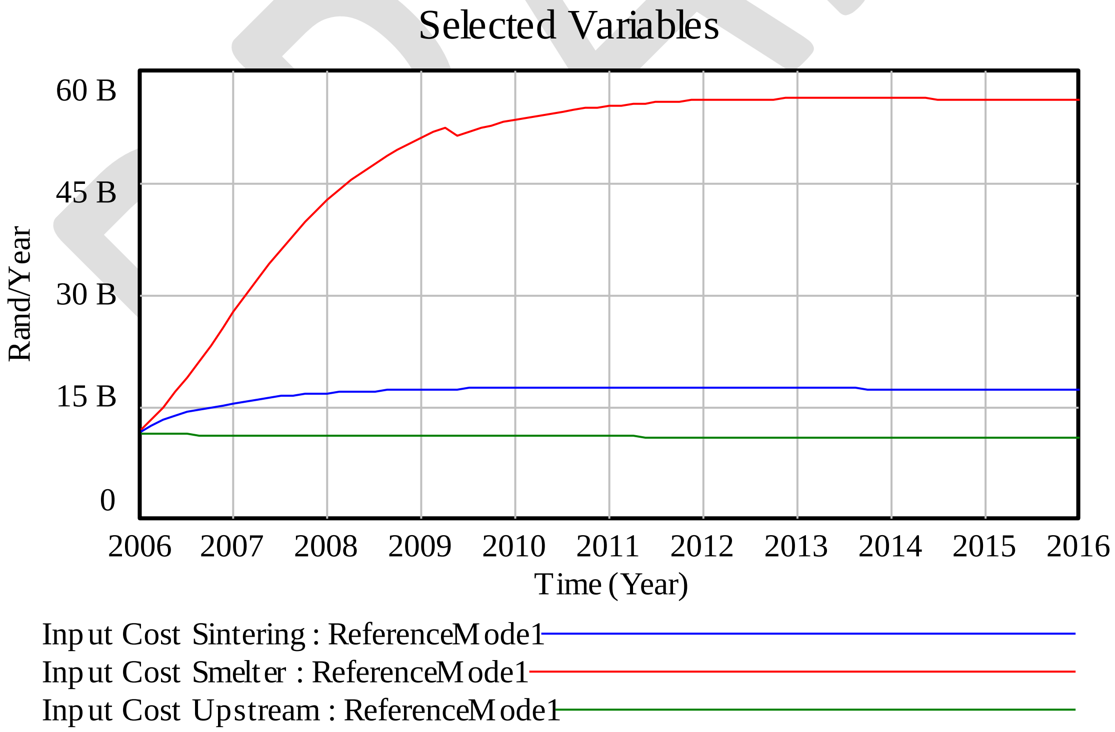


Figure 118: Effect of power cost increase on profitability compared

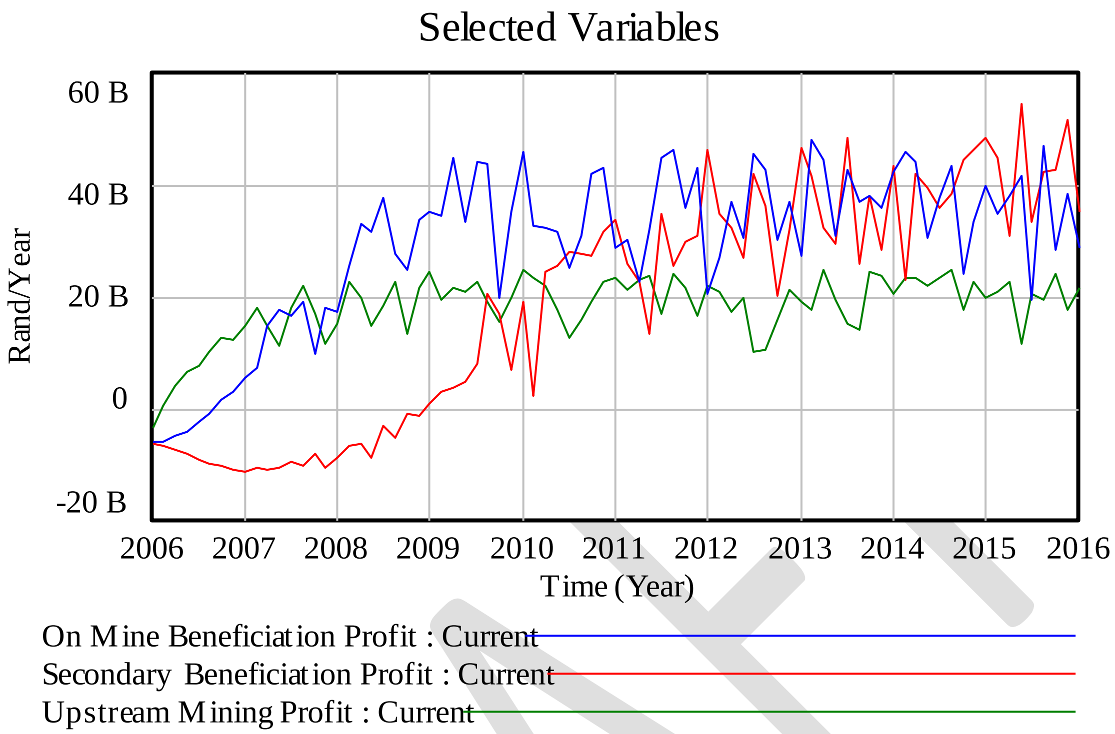


Figure 119: Effect of logistics cost decrease on profitability compared

Monte- Carlo Simulation results

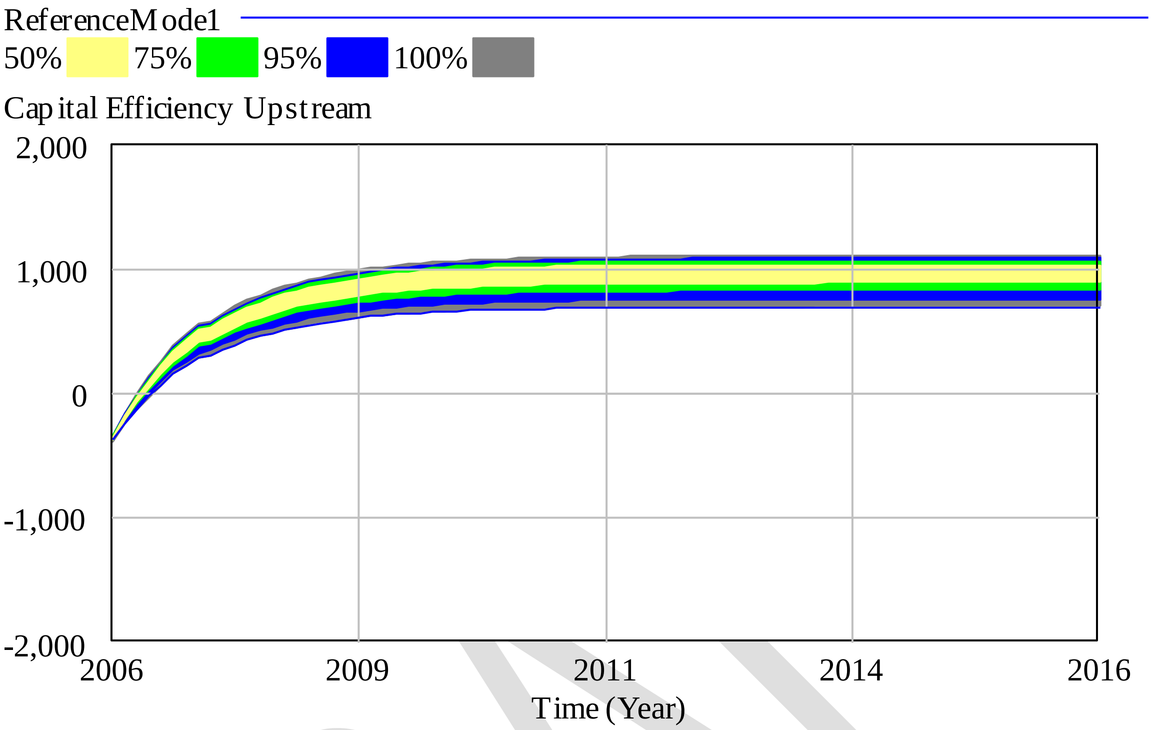


Figure 120: Impact of input cost and market price on upstream mining capital efficiency

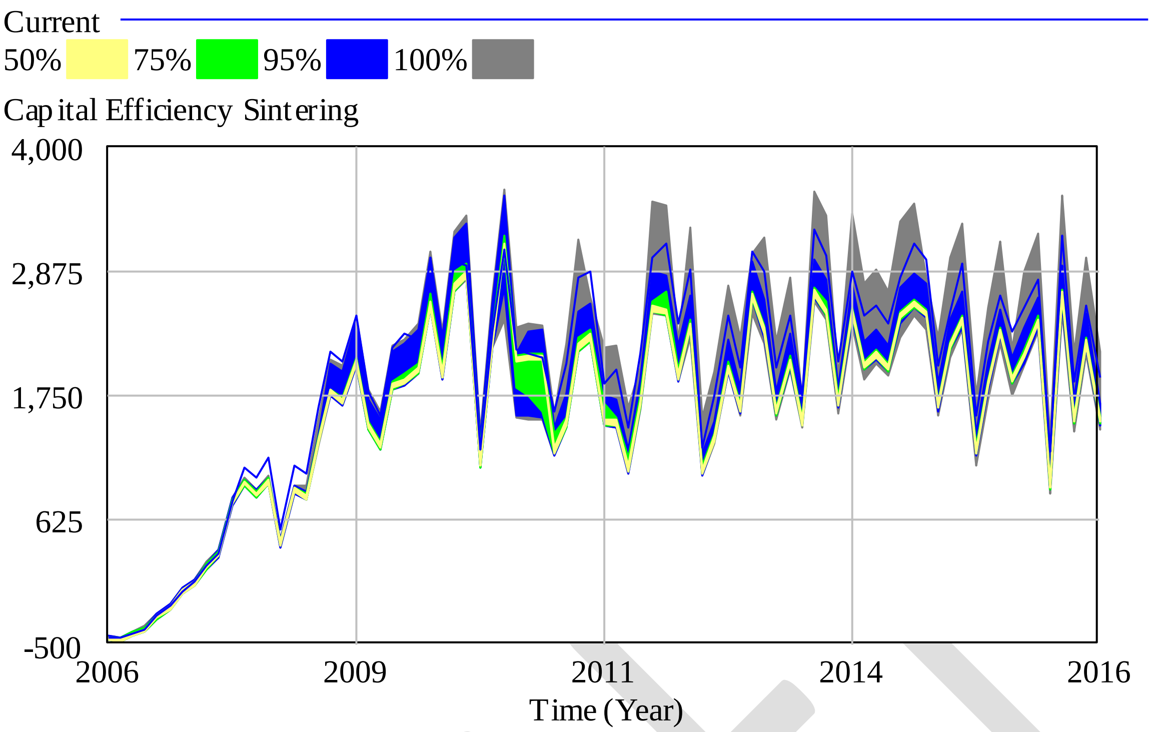


Figure 121: Impact of input cost and market price on primary beneficiation capital efficiency

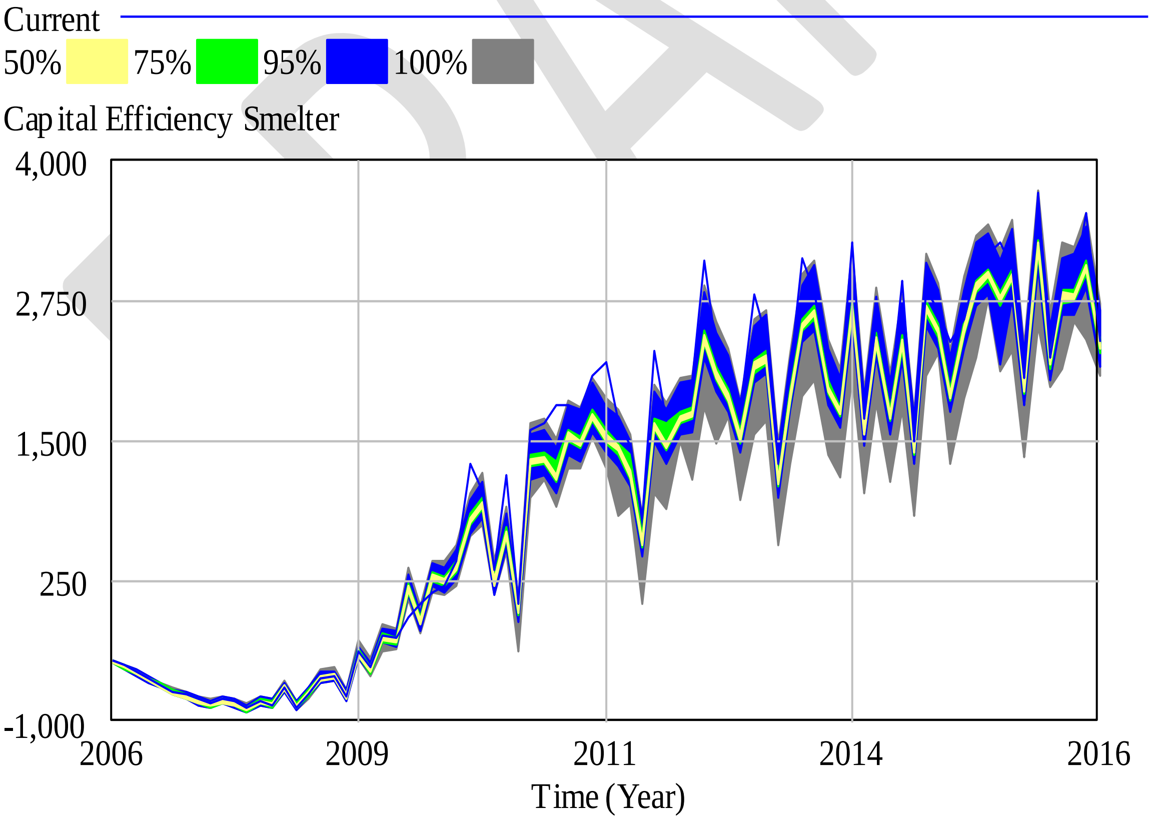


Figure 122: Impact of input cost and market price on secondary beneficiation capital efficiency

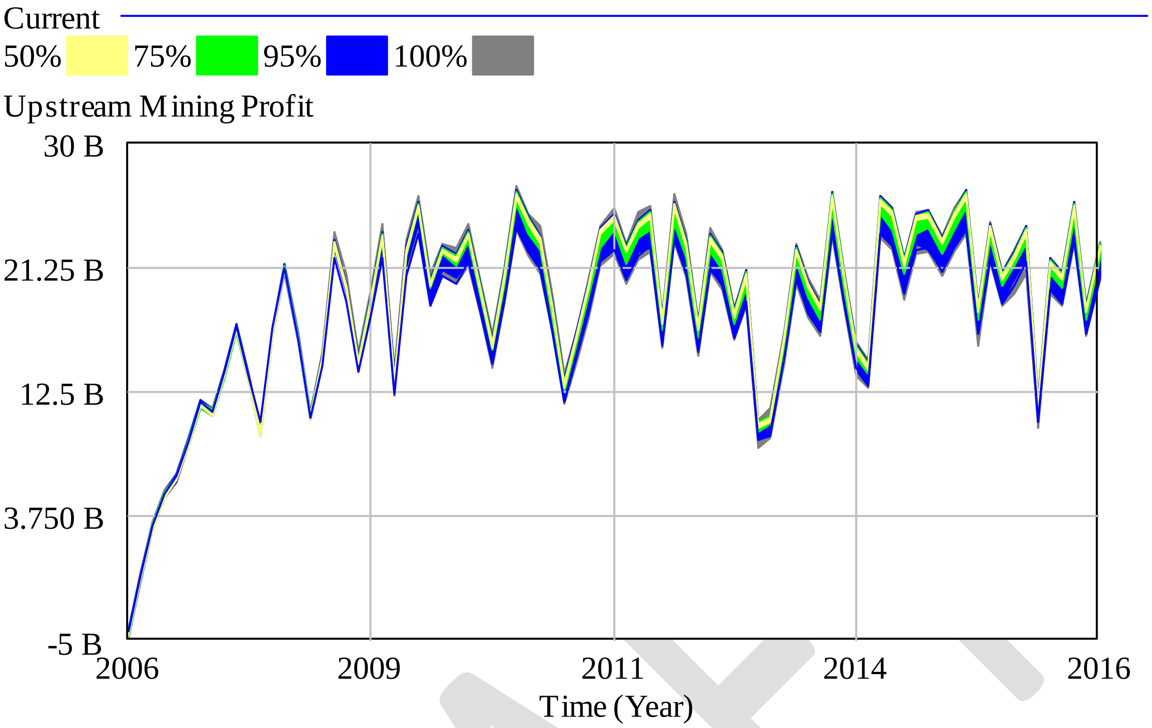


Figure 123: Impact of input cost and market price on upstream mining profit

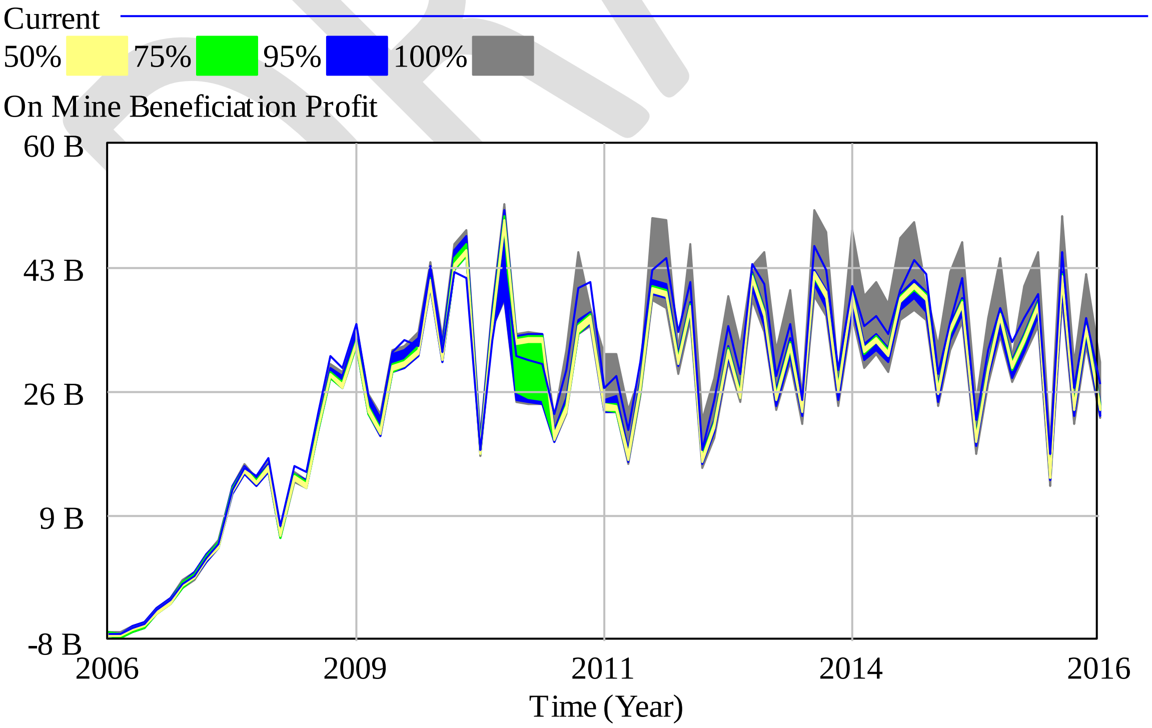


Figure 124: Impact of input cost and market price on primary beneficiation profit

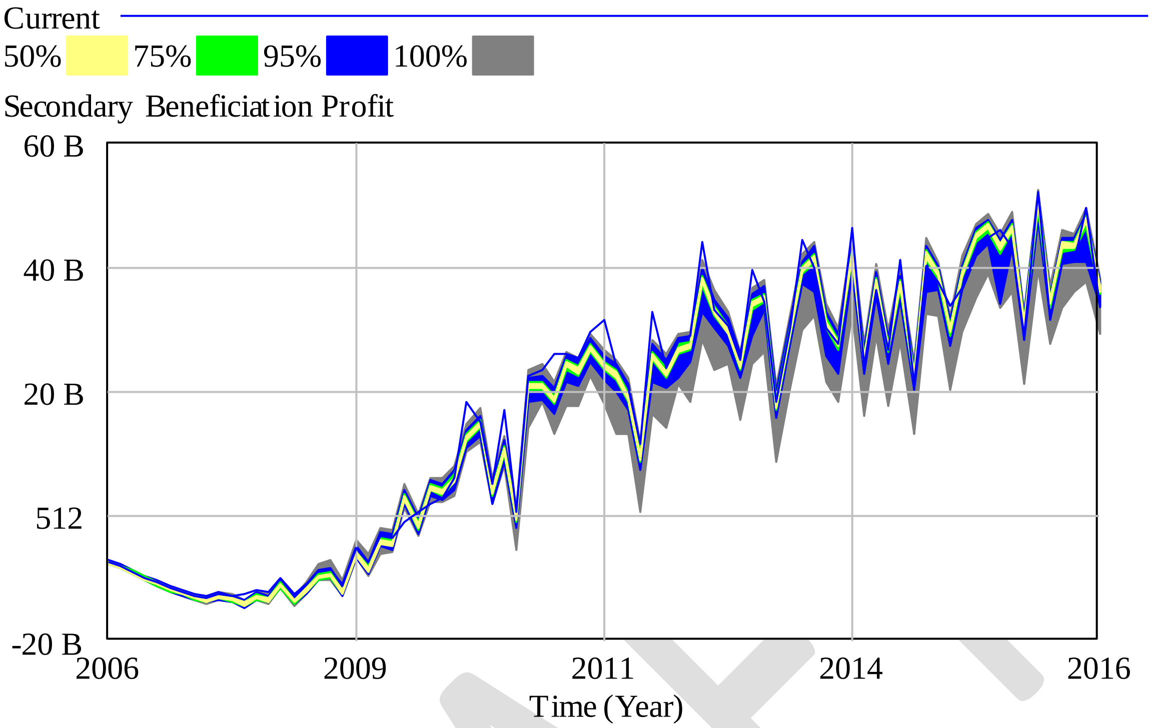


Figure 125: Impact of input cost and market price on secondary beneficiation profit

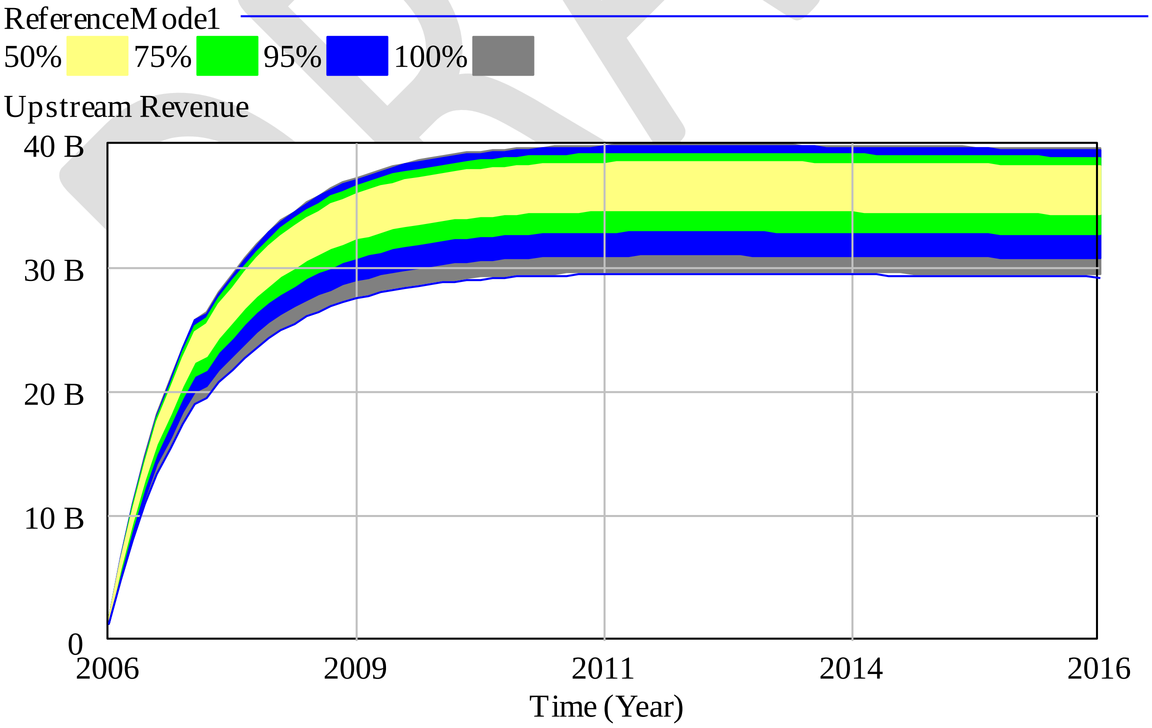


Figure 126: Upstream mining revenue on random input sensitivity

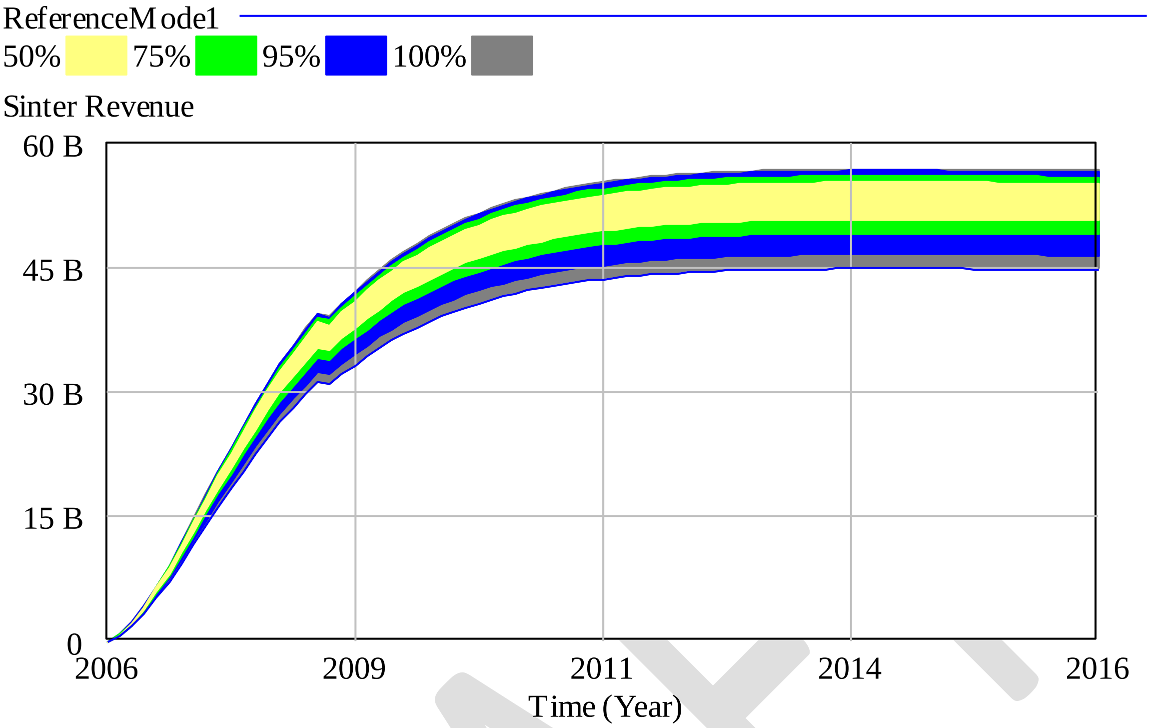


Figure 127 Impact of input cost and market price on primary beneficiation revenue

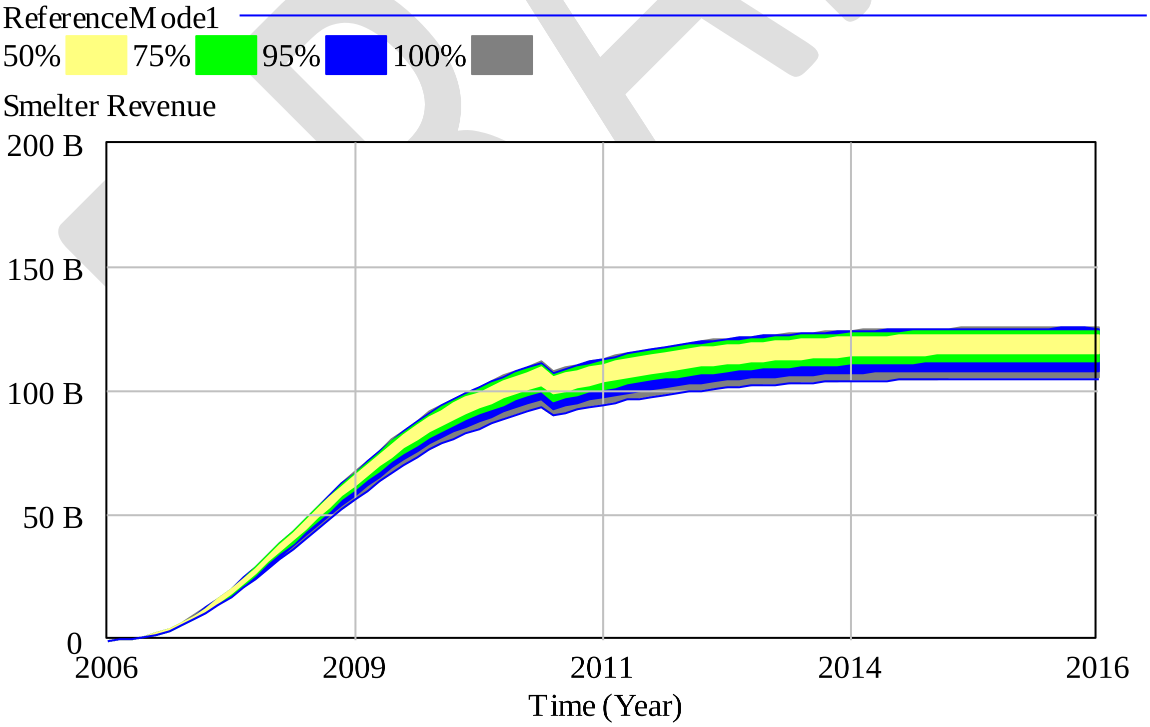


Figure 128: Impact of input cost and market price on secondary beneficiation revenue

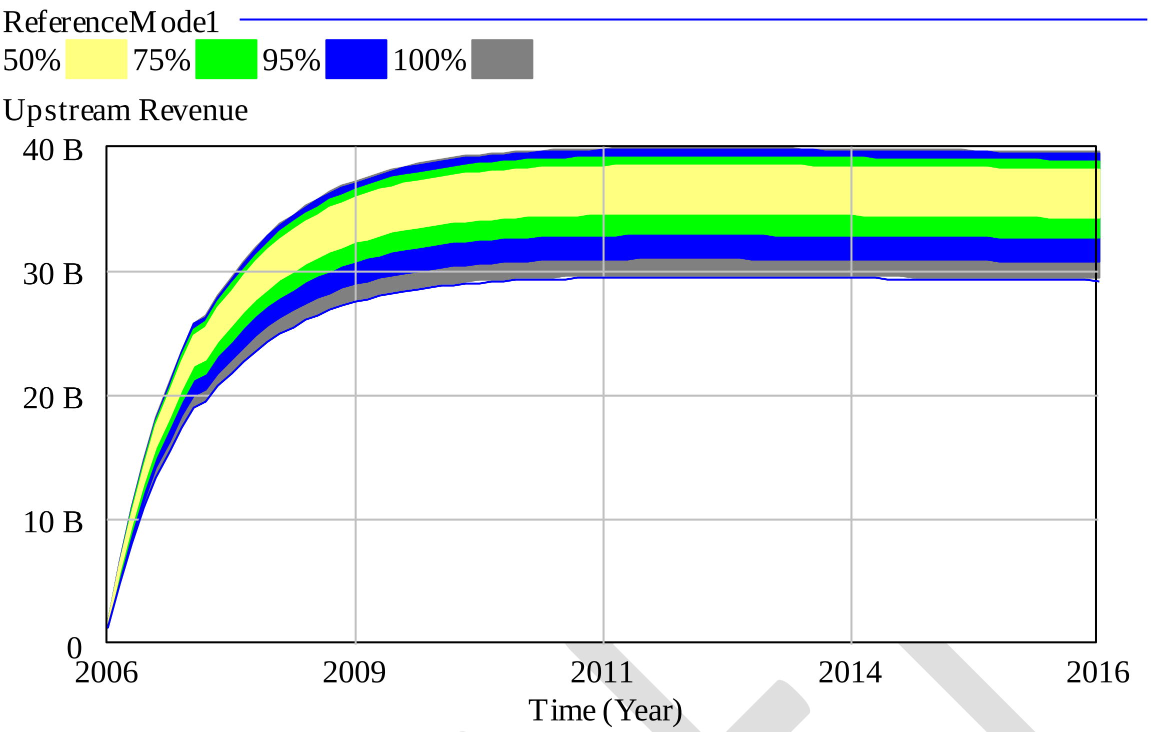


Figure 129: Upstream mining revenue on random input sensitivity

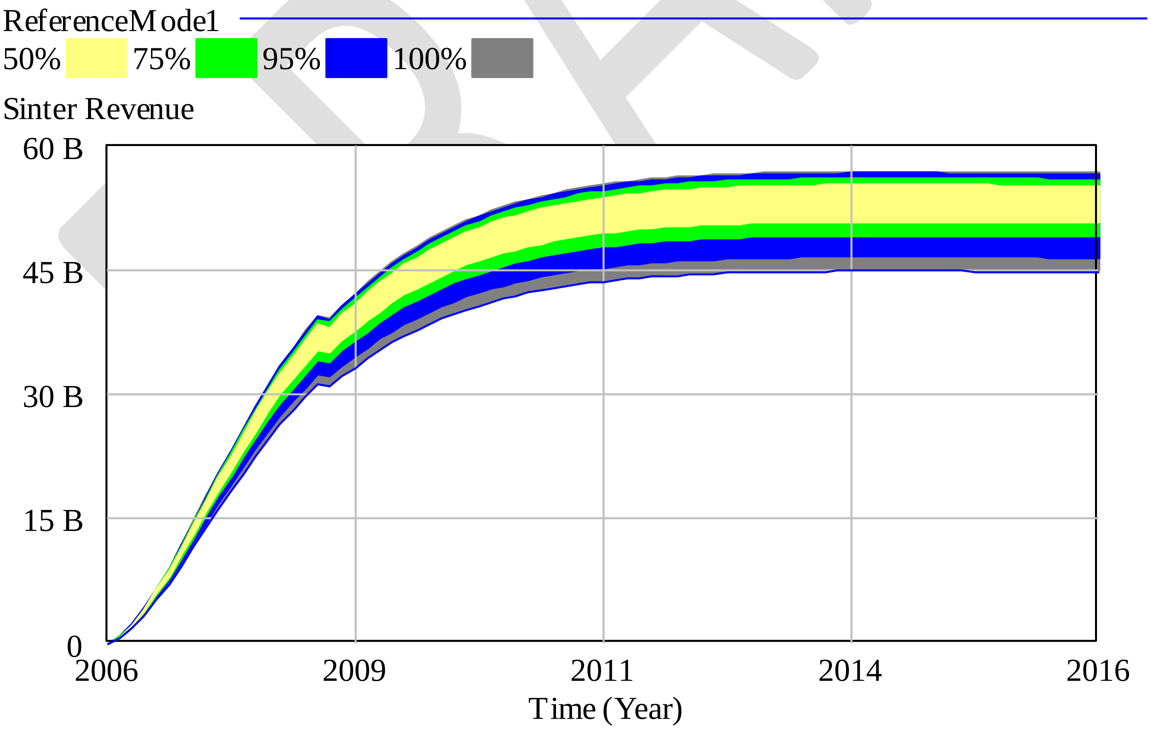


Figure 130: Primary beneficiation revenue on random input sensitivity

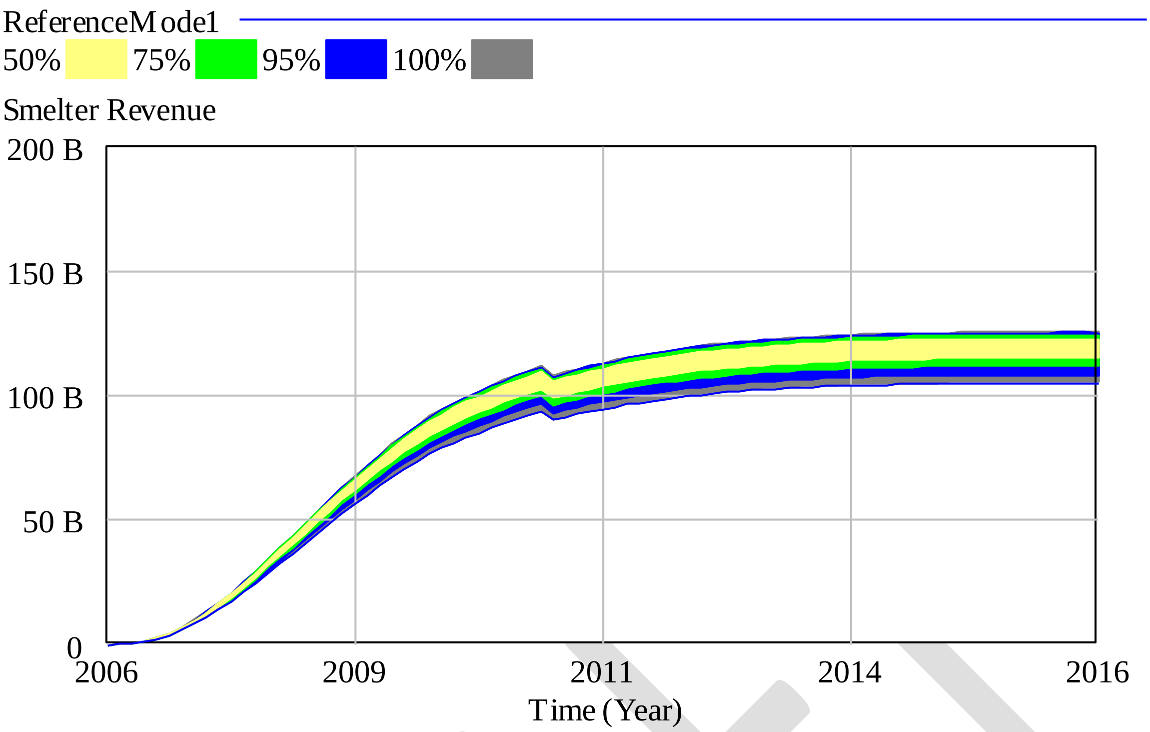


Figure 131: Secondary beneficiation revenue on random input sensitivity

10.5.2. Socio-economic development simulation results

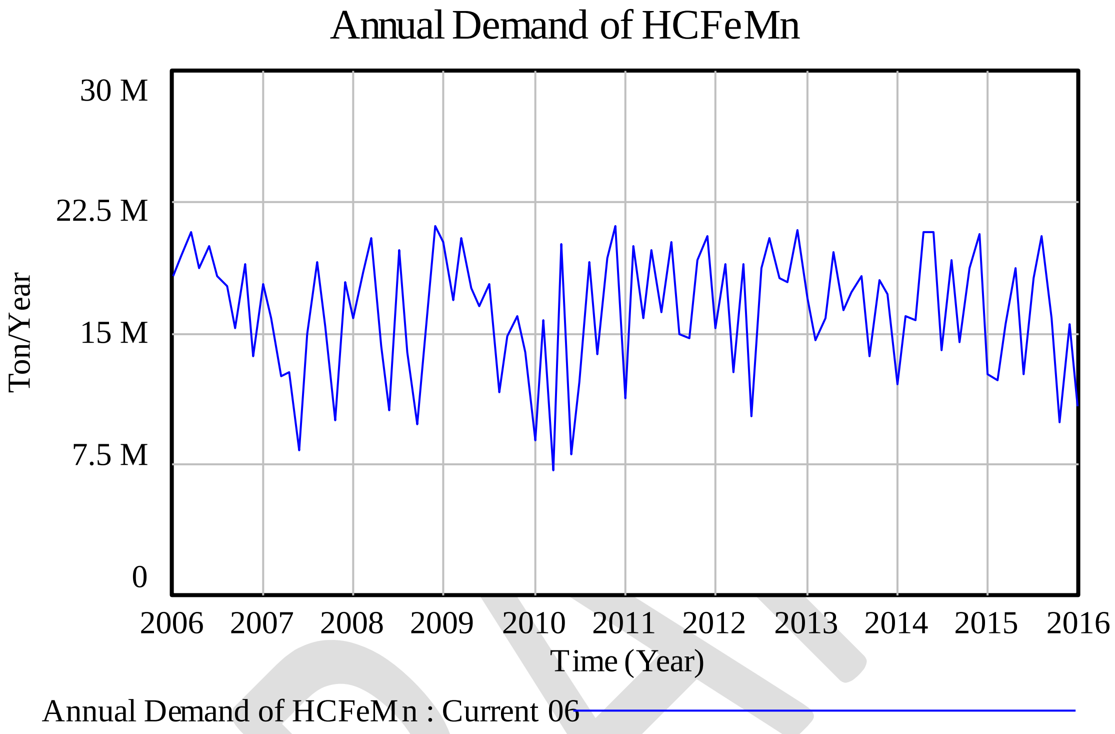


Figure 132: Manganese Ferro-alloys demand

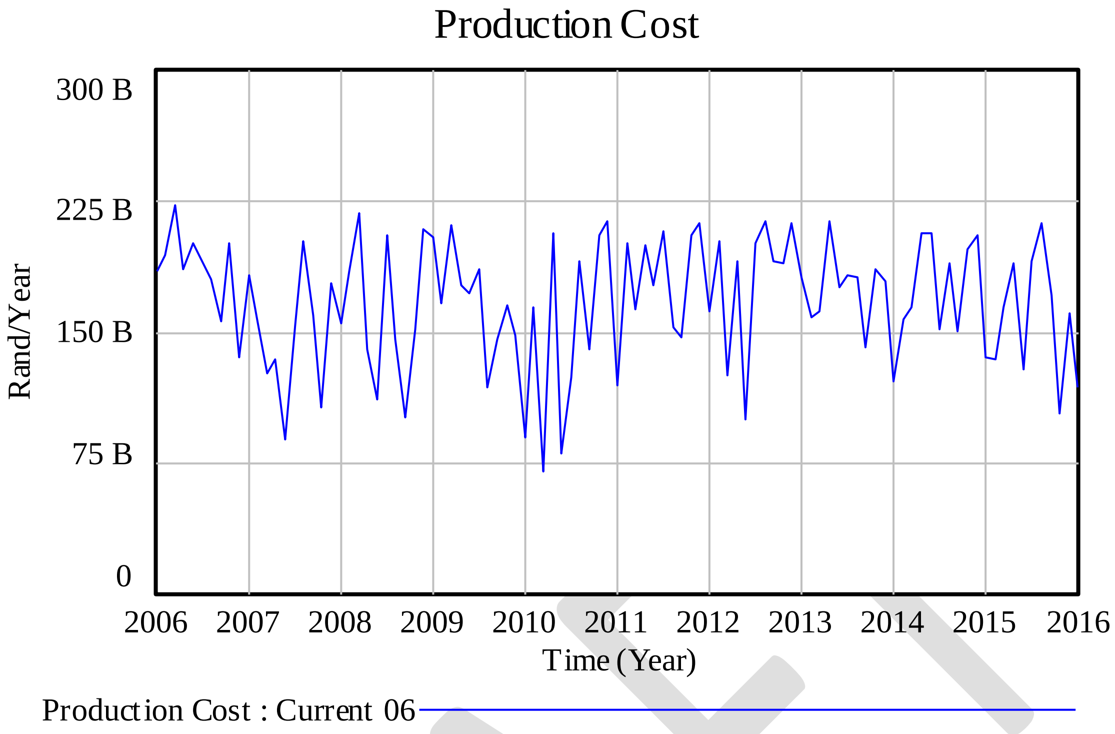


Figure 133: Total cost of producing Manganese Ferro-alloys

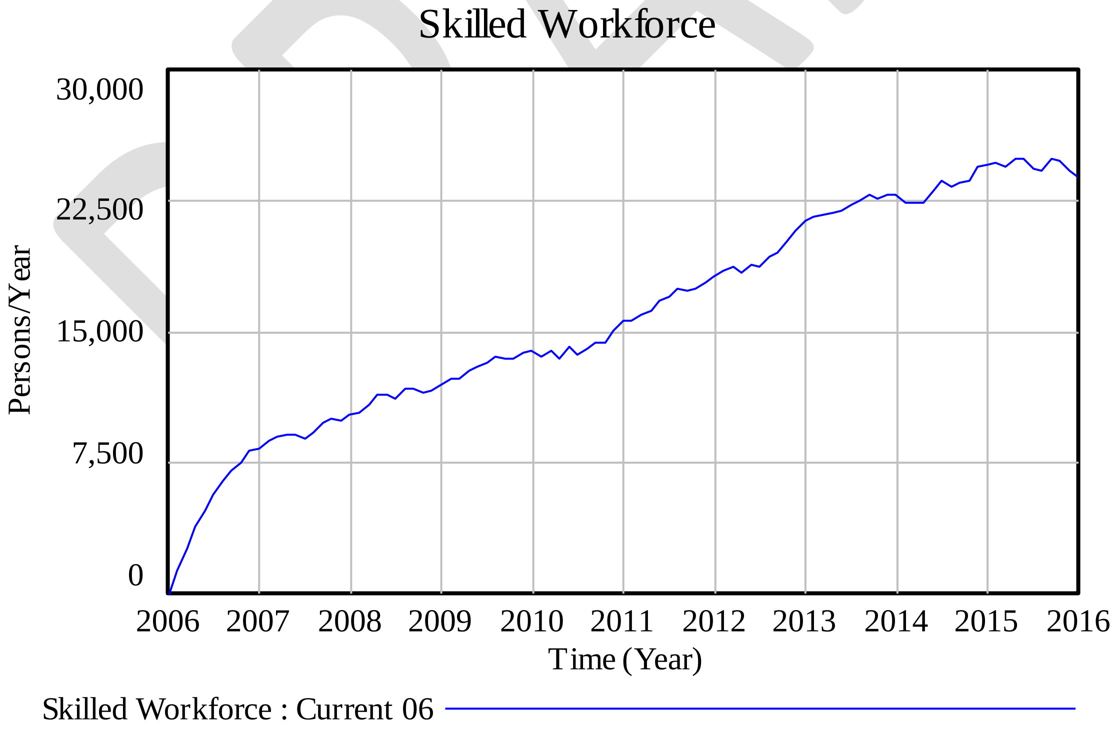


Figure 134: Number of skilled workforce created through employment in beneficiation activities

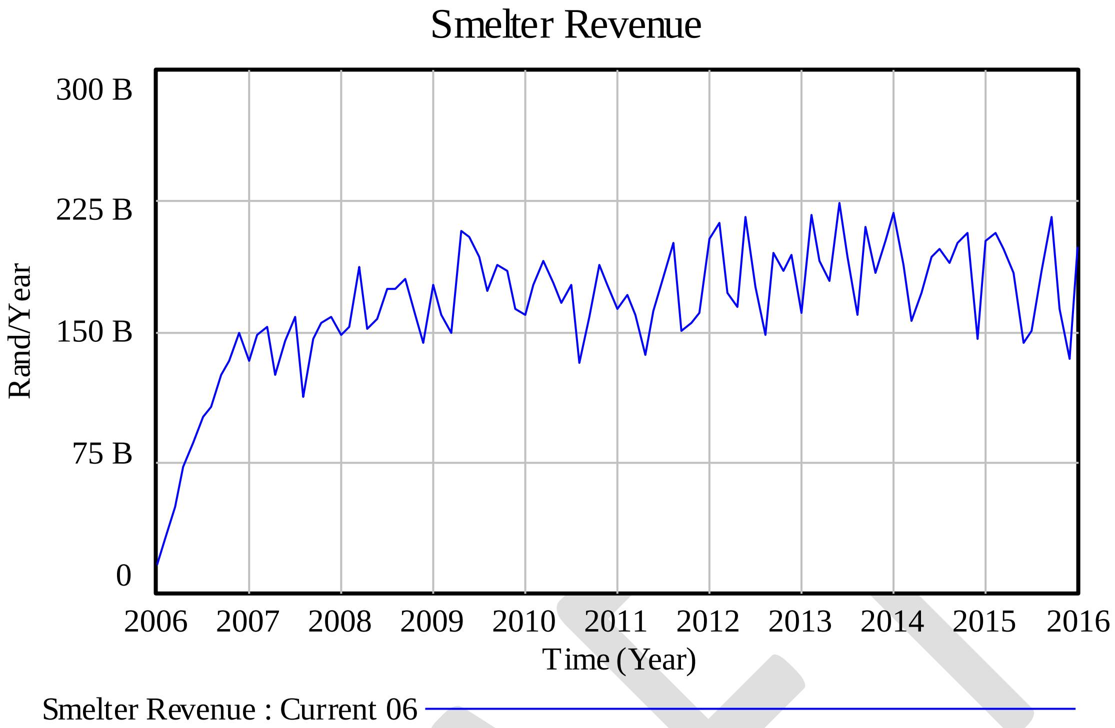


Figure 135: Mineral beneficiation revenue over the simulation period

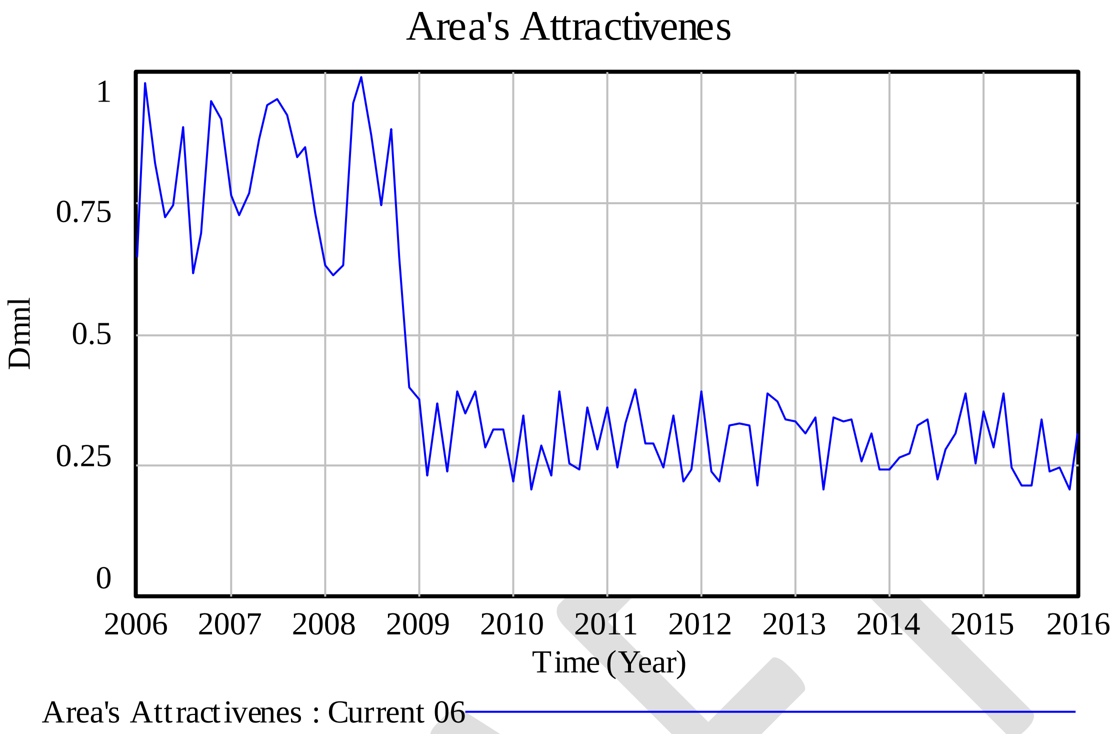


Figure 136: Area's attractiveness index over the simulation period

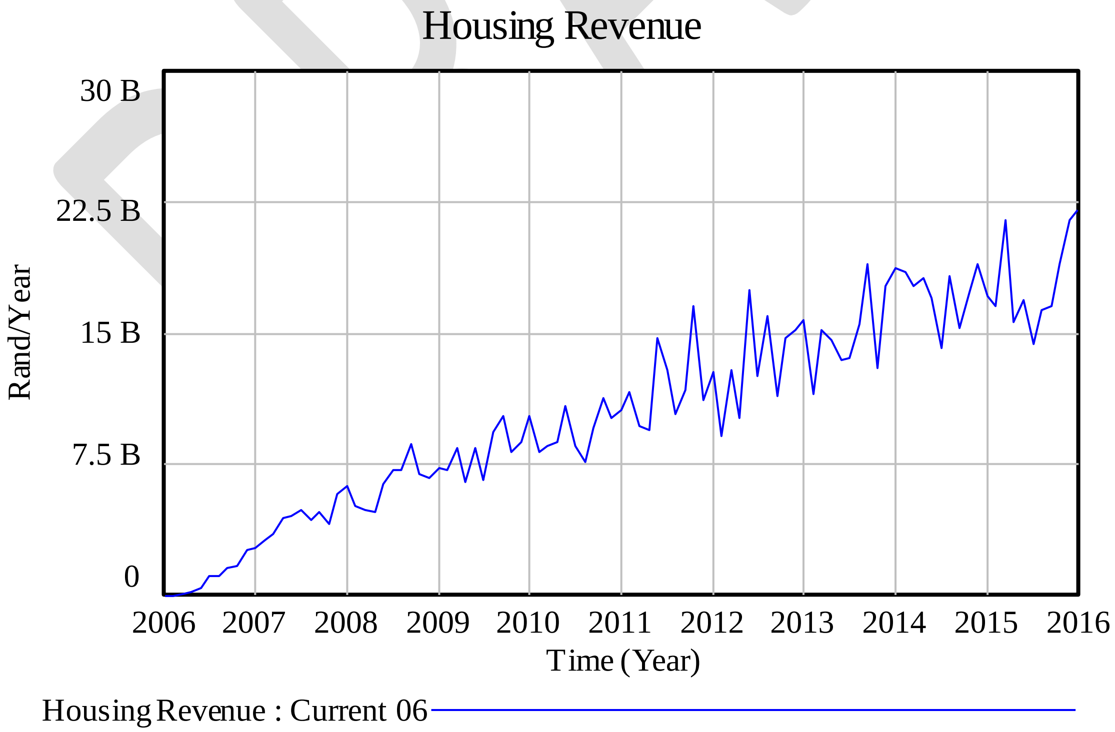


Figure 137: Housing revenue created over the simulation period

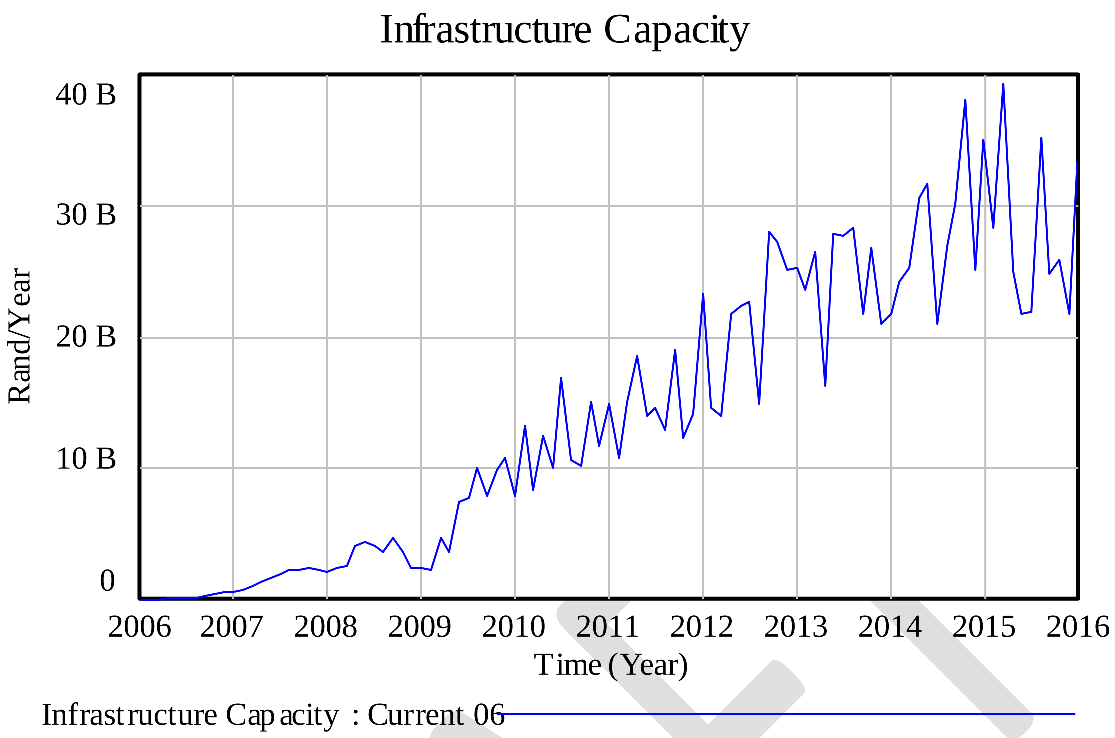


Figure 138: Infrastructure capacity in Rand value terms over the simulation period

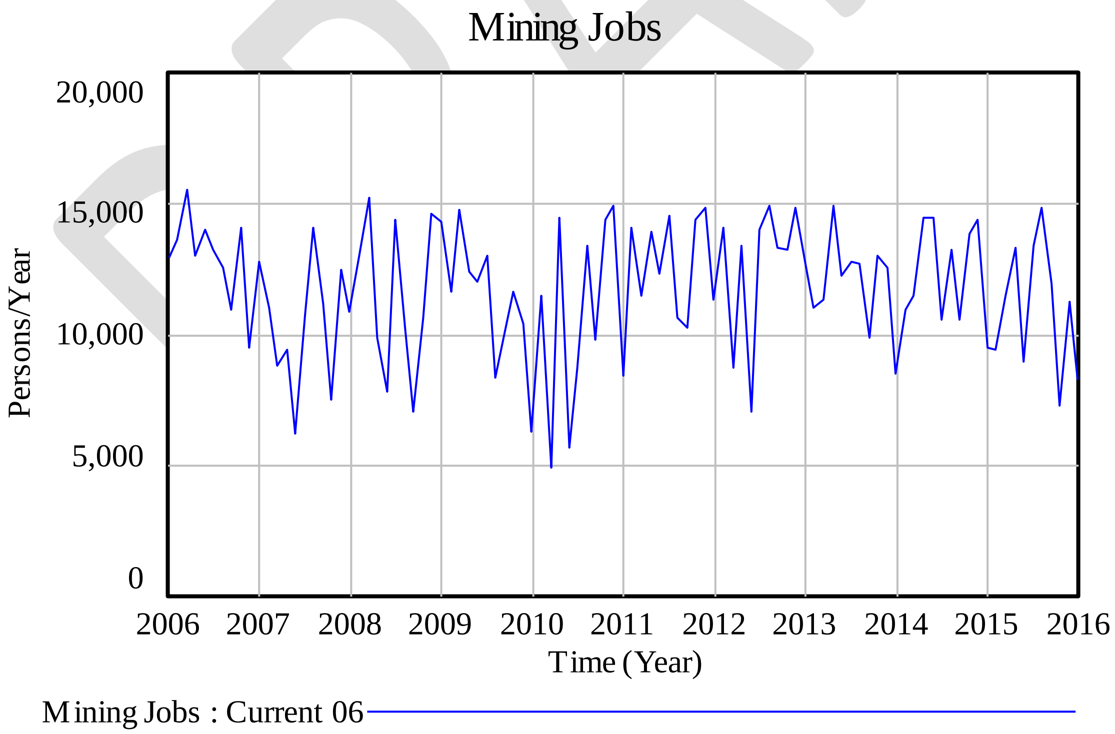


Figure 139: Number of direct mineral beneficiation jobs created and sustained annually

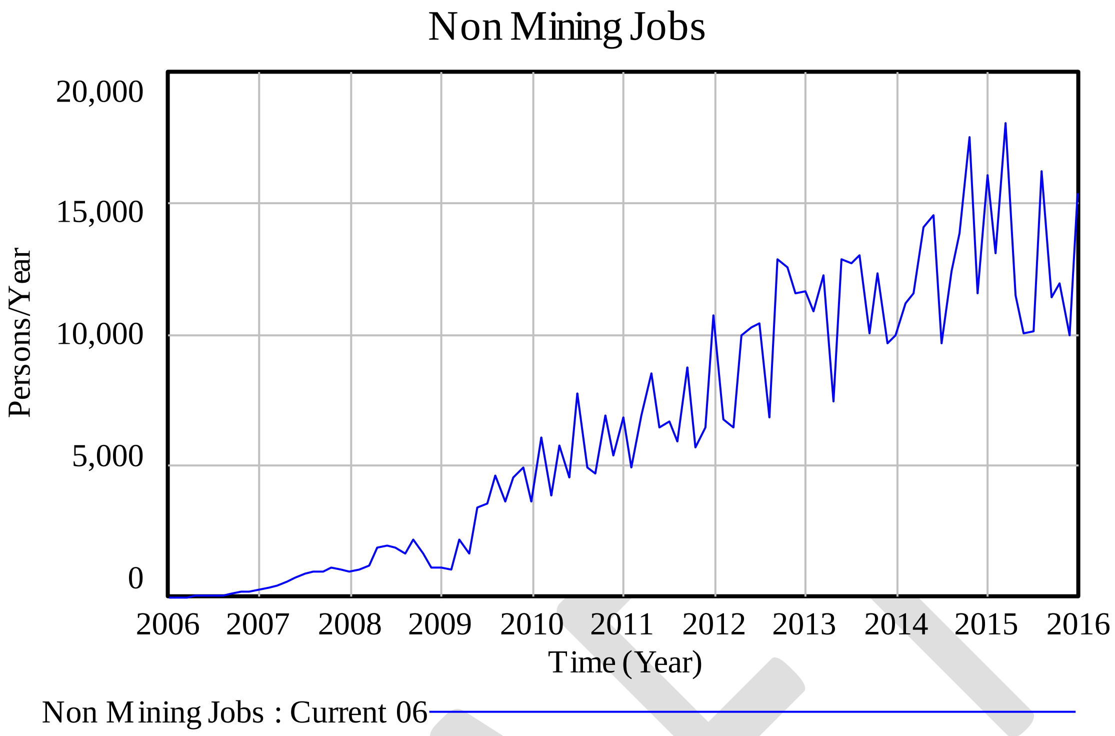


Figure 140: Number of non-mining jobs created in the area surrounding beneficiation activities

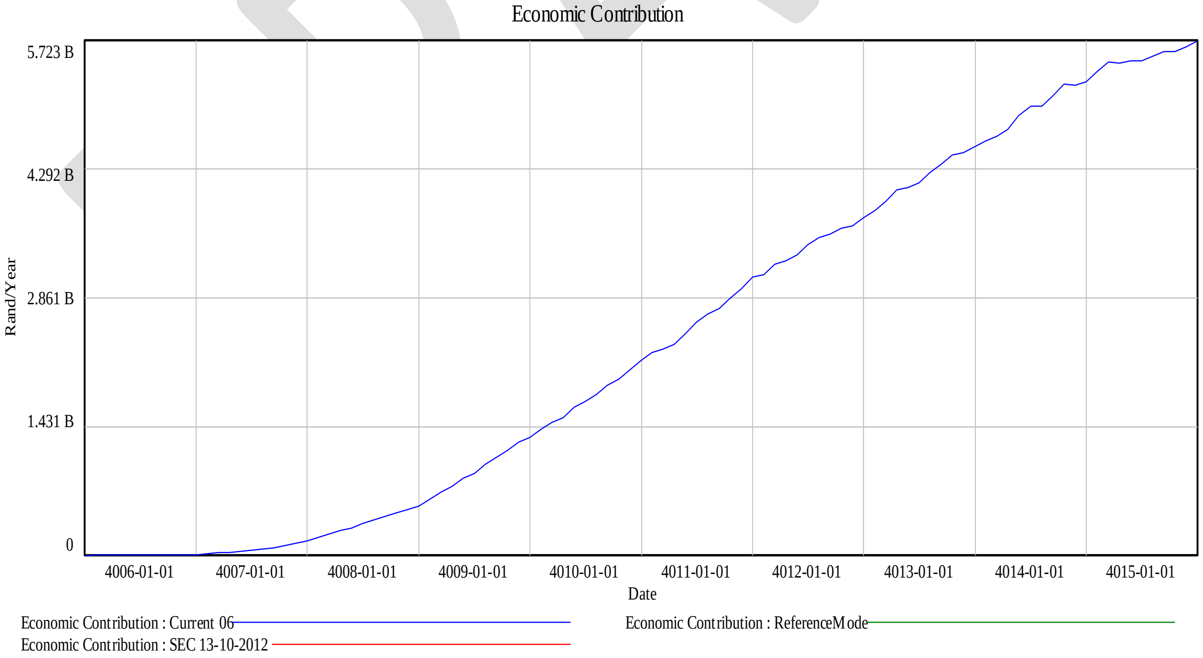


Figure 141: Rand value of impact due to mining and beneficiation activities on NC GDP

Socio Economic model Monte Carlo analysis results

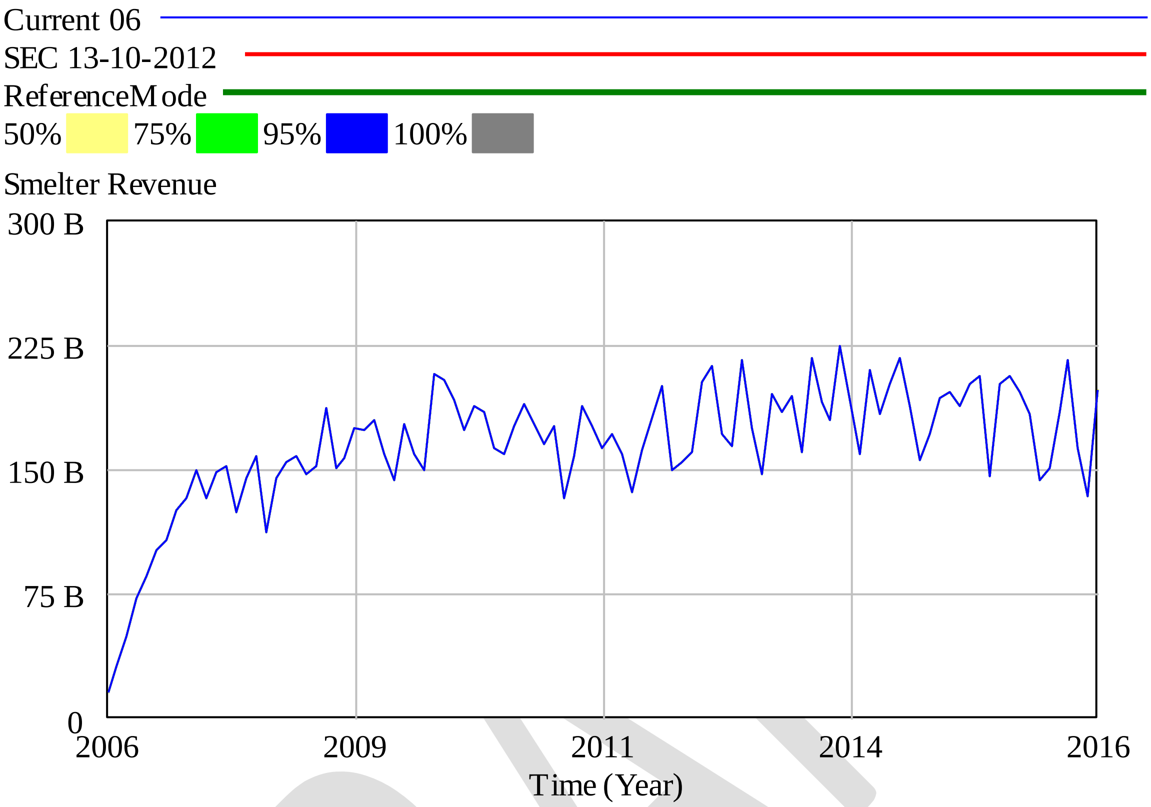


Figure 142: Beneficiation revenue on random sensitivity

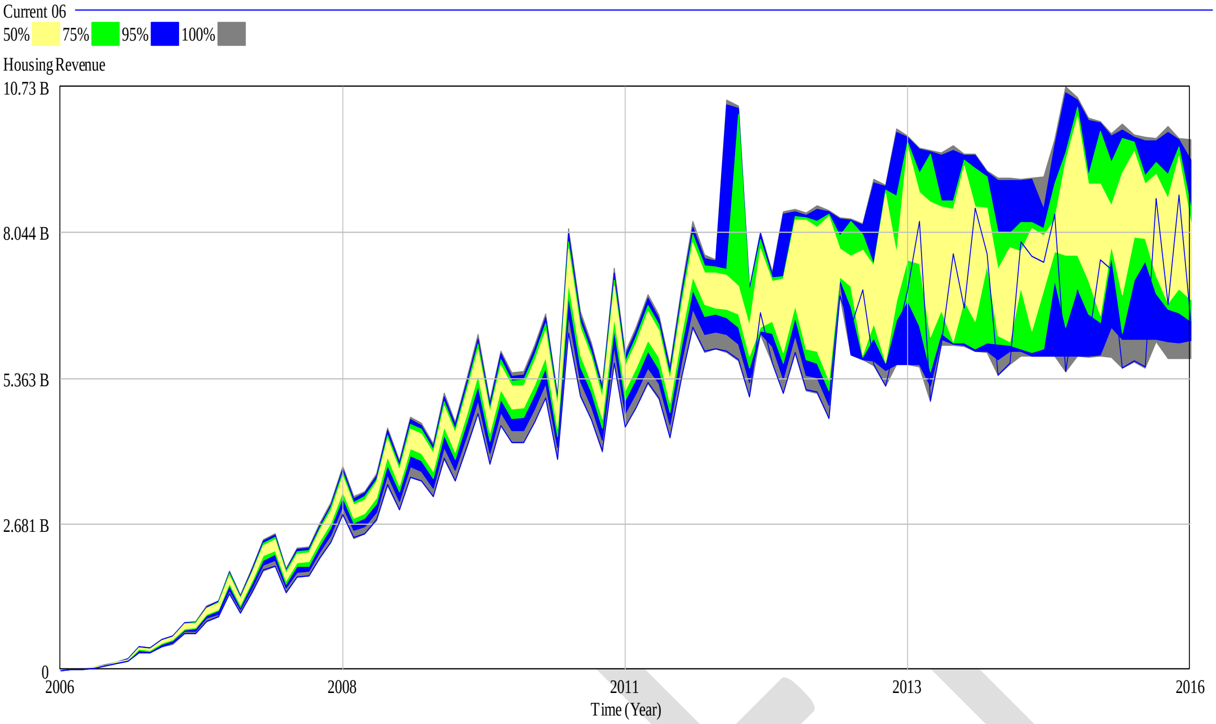


Figure 143: Housing revenue on random sensitivity

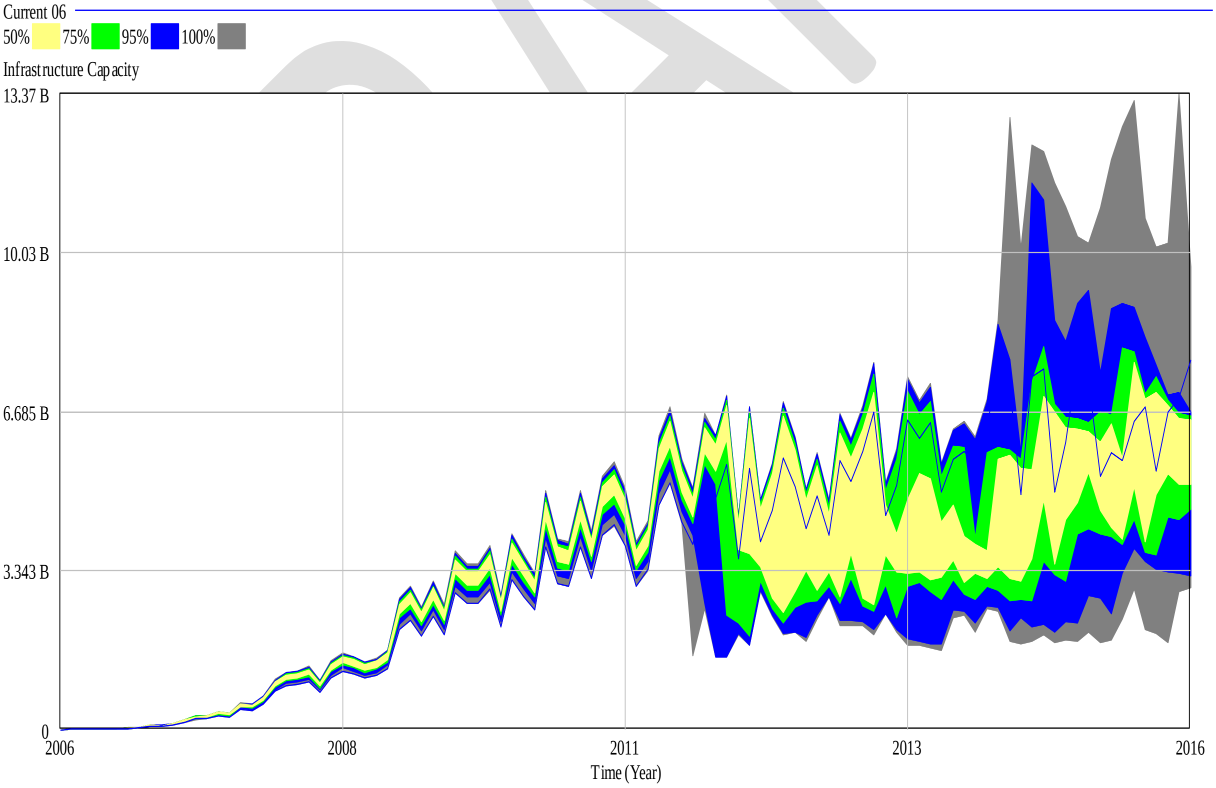


Figure 144: Infrastructure capacity on random sensitivity

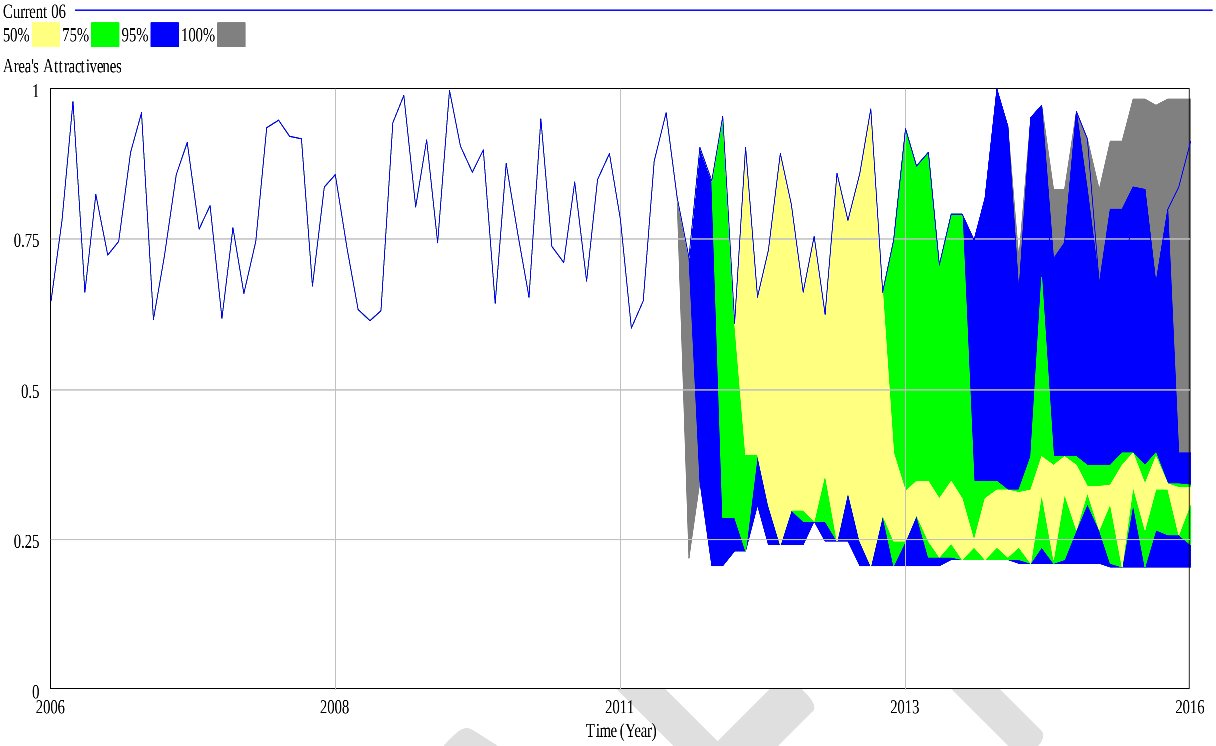


Figure 145: Area's attractiveness on random sensitivity

10.6. APENDIX F: Description of the Outokumpu facility in Tornio, Finland

An assessment of the Outokumpu beneficiation facility in Tornio, Finland was undertaken as part of the research to collect data on the performance of an integrated value chain of chrome mine with a beneficiation facility. Although the broader intent of the trip was to evaluate a Smelter design option for a South African company, this opportunity fitted the objective of this research due to the unique similarity of final application between Chrome and Manganese. The objective of the visit was to explore some environmental (green) aspects of the Smelter technology developed by Outokumpu in their Smelter furnace operations. This mine and beneficiation facility as depicted in Figure 146, was selected because it has demonstrated success in development of the value chain from upstream mining to downstream steel manufacturing as a complete (4 in 1) Chrome value chain business. This data was used for validation purposes against the results of the system dynamics simulation model described in the sections above.

10.6.1.1. Background and profile of the facility

The Outokumpu upstream integrated facility is the most integrated stainless steel manufacturing facility in Europe. Although it is based on upstream integration of a Chrome mining business and not Manganese, the two metaliferrous minerals find use in manufacturing of steel and have similar value chain dynamics. The steel plant in Tornio only imports scrap metals and reductants.

Outokumpu employs more than 8000 workers and operates in more than 30 countries. The company produces the bulk of its steel from a steel plant in Tornio, Finland. The focus of the case study is in their Tornio Sinter plant, Smelter and Steel Plants as well as their Chrome mine operations in Kemi, 30km away from their beneficiation operations. Outokumpu has an estimated 20% steel market share in Europe (Outokumpu: 2012). Outokumpu has the largest Chrome reserve in the European Union and are the sole producer of Ferrochrome in the region. Outokumpu produces 3.1 million tons of steel between its Tornio plant (2,350,000 tons) and another hired plant in in Bochum (750 000 tons), Germany. The following is a summary of the Outokumpu value chain in Finland:

Upstream Mining = 1,200,000 tons
Sinter and Ferrochrome= 265,000 tons
Stainless Steel= 2, 350,000 tons

Figure 146: Picture of the Outokumpu facility in Tornio and Kemi in Finland

10.6.1.2. Key success element of the Outokumpu facility

In analysing the performance of the Outokumpu facilities in Kemi and Tornio, a specific observation were made on Cost efficiencies, employment status, skills development, energy use ,carbon footprint and sustainability elements of the facilities. The findings are summarised in the sections that follow:

Cost efficiencies

The facilities setup in Kemi and Tornio has an advantage of savings on transportation costs. The longest distance between the facilities is between the mine (in Kemi) and the rest of the beneficiation facilities (in Tornio) which is about 30km. Transportation is done by road to allow flexibility of feedstock to the beneficiation site since no stockpiling is envisaged. This served to minimize the cost of Ore handling and inventory management on the beneficiation site at Tornio. The cost of transportation in South Africa would be much higher due to the distance from the mine to the port of export. The Manganese basin in the Kalahari Desert is situated about 900km from the nearest port. The only Manganese Smelter operation that is inland is 500km way from the Kalahari basin where most of the Manganese reserves are. The advantage of the Kemi-Tornio is at least 470km worth of transportation cost that is eliminated from the value chain.

In the Smelter operation itself, pelletized Sinter product is fed through the furnace which improves the efficiency of the furnace by reducing energy losses. The furnace design allows for recycling of emitted gasses for preheating of feed material into the furnace to reduce the total energy consumption per ton of Sinter treated in the furnace. This reuse of emitted gas not only reduces the cost of energy per ton of treated Sinter but minimizes the environmental liability of gas emissions and the cost related to it.

The steel manufacturing operation sees reduction in the input cost at the melt shop due to the proximity to the Smelter. The direct cost saving is the energy cost in the melting shop because the alloy is fed to the melt shop already heated and in molten state (Outokumpu, 2012). The Ferro-alloy material from the Smelter is transported through a short rail link in small quantities to suit the Smelter batching process. The full integration from Upstream to downstream product results in lots of savings in logistics and energy costs.

Jobs created vs. similar mining resources in in SA

From the chrome mine in Kemi, with a production of 1.2 million tons per annum of chromium Ore, such operation employs 600 permanent workers. The beneficiation plants in Tornio employ a further 3000 people. These jobs do not include jobs created in the cogeneration, Ore transportation and the slag beneficiation areas. The Steel plant in Tornio enjoys a lot of mechanisation than most plants around the world. The number of people employed in a similar operation would at least exceed that number. In a scenario where only Ore is mined without any beneficiation efforts, all the jobs would be lost.

Skills Development Program

The facilities in Kemi and Tornio provides vocational training and development opportunities from engineering and metallurgical graduates in all 4 different stages of the value chain starting with the Chrome mining in Kemi and the three stage beneficiation processes in Tornio. The flexibility allows the company to provide trainees and employees the option to move around the facilities. This gives the employees options to re-energise their careers after spending time in one area without leaving the company. The impact of this on the skill base is that, mining production trained personnel can also acquire manufacturing skills from the steel plant and vice-versa. This program has been very successful for Outokumpu and the employees and the result has been a very low turnover of employees out of the company.

Energy usage

The beneficiation facilities in Tornio and the mine get power from a hydro power plant in Kemi. This takes advantage of the excessive amount of water flowing through Kemi River for the greater part of the year. However, the Carbon monoxide (CO) emissions from the Sinter and Smelter process in the Outokumpu plant is utilised in the cogeneration plant to supplement the power from Kemi Power plant. The CO is however first utilised in the smelting process for pre-heating the material that is going to be fed to blast furnace. By doing this, the CO gets recycled into the process, making the process a closed loop system. The second advantage is that by pre-heating the material, the energy consumption of the furnace is reduced by up to 30%

Carbon Footprint

Of the 4 in 1 components, the mine is the furthest component at 30km distance from the rest of the facility. The transportation of Chrome from the mine to the facility represents what could be potential air pollution due to emissions of Sulphur Dioxide (SO_2) from haulage trucks. Although it is not in the scope of this research to quantify the exact impact of emissions of greenhouse gases (GhG) associated with the choice of a Manganese resources value chain scenario, it is worth pointing out that at a high level, the scenario comparison where Ore is trucked over 1000km from the Kalahari basin in non-beneficiated form will certainly present a higher impact on SO_2 and other GhG emissions that the example of the arrangement in the Tornio and Kemi 4 in 1 Chrome to Steel production facility.

Sustainability of the operation

The facility in Tornio enjoys a number of side-stream beneficiation of both CO emission and slag produced in the Smelter operations. The entire CO gas emitted from the furnaces during the Smelter operation is reused in the preheating of raw material as chemical energy and the rest used for co-generation of power. The business case for reuse of the CO gas in the preheating process is its reduction of consumed electricity in the furnace by up to 30%. In South Africa, electricity constitute up to 60% of the direct input cost per ton of ferroalloys production.

Slag produced in the Smelter process is used as building aggregate for roads and for bricks forming, making the facility 100% productive from a revenue generation point of view. In a country like Finland where temperature is extreme in winter, insulation is required; the slag becomes a secondary source of revenue. Another opportunity also exists for secondary processing of the slag to recover some minerals such as chrome and iron.

10.6.1.3. What can be concluded from the Outokumpu model

Outokumpu, through partnership with a technology company, Outotec GmBH have developed the 4 in 1 solution from 1968 in to what has become the biggest and most efficient upstream integrated steel manufacturing facility in the Eurozone. The key benchmark aspects of these facilities is the sustainability that is achieved through power and logistics cost savings that are uniquely attributable to the setup of the facility and its proximity to the chrome mine in Kemi. The facility integrates the side stream beneficiation aspect using the slag and Carbon Monoxide (CO) by-products in an efficient way so much that the facility creates very little closure cost liability due to its operation.

The 3 components of the integrated facility occupy a relatively smaller footprint in Tornio and this gives the operations leverage in transport logistics between the three beneficiation stages. By comparison to the South African Manganese setup, Manganese Ores have to be transported over a 1000km to the ports (Coega and Saldanha) in volumes that are more than double what could be transported if the Ores were beneficiated into Ferro-Alloys. The impact of the South African scenario is that the overall Green House Gas (GhG) emissions are higher irrespective of whether the Ore is transported by rail or road although the later represent the worst case scenario. The proximity of the Smelter to the steel plant in the Tornio facility allows the operator to transfer Ferrochrome in liquid uncooled form directly to the melt shop of the steel mill. This results in the reduced pre-heating requirement in the melt shop of the steel mill thereby saving on electricity consumption at this stage of the steel manufacturing process.

The benefits that have been highlighted in the case study were not achieved in one step of the operation but through a systematic integration of the value chain from upstream mining to final steel making process. The ability to influence input cost for stainless steel business makes the Tornio facility in Outokumpu more efficient than most of its competing plants in Europe and abroad. However this business case was not obvious at the beginning and as such required an integrated planning with a systems thinking view to the business. This is the view that the Manganese mining industry is grappling with in South Africa today.

The logistics limitation on the Coega and Port Elizabeth line from Hotazel and the shortage of power in the Kalahari basin are viewed by the industry as a key constraint for production growth in Manganese and by implication the Northern Cape region. This is notwithstanding the inefficiencies highlighted above in terms of the industry structure and the timing of the Eskom's generation and power distribution infrastructure in the country This view negate any benefit of investing in power distribution network to the area and establishment of the solar power projects in the area which have a potential of making the region a net exporter of power in the next 5 years (Eskom, 2012).

The observations made in the Tornio facility and the Kemi chrome mine, when contrasted against the Manganese industry setup in South Africa leads one to a conclusion that the Tornio setup is more sustainable both in terms of economic benefits to the area and minimizing impact to the environment. The South African Manganese industry can benefit from a similar arrangement considering the power cost and rail limitations challenges that the industry is facing.