6 Data analysis

The chapter contains the analysis of the data gathered through the research project and CSIR baseline study (refer to Appendix D.

6.1 Research project questionnaires

6.1.1 Nanotechnology segments

Figure 6-1 and Figure 6-2 illustrate the mean and standard deviation of the nanotechnology segment data (refer to Appendix D.1.1 for statistical data). The perceptions regarding future nanotechnology segments are:

- The segments increase almost linearly in time to market, from 1-5 years to 10-15 years time to market, with raw materials expected the earliest and machines expected the latest. Note that the time to market for machines (10-15 years) differs greatly from the other segments (between 1-5 years to 5-10 years), indicating that machines might still be very much a futuristic concept.
- The segments have medium to big market potential, with raw materials, devices and systems having the most and machines having the least.
- Tools, nanotubes and fullerenes are more complementary, with devices, systems and intelligent materials more replacing. The spread of answers between complementary and replacing for raw materials, structures and machines shifts the averages of these segments towards no opinion.
- The segments increase almost linearly in complexity from relatively complex to very complex, with raw materials the least complex and machines the most complex. Again note that the complexity, as with the time to market, for machines (very complex) differs greatly from the other segments (between relatively complex to complex), confirming that machines might still be a futuristic concept.

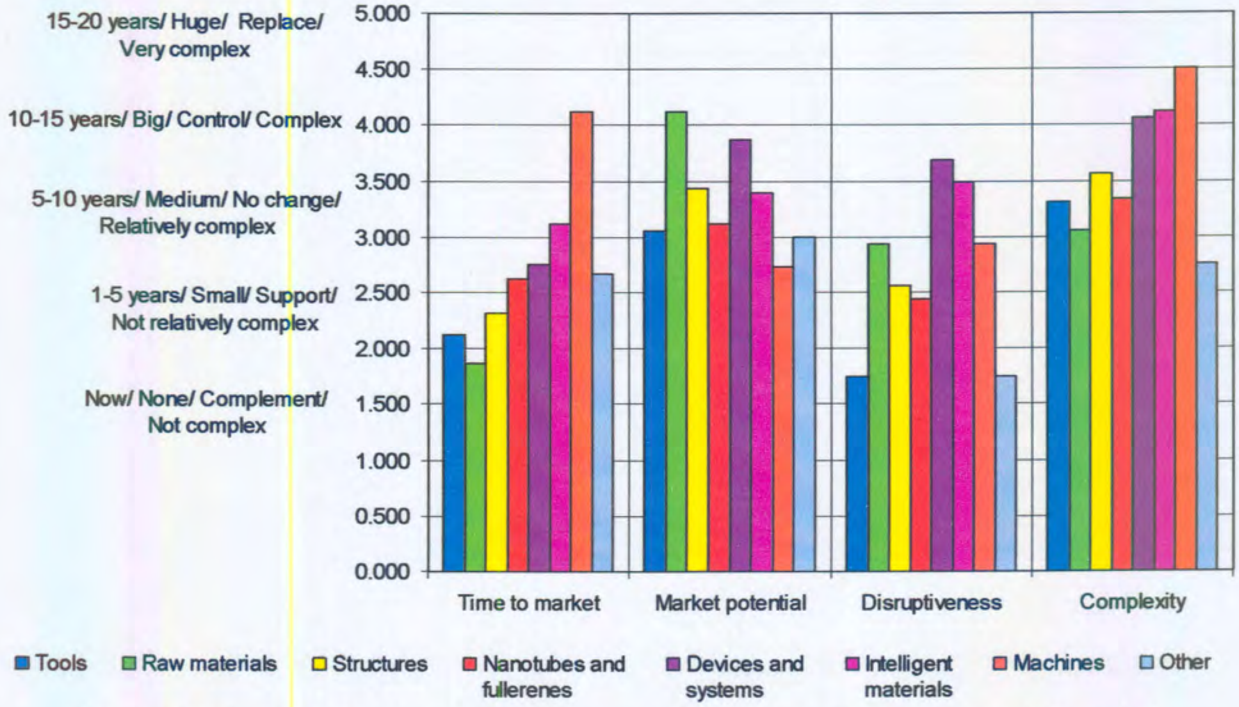

Figure 6-1. Bar chart of the nanotechnology segments' mean regarding time to market, market potential, disruptiveness and complexity.

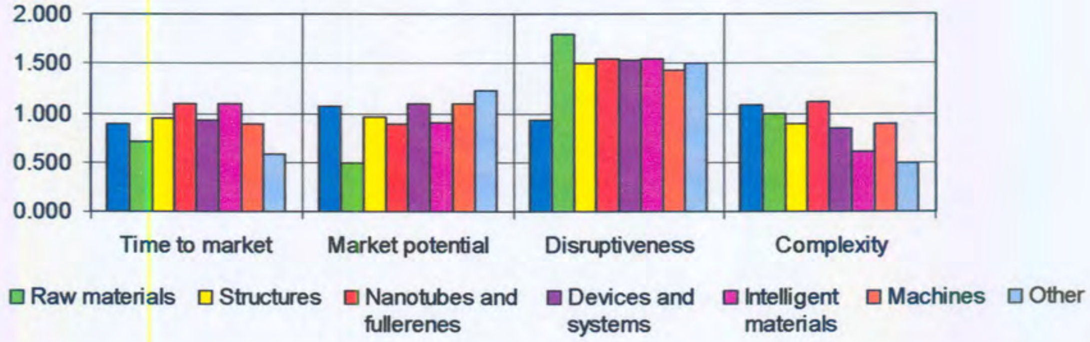

Figure 6-2. Bar chart of the nanotechnology segments' standard deviation regarding time to market, market potential, disruptiveness and complexity.

The change in the disruptive scale caused about a 0.400 increase in the standard deviation. The standard deviation regarding the raw materials' time to market (0.719) and market potential (0.500), the intelligent materials' complexity (0.619) and the tools' disruptiveness (0.931) indicated a relative agreement between participants in these areas. Interestingly the disruptiveness of raw materials has the highest standard deviation, thus the participants disagreed whether raw materials would fulfil a complementary or replacing role.

Referring to hypotheses listed in Table 3-3, based on empirical data, some conclusions are drawn:

- Tools, raw materials structures, nanotubes and fullerenes are most likely to emerge within the next 5 years supporting H2.4; devices, systems, intelligent materials and machines ,however, are most likely to emerge in 5 to 15 years supporting H3.4.
- All the nanotechnology segments possess a medium to big market potential supporting H2.5
- Tools, nanotubes and fullerenes will be more complementary, supporting H2.6, and devices, systems and intelligent materials will be more replacing, supporting H3.6.

Because only two participants answered the second questionnaire, the data was considered insignificant and not analysed. However, two conclusions that could be drawn from the answers are:

- Tools, raw materials, structures, nanotubes and fullerenes require a medium amount of skilled human resources to fully research, develop, manufacture, market and sell, while devices, systems, intelligent materials and machines require a huge amount of skilled human resources.
- The South African government will have to support research and development until feasible nanotechnology applications are generated, at which point venture capital would play a role in the exploitation of these nanotechnology incorporating products, processes and services.

Figure 6-1 hints at the correlation between the time to market and complexity of the nanotechnology segments. Figure 6-3 illustrates this possible positive linear correlation between time to market and complexity. Surprisingly, Figure 6-3 also shows a slight positive correlation between market potential and disruptiveness.

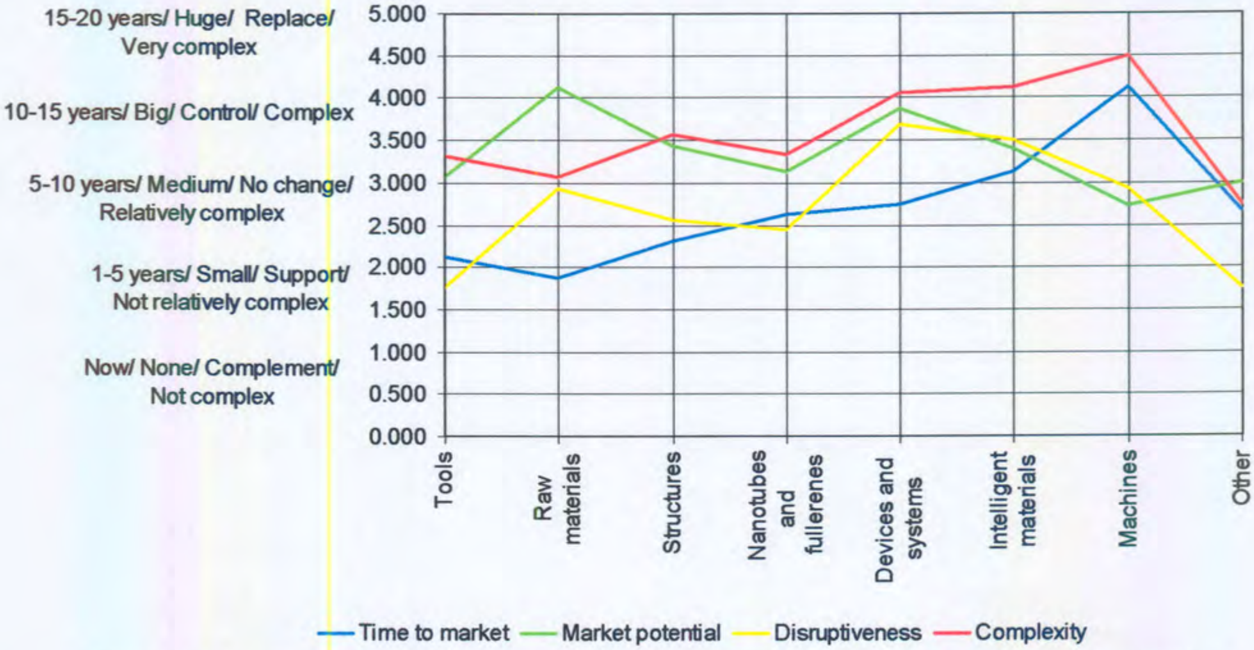

Figure 6-3. Interaction plots for nanotechnology segments' mean regarding time-to-market, market potential, disruptiveness and complexity.

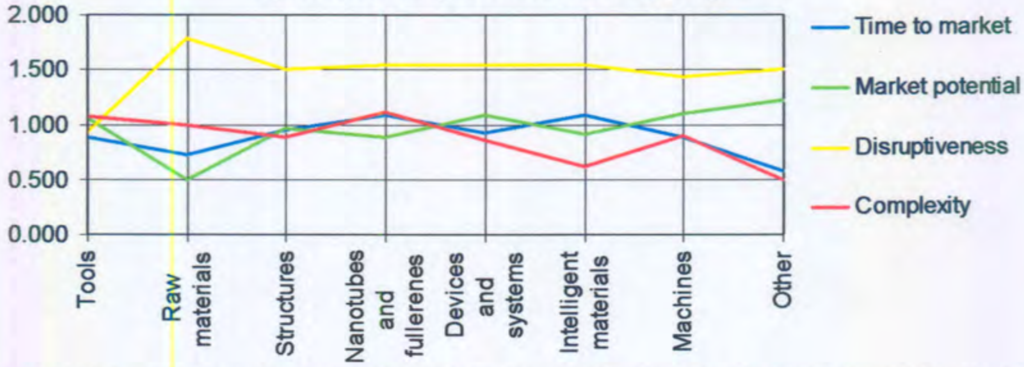

Figure 6-4. Interaction plots for nanotechnology segments' standard deviation regarding time to market, market potential, disruptiveness and complexity.

As stated earlier, the data is ordinal and discrete in nature, thus mathematically only cross-tabulations, instead of Spearman correlations may be implemented in investigating relationships between the variables. The summation of several ordinal variables into combined continuous ordinal variables or bigger sample sizes overcome this obstacle (Page and Meyer, 2000:146). Therefore, the time to market, market potential, disruptiveness and complexity data of each segment were summated, to construct continuous time to market, market potential, disruptiveness and complexity ordinal variables.

Table 6-1 confirms the correlation between time to market and complexity. There exists a relatively strong positive correlation between time to market and complexity (0.471) and interestingly enough a relatively strong negative correlation between time to market and market potential (-0.426).

These correlations indicate that as the complexity increases so does the time spent in the research, development, manufacturing, marketing and eventual time to market. The increase in time to market leads to a decrease in market potential. The reason for the last stated correlation might be due to a short-term perspective of when a return of investment is expected. If the time to market is too long, investors might perceive the segment as not having great short-term market potential and then would wait for the entry of dominant designs into the market before investing?

Spearman correlation	Variable	Time to market	Market potential	Disruptiveness	Complexity
Time to market	Correlation Coefficient	1.000	-0.426**	0.163	0.471**
	Sig. (2-tailed)	0.000	0.000	0.085	0.000
	N	115	113	112	113
Market potential	Correlation Coefficient	-0.426**	1.000	0.147	-0.061
	Sig. (2-tailed)	0.000	.	0.119	0.521
	N	113	115	113	113
Disruptiveness	Correlation Coefficient	0.163	0.147	1.000	0.115
	Sig. (2-tailed)	0.085	0.119	.	0.227
	N	112	113	114	113
Complexity	Correlation Coefficient	0.471**	-0.061	0.115	1.000
	Sig. (2-tailed)	0.000	0.521	0.227	.
	N	113	113	113	115

Table 6-1. Spearman correlation coefficient of nanotechnology segments' time to market, market potential, disruptiveness and complexity. ** Correlation is significant at the 0.01 level (2-tailed).

As mentioned previously, one of the objectives of the research project is to explore future nanotechnology segments and link them with current nanotechnology activities. The CSIR baseline study questionnaire includes nanotubes and fullerenes as nanomaterials, intelligent materials as structures, and nanobiotechnology as a separate nanotechnology segment.

The research project nanotechnology segments were adapted to fit these nanotechnology segments, with raw materials becoming nanomaterials (incorporating nanotubes and fullerenes) and nanostructures including intelligent materials (refer to Figure 6-5 and Appendix D.1.2 for statistical data).

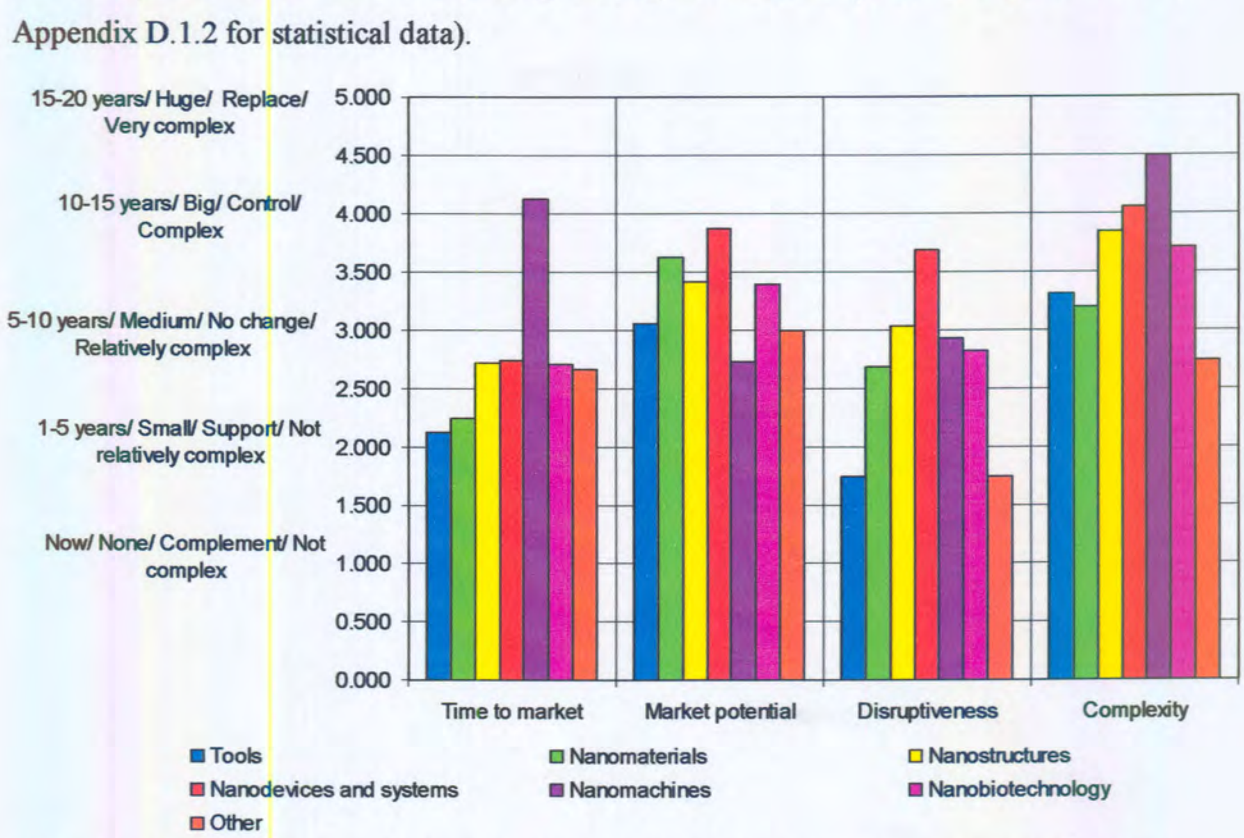

Figure 6-5. Bar chart of grouped nanotechnology segment' mean regarding time to market, market potential, disruptiveness and complexity.

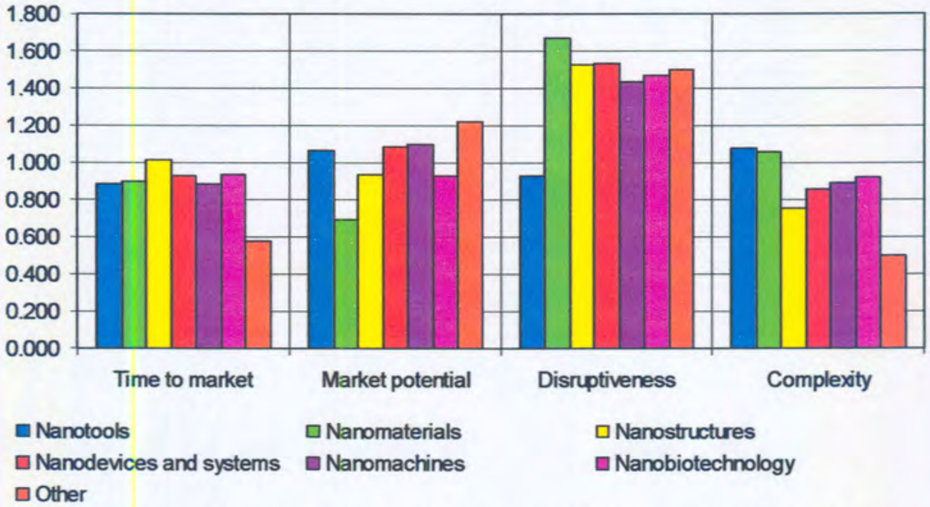

Figure 6-6. Bar chart of grouped nanotechnology segments' standard deviation regarding time to market, market complexity, disruptiveness and complexity.

The new nanomaterials have a longer time to market (+0.375), smaller market potential (-0.500), are more supportive (-0.248) and have the same level of complexity (+0.135). The new nanotechnology structures also have a longer time to market (+0.406), the same market potential (-0.019), greater diversity in disruptiveness and greater complexity (+0.281).

Nanobiotechnology encompasses elements of all the other nanotechnology segments, and is complex with a 5-10 years time to market and medium to big market potential. Nanobiotechnology is so diverse in its definition, that obtaining the combined average of all the nanotechnology segments seemed fair. Future studies must strive to define what constitutes nanobiotechnology, and characterise each subsegment separately.

The inclusion of nanotubes and fullerenes caused the nanomaterials' time to market and market potential standard deviation to increase with 0.185 and 0.193, and disruptiveness to decrease with 0.122. The inclusion of intelligent materials in structures decreased the complexity standard deviation with 0.136, and no significant change to other standard deviations (refer to Figure 6-6).

6.1.2 Innovation hampers

Figure 6-7 illustrates the mean and standard deviation of the innovation hampers data (refer to Appendix D.1.3 for statistical data). The five most important South African nanotechnology innovation hampers are:

- Lack of tools, equipment and techniques (hardware - microscopes, software - computer simulations)
- Insufficient funding (lack of appropriate government or other external funding)
- Lack of qualified personnel (insufficient training)
- Uncertainty in the net economic effect (breadth, growth and impact of nanotechnology unsure)
- Costs involved (estimated cost too high)

These five innovation hampers create a dangerous cocktail. The proposition is that the participants perceive that nanotechnology must be sufficiently invested in (by government and venture capitalists, etc) so that:

- the necessary tools and equipment can be bought,
- the personnel can be trained and recruited, and
- operating expenses can be covered.

Due to the uncertainty of what the future of nanotechnology holds (regarding the time to market, market potential and disruptiveness) this might hamper nanotechnology innovation.

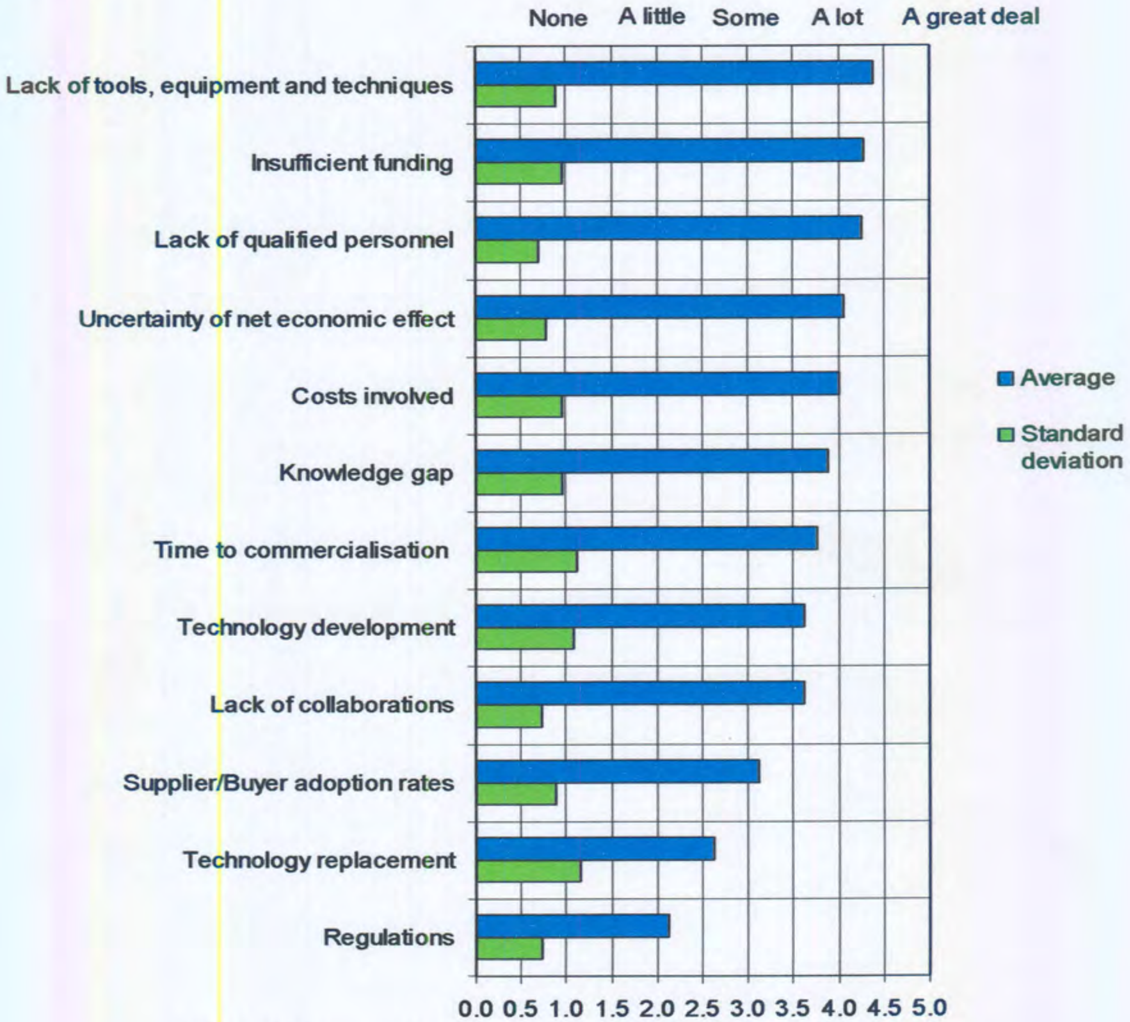

Figure 6-7. Innovation hampers' mean and standard deviation.

As stated in chapter 5, some innovation hampers not mentioned were corruption, the misuse or mismanagement of funds, lack of stakeholder initiatives, the support from government and the education of new scientists and researchers that would lead the development of nanotechnology.

The five least important South African nanotechnology innovation hampers are:

- Regulations (governmental and other legal restrictions)
- Technology replacement (potential for other newer nanotechnology products or processes to replace existing or up-and-coming nanotechnology products or processes)

- Supplier/Buyer adoption rates (when to switch from known product/processes to new nanotechnology product/processes)
- Lack of collaborations (relationships with other innovative organisations)
- Technology development (the disruptiveness and unfamiliarity of nanotechnology)

The proposition is that the participants perceive that:

- South African and world regulations will not hamper nanotechnology development;
- enough relationships are in place, or possible, with local and international nanotechnology firms;
- current markets will adapt fluently and quickly to new nanotechnology products and processes, and
- new nanotechnology markets will be sustainable.

Referring to hypotheses listed in Table 3-3, based on empirical data, the lack of tools, equipment, techniques and funding, together with the lack of personnel, was found as the biggest innovations hampers – supporting H0.2.

6.1.3 Nanotechnology actors

Countries perceive to fulfil the following nanotechnology roles (refer to Figure 6-8 and Appendix D.1.4 for statistical data):

- The most important buyers are North America, Asia and Europe. This is understandable if you look at the current amount of R&D activities in countries like the United States, China, Singapore, Germany and France. The second most important buyers are Australia, New Zealand and South Africa, with no opinion on South America and other African countries.
- The most important suppliers and competitors are North America, Asia and Europe. The second most important suppliers are Australia and New Zealand, with no opinion on South Africa and South America, and other African countries not seen as suppliers or competitors.
- The most important sources of relationships are Europe, South Africa and North America. South Africa already has strong innovation relationships with European countries (Oerlemans, Pretorius, Buys and Rooks 2003:78). Asia, Australia and

New Zealand can be seen as the second most important source of relationships, with no opinion on South America and other African countries.

As illustrated in Figure 6-9 the greatest amount of standard deviation was with South Africa as buyers and suppliers, with other African countries as buyers and/or relationships, and with South America in almost every role.

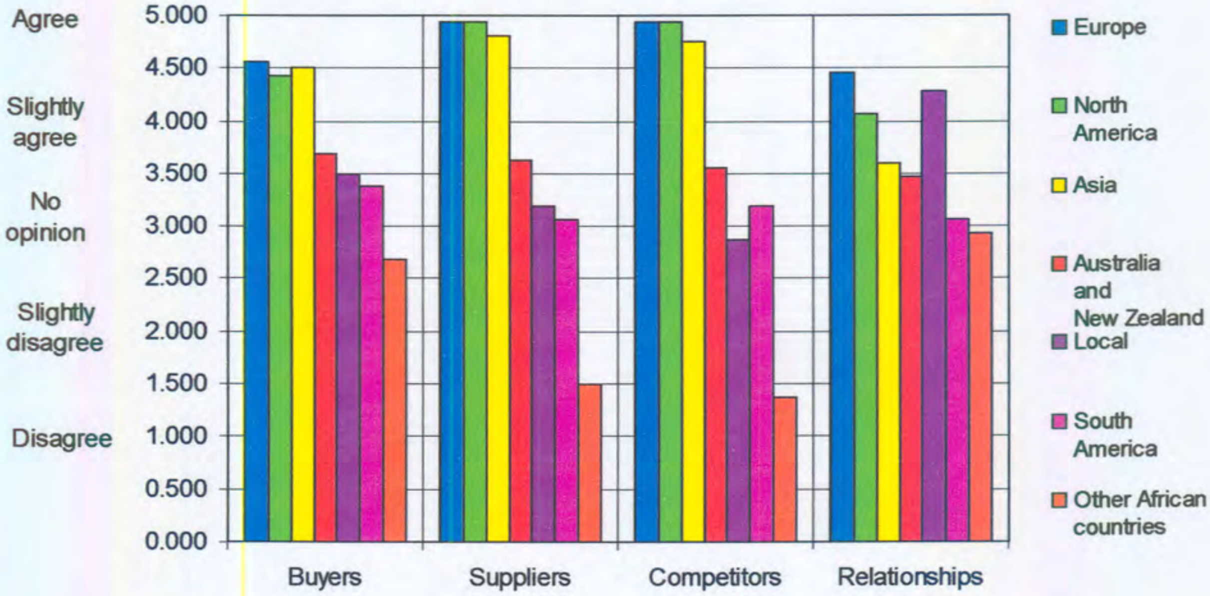

Figure 6-8. Bar chart of the nanotechnology actors' mean regarding each of the roles fulfilled.

Figure 6-9. Bar chart of the nanotechnology actors' standard deviation regarding each of the roles fulfilled.

Some propositions are that, with some certainty, Europe and North America will be the suppliers and competitors, South Africa will form relationships with European countries, and Asian countries will be the buyers and suppliers in nanotechnology products and processes.

South Africans feel a strong, but mixed, social responsibility to develop local and other African nanotechnology-related technologies and infrastructure, thus towards the formation of relationships with other African countries. South Africa might serve as the gateway of nanotechnology products and processes into the rest of Africa.

Figure 6-8 hints at the correlation between different nanotechnology roles, which are clearly illustrated by Figure 6-10. The greatest amount of standard deviation regarded the various nanotechnology roles of South Africa and South America (refer to

Figure 6-11). The positive perception of South Africa as a huge supplier in certain nanotechnology segments, like raw materials, but maybe not in other areas of high technology, was the cause of the big standard deviation regarding South Africa as a supplier of nanotechnology products and processes. The least amount of standard deviation regarded Europe and Asia. The participants therefore agree on the nanotechnology roles these countries will fulfil in the future.

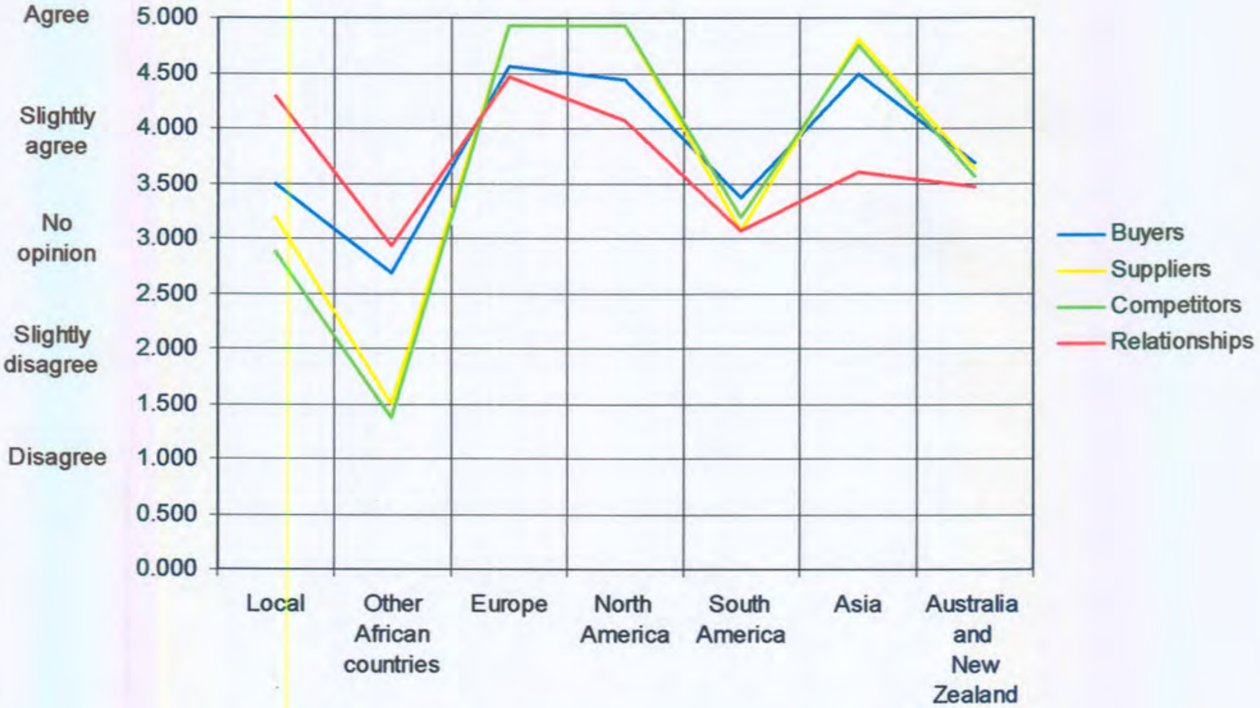

Figure 6-10. Interactive plots for nanotechnology actors' means regarding each country.

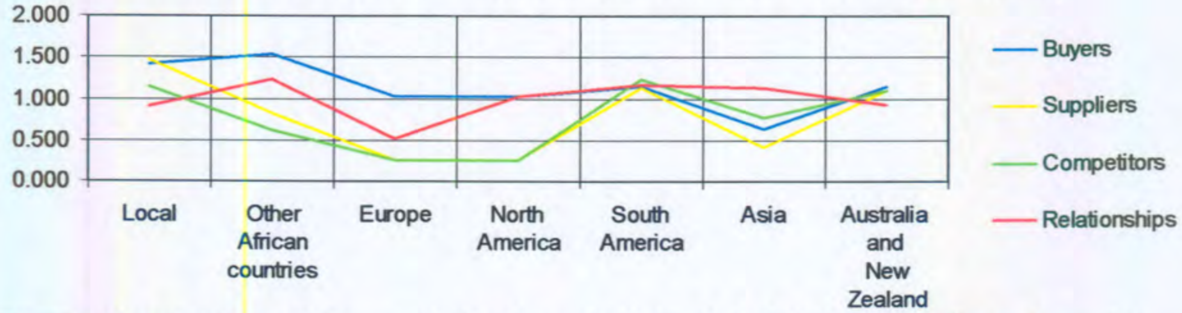

Figure 6-11. Interactive plots for nanotechnology actors' standard deviations regarding each country.

As illustrated in Table 6-2, there exist strong, positive correlations between all of the nanotechnology roles. The strongest correlations are between suppliers and competitors (0.922), buyers and suppliers (0.601), and buyer and competitors (0.581).

The proposition is that the buyers and suppliers of nanotechnology are also the most important competitors, with suppliers exerting the greatest competitive force. Interestingly the strongest correlation regarding relationships was with competitors (0.441). So indirectly, the most important relationships must be with suppliers.

Spearman correlation	Variable	Buyer	Supplier	Competitor	Relationship
Buyer	Correlation Coefficient	1.000	0.601**	0.581**	0.381**
	Sig. (2-tailed)	.	0.000	0.000	. 0.000
	N	112	112	112	104
Supplier	Correlation Coefficient	0.601**	1.000	0.922**	0.420**
	Sig. (2-tailed)	0.000	.	0.000	0.000
	N	112	112	112	104
Competitor	Correlation Coefficient	0.581**	0.922**	1.000	0.441**
	Sig. (2-tailed)	0.000	0.000	.	0.000
	N	112	112	112	104
Relationship	Correlation Coefficient	0.381**	0.420**	0.441**	1.000
	Sig. (2-tailed)	0.000	0.000	0.000	.
	N	104	104	104	104

Table 6-2. The Spearman correlation of questions 8 to 11. **Correlation is significant at the .01 level (2-tailed).

Referring to hypotheses listed in Table 3-3, based on empirical data, Europe is regarded as the most important buyer, supplier, competitor and source of relationships – supporting H0.3

6.1.4 SWOT analysis

The author proposes the following analogy to define strengths, weakness, opportunities and threats: "The moment time is frozen, the forces internal to a system (defined by a set of boundaries) that one have or not have is defined as a strength or weakness. The forces that only influence the system, when the time is continued (either pushing or pulling), external to the system are defined as an opportunity or threat." The information from the SANi and

AMTS SWOT analyses was reviewed and combined with the SWOT data provided by the participants. Table 6-3 illustrates the SWOT internal and external factors.

Key internal factors
Strengths (S)
1. South Africa possess selected nanotechnology-related knowledge, skills and experience
2. South Africa possess cost-efficient human resource practices (research and labour)
3. Good tertiary education standard
4. Innovative human resources
5. South African nanotechnology strategy in place
6. South African nanotechnology community have strong collaborations
7. Dedicated professionals
Weaknesses (W)
1. Insufficient funding
2. Insufficient amount of knowledgeable, skilled and experienced human resources
3. Insufficient equipment
4. Limited knowledge in some nanotechnology fields – lack of access to information, dependent on developed countries
5. Fragmentation of nanotechnology community (geographically)
6. Lack of nanotechnology focus areas
7. Lack of blue sky R&D
Key external factors
Opportunities (O)
1. Abundance of natural resources
2. Increased support for social development (energy, environment and health)
3. Increased support for centres of excellence development in nanotechnology-related knowledge, skills and experience
4. Untapped South African nanotechnology market
5. Untapped international nanotechnology market
6. Developed countries developing pacing technologies creating learning opportunities
7. Increased support for skilled human resource development supporting nanotechnology
Threats (T)
1. Pace of overseas nanotechnology development
2. South African tendency to licence technologies
3. International countries have greater resources available (human)
4. Increased international competition
5. Loss of knowledgeable, skilled and experienced human resources (immigration, HIV/Aids)
6. Incorrect allocation of South African funds
7. Increase in nanotechnology social/ethical/legal implications

Table 6-3. SWOT internal and external factors.

Table 6-4 and Table 6-5 discuss the strategies developed from the SWOT factors.

Capitalising on strengths and maximising opportunities (offensive strategies)	
Factors used	**Description of strategy**
S1, S2, S4, O1	Combine innovative nanotechnology knowledge, skills and experience in natural resource processing to develop cost-efficient products and processes implementing beneficiated natural resources.
S6, O4, O5	Use strong collaborations with Europe to penetrate foreign niche markets, and create strong relationship with other African countries to become a supplier of nanotechnology products and processes to sub-Saharan Africa.
S3, S6, S7, O6	Use strong collaboration with Europe to create more learning opportunities for dedicated South African students and personnel in European countries
S1, S5, S6, O2, O3, O6, O7	Illustrate through current nanotechnology knowledge, skills and expertise, and South African nanotechnology strategy to South African government, European nanotechnology institutions and other support organisations that the South African nanotechnology community are capable of developing industry leading nanotechnology products, processes and services
S1, O6	Offer South African nanotechnology knowledge, skills and expertise to international universities, investors, firms, etc. interested in nanotechnology research and development.
Addressing weaknesses through maximising opportunities (developmental strategies)	
Factors used	**Description of strategy**
W1, W2, W3, O2, O3, O6, O7	Appeal to South African government, European nanotechnology institutions and other support organisations that the South African nanotechnology community need support in the form of funding, equipment and training structures.
W2, W7, O4	Create awareness of the strengths, weaknesses, opportunities and threats of South African nanotechnology community and nanotechnology products, processes and services to South African public, universities, industry and science councils.
W4, O6	Create strong relationships with European, North American and Asian institutions to facilitate the training in and licensing of foreign nanotechnology products, processes and services research and development.
W5, W6, W7, O3	Create nanotechnology centres of excellence capable of funding, coordinating and facilitating South African nanotechnology product life cycle activities.
W6, O1	Focus nanotechnology research and development on the abundance of South African natural resources. Find applications for the natural resources.

Table 6-4. South African offensive and developmental nanotechnology strategies.

Minimising threats through capitalising on strengths (competitive strategies)	
Factors used	**Description of strategy**
S1, S4, S7, T1, T3, T4	Focus South African nanotechnology knowledge, skills and expertise on possible nanotechnology markets not identified or occupied by international nanotechnology researchers, developers and manufacturers.
S1, S2, S4, T2	Negotiate short-term licensing agreements with international nanotechnology research, developers and manufacturers with the goal of innovatively and cost-efficiently imitating these licensed nanotechnologies.
S3, S6, T1, T3	Use strong collaborations with European institutions to learn research, development and manufacturing practises, and negotiate separate areas of nanotechnology research, development and manufacturing. For instance, let South African researchers focus on materials beneficiation and European researchers on the implementation of the beneficiated materials.
S5, S6, T1, T7	Learn through international collaborations of the social, legal and ethical implications involved in nanotechnology research, development and manufacturing. Place the knowledge gained through these learning opportunities in the South African strategy as guidelines for South African nanotechnology researchers, developers and manufacturers.
S5, T6	Formulate the South African nanotechnology strategy to include funding structures, income statements, balance sheets, etc. of the South African nanotechnology community.
S6, T5	Regarding the loss of nanotechnology students and personnel due to immigration, keep strong collaboration with these individuals and firms. These collaborations could provide entry points into international nanotechnology markets and create international learning opportunities.
Minimising threats and avoiding weaknesses (defensive strategies)	
Factors used	**Description of strategy**
W1, W2, W3, W4, T1, T3	Negotiate collaborations with the international institutions, contract foreign human resources for the development of South African nanotechnology products, processes, services, knowledge and skills. Build relationships with the institution supporting their nanotechnology research, development and manufacturing.
W6, W7, T2	Use licensing technologies to create or identify South African nanotechnology focus areas and implement backward integration nanotechnology strategies.
W4, T4	Appeal to international nanotechnology institutions to support in the development of African technologies and economies. Appeal to their moral and ethical responsibility to improve the social and financial situation of developing countries. Offer competition free markets for these institutions in exchange for nanotechnology support.
W1, T6	Create necessary South African accounting and funding structures.
W5, T5	Do not regard immigration of nanotechnology students and personnel as negative, but rather build relationships with potential researchers, developers and manufacturers and keep these relationships even after immigration.

Table 6-5. South African competitive and defensive nanotechnology strategies.

6.2 CSIR baseline study questionnaire

6.2.1 South African nanotechnology activity formulation

The figures in Section 5.2.1 illustrated the number of participants involved in each nanotechnology product life cycle and nanotechnology segment. The purpose of the research project is, however, to estimate the number of activities in each nanotechnology product life cycle and nanotechnology segment.

The product life cycles of the CSIR baseline study questionnaire were transformed into product life cycles of the De Wet-Buys model (refer to Table 6-6). 'R&D' was cross-tabulated with 'Fundamental research', dividing 'R&D' into research and technology development.

De Wet-Buys model product life cycles	Product life cycle involvement question used	Nanotechnology involvement question used
Research	R&D	Fundamental research
Technology development	R&D	None
Product and process development	Use nanotechnology in process Use nanotechnology in product	None
Product and process improvement	Use nanotechnology in process Use nanotechnology in product Description written in other	None
Product and manufacture	Manufacture nanotechnology in process	None
Distribution, marketing, sales and service	Import and sell nanotechnology Nanomaterials or devices	None
Other	Other	None

Table 6-6. CSIR baseline questions used as indicators of each nanotechnology product life cycle activity.

The comments of the participants provided a method to distinguish between process and product development and improvement.

The CSIR baseline study questionnaire nanotechnology involvement areas were grouped similarly to the nanotechnology segments used in the research project questionnaire (refer to Table 6-7). The aim was to create a relationship between the present nanotechnology segment developments and what the research project questionnaire experts perceive the future of these nanotechnology segments are. The classifications provided by Gordon (2002), confirmed through interviews with Mr. M Scriba, serve as the basis for the groupings.

Drug delivery was interpreted as drug delivery systems, thus classifying under nanodevices and systems. Membranes belong to the nanostructures segment.

A proposition is that other information regarding the nanotechnology source of funding, personnel, education, networking, collaboration and equipment serve only as background information, supporting the nanotechnology activity information. It would be fruitless, for instance, to estimate the number of personnel or student activities per nanotechnology product life cycle and nanotechnology segment – The cross-tabulation would be a carbon copy of the cross tabulation of the amount of university, industry and/or science activities per nanotechnology product life cycle and nanotechnology segment.

Research project nanotechnology segment	CSIR baseline study nanotechnology areas
Tools	Atomic modelling and characterisation
Nanomaterials	Nanomaterials (Particles, tubes, composites), catalysis, Nano-emulsions and coatings
Nanostructures	Membranes
Nanodevices and systems	Drug delivery and nanodevices
Nanomachines	None
Nanobiotechnology	Nanobiotechnology
Other	Other

Table 6-7. Grouping of CSIR baseline questionnaire nanotechnology involvement areas into research project questionnaire nanotechnology segments.

According to Page and Meyer (2000), only cross tabulations are bivariate measures of association between any discrete variables. Thus, in the analysis of the amount of nanotechnology activities, cross tabulations between the product life cycle involvement and nanotechnology segment involvement were calculated, and illustrated in terms of university, industry and science council activities.

Figure 6-12 illustrates these activities. Appendix D.2.1 and D.2.2 contain the full cross tabulation between the new nanotechnology product life cycles, the original and new groupings of nanotechnology segment involvement areas.

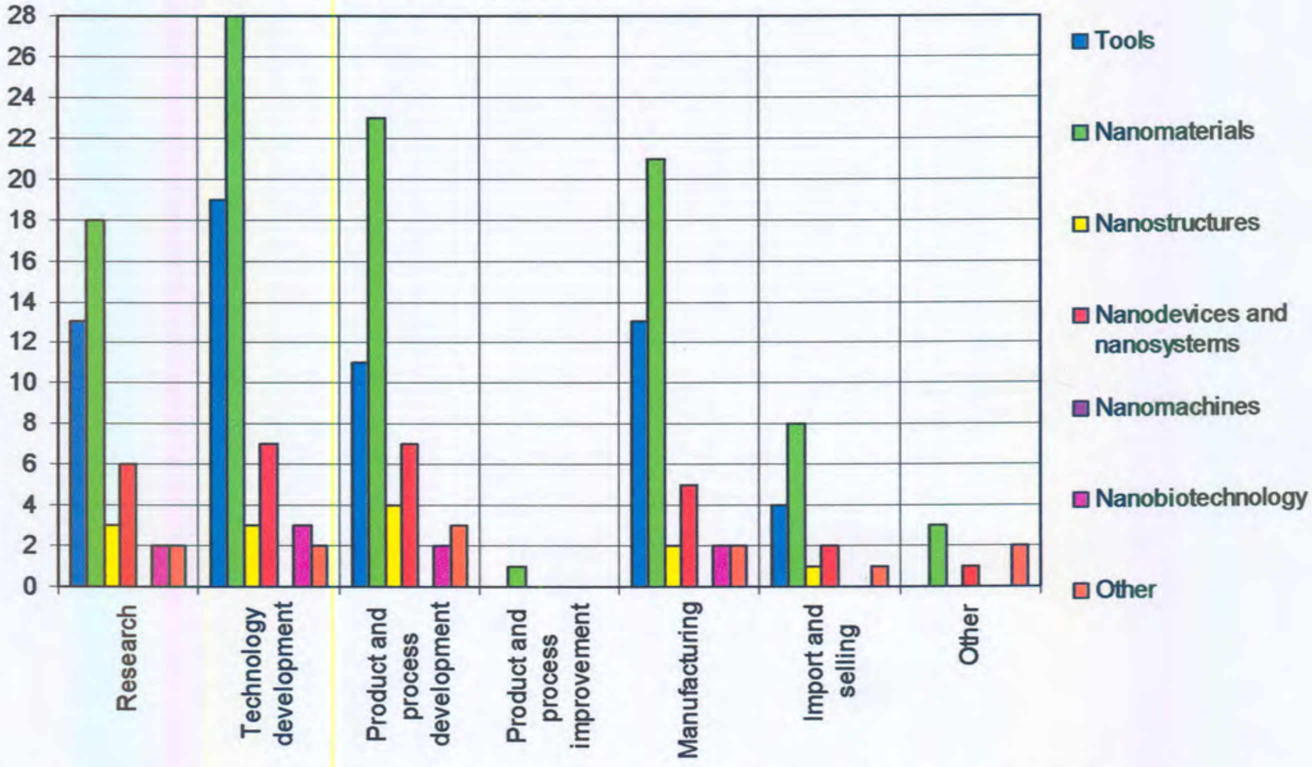

Figure 6-12. Bar chart of cross tabulation for nanotechnology product life cycle and involvement areas.

An extremely important assumption in performing the cross-tabulation was that the participants perform all the chosen nanotechnology product life cycles equally on all the chosen nanotechnology segments. The assumption might not be true, but in answering all the questions to gauge all the nanotechnology involvement segments and the product life cycles applicable to them would be daunting to the participants. In the original CSIR baseline questionnaire that would add up to thirteen nanotechnology segment multiple choice questions with six product life cycle options each, equalling a maximum of seventy-eight multiple choice answers. The assumption could be scratched, but would the participants even bother to look at the questions?

6.2.2 South African product life activities

As postulated earlier, the level of activities should gradually increase from research to distribution, marketing, sales and services. Figure 6-13 illustrates that the activity level increases from research to technology development, but slightly decreases to product and process development and dramatically decreases to product and process improvement. The level of manufacturing activities is comparable to product and process development, but again the amount of distribution, marketing, sales and services activities of manufactured products and processes are very low. The level of activities thus tends to decrease, instead of increase, towards distribution, marketing, sales and service with almost no product and process improvement activities.

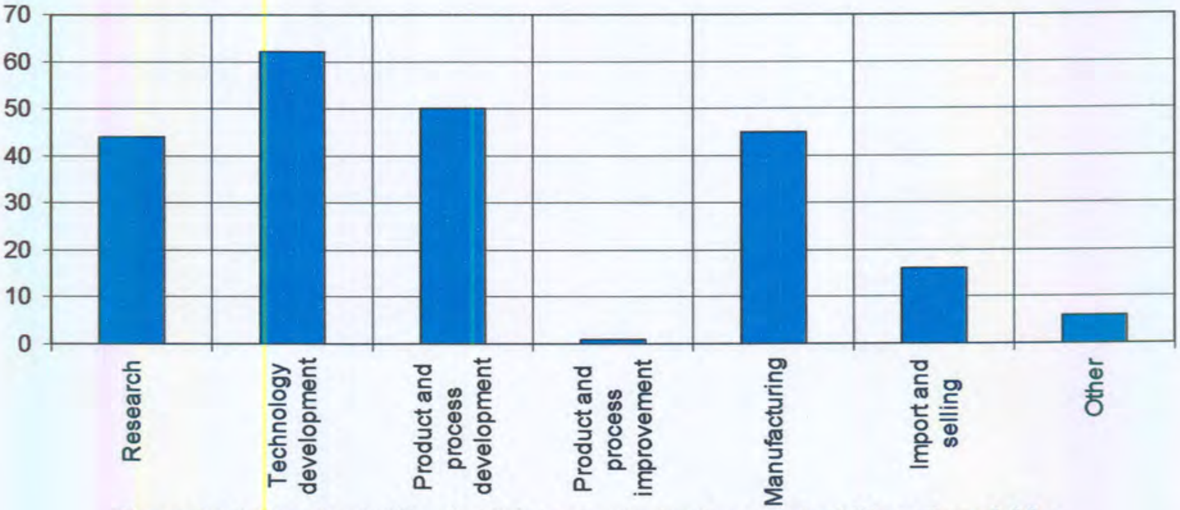

Figure 6-13. Bar chart of South African nanotechnology product life cycle activities.

The proposition is that most South African researchers focus on the first, second, third and fifth product life cycle. The focus is on development of fundamental knowledge, skills and human resources (the basis of technology).

Another proposition is that most of the manufacturing activities are small-scale manufacturing, with the aim of developing and testing products and processes. Interviews with Mr. M. Scriba confirmed these propositions. Possibly, only one participant (also involved in the product and process improvement) possesses large-scale manufacturing capabilities.

Other activities mentioned in the study was participants being interested in nanotechnology development and merely reading publications relating to nanotechnology developments, investments and international industry discussions.

Nanotechnology is still relatively unexplored; the majority of worldwide activities are only research, technology development, and product and process development. South Africa is currently on the right track. Internationally only a few products, featuring nanotechnology incremental improvements, have emerged. Thus, internationally the level of activity trend decreases from research to distribution, marketing, sales and services.

However, a worrying factor is that South African nanotechnology participants do not regard licensing as a source for product and process improvement (for backward integration according to Buys (2001)). This is evident in the fact that only seven participants imported some existing nanotechnology products and processes. Remember that from the research project questionnaire, many of the participants perceived that licensing as a South African weakness and felt threatened by the pace of overseas nanotechnology developments. These seven participants are also involved in other nanotechnology product life cycle activities (refer to Figure 6-14), which could be because of implemented backward integration strategies.

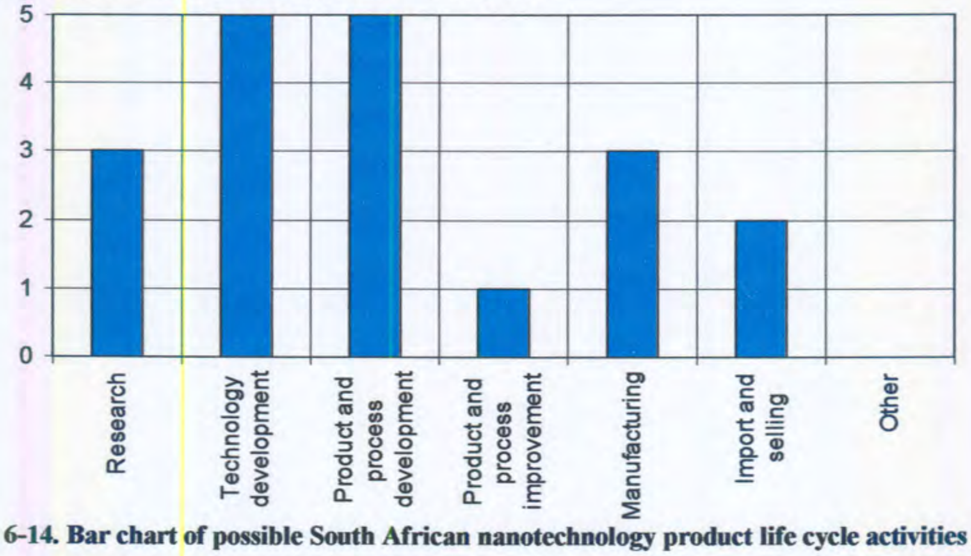

Figure 6-14. Bar chart of possible South African nanotechnology product life cycle activities relating to the import of nanotechnology products and processes.

Due to the amount of university participants (63% versus 28% industry and 9% science councils), it was assumed that the majority of activities would also be performed by personnel and students at these universities. The assumption proved to be true (refer to Figure 6-15).

There is, however, some interesting facts regarding the South African nanotechnology product life cycle activities:

- Universities perform twice as many research and technology development activities as industry and science councils.
- Universities and science councils perform almost the same amount of product and process development activities, and twice more than industry. This is astounding if taken into account that three times less science council participants took part in the CSIR baseline study.
- Only one participant performs known product and process improvements.
- Universities perform twice as many manufacturing activities as industry and science councils. This might also enforce the assumption that most of the manufacturing activities are small-scale manufacturing for testing and developing purposes.
- Universities perform the majority of the import and selling activities. The assumption is that the universities import nanotechnology with the goal of research and development in mind, not selling a product or process. Industries perform two import and selling activities.

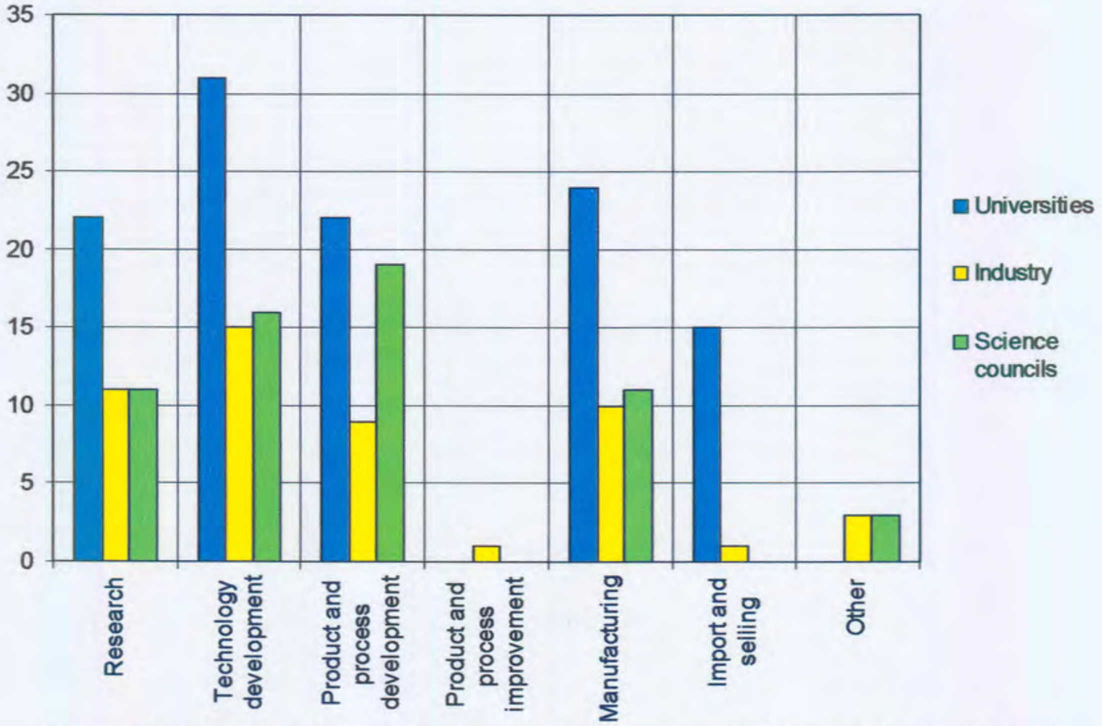

Figure 6-15. Bar chart of South African nanotechnology product life activities according to universities, industry and science councils.

6.2.3 South African nanotechnology focus area activities

Figure 6-16 illustrates the South African nanotechnology segment activities. The bulk of the activities concerns tools (with atomic modelling 18 and characterisation 42 activities) and nanomaterials (with nanomaterials 47, catalysis 23, nano-emulsions 14 and coatings 19). To a lesser extent, some activities focus on nanostructures (with membranes 14), nanodevices and systems (with drug delivery 13 and nanodevices 15). Other activities concern nanofluids (which could also form part of nanomaterials) and other modelling techniques.

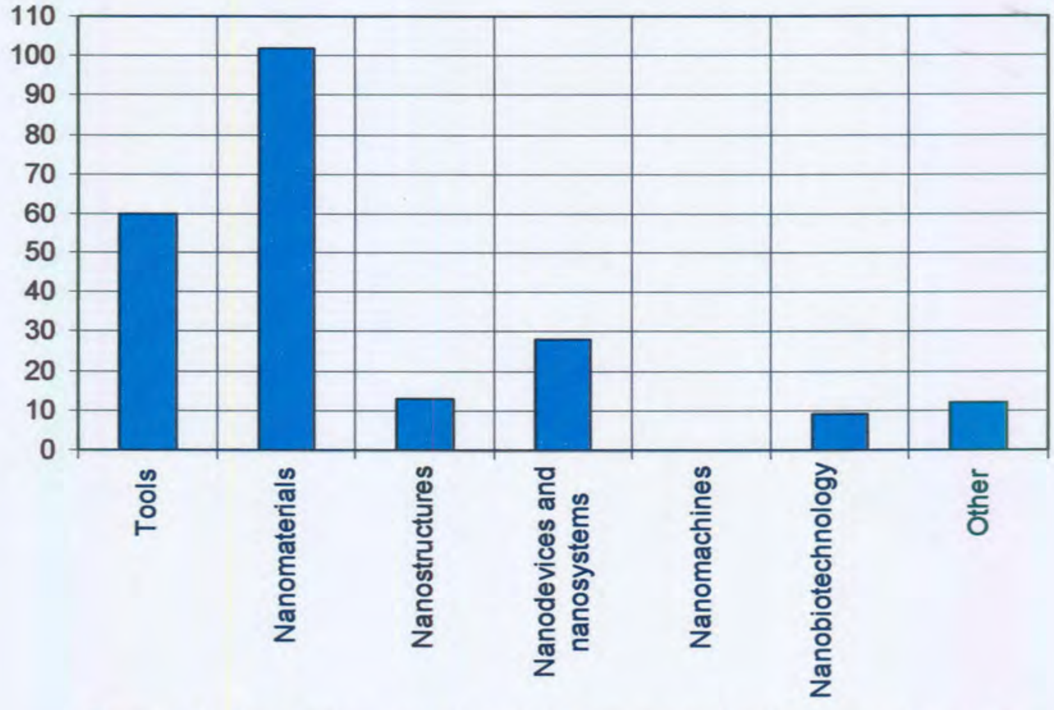

Figure 6-16. Bar chart of current South African nanotechnology segment activities.

When investigating the South African nanotechnology segment activities it was expected that universities would perform at least twice as much activities in multiple nanotechnology segments than industry and the science councils, due to the number of university participants. The figures proved otherwise (refer to Figure 6-17):

- Universities focus three times more on nanotechnology tools activities than industry and science councils do.
- Universities focus a third more on nanomaterials than industry, and two thirds more than science councils do.

- An almost even amount of activities are performed on nanostructures by all the institutions
- Only universities and science councils are involved in nanodevices and systems activities.
- Only industry and science councils are involved in nanobiotechnology activities.

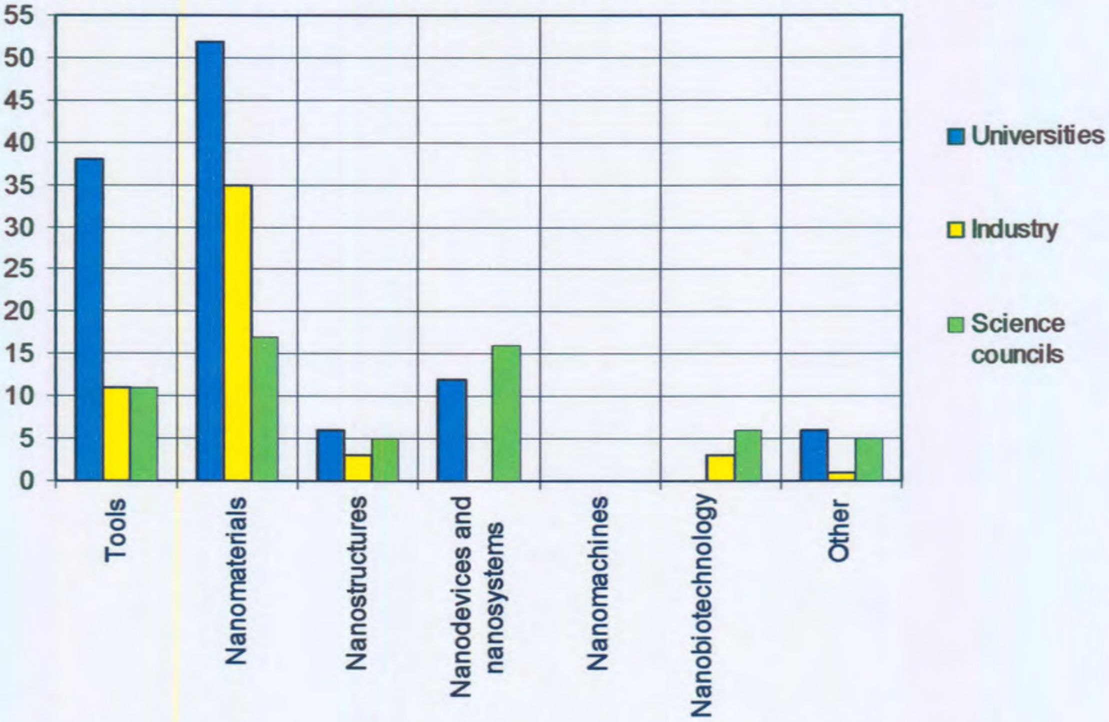

Figure 6-17. Bar chart of current South African nanotechnology segment activities according to universities, industry and science councils.

7 Conclusions and recommendations

7.1 Summary of research results

7.1.1 Background

De Wet (2000) classified South Africa as a technology colony. Industry has never been in a position to exploit the incremental innovations and cannot create opportunities by itself due to the lack of research and development. The trend is, however, shifting. South Africa has been active in nanotechnology development for the last few years, creating nanotechnology awareness, receiving limited funding from a variety of sources, devising a national strategy and developing a new generation of researchers with new nanotechnology knowledge, skills and experiences, and building relationships with local and international institutions.

Sixteen South African nanotechnology experts with diverse backgrounds and interests took part in the research project questionnaire process. Forty-seven South African nanotechnology researchers and developers from universities (65%), industry (28%) and science councils (9%) provided information for the CSIR baseline study.

Unfortunately, the funding data was seen as confidential (or in some instances unknown) by most of the participants, who then only stated the sources of their funding and not the amount of funding received. Universities, much more than industry and science councils, used public funding sources. Industry relied more on private and internal funding sources.

Universities employ the most nanotechnology personnel, followed by science councils and industry. There is more male than female nanotechnology personnel, with almost an equal number of non-white and white nanotechnology personnel.

One of the issues brought up in the research project questionnaire is the aging nanotechnology research community – and how this could be a weakness within the South African nanotechnology community. This is clearly not the case. The majority of the personnel are between the ages of 20 and 30, with only 10% of the personnel over the age of 50.

Universities employ more people between the ages of 20 and 30 than any other age group, thus it may be said that the nanotechnology community could have access to a range of young and diverse nanotechnology researchers. Industry and science councils possess a good distribution of young and old employees. Note that the total number of personnel might be slightly skewed because of the possible inclusion of students as personnel by many of the university departments. Students are able to act as junior lecturers, teaching and research assistants, while continuing their studies.

One hundred-and-sixty-two students are enrolled in nanotechnology curricula. Female nanotechnology students are more than female nanotechnology personnel and half of the male nanotechnology students. Non-white nanotechnology students are three times more than the white nanotechnology students. Eighty per cent of the nanotechnology students are South African, with a small number of students from other African countries, Europe and Asia.

Almost 80% of all taught nanotechnology programmes are aimed at PhD level students and an equal distribution of students (each about 30%) are enrolled in Honours, Master's and PhD programmes. Only 15% of Bachelor's students are enrolled for nanotechnology subjects.

The majority of nanotechnology collaborations are with firms and universities in Europe and with very few in North America, Australia and Asia. Curiously, no collaborations were noted with other African countries, since 13 students originated from other African countries.

Participants are aware of the existence of SANi (and most probably its activities), and do engage in national and international collaborations. Most of the national collaborators are groups from local universities. This might be an indication that most industry participants contract or fund a South African university in the development of nanotechnology knowledge and skills, and acquisition of nanotechnology equipment. Another proposition is that many of the employees of these industry participants, studied (or are still studying) at these universities.

Interestingly, it was found that national and international collaborations were equally relied on. This contradicts the notion that international funding is not significant. Why would many South African institutions engage in international collaborations, but they do not use these collaborations as funding mechanisms?

International projects are an indication of both the willingness to learn and to build international relationships. Universities primarily support most of the international projects. Only four universities stated that government arranged some of the collaborations.

Half of the participants felt the nanotechnology-related equipment was in a good condition, with 36% and 13% feeling that their equipment was average or bad. In the comparison of the equipment, 31% felt their equipment was on the same standard as the rest of the world's, with 42% and 27% feeling that their equipment are slightly and much worse. Most of the equipment belonged to universities and science councils. Industry has limited access to state-of-the-art equipment. Most of the universities stated that their equipment was funded either internally or through public funding mechanisms such as THRIP and the NRF. Some of the universities stated that they did already allow the use of their equipment by other departments, universities and industry.

7.1.2 Nanotechnology activities, segments, innovation hampers and relationships

Gordon (2002), amongst others, defined and plotted several nanotechnology segments as market potential versus value adding, complexity, time to market and risk. The research project took these nanotechnology segments and the nanotechnology focus areas of the CSIR baseline study, and adapted them to form six nanotechnology segments, namely:

- tools,
- nanomaterials,
- nanostructures,
- nanodevices and systems,
- nanobiotechnology, and
- nanomachines.

Figure 7-1, Figure 7-3 and Figure 7-2 plot the market potential against time to market, disruptiveness and complexity, and indicates the level of South African activities for each nanotechnology segment. The segments have medium to big market potential, with nanodevices and systems having the most and machines having the least. The segments increase almost linearly in time to market, from 1-5 years to 10-15 years time to market, with nanomaterials expected the earliest and nanomachines expected the latest. Note that the time to market for nanomachines (10-15 years) differs greatly from the other segments (between 1-5 years to 5-10 years), indicating that machines might still be very much a futuristic concept.

Tools and nanomaterials are more complementary than nanodevices and systems that are more replacing. The spread of answers between complementary and replacing for nanostructures, nanobiotechnology and nanomachines shifts the averages of these segments towards no opinion.

The segments increase almost linearly in complexity from relatively complex to very complex, with tools and nanomaterials the least complex and nanomachines the most complex. Again note that the complexity, as with the time to market, for nanomachines (very complex) differ greatly from the other segments (between relatively complex to complex), confirming that machines might still be a futuristic concept.

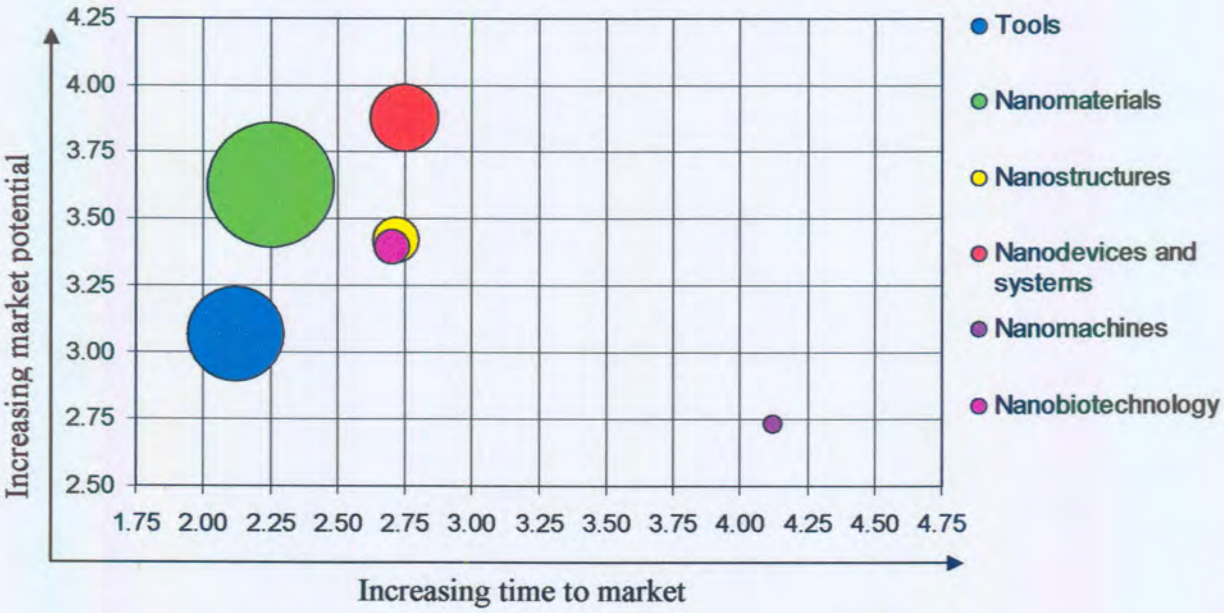

Figure 7-1. Time to market versus market potential of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment.

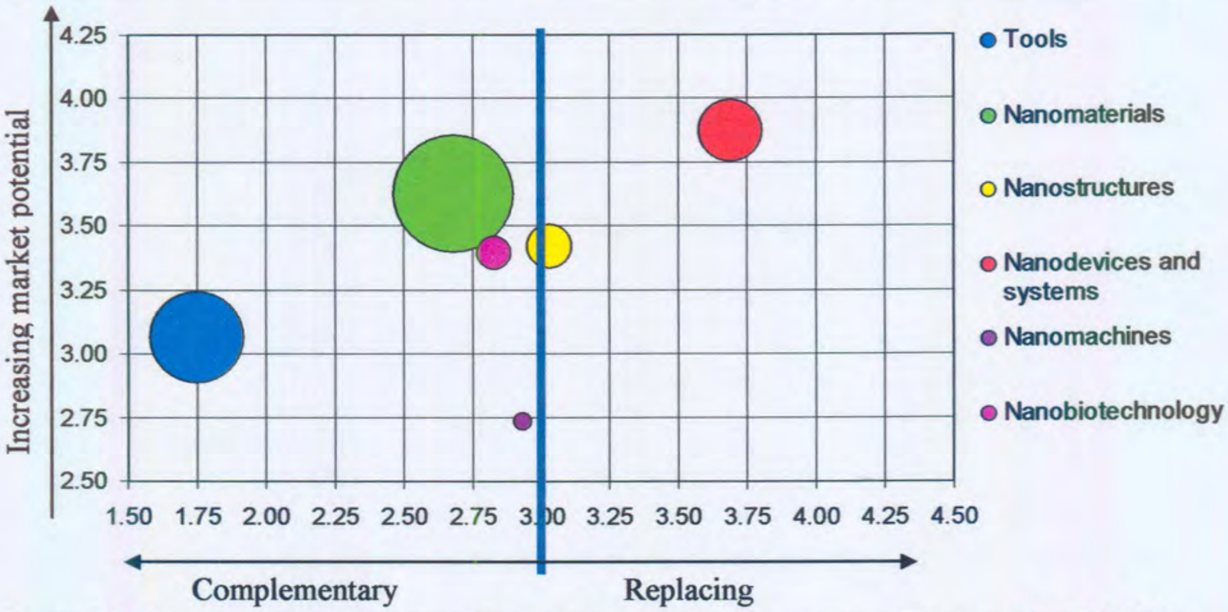

Figure 7-2. Time to market versus disruptiveness of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment.

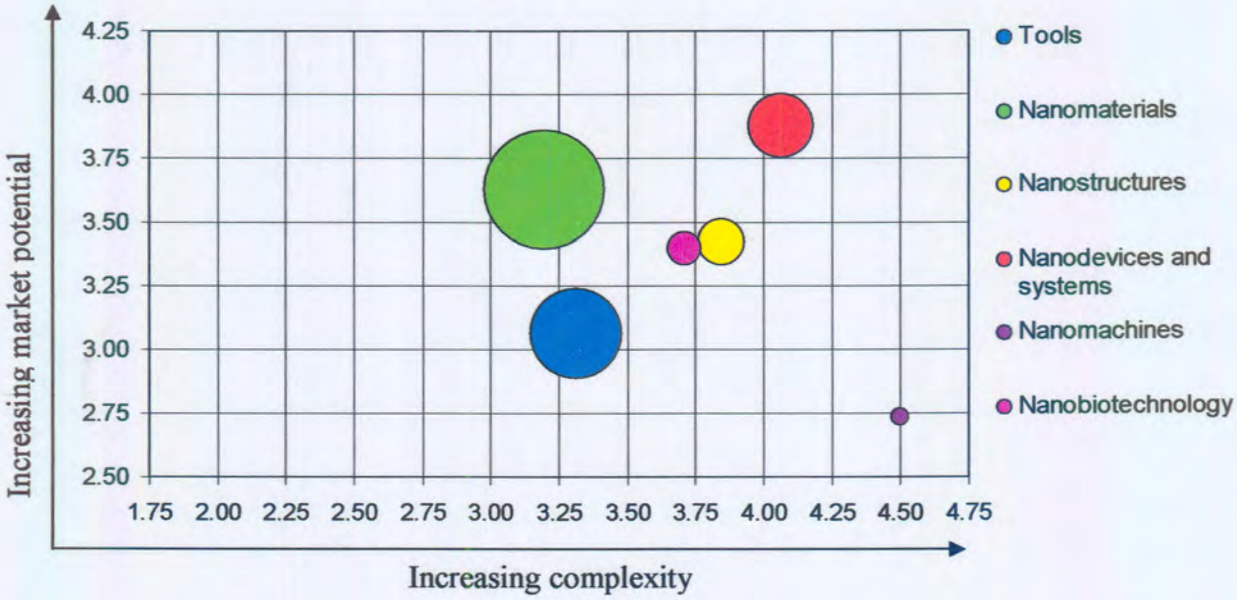

Figure 7-3. Time to market versus market potential of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment.

There exists a relatively strong positive correlation between time to market and complexity and interestingly enough, a relatively strong negative correlation between time to market and market potential. These correlations indicate that as the complexity increases so does the time spent in the research, development, manufacturing, marketing and eventual time to market. The increase in time to market leads to a decrease in market potential. The reason for the last stated correlation might be due to a short-term perspective of when a return of investment is expected. If the time to market is too long, investors might perceive the segment as not having great short-term market potential.

Because only two participants answered the second questionnaire, the data was considered insignificant and not analysed. However, two conclusions that could be drawn from the answers are:

- Tools, nanomaterials and nanostructures require a medium amount of skilled human resources to fully research, develop, manufacture, market and sell, while nanodevices, systems and nanomachines require a huge amount of skilled human resources.
- The South African government will have to support research and development until feasible nanotechnology applications are generated, at which point venture capital would play a role in the exploitation of these nanotechnology incorporating products, processes and services.

The five most important South African nanotechnology innovation hampers are and will be:

- Lack of tools, equipment and techniques (hardware – microscopes, software – computer simulations)
- Insufficient funding (lack of appropriate government or other external funding)
- Lack of qualified personnel (insufficient training)
- Uncertainty in the net economic effect (breadth, growth and impact of nanotechnology unsure)
- Costs involved (estimated cost too high)

The proposition is that the South African participants perceive that nanotechnology must be sufficiently invested in (by government and venture capitalists, etc) so that:

- the necessary tools and equipment can be bought,
- the personnel can be trained and recruited, and
- operating expenses can be covered.

Due to the uncertainty of what the future of nanotechnology holds (regarding the time to market, market potential and disruptiveness) this might hamper nanotechnology innovation.

Another proposition is that South African participants perceive that:

- the South African and world regulations will not hamper nanotechnology development;
- enough relationships are in place, or possible, with local and international nanotechnology firms;
- current markets will adapt fluently and quickly to new nanotechnology products and processes, and
- new nanotechnology markets will be sustainable.

Countries will fulfil the following nanotechnology roles regarding buyers, suppliers, competitors and relationships:

- The most important buyers are North America, Asia and Europe, followed by Australia, New Zealand and South Africa with no opinion on South America and other African countries.
- The most important suppliers and competitors are North America, Asia and Europe followed by Australia and New Zealand with no opinion on South Africa and South America, and other African countries not seen as suppliers or competitors.
- The most important sources of relationships are Europe, South Africa and North America, followed by Asia, Australia and New Zealand with no opinion on South America and other African countries.

Mixed perceptions surrounding other African countries were noticed, possibly, because South Africans feel a strong social responsibility to develop local and other African nanotechnology-related technologies and infrastructure.

The strongest correlations are between suppliers and competitors, buyers and suppliers, and buyers and competitors. The proposition is that the buyers and suppliers of nanotechnology are also the most important competitors, with suppliers exerting the greatest competitive force. Interestingly the strongest correlation regarding relationships was with competitors. Indirectly the most important relationship must be with suppliers.

The nanotechnology strategies developed in the research project, will be discussed in the sub-chapter regarding recommendations to the South African nanotechnology community. These strategies incorporated the opinions of the research project questionnaire participants, information gathered through the CSIR baseline study and other secondary data sources.

Figure 7-4 illustrates that the South African nanotechnology activity level increases from research to technology development, but slightly decreases to product and process development and dramatically decreases to product and process improvement. The level of manufacturing activities is comparable to product and process development, but again the amount of distribution, marketing, sales and services activities of manufactured products and processes are very low. Thus the level of activities tend to decrease, instead of increase, towards distribution, marketing, sales and service, with almost no product and process improvement activities.

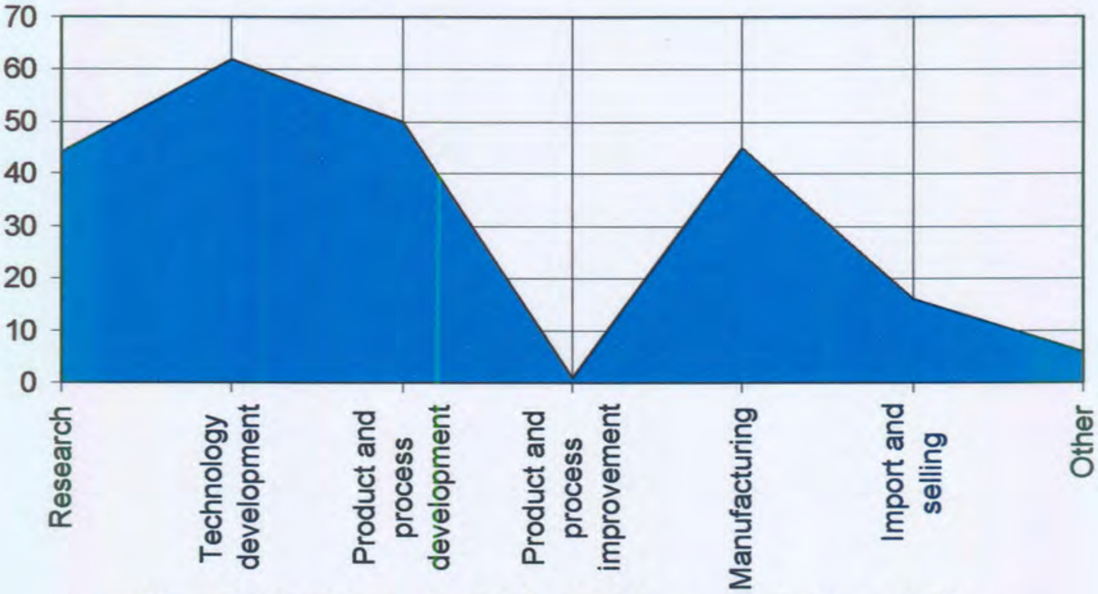

Figure 7-4. Stacked area chart of South African nanotechnology activities.

Nanotechnology is still relatively unexplored; the majority of worldwide activities are only research, technology development, and product and process development. Product and process improvements are only possible if extensive research, technology, product and process development have been performed. The resultant products, processes and services can then be improved, manufactured and sold (forward integration). Another product and process improvement possibility is foreign products, processes and services that are acquired with the aim of learning and improving or adapting them to local market needs (backward integration).

South Africa is currently on the right track. Internationally only a few products, featuring nanotechnology incremental improvements, have emerged. Thus, backward integration is not plausible now. The only way to develop nanotechnology products, processes and services might be to research and develop it locally, fostering entrepreneurship and through the aid of international collaborations. Internationally the level of activity trend decreases from research to distribution, marketing, sales and services.

However, a worrying factor is that South African nanotechnology participants do not regard licensing as a source for product and process improvement (for backward integration). This is evident in the fact that only seven participants imported some existing nanotechnology products and processes. Remember that from the research project questionnaire, many of the participants perceived licensing as a South African weakness and felt threatened by the pace of overseas nanotechnology developments. These seven participants are also involved in other nanotechnology product life cycle activities, which could be because of implemented backward integration strategies.

The bulk of the activities concerns tools and nanomaterials, and to a lesser extent some activities focussed on nanostructures, nanodevices and systems, and other activities concerning nanofluids and other modelling techniques (refer to Figure 7-5).

Universities focus three times more on nanotechnology tools than industry and science councils do, and a third more on nanomaterials than industry and two-thirds more than science councils. An almost even amount of activities is performed on nanostructures by all the institutions. Only universities and science councils are involved in nanodevices and systems activities. Only industry and science councils are involved in nanobiotechnology activities.

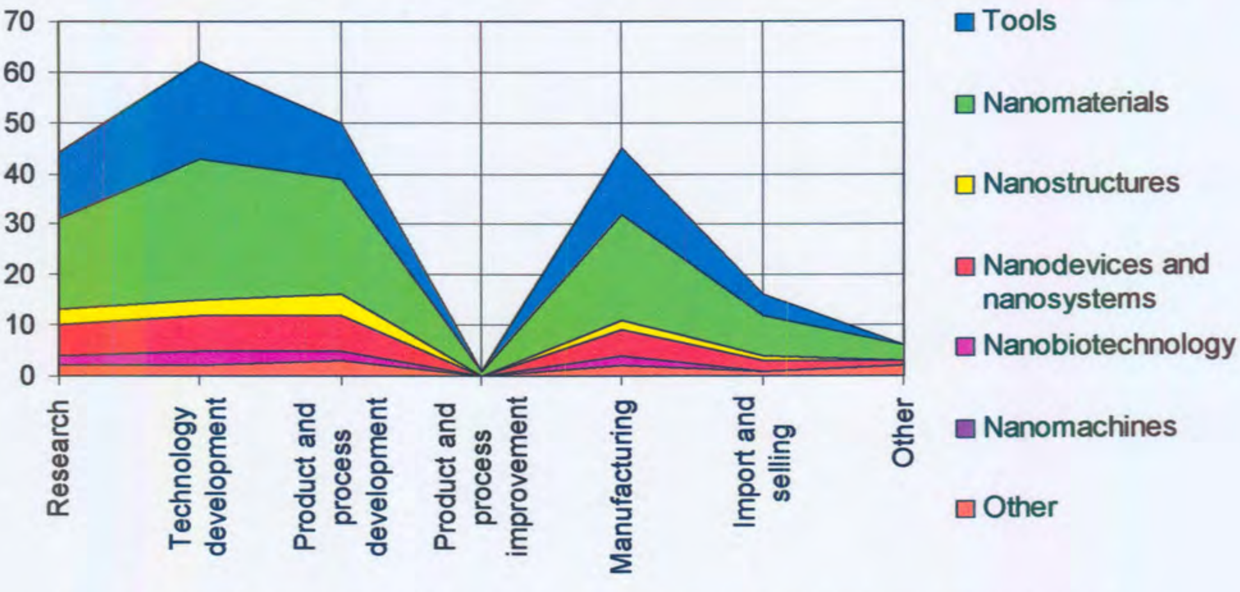

Figure 7-5. Stacked area chart of South African nanotechnology activities per nanotechnology segment.

Universities accounted for most of the nanotechnology product life cycle activities, with science councils focussing the most on product and process development, and industry focussing the most on technology development (refer to Figure 7-6). Only one participant performs product and process improvements.

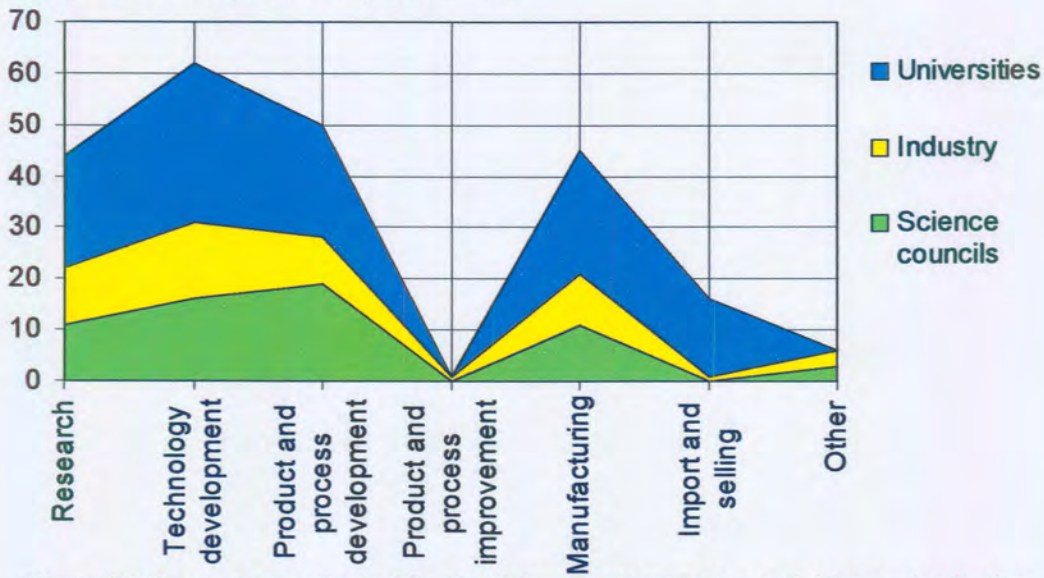

Figure 7-6. Stacked area chart of South African nanotechnology activities per institution.

Table 7-1 provides the conclusions drawn regarding the hypotheses, created in chapter 3.2, which guided the research project into exploring the facts of and relationships between the current and future South African nanotechnology development.

Primary hypotheses	Description of primary hypotheses	Conclusions
H0	Activities are centred on the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge	The majority of nanotechnology product life cycle activities are centred on research, technology development, product and process development and manufacturing, supporting to a greater extent H0
H1	Activities are not centred on the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge	
H2	Nanotechnology already impacts current products and markets	Nanotechnology tools, nanomaterials and probably some nanostructures does already impact some product and markets supporting H2
H3	Nanotechnology does not impact current products and markets	
Secondary hypotheses	**Description of secondary hypotheses**	**Conclusions**
H0.1	Universities perform the most research and technology development activities	Based on empirical data – universities do perform more research and technology development activities than any other institution supporting H0.1
H1.1	Universities do not perform the most research and technology development activities	
H0.2	Funding and equipment are the biggest nanotechnology innovation hampers	Based on empirical data – the lack of tools, equipment, techniques and funding was found as the biggest innovations hampers supporting H0.2, although the lack of personnel was also found as a big innovation hamper
H1.2	Funding and equipment are not the biggest nanotechnology innovation hampers	
H0.3	Europe is the biggest source for international nanotechnology transfer	Based on empirical data – Europe is regarded as the most important buyer, supplier, competitor and source of relationships supporting H0.3
H1.3	Europe is not the biggest source for international nanotechnology transfer	
H2.4	Nanotechnology products and processes will emerge within the next 5 years	Based on empirical data – tools, raw materials structures, nanotubes and fullerenes are most likely to emerge within the next 5 years supporting H2.4, however devices, systems, intelligent materials and machines are most likely to emerge in 5 to 15 years supporting H3.4
H3.4	Nanotechnology products and processes will not emerge within the next 5 years	
H2.5	Nanotechnology does possess better than good market potential	Based on empirical data – all the nanotechnology segment posses a medium to big market potential supporting H2.5
H3.5	Nanotechnology does not possess better than good market potential	
H2.6	Nanotechnology will complement current technologies	Based on empirical data – tools, nanotubes and fullerenes will be more complementary supporting H2.6 and devices, systems and intelligent materials will be more replacing supporting H3.6.
H3.6	Nanotechnology will not complement current technologies	

Table 7-1. Conclusions to research project hypotheses.

7.2 Implications for and contributions to the South African nanotechnology community

The research project was a successful collaboration between the author and the CSIR baseline study that supplements the South African strategy documentation (SANi 2003), and can act as a basis to facilitate the transformation of South Africa into an international nanotechnology competitive force.

The document contributes the following information:

- A classification of future nanotechnology industries regarding time to market, market potential, disruptiveness and complexity.
- An identification of innovation hampers for the South African nanotechnology community.
- A ranking of nanotechnology national and international nanotechnology buyers, suppliers, competitors and relationships.
- An analysis of the South African nanotechnology system of innovation.
  - Discussion of background information regarding nanotechnology awareness, involvement, funding, personnel, education, networking and equipment.
  - Calculation and illustration of figures on the level of nanotechnology activities for each product life cycle and per institution.
- Formulation of innovative strategies from information gathered on internal South African nanotechnology strengths and weaknesses, and external nanotechnology opportunities and threats.

The information extrapolates the current South African nanotechnology activities (strengths and weaknesses) with future nanotechnology industries, innovation hampers and actors (opportunities and threats).

South Africa is mainly involved in nanotechnology segments, nanotools and nanomaterials, with short time to market, and medium to big market potential, which are more complementary to current technologies. The fact suggests that South African innovation aims at short-term investment and development, which are easier to develop but still posses some market potential.

The current strategy may not be wrong; South Africa does possess knowledge, skills and expertise in selected nanotechnology fields such as modelling and the characterisation of nanomaterials. These knowledge, skills and expertise can be unique to South African researchers and development, difficult to imitate by developed countries or may even be implemented by developed countries in their nanotechnology products, processes and services. A number of institutions are involved in product and process development, which illustrates that South Africa's nanotechnology community could be able to deliver their own products, processes and services from research and development, through to the marketing and selling.

As illustrated in the study, most of the international investors (NanoInvestorNews, 2004) lean towards investment with medium to long-term investment periods, waiting for an opportunity to enter the market regarding nanotechnology-incorporating applications. This may hint that the fact most capital and support might be leveraged more towards nanodevices, systems, biotechnology and machines. These nanotechnology segments are not the primary focus of many South African researchers and developers.

Innovation hampers stand in the way of the research, development and eventual selling of the nanotechnology products, processes and services, and therefore will have to be addressed by the South African nanotechnology community itself, by industries that gain awareness of the opportunities and threats of nanotechnology or by the South African government that does support skilled human resource development.

The study illustrates that the South African nanotechnology community already possess a number of local and European relationships in the form of tertiary institution research and development collaborations or import of basic nanotechnology segments. Institutions from Europe, North America and Asia will be the most important buyers, suppliers, competitors and source of relationships. Other African countries might become a lucrative market with South Africa alleviating social, environmental and economical pressures through the implementation of nanotechnology applications. Relationships with other African countries could form through the exchange of students from these countries to South Africa (already present) and its overseas collaborators, to develop knowledge and capability bases in nanotechnology.

The nanotechnology community, with the research project information, analysis and strategies and other studies as the base, can draw and construct their own conclusions and strategies to enter competitively into the ever-growing nanotechnology markets.

7.3 Self assessment

The research project is the successful culmination of hundreds of hours of literature reviews, questionnaire designs, data gathering, database designs, and finally yet importantly report writing.

The author of the research project was fortunate enough to meet Mr. Manfred Scriba, the convenor and project coordinator of SANi. Without him, the research project would not have been a success. Mr. Manfred Scriba is an invaluable asset to any South African nanotechnology-related study. He possesses a great deal of knowledge of the South African nanotechnology national system of innovation, knowledge on technical knowledge nanotechnology fields and collaborations with many of the South African nanotechnology community members. The author aided in designing, distributing and gathering CSIR baseline questionnaires, and designing databases, and by plotting and analysing the gathered data. In return, the author of the research project could use the CSIR baseline study data.

The author gained a great deal of knowledge in fields such as innovation, technology management, research methodology, database design and manipulation, but also in softer skills such as business negotiations, politics and interviewing. The greatest limitation to the research project was gaining commitment from the South African nanotechnology community. Through numerous telephone conversation and interviews, and gaining the trust of many of the SANi members, this limitation was overcome.

Although initial mistakes were made, by not correlating the nanotechnology segments of the research project with those of the CSIR baseline study, and not sufficiently pre-testing the research project questionnaire, enough accurate and quality information was gathered to link both the studies and create a number of well-formulated innovation strategies.

Once again, it would have been most satisfying to have had participants stating what nanotechnology product life cycle they partake, in each nanotechnology segment, but this would have taken a tremendous amount of time and effort on the part of the participants. A decision had to be made where to draw the line on what information was really needed.

However, one aspect that the author would like to address is the change of the research design from a Delphi study to a single questionnaire, supported by feedback comments and the CSIR baseline study data. The timing of the research project and the CSIR baseline study questionnaire was not optimal, because of two reasons:

- the research project questionnaire started circulating about two weeks too late (because of a late change in the nanotechnology segments), and
- the CSIR baseline questionnaire was delayed by more than a month; this caused confusion in many of the participants.

The South African nanotechnology community are very positive about partaking in a national study, but are also particularly busy. The two questionnaires were supposed to be distributed at the same time, limiting confusion about the objectives of both questionnaires, but in the end, this was not the case. The author of the research project, after an interview with Mr. Manfred Scriba, decided to eliminate the Delphi study. A feedback form with the option of providing more information and comments on the analysed data from the first research project questionnaire was sent instead to all the participants, to which only two participants replied.

Despite all this, the author of the research project feels that the study was a huge success, an amazing learning opportunity and a great step towards further studies in the field of innovation and technology management.

7.4 Recommendations

7.4.1 Nanotechnology community

Nanotechnology is set to change the rules by which product and process development are governed. Just type in "Nanotechnology" into any internet search engine and there are bound to be more than 1,500,000 entries returned from all ends of the earth. In essence, nanotechnology enables us through new tools and techniques, to control the basic properties of materials, such as strength, weight, purity, etc. Endless opportunities are created through exciting new materials, while pushing the limits of current technical innovations.

South Africa possesses the nanotechnology expertise, natural resources, funding sources and hunger to develop nanotechnology-related products and processes - and succeed in global niche markets. The problem is that these separate value-adding activities must be coordinated and facilitated in order to grasp the economic, social and technological growth opportunities.

The South African nanotechnology community needs to formulate concrete and practical strategies, with clear and identifiable visions, goals and objectives. Referring to the nanotechnology strategies developed in the research project, most of the strategies are concerned with:

- Developing and combining innovative nanotechnology knowledge, skills and experience with other cross-functional competencies to develop cost-efficient products and processes.
- Creating South African nanotechnology awareness and gaining support from universities, industry, science councils and government, while creating the necessary support structures (financial, educational, etc.) for nanotechnology researchers and developers.
- Collaborating with local, European, North American and Asian nanotechnology researchers and developers, with the aim of developing relations, gaining support in the form of funding, equipment, personnel, learning opportunities and negotiating trade agreements.

- Focussing on nanotechnology niche markets that are either difficult to imitate by other countries, due the lack of natural resources etc., and could provide a sustainable and competitive environment for local researchers and developers.
- Licensing technologies to create or identify South African nanotechnology focus areas and implement backward integration strategies.
- Regarding the loss of nanotechnology students and personnel due to immigration as an opportunity to keep and build local and international relationships that could provide entry points into international nanotechnology markets.

Nanotechnology is an emerging technology and the South African nanotechnology system of innovation is not a technology colony, but the nanotechnology community does need support to prevent the formation of one. Nanotechnology also entails the convergence of biotechnology and electronics, thus research and development capabilities in these technologies must also be on the agenda.

An organisation that will provide this support, by offering products and services ranging from national and international nanotechnology market analysis and forecasting, funding incentives in order to facilitate the transfer of knowledge, skills and expertise between different industries and institutions is needed. The organisation can be based on the Senter[1], an initiative started by the Dutch government to facilitate the growth of strategic technology capabilities in the Netherlands. The growth of strategic technology capabilities is made possible through the effective allocation of government and industry incentives (supporting the researchers and developers), before venture capital enters the fray. The focus is on building strong R&D capabilities, which entrepreneurs can exploit.

A third party (facilitator) would be a linkage between professional societies, investors, government departments (with their policies) and different tertiary, industrial and science council institutions (refer to Figure 7-7). This third party might be the innovation hub or any other organisation that posses, among others, some nanotechnology, innovation and technology management, legal and project management expertise.

[1] www.senter.nl

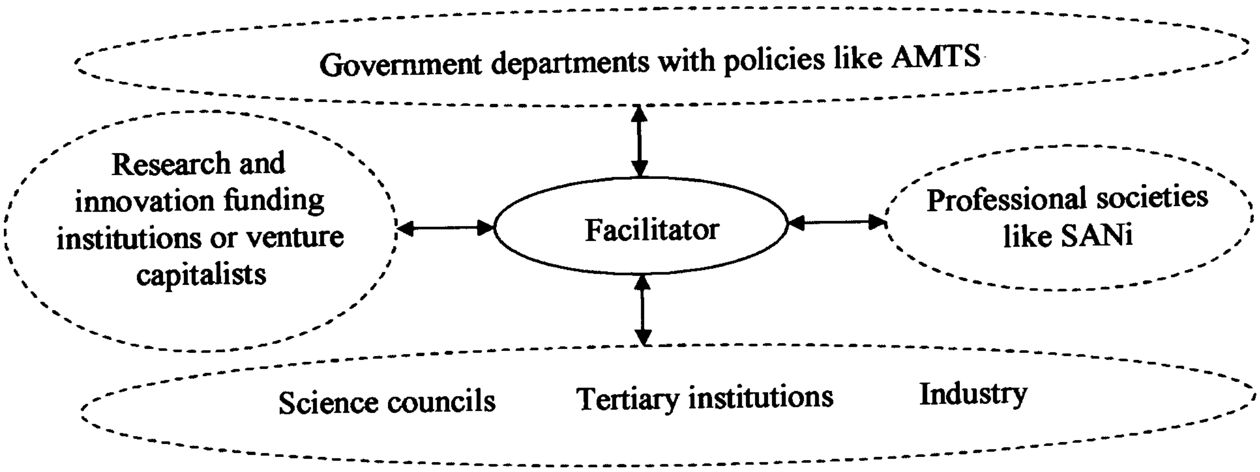

Figure 7-7. Logical illustration of supposed placement of a technology facilitator.

The organisation would offer all South African institutions and industries the opportunity to develop national and international nanotechnology relationships, build necessary capabilities to capitalise on nanotechnology innovative applications, empower formerly less privileged communities, encourage entrepreneurship and take full advantage of the funding sources offered by government and venture capitalists. The result will be that South Africa would gain possible footholds in nanotechnology niche markets, not dictated by developed countries – this would create an opportunity for job creation, sustainable energy development and active involvement of students from a wide range of disciplines.

With the breadth of nanotechnology development, anyone is a potential customer or collaborator, but the primary market will be South African nanotechnology actors. The secondary markets will range from South African firms and entrepreneurs (realising the opportunities and threats of nanotechnology) to international nanotechnology actors. Critical success factors would be creating South African awareness of the impact of nanotechnology on all institutions and industries, and safe, effective and efficient transfer of needed knowledge, funding, skills and expertise.

Facilitating directly connects a number of possible researchers, developers and manufacturers with each other through the generation, gathering and distribution of tenders to a wide range of nanotechnology requests for proposals. Key processes in delivering the service could be; gathering request for proposals from local and international nanotechnology actors (which would state the need for, or availability of, basic research, applied research, design, development and/or manufacturing technology of a specific product, process and/or service). Other local and international nanotechnology actors could tender to complete some of the product life cycles. The project could be awarded to a capable nanotechnology actor, negotiating and facilitating the agreement between the two parties. Once the collaboration has been set up, consultation services provided by the organisation could coordinate and help with the overall research, development, manufacturing and/or selling of the nanotechnology products, processes and services.

7.4.2 Future studies

The research project focussed on the softer sciences behind nanotechnology innovation. Many research areas are still unexplored on the technical aspects of nanotechnology.

A number of theoretical issues regarding nanotechnology innovation and technology management also remains (In Realis 2002), some of which are:

- How fast will buyers and intermediaries switch from current technologies and products to nanotechnology-related applications?
- How will the exploitation of nanotechnology influence productivity, the growth of current and new markets?
- How many products, organisations, markets and industries will nanotechnology influence?
- What are the consequences of nanotechnology on national and international economies?

The research project does provide a superb overview of South African nanotechnology current and future activities, but these issues will remain for many years to come. Although nobody can provide the absolute correct answer to any of these questions – forecasts, scenarios and strategies will help countries prepare for the nanotechnology age.

"Nanotechnology is an important and exciting emerging technology, and one that has the capacity to improve daily life for us all."

Nigel Griffiths, Minister of the United Kingdom's Department of Trade and Industry