Developing a Market Driven Social Housing Solution with a Focus on Facilities Location

by

Mareli Steyn

27055575

Submitted in partial fulfillment of the requirements for the degree of

BACHELORS OF INDUSTRIAL ENGINEERING

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2010

Executive Summary

EmpiriQ Advisory & Support Services (Pty.) Ltd. is a company supplying consultation services for businesses operating mostly in the lower income market. This company identified the need for an alternative housing solution for lower income households. Charity and governmental organisations' efforts have not been able to solve the housing problem experienced in the lower income sector. Furthermore, businesses supplying building materials to this market still operated from a business model that has been designed for the higher income market.

EmpiriQ came to the belief that a decentralised business model would be more effective than the centralised model of a single retailer serving a large market. For this model the exact number, location and capacity of decentralised facilities required needed to be determined.

The project undertaken had consequently been completed in three phases:

1. Prove of the feasibility of establishing a business in the lower income market and the viability of this market.
2. EmpiriQ's theory of decentralised facilities has been confirmed by a case study on CEMEX, a cement supplier in Mexico. Other sources have also been utilised in order to list important features for an effective business model.
3. Finally, a mathematical model has been designed to determine the optimal solution for required facilities with regards to amount, location and capacity (customer allocation). The solution had been obtained through the use of the metaheuristic solution technique, Tabu Search.

The final recommendation made to EmpiriQ was to build eight sales offices (SOs) and three cross docks (CDs). The locations of these facilities were indicated on a geographical map of the target area. Customer allocation per facility was also included in the recommendation. By implementing this solution, a maximum profit would be generated.

Table of Contents

List of Figures

List of Tables

1. Introduction and Background

EmpiriQ Advisory & Support Services (Pty.) Ltd. (hereafter referred to as EmpiriQ) is a company focusing on market driven socio-economic development. This company, founded in 2008, supplies management and supply chain consultation services to their clients, of whom the majority are doing business in the underdeveloped markets. (Truter, 2010).

During consultation work for their clients in this sector, EmpiriQ had identified the need for an alternative housing solution for lower income households. The dependency on public transport had lead to numerous problems when purchasing building materials and this had been the main reason for the current business model's inefficiency. This fact had led EmpiriQ to suspect that a business model with different types of decentralised facilities would be more efficient than the centralised model of a single retailer serving a large area.

EmpiriQ had launched a project some time ago in collaboration with private companies in the construction sector to be able to grasp this opportunity. The planned target market had been the lower income living area of KwaMhlanga, 70 kilometres North East of Pretoria. The area, situated in the previous KwaNdebele homeland, is home to approximately 800 000, mostly Ndebele, people. EmpiriQ had known this area well since it had been operating here since its establishment in 2008.

Instead of a single retailer, EmpiriQ believed that scattered sales offices and cross docks, which would be supplied with materials from a warehouse outside KwaMhlanga, would serve its target market most effectively. The purpose of the sales offices would be to function as a point near potential customers where they can order building materials, draw up building plans and receive masonry advice. The purpose of the cross docks would be to serve as distribution points as well as temporary storage facilities. Furthermore, ordered materials would be transported from the cross docks to the homes. To put this in greater detail:

Distribution Point Functionality of Cross Docks

Products and materials transported from the warehouse at a location outside KwaMhlanga, are to be delivered at a cross-dock. Here products will be taken out of bulk packaging and different products will be packed together for the specific orders. From the cross docks, the different orders are to be distributed to the homes.

Temporary Storage Functionality of Cross Docks

Due to the small buying power of the customers, order sizes will be small and sometimes not even the combination of various customers' orders will be of significant size. In these cases, the company might still want to order in bulk from its suppliers in order to obtain certain discounts. The surplus materials will then be stored at a cross-dock.

A scientific method was required to determine the exact number of each type of decentralised facility (sales offices and cross docks), as well as each facility's capacity (or customer allocation) and location in order to be able to serve the target area effectively. EmpiriQ had consequently decided to consult an Industrial Engineering student to design the optimal business model in this regard. However, before this model could have been designed, the viability of the lower income sector as a target market had to be investigated, and what a business model should look like (to validate EmpiriQ's idea of a decentralised model) in order to successfully conduct business in this market.

The project undertaken had therefore been divided into three phases:

1. Determination of viability of the lower income sector as a market. A market driven (or business oriented) solution would only be successful if the target market could be proved to have enough buying power.
2. If the lower income sector has proved to be a viable market, research had to be done to determine key changes necessary for the existing business model of providing building materials to this sector. The business model used at the time had been similar to the one designed for the higher income sector. EmpiriQ believed that this model was not effective since it had never been adapted to suit the unique needs of this market.

3. The creation of the actual practical model desired by EmpiriQ. As soon as a theoretical business model had been defined, a practical model had to be designed to operate in the lower income living area of KwaMhlanga. The theory defined in Phase Two had to be incorporated into the design of the practical model. This implied that a solution method had to be used that incorporated the lower income market's unique requirements in terms of infrastructure, facilities, finance, geography, etc.

2. Project Aim

The central aim of the project had been the design of the optimal business model in terms of the number and type (sales office or cross-dock) of decentralised building supply facilities, as well as each facility's capacity and location. To achieve this, three different project phases had to be completed, each with its own aim.

The first two phases were aimed at theoretically proving that a market-driven approach to lower income sector housing had been necessary and possible. Phases One and Two had thus served as introductory background and support to the decisions made in Phase Three.

During Phase One, the viability of the lower income sector as a target market had to be determined. In Phase Two, research had to be conducted on key changes necessary for a typical business model serving the lower income market to ensure that the model designed in Phase Three was feasible. In Phase Three, the practical model designed for KwaMhlanga had to provide optimal requirements for building materials supplies facilities (sales offices and cross docks) in terms of amount, distribution and capacity.

3. Project Scope

3.1 Inclusions

The project had been aimed at creating a more efficient total system of supplying building materials to the lower income sector. The focus had been on the optimisation of outbound logistics, with an in-depth focus on the physical distribution of facilities in the KwaMhlanga area. The design of the optimal facilities location solution within the limits of the fixed budget and an intelligent estimate of fixed (building) and variable (specifically transportation) costs for the sales offices and the cross-docking facilities had to be provided.

3.2 Exclusions

Optimal vehicle routing for the distribution of ordered products had not been included in this project's scope. Inbound logistics of factories and warehouses, as well as internal facilities planning (layout of facilities) and optimal personnel appointments had been excluded as well. Furthermore, a detailed cash flow analysis for the whole system had been excluded from this project.

Although direct building material costs influences total systems cost, the possibilities of reduction (eg. through optimising the manufacturing methods) had not been investigated.

During Phase Two the research had to provide broad guidelines in terms of the way a company should operate (important features for the business model) in the lower income market. Excluded, however, had been the definition of the exact and final business model or implementation plan. This task had been left to the discretion of the management of EmpiriQ. The drafting of a training curriculum for the promoters will also be executed by the management of EmpiriQ.

A complete systems solution would have included the design of a database for the new business structure for capturing client details, tracking of the building material orders and other information. However, the database design had not been included in the scope of this project.

4. Literature Review

The literature review had been divided into three sections according to the three phases of this project. Phases One and Two of the project are both purely theoretical and had therefore been completed in the form of a literature study. The third section is the literature review component of the final and practical Phase Three.

4.1 Phase One Literature Review

Firstly, the problems of housing for the low income sector at the time had been defined to illustrate why an alternative solution had been imperative.

4.1.1 Current Problems with Low Cost Housing

The need for low cost houses in South Africa up to the end of 2009 had been 2.6 million units. However, only 248 850 low cost houses had been built on average each year. (Statistics SA, 2009)

Governmental and charity organisations had always attempted to solve the housing problem. These two groups however could never provide sustainable solutions to the problem. On a macro scale, these approaches had failed due to economical and metaphysical reasons.

Economical Reasons

The economical scale of the problem was immense. The need for 2.6 million houses at a cost of R70 000 per RDP unit yielded a total need of R182 billion for housing. The expenditure of the governmental Reconstruction and Development Programme fund, RDP, for 2007 and 2008 were R1.324 billion and R1.271 billion respectively. (National Treasury, 2008) Since 1994 and up to 2009, the governmental expenditure on RDP houses had totalled R37 billion (Statistics SA, 2009). These figures clearly indicated that the government had not been winning the housing battle.

Metaphysical Reasons

In some instances the provision of housing to the poor by governmental or charity organisations created attitudes of dependency and begging. It discouraged initiatives to become independent and self-sufficient. A lack of ownership and pride taken in provided homes also contributed.

Where lower income households had taken the required initiatives to address their own housing needs, numerous problems emerged. EmpiriQ had believed that these had been the results of an inefficient business model supplying building materials to this sector. The following problems contributed to the fact that housing had been a tedious, inefficient and overly expensive process for the poor where only the centralised business model existed:

Environmental Problems

A lack of knowledge regarding environmental factors that influenced the success of new housing, such as flood levels, orientation and thermal considerations. The result had been uncomfortable and impractical houses.

Construction Planning and Design Problems

Inefficient building designs that caused building to be tedious and the final structure to be impractical or worthless. According to Truter (2010) there also existed a tendency to borrow a building design from a relative instead of addressing the particular family's unique housing needs. (Truter, 2010)

Quantity surveillance was problematic since the lack of construction knowledge resulted in the purchasing of wrong volumes and incorrect or unnecessary materials. Additional transportation was required when too small volumes had been purchased. On the other hand, the purchase of too large volumes combined with the common lack of storage capacity left the materials exposed to weather conditions and theft.

In general, poor planning and dysfunctional designs ultimately resulted in over-expenditure and/or insufficient homes that called for alterations and additions to be made at a later stage.

Building Skills

Houses were often built by unreliable or inexperienced builders. (Prahalad, 2005) This again might have led to the destruction and rebuilding of dysfunctional building structures.

Transportation and Purchasing Power Problems

Acquiring building materials was a tedious and expensive process due to low buying power and the use of public transport. Typically only one room could be built at a time, straining progress.

When utilising public transport, only a few and small items could be purchased at one time. For items too large for transport by bus or taxi, alternative transportation had to be hired. Due to the lack of buying power, the full truckload capacity could not be utilised. Both of these scenarios contributed to large transportation fees relative to the total expenses of building a house.

Localised Supply

Investigating the difference in the price of materials at different building supplies retailers was a tedious and expensive process since public transport needed to be used. Retailers exploited this fact by setting prices too high.

Concluding, it had been proved that governmental and charity organisations had been struggling to address the macro need for housing, and based on the statistics, it had not seemed likely that these organisations would have been able to provide sustainable solutions in future, unless they changed their approach.

In addition, it seemed that the centralised business model for the supply of building materials to the lower income sector had several shortcomings that prevented this sector from solving their own housing problems.

Consequently it had to be determined whether the lower income sector was a viable market or not.

4.1.2 The viability of the lower income sector as a market

The lower income sector can also be referred to as the Bottom of the Pyramid, BOP. The BOP is defined as all households earning between R500 and R3000 per month. The World Resources Institute and International Finance Corporation had determined in their report, The Next 4 Billion, that between 60% and 70% of all global consumers fell into the BOP category, which had made this a $5 trillion market. Of the African population, 95% lied within the BOP market. In South Africa 75% of all consumers (37.5 million people) fell within this market. (Hammond, Kramer, Katz, Tran, & Walker, 2007)

This report had claimed furthermore that there were seven main categories for household expenditure in South Africa: food, housing, household goods, energy, water, health, information and communication technology, transportation and education. Of these seven, housing had been the BOP market's largest expenditure. The national expenditure on housing had totaled $14 359.7 million, of which the BOP market had represented an enormous 30.9%, or $4437.15 million. (Hammond et al., 2007)

Compared to the average governmental expenditure on low cost housing per year of approximately R1.300 billion, the BOP itself spent R32.541 billion ($4.4437 at the R/US$ exchange rate of R7.334) per year.

The lower income market furthermore had shown to be very stable, even in economic downturns. In his article, 'Rural edge' sees Cashbuild soar, on Fin24.com, Nicole Rego had indicated that building material supplier Cashbuild's cement sales in the recent economic recession had proved that the lower income sector, Cashbuild's target market, had been a steady foundation for the industry. (Rego, 2009)

David Shapiro of Sasfin had believed that the lower income consumer's spending on building materials stayed relatively stable, even in economically trying times. This might have been due to the fact that retrenchment packages had often been spent on building materials to finish what these persons had been doing on weekends (building houses or additions) anyway. According to Alistair Lea, manager of Coronation Fund, the lower end consumer's stable spending had also been the reason for the outperformance of food supplier Shoprite over Woolworths. (Shapiro, 2009)

From these statistics it had been proved that the BOP market was indeed a viable market to invest in and that they had the potential to address their own needs better than charity or governmental organisations.

4.1.3 Conclusion of Phase One

It had been shown that the traditional approaches of supplying housing to the lower income sector had not been sufficiently addressing the growing need. Furthermore, the lower income sector itself held the potential to address its problem since it had been proved that this sector was a viable market.

4.2 Phase Two Literature Review

4.2.1 How to Enter the Lower Income Market

Unnecessary expenses were incurred when building a low cost house. This was due to the fact that the vast majority of business structures had been designed for higher income households. (Prahalad, 2005) Research done by EmpiriQ had shown that, in South Africa's lower income sector, transportation would typically account for a very significant 25% of the total building cost of a house. (Truter, 2010)

If an alternative business model could be created to enable the lower income sector to spend their money more efficiently, eliminating all unnecessary costs, the benefit would be twofold:

- The BOP masses would be able to build homes that suit their unique needs cheaper and faster.
- A small percentage of the total savings could be set aside for profit, therefore making it an attractive business opportunity for entrepreneurs.

This had supported the central theme proclaimed by Prahalad (2005) in his book The Fortune at the Bottom of the Pyramid. It had stated that poverty should be eradicated not by charity but by profits. (Prahalad, 2005)

It consequently had to be determined what a business model should look like to enter the BOP market.

According to Budinich, 2005 of Ashoka, the largest global firm for social entrepreneurs, there had been three factors limiting private businesses to enter the BOP market (Budinich, 2005):

a. Limited individual buying power of persons in this market
b. The market's need for small transactions in high volumes
c. Poor understanding of the market's social and human capital

The article that had been posted by an anonymous eHow Contributing Writer, How to Market to a Low-Income Group, on www.ehow.com gave a good recapitulation with regards to a method to enter the BOP market. These steps could be summarised as follows:

a) Product packaging must be fit for consumption in small amounts.
b) Infrastructure must be fit for products to reach customers even in rural areas.
c) In-depth market research is required to understand the market in terms of lifestyle, social structures, religion, habits etc. This needs to be done in order to supply a product that will successfully address their needs.
d) Persons with strong community influence must be identified and trained to market the product.
e) Credit services must be provided.
f) All unnecessary features of the product must be removed to minimise its price.
g) Community education must be provided on the value and functionality of the product.

(Anonymous)

Budinich, 2005 had added two more steps to these:

a. The infrastructure through which the products should reach customers must be able to handle tiny transactions on a large scale.
b. Involve the community in the business by offering micro-entrepreneurial opportunities.

C.K. Prahalad had done research on the innovation required by businesses seeking entrance to the BOP market. Prahalad, 2005 had stated that businesses should think innovative and re-engineer products to suit the BOP's specific needs. The BOP consumer earns daily or weekly and in the vast majority of cases cannot afford to buy in bulk. (Anonymous) Prahalad (2005) had continued by saying that businesses targeting the BOP market should sell products in small unit packages at a low profit margin and in high volumes. (Prahalad, 2005) An example of such a market specific product that had been given on www.wikipedia.org, was a shampoo marketed by UNILever that was designed to work with cold water and sold in few-use quantities. (Wikipedia, 1996) Budinich (2005) had said that innovation along the whole value chain was necessary, including production, distribution, delivery and promotion in order to bring down total systems cost and consequently product price. (Budinich, 2005)

It had however been very important not to compromise on quality in order to lower prices. The BOP's numbers enable high volume sales, which must compromise for their limited individual buying power. The world's third largest cement manufacturer CEMEX had found that average revenue per customer was the biggest difference between informal sector and formal sector customers. This is graphically represented in Figure 1.

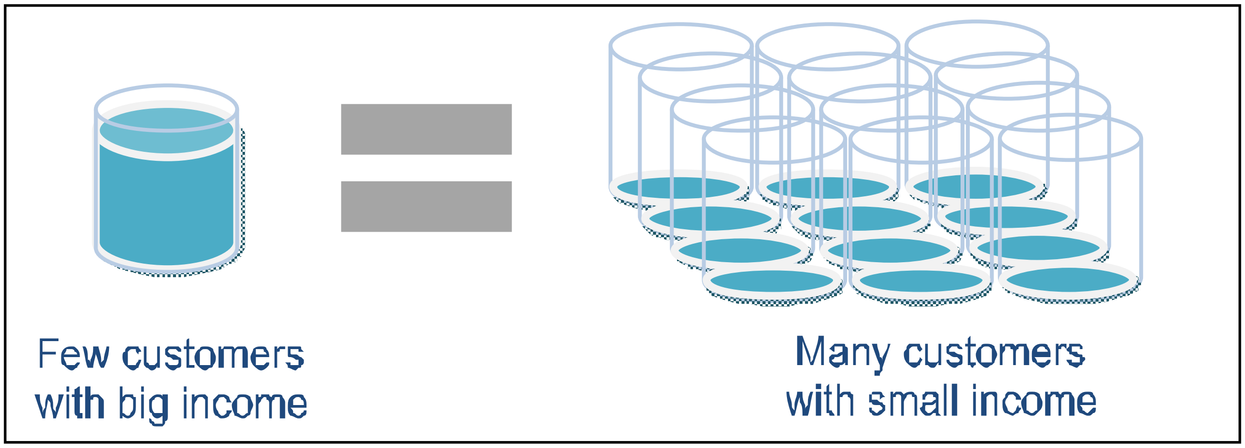


Figure 1: The revenue difference between formal and informal customers

It was the understanding of the concept illustrated in Figure 1 that had led to the ingenious development of the Aravind Eye Care System in India. In Fortune at the Bottom of the Pyramid, C.K. Prahalad (2005) described this company's story. Founder Padmashree Dr. G. Venkataswamy, a.k.a. 'Dr. V', had invented a solution to the problem of maintaining high quality standards while lowering prices substantially. Dr. V had built a medical centre that had only one function: to perform a specific eye operation that could normally not be afforded whatsoever by a person of the lower income class. The doctors of this medical centre had performed only this single medical procedure, in which they were also specialists. This had resulted in an increase of service quality. In 2005, the centre has had a larger capacity for eye operations than any other medical institution in the country, lowering the price of the operation dramatically. This had led to high client volumes, which, combined with the fact that no other medical services were offered at this centre (no unnecessary machines, building space etc.), had led to minimised overhead costs. In a sense, the Aravind Eye Care System could be compared to mass production in that the overhead costs are minimised. (Prahalad, 2005) The possibilities of altering this approach to be applicable to the construction sector should be explored by EmpiriQ.

Another very important feature of a business targeting the BOP was the supply of microcredit. Muhammad Yunus, founder of Grameen Bank and winner of the Noble Peace Prize in 2006, hd stated in his book, Banker to the Poor, that access to credit was a basic human right. (Yunus, 1999) The poor could usually not afford credit. Due to the fact that they could not supply sufficient security when applying for a loan, the only way to borrow money was by doing so under the poverty penalty, an absurd interest rate that could range from 300% to 600%. Yunus therefore had invented the Grameencredit system. The main premises of this system can be summarised as follows:

A person seeking a loan had to join a small group of say 5 borrowers. The group then registered for individual loans. The microcredit supplier at first only granted two members their loans, which was payable in weekly or bi-weekly installments. If the loans were repaid according to this agreement, the next, say two, members were granted their loans. Trust among group members therefore urged them to repay their loans and so 'peer pressure' served as the collateral in this system. During his research, Yunus had found women to be the drivers behind savings for their families and therefore insisted that half of all borrowers had to be female. Grameencredit was furthermore only granted for housing and income-generating activities. The purpose of Grameencredit was not to enable consumption expenses.

A lot could be learned from this system and its principles could be applied to one's own business. In fact, by the start of 2010 over 250 institutions had been operating off Grameen microcredit principles. Yunus's work had made the world realise that it is economically viable to lend in small amounts to people with no collateral in the form of assets. (Titus, 2005)

The case study on CEMEX in C.K. Prahalad's book, The Fortune at the Bottom of the Pyramid (pp. 152-156), had portrayed a similar situation and had provided practical solutions. CEMEX, situated in Mexico, is the world's third largest cement manufacturer. This company had noticed a drop in cement sales during the Mexican economic crisis in 1994 and 1995. When the data was closely examined, it was discovered that the sales drop under formal segment customers had totaled approximately 50%, while the drop under informal segment customers had been a low

15%. CEMEX had realised the value and dependability of their lower end customers and decided to expand their market segment in this sector. The company had also realised that they would have to know and understand their market better in order to provide a better and more attractive service. A team had consequently been sent into an identified lower income region in Mexico, Guadalajara, to establish closer relationships with the community and to study the decision-making processes with regards to building and housing in these areas. (Prahalad, 2005)

The insights this team came to, led to the establishment of one of the world's most successful programs for lower income housing called Patrimonio Hoy, which means savings/property today. (Budinich, 2005). The business model on which Patrimonio Hoy had been built took into account all previously mentioned guidelines and advice for companies wishing to operate in the BOP market. Furthermore, it had been specifically designed for a company in the building industry. This was the reason for its business model to be extremely applicable for the company EmpiriQ had in mind to establish. The findings of the Patriomonio Hoy research are consequently discussed:

The Patrimonio Hoy Business Model

One small office per 50 000-100 000 inhabitants (or 20 000 families or 5000 customers) had been erected in Guadalajara. Between 1 and 5 personnel had been appointed per office. These personnel could include a general manager (to identify promoters marketing the product in the area), a technical advisor or architect, a supplies manager (to negotiate with CEMEX), a customer service and admin clerk and an Engineer.

The Patrimonio team had originally been influenced by the Grameen Bank's group micro-lending idea. They had also found that not only were women the money savers of their families, but that 70% of all women who saved money were saving for building homes or additional rooms to their homes. The team had therefore designed a system in which customers, mostly women, had had to form groups of three. According to Prahalad (2005), this had been done to enforce payment discipline and also to establish supportive relationships amongst group members.

Promoters, of which 98% were women, had been identified to sell CEMEX products in the communities. Commission was paid based on the number of groups as well as for the length of time the group conducted business with CEMEX. The promoter concept was very successful since these sales people, in contrary to typical transaction-focused approaches, focused on the aspirations of the families to live more comfortably.

The system designed by Patrimonio Hoy, worked as follows:

As soon as a borrowing group had been formed, it had to be registered at the nearest small office. Each group member had to pay approximately $10 per week for a fixed period of minimum 70 weeks and had to make an appointment with the technical advisor/architect at a small cost. The customer was then assisted with regards to building method and materials needed. As soon as this had happened, the prices of the desired products were frozen for the whole payment period. Patrimonio Hoy took 12.5% of each group member's weekly payment as membership fee.

After the first five weeks of weekly payments by each group member, Patrimonio Hoy delivered materials worth of ten weeks' payments. In doing this, Patrimonio Hoy was extending credit to its customers, and thereby establishing trust among them. If the group stayed committed during the first ten weeks, the consequent delivery of materials worth of ten weeks' payments, would take place after two (not five) weeks' payments.
(Prahalad, 2005, pp. 152 - 156)

Analysis of the Patrimonio Hoy Model:

A. Revenues

This had been generated by cement sales, membership fees and intermediation fee from distributors.

B. Marketing

Mass marketing had been found to be ineffective. Personal relationships and trust was of high importance. Word of mouth, periodic public meetings and literature (for example booklets) had been found to be effective.

C. Costs

Approximately 700 groups had been required for a cell to break even.

D. Prices

Neither products' prices nor quality had been compromised. Patrimonio Hoy focused on volumes of sales to increase revenue as illustrated in Figure 1.

E. Important lessons learned

- The most difficult task had been to establish loyalty among customers (to stay in the program after they had completed building one room).
- The Patrimonio Hoy training plan to teach customers to self-construct was very important since customers could not afford masonry fees together with material costs instalments.

(Prahalad, 2005)

4.2.2 Conclusions of Phase 2

The literature study on business practices in the lower income market confirmed EmpiriQ's theory that there is a need for a different approach in doing business in this market than in the higher income market.

Research had been conducted to determine the features imperative for successfully serving the lower income market. Numerous resources were utilised. If the key features for a lower income market business as mentioned were to be incorporated into EmpiriQ's planned business, the problems usually experienced with low cost housing, as discussed in Phase One Literature Review, should in all probability be eliminated. These principles also provided a clear indicator of the way forward in terms of the mathematical design of the business model in the KwaMhlanga area.

Furthermore, by keeping in mind all the mentioned principles (necessary features for a business model), any solution obtained by the model that is to be built in Phase Three, could be critically evaluated.

4.3 Phase Three Literature Review

EmpiriQ's management team identified and numbered numerous possible sites fit for the building of sales offices and cross docks. These sites were plotted on a geographical map of the KwaMhlanga area. Out of these sites the optimal amount, location and capacity (number of customers allocated) had to be determined in order to provide maximal service delivery to the KwaMhlanga area. This had to be done for both facility types: sales offices and cross docks. This type of problem is commonly known as a facilities location problem (FLP).

4.3.1 Determining Appropriate Methods/Techniques for Solving an FLP

According to Coyle et al. (2003), the three primary modeling techniques to solve FLPs are optimisation, simulation and heuristics.

Optimisation techniques are aimed at finding the very optimal solution to a problem while considering all defined constraints. (Coyle et al.,2003)

Simulation models are created to represent a real scenario of the system. The goal is to enable the user of the model to perform experiments to evaluate alternative operational strategies or to understand the functioning of the existing system better. (Shannon, 1975) Simulation models are not intended to identify optimum solutions, but are only able to create realistic replicas of scenarios defined by the user. (Bowersox & Closs, 1989)

Heuristic models had been developed to assist with the solving of complex optimisation problems. These models do not guarantee an optimal solution, but rather aim for good, or almost, optimal solutions. (Winston & Venkataramanan, 2003) Problems that can be solved by heuristics are said to be of NP (Nondeterministic Polynomial) class type. Included in this class are simple optimisation problems as well as more difficult problems for which no polynomial algorithms are known. These more difficult problems are classified once more: NP-complete problems (certificate checking is possible in polynomial time) and NP-hard problems (certificate checking is not possible in polynomial time). (Winston & Venkataramanan, 2003)

EmpiriQ wanted the outcome of the particular FLP as defined by them to be as close to optimal as possible. This eliminated simulation as a possible modeling technique.

Optimisation models are suitable for problems with problem definitions that is not too large. These models aim at finding the "best" solution, whereas heuristics are known to be able to generate a good solution for problems of any complexity level. Arostegui et al. (2006) stated that heuristics were the only truly viable method of finding a solution to FLPs due to the complex nature of most of these problems. (Arostegui et al., 2006) This statement was made after large scale problems (for example 100 facilites and 200 customers) had been attempted in their research. In EmpiriQ's FLP, numerous possible sites in 8 areas of 20 000 homes each were to be evaluated for optimal sales office locations. After this had been completed, another search had to determine where cross docks should be located. Consequently heuristics were selected as modeling technique. It was however decided to validate the necessity for a heuristic solution methodology by firstly attempting to solve the cross docks FLP with an optimisation model (exact solution methodology).

Heuristic Models

Heuristic models can handle large problem definitions but have the significant disadvantage of stopping the search for a global optimum as soon as a local optimum had been reached. An example of a classic heuristic that had seemed feasible for the solving of FLPs, is the Grid Technique, also known as the Centre of Gravity Technique. The Grid Technique is aimed at finding the minimum-cost centre of gravity. (Coyle et al., 2003) This technique requires the area of consideration to be covered by a coordination grid, and all possible locations to be defined by a horisontal and a vertical coordinate in terms of its location on the grid. It then determines the optimal horisontal and vertical coordinate by dividing the sum of all possible sites' respective coordinates by a chosen weight.

However, this model has big disadvantages and was defined by Coyle et al. (2003) to be:

- Solutions generated are static and no longer valid should any location variables (such as transportation rates) be changed.

- The technique does not accommodate non-linear transportation rate increases with distance.
- Only the exact optimal coordinates are given regardless of the topographic considerations of the site. Therefore, the optimum may be given to be situated in a river.

To overcome the problems of heuristic methods, metaheuristics had been developed. Metaheuristic models make use of artificial intelligence and different techniques to prevent the algorithm from stopping at a local optimum. (Winston & Venkataramanan, 2003)

Three metaheuristics were discussed by Winston and Venkataramanan (2003): the Genetic Algorithm (GA), Simulated Annealing (SA) and Tabu Search (TS). These were also the three methods Arostegui et al (2006) recommended to be tried first in order to solve an FLP. In their study, the authors narrowed this recommendation down even more by a comparison of the effectiveness of these three metaheuristics in terms of solving FLPs.

Arostegui et al. (2006) tested the performance of the TS, GA and SA under three different conditions. The first condition had time as limitation, the second limited the outcome of the solution and thirdly the models' performances in unrestricted conditions (with reference to time and outcome) were determined. The result was that the effectiveness of SA and GA were very dependent on the specific nature of the problem, while the TS method performed very well under most conditions. Arostegui et al (2006) concluded that TS should always be attempted first to solve FLPs since it produced very good or even more accurate solutions than SA and GA. In addition, TS is simple to develop and use. (Arostegui et al., 2006)

Tabu Search

TS differs from SA and GA in that TS uses memory to keep track of where the algorithm has been before. (Winston & Venkataramanan, 2003). Furthermore, it searches with a systematic search mechanism (as opposed to random searches) and can start with a single or a population of solutions, in contrast to SA and GA. (Winston & Venkataramanan, 2003)

The memory of TS is both short-term and long-term. The short-term memory prevents certain moves to be made by the algorithm, while the long-term memory enables searches in areas that seem to have possible solutions. The main features of the TS algorithm are listed and described with regards to functionality (Table 1).

FEATURES OF THE TABU SEARCH ALGORITHM	
Feature	**Function**
Short-term Memory Tabu Rules	Determination of forbidden moves of Short-term Memory List.
Short-term Memory List Size	Determination of number of forbidden moves to support move evaluation.
Long-term Memory Tabu Rules	Determination of members of Long-term Memory List
Long-term Memory List Size	Determination of number of forbidden moves for move evaluation.
Candidate Moves List	Provision of list of possible moves that can be evaluated by TS. Search is continued after one or more move is picked. Beam search is the term used if alternatives are searched in parallel.
Aspiration Criteria	Analysis of move quality and overriding of Tabu List if necessary.
Intensification	Enable systematic in-depth search of attractive solution areas.
Diversification	In short-term memory: allow unattractive moves. In long-term memory: prevention from cycling in attractive areas.
Strategic Oscillation	Improvement of TS solution by alternating the use of intensification and diversification functions around target boundary.

Table 1: Features of the TS algorithm

(Winston & Venkataramanan, 2003)

The following generic TS algorithm was given by Winston & Venkataramanan (2003):

Create a starting solution x_0 and list of elite candidates from the predetermined possible sites (this is for the long-term memory). Set Tabu tenure, list size, short-term iteration count limit m and Tabu criteria.

1. Pick one of the elite candidates from the list.
2. Compile a list of short-term candidates and set the count to 0.
3. While (count <= m), do

From candidate list: create move to generate a solution x_{count} from $x_{current}$

If Tabu-criteria is met, a Tabu evaluation must be created

Else If Tabu-criteria is not met, a penalised Tabu evaluation must be created

Else Tabu evaluation must be created

End If

End If

Set $x_{best} = x_{current}$ (if x_{count} is best move so far)

Update count: count = 1+ count

End while

4. If the elite list consists of more candidates, proceed to step 2 again.
5. Present optimal solution

(Winston & Venkataramanan, 2003)

For the sales offices problem, TS needed to determine which sites throughout the area would maximise accessibility of the area's residents to a sales office – therefore the 'coverage' of potential customers was to be maximised. This problem is known as the classical Hierarchical Covering Location Problem (HCLP). (Lee & Lee, 2010) In this model, a customer living inside a certain service radius from a sales office is considered to be covered. The generalised HCLP adjusts the classical model by allowing partial coverage of a customer. Therefore two radii parameters exist – if a customer falls within the smaller radius, S, he is considered to be fully covered. A customer living outside the smaller radius but still inside the larger radius, L, is considered to be partially covered. (Lee & Lee, 2010) In their study on the generalised HCLP, Lee & Lee (2010) used Tabu-based heuristics to solve their FLP. This method was consequently selected for EmpiriQ's FLP too.

For the cross docks FLP, it was decided to investigate the complexity of the problem by comparing the result of an exact solution method (optimisation model) with a metaheuristic method (Tabu Search). The result of the comparison would indicate the way forward as to modeling method.

For the exact solution, the computer package LINGO was decided upon. This is a package that is designed to solve linear programming problems. The linear programming problem is stated using program-specific mathematical programming language.

The metaheuristic program was programmed in the computer package Octave. This package is based on Matlab programming language and can solve complex mathematical problems in very short run times.

Sensitivity analyses were performed after TS had generated a solution. Sensitivity Analysis is a method to investigate the effect of certain 'what if' scenarios on the optimal cost locations (Coyle, Bardi, & Langley, 2003) to increase the user's confidence in the solution finally chosen to be implemented (Savage, 2003). Sensitivity analyses therefore verify the validity of a solution generated if certain model parameters are added, changed, relaxed, or removed. The user may want to change certain constraints in the problem definition if the benefit realised by such changes is proved to outweigh the cost.

4.3.2 Conclusion of Literature Review Component of Phase 3:

Using the metaheuristic method of Tabu Search, a complex facility location problem can be solved. The complexity of such a problem can be determined by attempting an exact solution methodology in parallel to the metaheuristic method and comparing the two methods' results. The accuracy of the chosen methods (generalised HCLP for the sales offices FLP and the best performing method, exact or metaheuristic, for the cross docks FLP) should finally be tested using sensitivity analysis.

5. Development of Solution

As stated in the aim of the project, EmpiriQ wanted to determine the number and location of the required facilities for a building materials supplier in KwaMhlanga. The locations of the cross dock and sales offices are independent. Each has been determined using a separate FLP model.

5.1 Sales Offices Location Problem

The purpose of the sales offices (SOs) was to function as a central point close to potential customers where they could order building materials, draw up building plans and receive masonry advice. Therefore, the aim of TS was to determine the ideal sites for the sales offices in order to maximise accessibility for potential customers. To be able to formulate the problem properly for TS, possible sites for sales offices were identified throughout the area.

The larger KwaMhlanga area has 800 000 residents. This represents roughly 160 000 homes. The research conducted by CEMEX determined that one fixed-capacity sales office was required to serve 100 000 people, or 20 000 families. This implied that EmpiriQ had to build eight sales offices throughout their target market, the KwaMhlanga area. However, due to budgetary constraints, the company had indicated that they would only be able to erect five sales offices.
To determine the distance from each possible sales office sites to each of the 160 000 homes in the region, would have been a cumbersome and inefficient process. This was bridged by the concept of gravity points (GPs) that had been developed. A GP represented a certain amount of homes. Several positions throughout the area had been identified for GPs. Each GP was numbered and the number of homes it represents, based on an intelligent estimate, recorded. Finally, the distance from all possible sales office sites were measured to each GP.

TS needed to determine which five sites throughout the area will maximise accessibility of the area's residents to a sales office, therefore maximizing the number of potential customers. For this FLP, the generalised HCLP was used. The smaller, S, and larger, L, radius parameter was set to 5 km and 12 km respectively. EmpiriQ's management determined these figures, based on the distance people would be willing to walk to a sales office. Customer service coverage decreases linearly from a value of 1 to 0 between S and L. Any customer living outside L is not covered. An illustration of the Service Coverage Model can be seen in Figure 2.

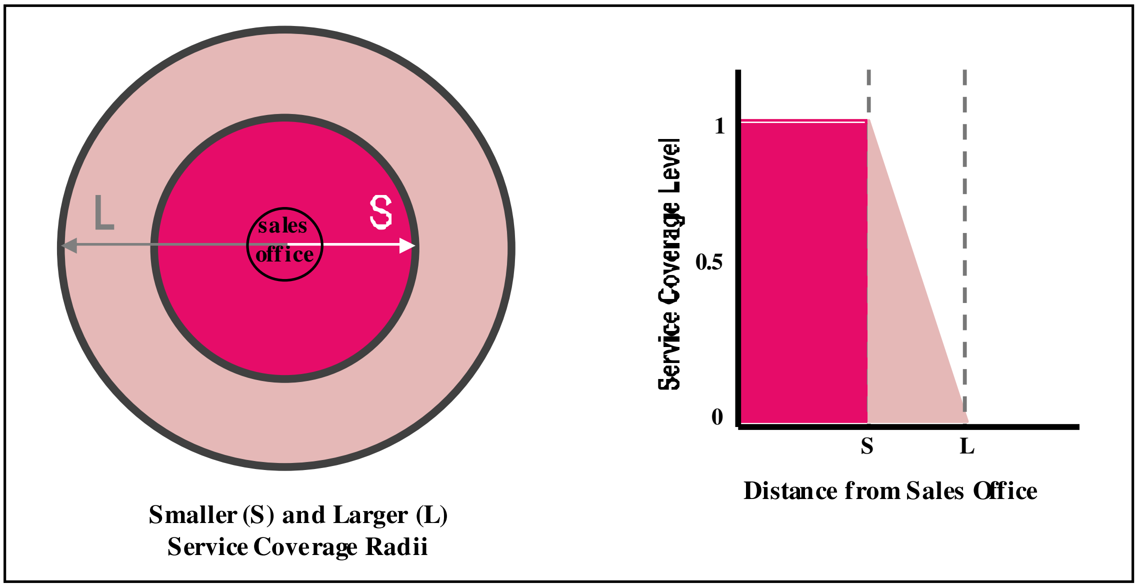


Figure 2: Service Coverage Model

(Lee & Lee, 2010)

Excel was programmed to determine, using the Service Coverage Model mentioned, the amount of customer homes served for each possible sales office site and GP combination. The formula used for every combination of GP and sales office site, was:

$$(number\ of\ homes) * (distance\ of\ GP\ to\ sales\ office) * (service\ coverage\ ratio)$$

The formula used to determine the service coverage ratio, was:

$$service\ coverage\ ratio = 1 \qquad if\ distance\ d_{ij}\ from\ GP\ i\ to\ SO\ j\ \leq 5km$$

$$service\ coverage\ ratio = -\frac{1}{7}d_{ij} + \frac{12}{7} \qquad if\ 5\,km < d_{ij} < 12\ km$$

$$service\ coverage\ ratio = 0 \qquad if\ distance\ d_{ij}\ from\ GP\ i\ to\ SO\ j\ \geq 12\ km$$

The formula used when GP_i is between 5 km and 12 km from SO_j, is a result of the linearly decreasing service coverage from a value of 1.0 (distance 5 km) to a value of 0 (distance 12 km).

5.2 Cross docks Location Problem

The purpose of the cross docks (CDs) was to serve as distribution points as well as temporary storage facilities. Ordered materials would be transported from the cross docks to the homes. This FLP required an optimal solution with regards to quantity, location and capacity (customers allocated) of cross docking facilities to be established. The problem did not accommodate partial service coverage since any part of the area had to be reached for deliveries.

Sites were again identified on the geographical map to possibly serve as cross-docking facilities. Materials were to be distributed directly from the cross docks to the customer's location. By providing this service, a major component of building cost to the customers, transportation, was eliminated. Since the GPs represented potential customers' homes, this concept was also used in the cross dock problem formulation. However, only the GPs receiving some service coverage by the sales offices were considered potential customers requiring service from the cross docks. Residents of KwaMhlanga that were not 'covered' by sales offices were not regarded as potential customers. For each covered GP the distance to all possible cross docking sites was measured and used in solution techniques.

Several costs had to be considered with the cross docks problem since the objective of the cross docks solution methodology was to minimise total system cost. Numerous costs are involved in a problem like this, but for the purpose of designing an optimisation model, these had to be scaled down to only the most important. Consequently, in co-operation with the management of EmpiriQ, the costs considered to be essential were listed and allocated fixed values. These, together with their values and abbreviations as used in the solution models, can be viewed in Table 2.

Cost Component	Value	Abbreviation Used in Model
Fixed setup cost of any cross dock	R500,000	s
Fixed overhead of any cross dock per week	R10,000	of
Variable overhead (per customer order)	R12.50*	ov
Purchase price per truck	R600,000	p
Operating cost (insurance, depreciation, licensing,	R4.9**	t

fuel, maintenance) per km travelled		
Percentage of homes placing an order per week	1%	m
Maximum distance a truck can travel per week	1,920 km***	b
Truckload capacity (max no. of orders)	5	c
Maximum amount of orders a cross dock can accommodate per week	700	u
Least amount of orders per week for a cross dock to operate viably	70	l

Table 2: Essential costs to be considered in the cross docks problem

*Variable overhead per month:

10% of setup cost = 50 000 / approximately 4000 customers per month (1% per week x 4 weeks)

**AA Insurance rate as calculated from the Vehicle Operating Costs Tables on www.aa.co.za (AA Insurance, 2010)

***Assuming a truck will be written off after five years, that it can travel a maximum of 500 000 kilometres in its life, and that a retail building supplies business conducts business 52 weeks per year: *500000/5years/52weeks*

Finally, after the solution models were developed for both FLPs, sensitivity analyses were performed in order to determine the effect of certain model parameter changes on the solutions.

5.3 Geographical Map

A map of the KwaMhlanga area was obtained from Google Earth, and as this program is made available by Google for planning purposes (Google Earth, 2010), EmpiriQ indicated which sites were regarded to be favourable for the use of sales offices and cross docks. Furthermore, the total area was divided into 35 sections of which the centre points formed the model's 35 gravity points (GPs).

On the map (Figure 3) below, these sections were circled in red and each section's GP number was numbered in red. A possible sales office or cross dock site was indicated with a yellow pin and named in white.

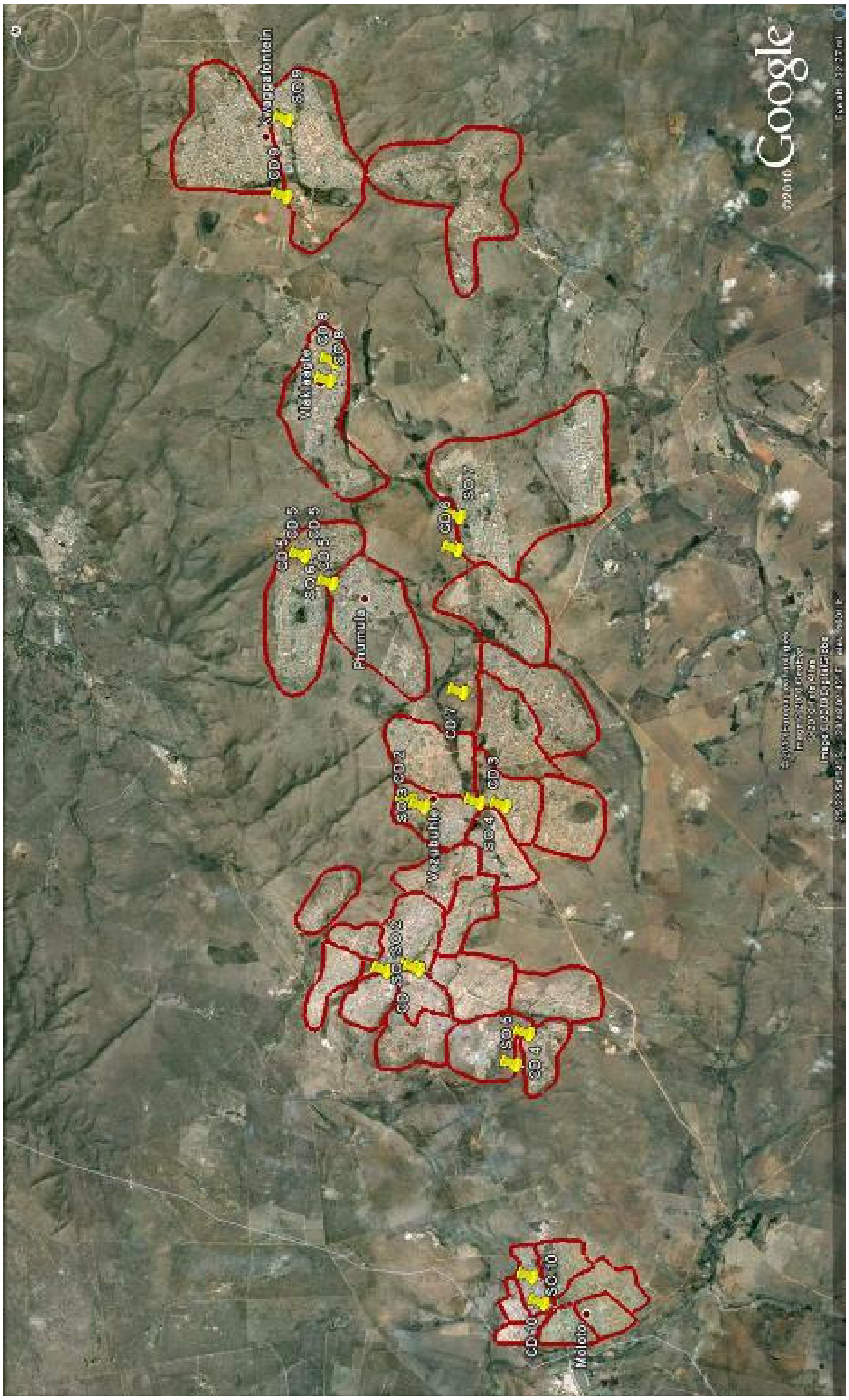


Figure 3: Total target area (KwaMhlanga)

(Google Earth, 2010)

6. Solution

6.1 Sales Offices Solution

A matrix was constructed in MS Excel to capture the amount of possible sites, the amount of GPs and the amount of homes each GP represents, and the distance between each possible site and GP.

Excel was then programmed to determine, using the Service Coverage Model mentioned previously, the amount of customer homes served for each possible sales office site and GP combination.

The table containing the data that was exported to the computer programming package Octave, can be viewed in Appendix A. A TS algorithm was consequently programmed using this data as input. The coding of the TS algorithm for the sales offices problem can be viewed in Appendix B. Figure 4 explains the logic of the metaheuristic (TS) programming for the sales offices.

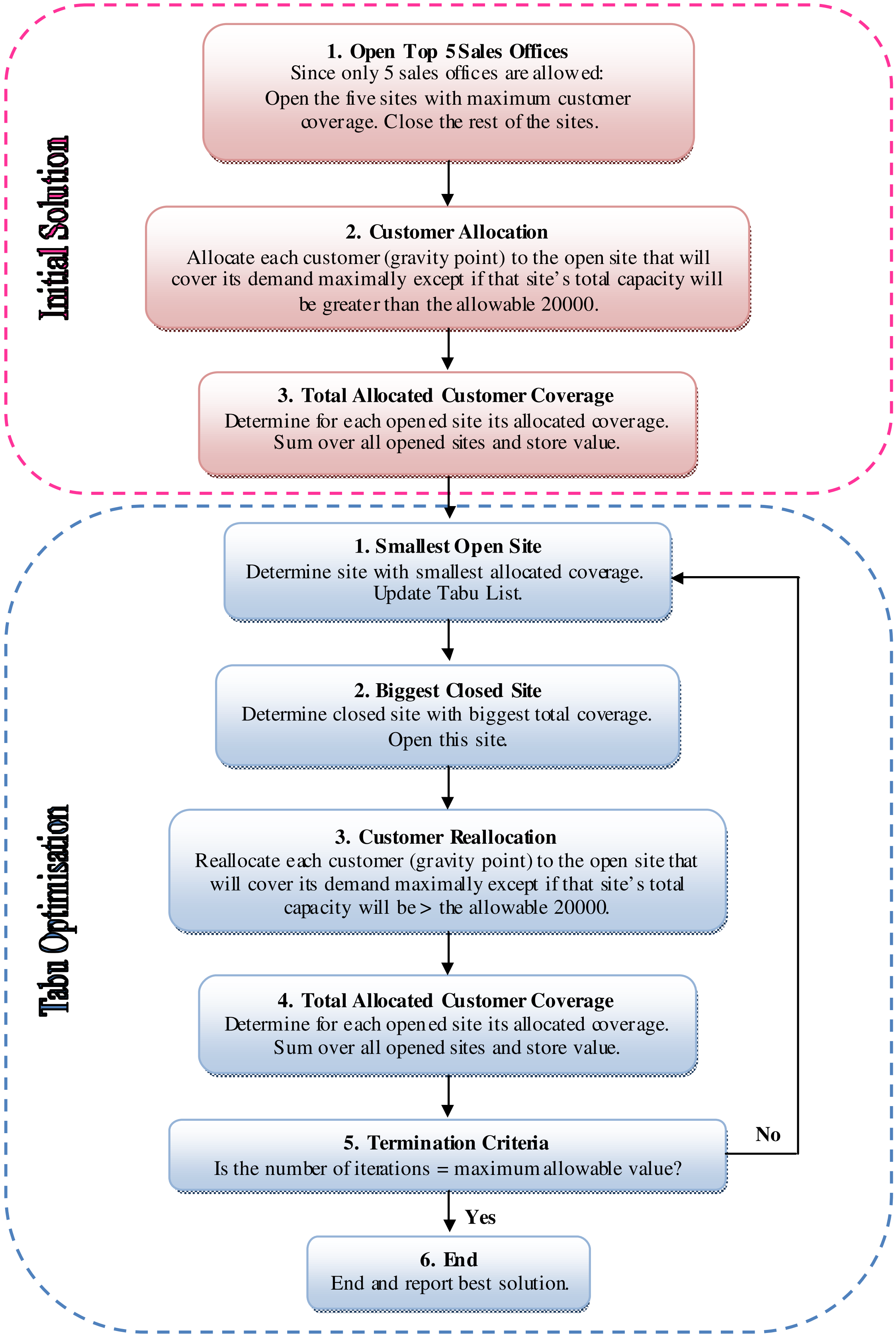


Figure 4: Metaheuristic programming logic for the sales offices problem

TS determined, with the amount limited to five due to budgetary constraints specified by EmpiriQ, where the sales offices should be located in order to maximise the service coverage of potential customers.

The data used in the Sales Offices problem can be viewed in Appendix A.

The solution TS generated is displayed below:

- **Sales Offices Opened:**

  $$SO_j = 1 \quad \forall \; j \in \{1; 2; 3; 4; 5\}$$

  Therefore sites 1, 2, 3, 4 and 5 were considered to be optimally located for sales offices.

- **Service coverage**

  97,303 homes. This is the number of homes considered as future potential customers because a sales office is located 12 kilometres or less from each of these homes. TS was aimed at maximising the service coverage. Out of a total of 159,900 homes in the area, this maximum coverage represents 60.9%.

- **Customer allocation per sales office**

  Due to the service capacity constraint of each office (20,000 homes per office) some GPs received full coverage by an office, while others could only be partially covered. Some GPs (such as GP 2) were not covered whatsoever since no sales office was located a distance of 12 km or less to it. TS also provided the allocation of GPs, and the number of homes served per GP, to each of the five opened SOs. These allocations can be viewed in Table 3.

GP receiving (some) service coverage	Sales Offices (SOs) opened and number of homes per Gravity Point (GP) allocated to each SO				
	1	**2**	**3**	**4**	**5**
1					1812
3					2897
4					3379
7		111			
8		3900			
9	1300				
10		3900			
11	6500				
12	6500				
13	5200				
14		3900			
16			6500		
17					3527
18				5200	
19			6500		
20					3900
21		5200			
22			6500		
23				6500	
24				6500	
25					4160
26		2971			
28	446				
	19946	19982	19500	18200	19675

Table 3: Optimal sales offices with gravity points allocated to each

From Table 3, it can be seen that the all of the offices' service capacities are almost fully utilised. With this solution, a total service coverage of 97,303 homes is obtained.

6.2 Cross Docks Solution

6.2.1 Comparison between Exact and Metaheuristic Solution Methods

A matrix was constructed in MS Excel to capture the amount of possible sites, the distance between each possible cross dock site and GP (only the GPs receiving service coverage value bigger than zero from a sales office were seen as potential customers) and the amount of homes each of these GPs represents.

This data can be viewed in Appendix C.

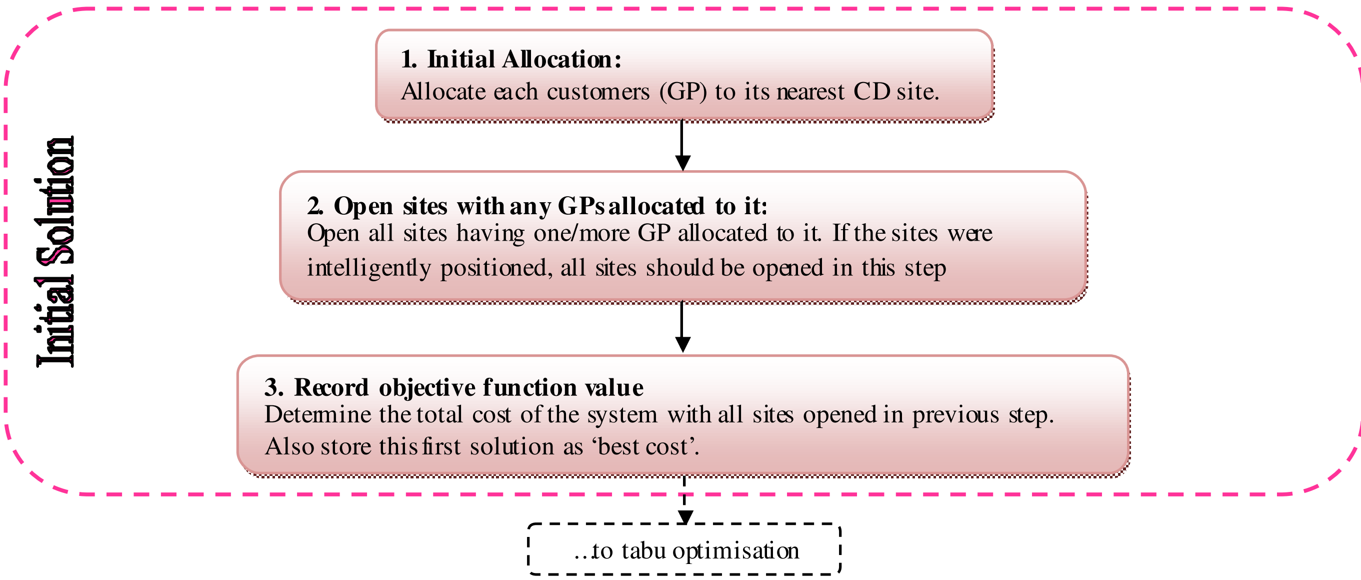
Some literature indicated that an FLP can be solved linearly (an exact solution can be determined) if its problem definition is 'not too large'. Since 'not too large' is a vague concept, it was decided to compare an exact solution methodology with the metaheuristic TS with regards to solution accuracy and run time (whether the run time of an exact solution program is realistic compared to that of a metaheuristic such as TS).

For the comparison of the mentioned methods artificial, though realistic, data was used since no real data had been available at that stage of the project's progress. This data can be viewed in Appendix C.

First, an exact (precise) solution had been attempted by a mixed integer linear program. This program, of which the code can be viewed in Appendix D, was run on the software program Lingo version 7 with the mentioned data as input. Lingo was designed to find exact solutions for linear programs.

The program was run on Lingo for 45 hours before it was deliberately interrupted since reaching a global optimum had not seemed likely within a realistic run time period. The solution generated by the exact solution methodology is discussed under 'Results', p. 36.

The second strategy was TS. To develop a good metaheuristic solution algorithm for this problem, certain literature by Michel & Van Hentenryck (2003) was combined with a modification of the generic algorithm. The problem's data was exported to the computer programming package Octave which is based on the Matlab programming language. A TS algorithm was consequently programmed. The developed TS algorithm for the sales offices problem can be viewed in Appendix F. The TS algorithm took 11.04 seconds to generate a very good objective function value. The solution TS generated is also discussed under 'Results', p. 36. Figure 5 explains the logic of the metaheuristic programming for the cross docks.



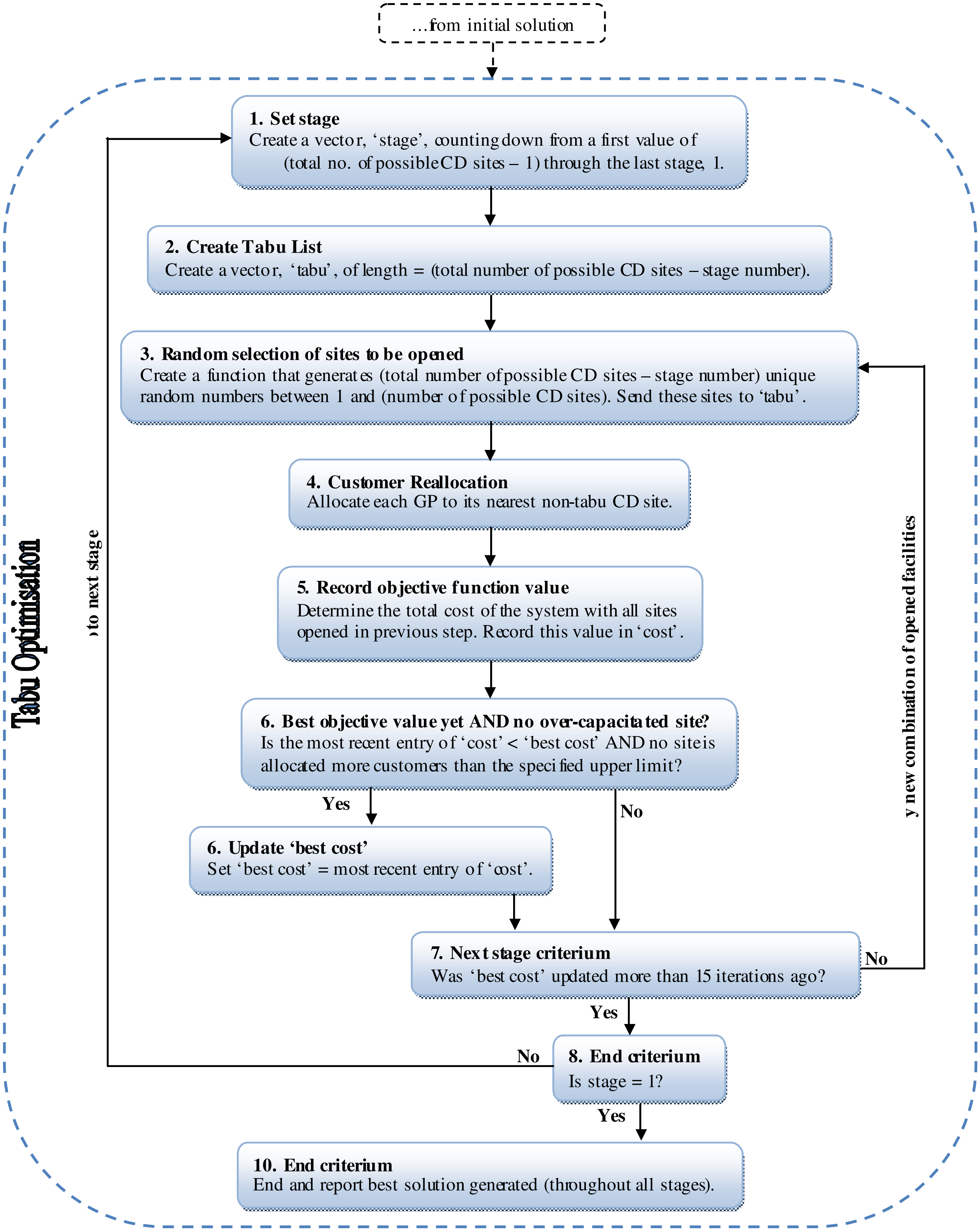


Figure 5: Metaheuristic programming logic for the cross docks problem

Results

Exact Solution

The best solution generated by the linear program in 45 hours' run time (for the artificial data) was a total cost of R 4 264 707. For this lowest cost, the solution looked as follows:

- **Cross Docks Opened:**

$$CD_j = 1 \quad \forall \; j \in \{2; 7\}$$

Therefore sites 2 and 7 were considered to be optimally located for cross docks for the system where five sales offices are opened. All GPs were allocated between these two facilities.

- **Trucks Assigned:**

$$n_j = 1 \quad \forall \; j \in \{2; 7\}$$

Therefore one truck was assigned to both CDs 2 and 7. (All other sites were not allocated any trucks since they were not opened in this solution.)

TS Solution

Since the TS algorithm makes use of the 'rand' function which generates a random number in order to do certain moves, the algorithm's output may differ from time to time. Therefore the algorithm was run twenty times and each solution was recorded. Each run took an average time of 11.04 seconds.

The best objective function value generated by the TS in the twenty runs was a total cost of R3,462,500. This was generated in 40% of the runs. Of the twenty runs, the biggest objective function value generated (which was generated in only 5% of the runs), was R3 463 900. The difference between the two solutions is a cost of only R1400, an insignificant figure in the scope of a large business such as EmpiriQ. Therefore the Tabu Search proved to constantly deliver very good results.

For the lowest cost, the solution looked as follows:

- **Cross Docks Opened:**

$$CD_j = 1 \quad \forall \; j \in \{6; 7\}$$

Therefore sites 6 and 7 were considered to be optimally located for cross docks for the system where five sales offices are opened. All GPs were allocated between these two facilities.

- **Trucks Assigned:**

$$n_j = 2 \quad \forall \; j \in \{6; 7\}$$

Therefore two trucks were assigned to both CDs 6 and 7. (All other sites were not allocated any trucks since they were not opened in this solution.)

Comparison of Methods and Conclusion

The exact solution was consequently compared with that of TS and is summarised in Table 4.

Parameter	**Exact Method**	**Metaheuristic (TS) Method**
Run Time	> 45 hours	11.04 seconds
Result Optimality	Average	Very good

Table 4: Comparison between exact and metaheuristic solving methods

Conclusion of Comparison

The exact solution method

- iterated without reaching a global optimum for a period of 45 hours and
- provided a solution less optimal than TS.

The metaheuristic method, TS

- reached a better solution than the exact method
- after iterating for a low 11.04 seconds and
- never provided a solution set that differed from the optimum (due to the ‘rand’ function in the algorithm) by more than R1400.

It was therefore concluded that, as previously indicated by the literature studied on this matter, TS was indeed the best way to solve EmpiriQ's FLPs as it constantly provided a very good solution to an FLP.

6.2.2 Real Data: Original Problem Statement

The data used in the real Cross Docks problem can be viewed in Appendix E.

Since the TS algorithm makes use of the 'rand' function which generates a random number in order to do certain moves, the algorithm's output differs each time. Therefore the algorithm was run twenty times to ensure the best solution is being obtained. Each solution of the twenty iterations was recorded. The recorded solutions can be viewed in Table 5.

Run Number	Open facilities	Objective Function Value (Total Cost) (R million)
1	1, 2	2.2376
2	1, 3	2.2374
3	1, 2	2.2376
4	1, 3	2.2374
5	1, 2	2.2376
6	1, 3	2.2374
7	1, 3	2.2374
8	1, 2	2.2376
9	1, 3	2.2374
10	1, 3	2.2374
11	1, 2	2.2376
12	3, 4	2.2377
13	1, 3	2.2374
14	1, 3	2.2374
15	3, 4	2.2377
16	1, 2	2.2376
17	1, 3	2.2374
18	1, 3	2.2374
19	1, 3	2.2374
20	3, 4	2.2377

Table 5: Solutions generated by Tabu Search

For the lowest cost (R2.2374 million), the system looked as follows:

- **Cross Docks Opened:**

$$CD_j = 1 \quad \forall\ j \in \{1; 3\}$$

Therefore sites 1 and 3 were considered to be optimally located for cross docks for the system where five sales offices are opened.

- **Cross Dock System Cost (Best Objective Function Value)**

The best objective function value generated by the TS in the twenty runs was a cost of R2.2374 million. This amount can be separated into fixed costs (buildings and vehicles) of R2.2 million and weekly operational costs of R37,400 (excluding instalment on fixed building and vehicle costs). (This solution is optimal in the system where five sales offices are opened. Thus 60.9% of the total area was considered potential customers to whom deliveries would have to be made from the cross docks.) The optimal cross dock solution of R2.2374 million was generated in 55% of the runs. Of the twenty runs, the biggest objective function value generated (which was generated in only 5% of the runs), was R2.2377 million. The difference between the two solutions is a cost of only R300. Therefore the Tabu Search proved to constantly deliver very good results.

- **Delivery Area Allocation per Cross Dock**

Only the GPs that had received some service coverage by a sales office were considered potential customers to whom ordered supplies would have to be delivered directly. TS provided the allocation of delivery areas (GPs) to each opened CD. These allocations can be viewed in Table 6. Once again, where a GP was not assigned to any CD, it means that the particular GP received no service coverage from one of the five opened SOs and was therefore not considered a potential customer.

GPs Allocated to each CD	
CD 1	**CD 3**
1	
3	
4	
7	
8	
9	
10	
11	
12	
13	
14	
16	
	17
18	
19	
20	
	21
	22
	23
	24
	25
	26
	28

Table 6: Delivery area allocation per opened CD

- **Trucks Assigned:**

$$n_j = 1 \quad \forall \; j \in \{1, 3\}$$

Therefore one truck was assigned to both CDs 1 and 3. (All other sites were not allocated any trucks since they were not opened in this solution.)

7. Sensitivity Analysis

Three scenarios different from the original problem statement were consequently analysed to determine the effect of certain parameter changes on the model. The original problem was therefore considered Scenario 1 and the three scenarios investigated in this section, Scenario 2, 3 and 4 respectively.

Scenario 2: No budgetary constraints

If EmpiriQ did not have any budgetary constraints, the ideal number of eight sales offices could be erected. The sales office and cross dock TS algorithms was altered to determine the system solution if eight offices were allowed.

The sales office TS yielded the following solution:

- **Sales Offices Opened:**

$$SO_j = 1 \; \forall j \in \{1; 2; 3; 4; 5; 6; 7; 10\}$$

Therefore sites 1, 2, 3, 4, 5, 6, 7 and 10 were considered to be optimally located for sales offices.

- **Service coverage**

141,006 homes. Out of a total of 159,900 homes in the area, this coverage represents 88.2%. This is a significant improvement on the 60.9% where budgetary constraints were taken into account.

- **Customer allocation per sales office**

In this solution, only GP 33 did not receive any service coverage. The number of customers served by each of the eight offices, were 19,500; 19,500; 19,500; 18,200; 13,457; 18,757, 12,592 and 19,500 respectively.

Therefore most of the offices' service capacities were almost fully utilised. With this solution, a total service coverage of 141,006 homes was obtained.

Since a bigger portion (88.2%) of the KwaMhlanga area was regarded as potential customers due to the addition of three more sales offices, more deliveries would be required to be made from the cross docks. The cross dock TS algorithm was adapted to accommodate this bigger service area and delivered the following solution:

- **Cross Docks Opened:**

$$CD_j = 1 \quad \forall\ j \in \{1; 7; 10\}$$

Therefore sites 1, 7 and 10 were considered to be optimally located for cross docks for the system where eight sales offices are opened.

- **Cross Dock System Cost (Best Objective Function Value)**

R3.3547 million. (Fixed cost: R3.3 million, weekly operational cost: R54,700.)

- **Trucks Assigned:**

$$n_j = 1 \quad \forall\ j \in \{1; 7; 10\}$$

Therefore 1 truck was assigned to each of CDs 1, 7 and 10.

- **Analysis of Solution**

If eight sales offices are opened, 43,703 more homes have access to a sales office (is closer than or equal to 12 km from the nearest sales office).

The solution of opening cross docks 1, 7 and 10 was more expensive than opening only cross docks 1 and 3. Considering only the additional cross dock, fixed building and vehicle costs were R1.1 million more and weekly operating costs were R17,300 more than the original solution. These higher figures are the result of a bigger delivery area (additional customers) and costs associated with building an additional cross dock facility. (However, a bigger customer base also implied increased profits.)

If EmpiriQ could acquire additional financing for the three more sales offices, three cross docks had to be opened: one at each of sites 1, 7 and 10. Analysis was necessary to determine whether the expenses associated with this scenario of no-budgetary constraints would be covered by the revenue gained from it. Only if this had been the case could EmpiriQ consider implementing this solution.

The following figures were forecasted in EmpiriQ's business plan:

Revenue per customer per week	R250
Material cost per order	70%
Profit margin per order	30%
Fixed building cost per sales office	R90,000
Operating cost per sales office per week	R3750 (=R15,000 per month)
Instalment rate on fixed assets, per month	2%
Amount of customers conducting business with EmpiriQ per week	1% of potential customers (homes 'covered' by the sales offices service coverage model)

Table 7: Forecasted business data

Using these figures, the following calculations were made:

$$Weekly\ customers = 141{,}006 \times 0.01 = 1410$$

$$Weekly\ profit = R250 \times 0.30 \times 1410 = R105{,}750$$

$$Fixed\ asset\ cost\ (8\ sales\ offices) = R90{,}000 \times 8 = R720{,}000$$

$$Fixed\ asset\ cost\ (3\ cross\ dock + 3\ trucks) = 3 \times (R500{,}000 + R600{,}000)$$
$$= R3{,}300{,}000$$

$$Fixed\ assets\ weekly\ loan\ instalment = (R720{,}000 + R3{,}3000{,}000) \times \frac{0.02}{4} = R20{,}100$$

$$Weekly\ operating\ cost\ (8\ offices\ \&\ 3\ cross\ docks) = R3750 \times 8 + R54{,}700$$
$$= R84{,}700$$

To justify the building of three additional offices, the income generated from the additional customers retained should at least cover all expenses. The expenses were the instalment on the buildings of R20,100 per week and operational cost of R84,700 per week and had to be covered by the weekly profit (R105,750).

Therefore, the weekly profit in this scenario is

$$R105{,}750 - (R20{,}100 + R84{,}700) = R950$$

If the same calculations are made for the original problem statement, a weekly profit of R3580 is realised.

To summarise, in this scenario more customers would be retained and the eight sales offices' available capacity would be almost fully utilised. However, the expenses associated with this scenario resulted in a lower weekly profit than the original solution, and therefore this solution was not recommended for implementation by EmpiriQ.

Scenario 3: Budgetary constraints, but no upper service limit

In this scenario, the system solution was analysed for the situation where there existed no upper limit on the amount of orders a cross dock can accommodate.

In the original problem, the upper service limit had been 700 orders due to the size of a cross dock EmpiriQ had in mind. In this scenario however, that parameter was removed. The fixed cost per cross dock was increased from R500,000 to R750,000, since a cross dock with an unlimited service capacity could be assumed to require a bigger facility and therefore to incur a higher setup cost.

- **System Cost (Best Objective Function Value)**

  Where five sales offices were used, the lowest cost (including all costs associated with both the sales offices and the cross docks) was R1,847,750. (R1.8 million fixed + R47,750 weekly operations).

- **Sales Offices Opened:**

$$SO_j = 1 \ \forall j \in \{1;\ 2;\ 3;\ 4;\ 5\}$$

  Therefore sites 1, 2, 3, 4 and 5 were considered to be optimally located for sales offices.

- **Cross Docks Opened:**

$$CD_j = 1 \quad \forall \; j \in \{1\}$$

Therefore site 1 was considered to be optimally located for a cross dock.

- **Trucks Assigned:**

$$n_j = 1 \quad \forall \; j \in \{1\}$$

Therefore 1 truck was assigned to CD 1.

- **Analysis of Solution**

When the same calculations as in Scenario 2 was performed to determine the profit generated, it was revealed that this scenario yielded a weekly profit of R16,227. This is higher than the weekly profit of R3,580 of the original solution. EmpiriQ was therefore compelled to reconsider the necessity of the upper service limit constraint that had been specified by them. Before a final recommendation could be made, Scenario 4 had to be investigated.

Scenario 4: No budgetary constraints and no upper service limit

In this scenario, the system solution was analysed for the situation where there existed no upper limit on the amount of orders a cross dock can accommodate, but also assuming that additional financing was available if necessary to afford extra facilities.

In the original problem, the upper service limit had been 700 orders due to the size of a cross dock EmpiriQ had in mind. In this scenario however, that parameter was again removed. The fixed cost per cross dock was again set to R750,000, since a cross dock with an unlimited service capacity could be assumed to require a bigger facility (than one handling a limited amount of customer orders) and therefore to incur a higher setup cost.

- **System Cost (Best Objective Function Value)**

Where the ideal of eight sales offices were used, the lowest cost (including all costs associated with both the sales offices and the cross docks) was R 1.9897 (R2.67 million fixed + R69,700 weekly operations).

- **Sales Offices Opened:**

$$SO_j = 1 \ \forall j \in \{1; 2; 3; 4; 5; 6; 7; 10\}$$

Therefore sites 1, 2, 3, 4, 5, 6, 7 and 10 were considered to be optimally located for sales offices.

- **Cross Docks Opened:**

$$CD_j = 1 \quad \forall \ j \in \{3\}$$

Therefore site 3 was considered to be optimally located for a cross dock.

- **Trucks Assigned:**

$$n_j = 2 \quad \forall \ j \in \{3\}$$

Therefore 2 trucks were assigned to CD 3.

- **Analysis of solution**

  When the same calculations as in Scenario 2 and 3 was performed to determine the profit generated, it was revealed that this scenario yielded a weekly profit of R22,704.50. This was higher than the profit generated original solution (Scenario 1) as well as the profit generated in Scenario 2 and 3. Once again, EmpiriQ was seriously asked to reconsider the necessity of the upper service limit constraint that had been specified by them. If this limit could be removed at all, implementing the last solution in its business was recommended to EmpiriQ. Since this was the final recommendation, the solution was displayed in further detail:

- **Customer allocation per sales office**

  The allocations of GPs to SOs can be viewed in Table 8.

	Sales Offices (SOs) opened and number of homes per Gravity Point (GP) allocated to each SO							
GP receiving (some) service coverage	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**10**
1								3900
2								2600
3								5200
4								5200
5								2600
6					995			
7					875			
8		3900						
9	1300							
10		3900						
11	6500							
12	6500							
13	5200							
14		3900						
15		2600						
16			6500					
17					3527			
18				5200				
19			6500					
20					3900			
21		5200						
22			6500					
23				6500				
24				6500				
25					4160			
26						4457		
27							3176	
28						3900		
29						6500		
30						3900		
31							5200	
32							3399	
34							186	
35							631	
	19500	19500	19500	18200	13457	18757	12592	19500

Table 8: Sensitivity analysis optimal scenario: customer allocation per sales office

- **Delivery Area Allocation per Cross Dock**

All GPs covered by the sales offices were allocated to CD 3. These allocations can be viewed in Table 9.

GP to which deliveries must be made	Number of homes per Gravity Point (GP) allocated to CD 3
1	3900
2	2600
3	5200
4	5200
5	2600
6	995
7	875
8	3900
9	1300
10	3900
11	6500
12	6500
13	5200
14	3900
15	2600
16	6500
17	3527
18	5200
19	6500
20	3900
21	5200
22	6500
23	6500
24	6500
25	4160
26	4457
27	3176
28	3900
29	6500
30	3900
31	5200
32	3399
34	186
35	631

Table 9: Sensitivity analysis optimal scenario: customer allocation to CD 3

8. Results Summary

All results were consequently summarised for ease of comparison.

Scenario	Sales Offices Opened	Number of Potential Customers	Cross Docks Opened	Total weekly sales offices costs, R *	Total weekly cross docks costs, R *	Total weekly materials cost, R **	Total weekly system cost, R	Total weekly system revenue, R	Total weekly system profit, R ***
1. Budgetary constraints (original solution)	1; 2; 3; 4; 5	97303	1; 3	21000	48400	170280	239680	243258	3577
2. No budgetary constraints	1; 2; 3; 4; 5; 6; 7; 10	141006	1; 7; 10	33600	71200	246761	351561	352515	955
3. Budgetary constraints but no service limit on cross docks	1; 2; 3; 4; 5	97303	1	21000	35750	170280	227030	243258	16227
4. No budgetary constraints and no service limit on cross docks	1; 2; 3; 4; 5; 6; 7; 10	141006	3	33600	49450	246761	329811	352515	22705

Table 10: Tabular summary of all results

* = weekly instalment on buildings & vehicles (if appropriate) + weekly operational costs
** = 70% of the average customer order of R300
*** = total weekly system revenue – total weekly system cost

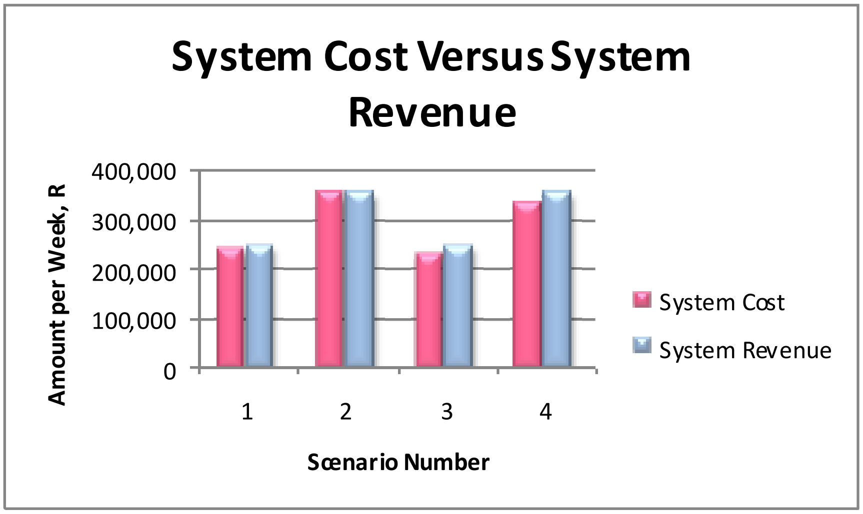


Figure 6: Graphical summary of system cost and revenue for different scenarios

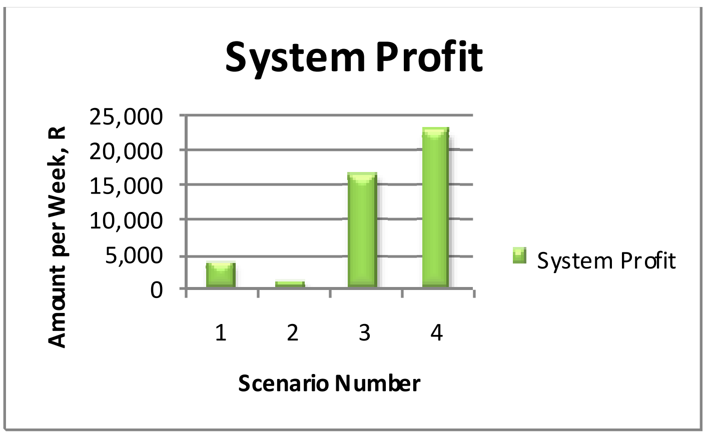


Figure 7: Graphical summary of system profit for different scenarios

It was finally recommended that EmpiriQ should apply for financing in order to build additional facilities than what had initially been considered to be possible with the company's budgetary constraints. This additional financing should be added to initially available funds in order to build eight sales offices and three cross docks. One sales office should be built at each of SO sites 1, 2, 3, 4, 5, 6, 7 and 10 and one cross dock at each of CD sites 1, 7 and 10. This system would ensure a business permanently generating a maximum weekly profit of R22,705 (R90,820 each month).

These optimal sites were marked on Figure 8 below.

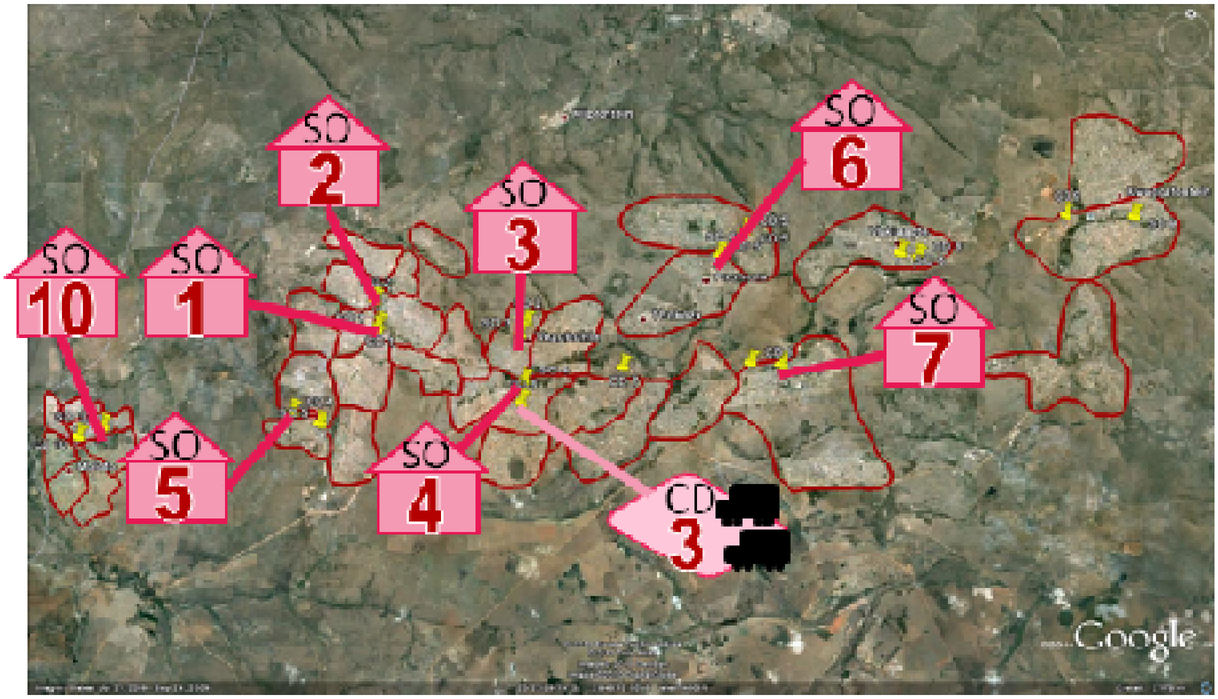


Figure 8: Optimal solution displayed on the geographical map of the target area

9. Conclusion

Doing business in the lower income sector can be done profitably, but in order for this to be possible, a specific approach is required. A business model different from the traditional one designed for the middle and high income classes, is required.

In South Africa, the lower income market experiences numerous problems and incurs many unnecessary expenses when dealing with businesses operating from the traditional business model. These, of which transport cost is the biggest, were all discussed in this report. Alterations necessary to be made to the traditional business model, such as decentralised facilities and provision of micro credit, were also investigated and discussed.

EmpiriQ Advisory and Support Services had decided to implement the proposed business model in the lower income area KwaMhlanga near Pretoria. In order to do this, they had required a mathematically defined model with regards to the amount, locations and customer allocations of decentralised facilities.

A type-specific Tabu Search metaheuristic algorithm was developed for each of the two facility types to determine the best amount and locations (from those EmpiriQ indicated to be favourable on a geographical map) of each facility type.

After numerous sensitivity analyses had been performed, a final recommendation was made to EmpiriQ. This final recommendation was to apply for the financing of the additional facilities that would yield an optimal system. Therefore, different from what had initially been considered to be possible with the company's budgetary constraints, EmpiriQ had to build eight sales offices and three cross docks. One sales office had to be built at each of SO sites 1, 2, 3, 4, 5, 6, 7 and 10 and one cross dock at each of CD sites 1, 7 and 10. Furthermore, the upper service limit of 700 orders per cross dock should be removed and a cross dock's size should be determined by its demand.

This system would generate a maximum weekly profit of R22,705 (R90,820 per month).

References

AA Insurance 2010, 'Vehicle Operating Costs', *AA Insurance: www.aa.co.za/content/62/vehicle-oper.costs*.

Anonymous 2010, 'How to Market to a Low-Income Group', 2010, *www.ehow.com: http://www.ehow.com/how_2317682_market-lowincome-group.html*.

Arostegui, MA, Kadipasaoglu, SN & Khumawala, BM 2006, 'An empirical comparison of Tabu Search, Simulated Annealing and Genetic Algorithms for facilities location problems', *International Journal of Production Economics*, pp. 742–754.

Bowersox, DJ & Closs, DJ 1989, 'Simulation in Logistics: A Review of Present Practice and a Look into the Future', *Journal of Business Logistics 10, no. 1*, pp. 122-132.

Budinich, V 2005, 'Market-Based Strategies Serving Low-Income Populations: A Framework for Action', *Ashoka Innovators for the Public*, pp. 4-8.

Coyle, JJ, Bardi, EJ, & Langley, CJ 2003, '*The Management of Business Logistics: A Supply Chain Perspective*', Thomson South-Western, Ohio.

Google Earth 2010, 'Map of KwaMhlanga, Pretoria, South Africa'.

Grameen Bank 2010, 'What is Microcredit?', *www.grameen-info.org*: *http://www.grameen-info.org/index.php?option=com_content&task=view&id=28&Itemid=108*.

Hammond, AL, Kramer, WJ, Katz, RS, Tran, JT & Walker, C 2007, *The next 4 billion,* World Resources Institute and International Finance Corporation, Washington DC, p 153.

Lee, JM & Lee, YH 2010, 'Tabu based heuristics for the generalized hierarchical covering location problem', *Elsevier*, pp. 638 - 645.

National Treasury 2008, 'Reconstruction and Development Programme Fund Annual Financial Statements for the year ended 31 March 2008'.

Prahalad, CK 2005, *The Fortune at the Bottom of the Pyramid,* Wharton School Publishing, NJ.

Rego, N 2009, ' 'Rural edge' sees Cashbuild soar', *fin24.com, http://www.fin24.com/articles/default/display_article.aspx?ArticleId=2553168.*

Savage, SL 2003, *Decision Making with Insight*, Thomson Brooks/Cole, CA.

Shannon, RE 1975, *Systems Simulation: The Art and Science.* Englewood Cliffs, NJ: Prentice-Hall.

Shapiro, D 2009, 'Cashbuild sees revenue growth' (N. Rego, Interviewer).

Statistics SA 2009, *Building statistics 2007.*

Titus, M 2005, 'Helping themselves', *The Economist.*

Truter, JT 2010, Interviewer: Steyn, M.

Wikipedia 1996, 'Bottom of the Pyramid', *www.wikipedia.org: http://en.wikipedia.org/wiki/Bottom_of_the_pyramid.*

Winston, WL & Venkataramanan, M 2003, '*Introduction to Mathematical Programming, Operations Research: Volume One,* Thomson Brooks/Cole, CA.

Yunus, M 1999, *Banker to the Poor,* PublicAffairs, NY.

Appendix A: Sales Offices Data

	Distance (km) from GP(i) to possible SO(j)									
GP	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	10.6	11.2	15.5	15.4	8.7	22.3	23.7	28.4	36	1.1
2	11	11.6	15.7	15.3	8.6	22.5	23.7	28.4	36	0.5
3	10.1	11	14.7	14.6	8.1	21.7	23	27.4	35.2	1.1
4	9.6	10.2	14.2	14	7.5	21.3	22.5	26.9	34.7	1
5	11.2	12.4	15.6	15.1	8.3	22.4	23.5	26.6	35.9	1.2
6	9.3	9.8	13.8	13.4	6.6	20.8	21.9	28.2	34.2	1.3
7	10.4	11.4	14.6	14.2	7.3	21.6	22.6	26.7	35	1.5
8	3.9	4.5	7.6	7.2	0.5	14.6	15.7	27.2	28	7.7
9	2.7	3.5	7.1	7	1.8	14.3	15.5	20.2	27.5	8
10	1.9	1.9	6.8	7.2	3.6	13.3	15.4	19.8	27	8.8
11	1.7	1.4	6	6.5	4.9	12	15.4	19.4	25.7	10.4
12	0.7	1	5.5	5.8	3.6	12	14.4	18.1	25.7	9.8
13	2.5	1.7	5.5	6.6	6.2	11.2	14	17.9	24.8	11.6
14	2.1	1.4	4.4	5.3	5.8	10.4	14	17.3	24	12
15	3.6	3	4	5.3	7.3	9.2	12.8	16.3	22.8	13.6
16	1.2	1.2	3.6	4.3	5.0	10.2	11.8	15.1	23.7	11.7
17	2.8	3.1	2	2.5	5.7	8.8	12.2	14.5	23.6	12.9
18	2.1	2.5	3	3.1	4.4	10	10.4	15.5	22.4	12
19	1.5	2.3	3.4	5.2	2.3	12.3	11.5	18	25.6	9.7
20	3.7	4.5	6.3	5.6	1.1	13.2	13.6	18.8	26.4	9
21	4	4.5	2.1	1.4	5.5	8.7	14.1	14.3	22	13.6
22	4.6	4.8	0	1.8	7.3	7.1	9.7	12.8	20.6	14.7
23	6.2	6.4	1.5	2.3	8.6	5.6	8.8	11.3	18.9	16.4
24	5.5	5.9	2.2	0.6	7.1	7.6	7.2	13	20.6	14.9
25	6.1	6.8	3.6	2	6.4	9.1	8	14	21.5	14.3
26	7.3	8	3.2	2.4	9.1	6	9.1	11	18.7	17.2
27	8.6	9	4.6	3.4	10	6.7	6.3	11	18.3	18.1
28	11.2	10.8	6.4	7.1	13.8	0.6	5	6.2	14	21.5
29	11.6	11.1	7.3	8.3	14.6	1.3	3.8	6.1	13.7	22
30	10.8	11	6.1	5.7	12.4	4.5	5.5	7.8	15.2	20.5
31	14.6	14.8	10	9.5	16.8	5.1	2.8	4.9	12	24.4
32	17.2	16.9	12.6	12.7	19.6	5.8	5.9	0.5	8.4	27.4
33	25	24.4	20.3	20.1	27.5	13.6	13	7.8	2.1	35.4
34	24.8	24.5	20.1	20.1	26.9	13.5	11.8	7.2	0.7	34.9
35	22.8	23	18	18.5	25.6	12.6	10.3	7	4.7	33.5

Table 11: Distances (km) from each GP to each possible SO site

		Service Coverage Ratio of GP(i) by SO(j)									
GP	**No. of homes GP(i) represents**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	3900	0.20	0.11	0.00	0.00	0.46	0.00	0.00	0.00	0.00	1.00
2	2600	0.14	0.06	0.00	0.00	0.49	0.00	0.00	0.00	0.00	1.00
3	5200	0.27	0.14	0.00	0.00	0.56	0.00	0.00	0.00	0.00	1.00
4	5200	0.34	0.26	0.00	0.00	0.65	0.00	0.00	0.00	0.00	1.00
5	2600	0.11	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	1.00
6	1300	0.39	0.31	0.00	0.00	0.77	0.00	0.00	0.00	0.00	1.00
7	1300	0.23	0.09	0.00	0.00	0.67	0.00	0.00	0.00	0.00	1.00
8	3900	1.00	1.00	0.63	0.69	1.00	0.00	0.00	0.00	0.00	0.61
9	1300	1.00	1.00	0.70	0.71	1.00	0.00	0.00	0.00	0.00	0.57
10	3900	1.00	1.00	0.74	0.69	1.00	0.00	0.00	0.00	0.00	0.46
11	6500	1.00	1.00	0.86	0.79	1.00	0.00	0.00	0.00	0.00	0.23
12	6500	1.00	1.00	0.93	0.89	1.00	0.00	0.00	0.00	0.00	0.31
13	5200	1.00	1.00	0.93	0.77	0.83	0.11	0.00	0.00	0.00	0.06
14	3900	1.00	1.00	1.00	0.96	0.88	0.23	0.00	0.00	0.00	0.00
15	2600	1.00	1.00	1.00	0.96	0.67	0.40	0.00	0.00	0.00	0.00
16	6500	1.00	1.00	1.00	1.00	1.00	0.26	0.03	0.00	0.00	0.04
17	3900	1.00	1.00	1.00	1.00	0.90	0.46	0.00	0.00	0.00	0.00
18	5200	1.00	1.00	1.00	1.00	1.00	0.29	0.23	0.00	0.00	0.00
19	6500	1.00	1.00	1.00	0.97	1.00	0.00	0.07	0.00	0.00	0.33
20	3900	1.00	1.00	0.81	0.91	1.00	0.00	0.00	0.00	0.00	0.43
21	5200	1.00	1.00	1.00	1.00	0.93	0.47	0.00	0.00	0.00	0.00
22	6500	1.00	1.00	1.00	1.00	0.67	0.70	0.33	0.00	0.00	0.00
23	6500	0.83	0.80	1.00	1.00	0.49	0.91	0.46	0.10	0.00	0.00
24	6500	0.93	0.87	1.00	1.00	0.70	0.63	0.69	0.00	0.00	0.00
25	5200	0.84	0.74	1.00	1.00	0.80	0.41	0.57	0.00	0.00	0.00
26	5200	0.67	0.57	1.00	1.00	0.41	0.86	0.41	0.14	0.00	0.00
27	3900	0.49	0.43	1.00	1.00	0.29	0.76	0.81	0.14	0.00	0.00
28	3900	0.11	0.17	0.80	0.70	0.00	1.00	1.00	0.83	0.00	0.00
29	6500	0.06	0.13	0.67	0.53	0.00	1.00	1.00	0.84	0.00	0.00
30	3900	0.17	0.14	0.84	0.90	0.00	1.00	0.93	0.60	0.00	0.00
31	5200	0.00	0.00	0.29	0.36	0.00	0.99	1.00	1.00	0.00	0.00
32	3900	0.00	0.00	0.00	0.00	0.00	0.89	0.87	1.00	0.51	0.00
33	6500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	1.00	0.00
34	6500	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.69	1.00	0.00
35	2600	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.71	1.00	0.00

Total: 159900

Table 12: Service coverage ratio of GP(i) by SO(j), based on the Service Coverage Model (Figure 2)

	Service Coverage (no. of homes) of GP(i) by SO(j)									
GP	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	780	446	0	0	1812	0	0	0	0	3900
2	371	149	0	0	1268	0	0	0	0	2600
3	1411	743	0	0	2897	0	0	0	0	5200
4	1783	1337	0	0	3379	0	0	0	0	5200
5	297	0	0	0	1388	0	0	0	0	2600
6	501	409	0	0	995	0	0	0	0	1300
7	297	111	0	0	875	0	0	0	0	1300
8	3900	3900	2451	2674	3900	0	0	0	0	2396
9	1300	1300	910	929	1300	0	0	0	0	743
10	3900	3900	2897	2674	3900	0	0	0	0	1783
11	6500	6500	5571	5107	6500	0	0	0	0	1486
12	6500	6500	6036	5757	6500	0	0	0	0	2043
13	5200	5200	4829	4011	4341	594	0	0	0	297
14	3900	3900	3900	3733	3436	891	0	0	0	0
15	2600	2600	2600	2489	1749	1040	0	0	0	0
16	6500	6500	6500	6500	6480	1671	186	0	0	279
17	3900	3900	3900	3900	3527	1783	0	0	0	0
18	5200	5200	5200	5200	5200	1486	1189	0	0	0
19	6500	6500	6500	6314	6500	0	464	0	0	2136
20	3900	3900	3176	3566	3900	0	0	0	0	1671
21	5200	5200	5200	5200	4823	2451	0	0	0	0
22	6500	6500	6500	6500	4364	4550	2136	0	0	0
23	5386	5200	6500	6500	3157	5943	2971	650	0	0
24	6036	5664	6500	6500	4550	4086	4457	0	0	0
25	4383	3863	5200	5200	4160	2154	2971	0	0	0
26	3491	2971	5200	5200	2154	4457	2154	743	0	0
27	1894	1671	3900	3900	1114	2953	3176	557	0	0
28	446	669	3120	2730	0	3900	3900	3231	0	0
29	371	836	4364	3436	0	6500	6500	5479	0	0
30	669	557	3287	3510	0	3900	3621	2340	0	0
31	0	0	1486	1857	0	5126	5200	5200	0	0
32	0	0	0	0	0	3454	3399	3900	2006	0
33	0	0	0	0	0	0	0	3900	6500	0
34	0	0	0	0	0	0	186	4457	6500	0
35	0	0	0	0	0	0	631	1857	2600	0
	99617	96126	105727	103387	94170	56940	43141	32314	17606	34933

Table 13: No. of homes in GP(i) covered by SO(j), based on the Service Coverage Model (Figure 2)

Appendix B: Tabu Search Algorithm for Sales Offices

```
SOmatrix  = %Table 7 data inserted here
[n,m] = size(SOmatrix);
maxamountSOs = 5; %User input
x = maxamountSOs;
tabucoeff = 6; %used for determining tabulist size
tabulistsize = m-tabucoeff;
y = tabulistsize;
tabu = zeros(n,y);

itermax = 200; %User input. Never make bigger than 500.
iterations = 0;
servicecoverage = zeros(itermax,tabucoeff);

closed = SOmatrix;
opened = zeros(n,x);


%Initial Solution Part A: choose top x sales offices
iterations = iterations + 1;
for a = 1:1:x %search for x SOs with maxTC to open
  TCmax = max(closed(n,:)); %search for facility with maxTC

  z = 0;
  do %to determine in what column (or facility no.) max OC is
    z = z + 1;
  until closed(n,z) == max(closed(n,:));

  z;
  opened(:,a) = closed(:,z); %put this SO in 'opened'
  closed(:,z) = 0; %take facility out of 'closed'
end

closed;
opened;

%Initial solution part B: customer allocation
allocatefrom = opened;
allocated = zeros(n,x);
allocated(1,:) = opened(1,:);

do
  most = max(allocatefrom(2:(n-1),:)); %search for max OC

  j = 0;
  do %to determine in what column (or facility no.) max OC is
    j = j + 1;
  until most(j) == max(most);

  j;
  i = 0;

  do
```

```
    i = i + 1;
  until allocatefrom(i,j) == max(allocatefrom(2:(n-1),j));

  i;
  j;

  allocatefrom(i,j) = 0;

  if sum(allocated(2:(n-1),j)) + max(most) < 20000
    allocated(i,j) = max(most);
    allocated(n,j) = sum(allocated(2:(n-1),j));
          allocatefrom(i,:) = 0;
  end

until allocatefrom(2:(n-1),:) == 0

allocatefrom(:,:) = 0;
servicecoverage(iterations,1) = sum(allocated(n,:));
servicecoverage(iterations,2:tabucoeff) = allocated(1,:);
bestsol = allocated;


%Tabu Part A: Facility exchange
%1. Close SO in 'allocated' with lowest AC
while iterations < itermax
iterations = iterations + 1;
minAC = min(allocated(n,:));

q = 0;
do
  q = q + 1;
until allocated(n,q) == minAC

q;
r = tabu(1,y);

if r > 0
  closed(:,r) = tabu(:,y); %haal lid wat lank genoeg tabu was uit
end

for h = y:(-1):2 %tabu loop
  tabu(:,h) = tabu(:,(h-1));
end
tabu(:,1) = opened(:,q);

opened(:,q) = 0;

%2. Open SO in 'closed' with highest TC
z = 0;
do %to determine in what column (or facility no.) max OC is
  z = z + 1;
until closed(n,z) == max(closed(n,:));

z;
opened(:,q) = closed(:,z); %put this SO in 'opened'
closed(:,z) = 0; %take facility out of 'closed'
```

```
%Tabu Part B: Customer allocation
allocatefrom = opened;
allocated = zeros(n,x);
allocated(1,:) = opened(1,:);

do
  most = max(allocatefrom(2:(n-1),:)); %search for max OC

  j =0;
  do %to determine in what column (or facility no.) max OC is
    j =j + 1;
  until most(j) == max(most);

  j;
  i =0;

  do
    i =i + 1;
  until allocatefrom(i,j) == max(allocatefrom(2:(n-1),j));

  i;
  j;
  max(most);

  allocatefrom(i,:) = 0;

  if sum(allocated(2:(n-1),j)) + max(most) < 20000
    allocated(i,j) = max(most);
    allocated(n,j) = sum(allocated(2:(n-1),j));
  end

until allocatefrom(2:(n-1),:) == 0

allocatefrom(:,:) = 0;
servicecoverage(iterations,1) = sum(allocated(n,:));
servicecoverage(iterations,2:tabucoeff) = allocated(1,:);

if servicecoverage(iterations,1) == max(servicecoverage(:,1))
  bestsol = allocated;
end

bestsolcoverage = max(servicecoverage(:,1));
end

servicecoverage
bestsolcoverage
bestsol
```

Appendix C: Artificial Data for a Comparison between Possible Solution Methods

	Distance from GP(i) to possible CD(j)										
GP	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**No. of homes GP(i) represents**
1	48	51	48	31	41	50	34	58	34	39	2100
2	47	41	43	37	39	54	58	41	58	53	2000
3	45	54	42	39	37	37	47	58	57	35	1000
4	57	50	42	41	54	55	33	39	39	46	1000
5	45	50	33	44	35	36	43	57	57	55	2200
6	32	44	41	56	57	39	59	55	55	54	3500
7	50	52	43	53	42	54	48	55	40	30	1000
8	39	41	56	42	54	56	32	33	36	44	1000
9	49	57	56	31	56	37	41	35	46	31	500
10	58	32	58	38	56	54	31	30	59	46	2000
11	53	33	50	39	41	35	43	53	58	34	1000
12	60	52	31	53	54	45	57	35	34	41	2000
13	38	36	46	57	44	49	31	32	45	48	1000
14	34	46	46	47	43	42	56	38	34	58	1000
15	44	49	40	41	42	48	44	30	48	58	1000
16	49	49	51	31	38	44	32	46	45	33	3000
17	42	35	31	41	57	31	40	47	52	42	2100
18	34	43	60	59	33	54	50	55	57	44	1000
19	40	49	58	38	50	41	57	30	39	45	1000
20	54	58	49	57	32	35	38	60	44	30	2000
21	44	50	41	44	32	33	43	35	46	40	3000
22	51	31	34	33	30	59	31	41	56	36	2000
23	43	41	45	50	55	49	45	50	55	56	1500
24	54	60	58	52	42	33	43	41	37	43	2500
25	41	50	60	32	53	57	38	38	41	50	2600
26	59	44	42	40	35	56	33	34	57	42	3100
27	37	56	46	34	46	38	60	55	40	43	1200
28	56	56	40	36	35	49	31	55	36	47	4000
29	34	40	43	54	35	53	37	43	42	46	3300
30	38	30	59	46	46	53	34	60	30	40	2000
31	32	37	48	49	41	31	38	42	52	44	1800
32	41	36	49	34	47	56	45	33	31	39	1900
33	56	42	55	38	53	58	33	41	56	43	2000
34	60	59	49	38	45	40	53	55	46	52	1900
35	42	35	38	50	34	50	36	42	56	51	1500
36	35	49	38	53	54	47	36	44	40	57	2500
37	44	46	30	35	38	41	46	48	45	30	1900
38	56	40	59	52	42	46	51	31	57	34	2000
39	50	52	43	39	51	35	41	57	43	51	1900
40	32	56	60	56	52	55	54	52	34	40	1500
41	34	38	32	31	37	34	34	60	52	58	2500
42	39	33	49	43	47	51	38	52	50	41	1400
43	37	55	51	49	45	42	54	35	41	58	1600
44	60	51	39	56	36	50	51	54	55	36	2600
45	31	58	31	49	49	60	44	44	48	40	2300

Table 14: Artificial data

Appendix D: Data for Tabu Search Algorithm for Cross Docks

Variables:

$x_{ij} = 1 \ if \ GP \ i \in I \ allocated \ to \ CD \ j \in J$
$\quad 0 \ otherwise$

$y_j = 1 \ if \ CD \ j \in J \ is \ opened$
$\quad 0 \ otherwise$

$n_j \triangleq amount \ of \ truck \ equivalents \ required \ at \ CD \ j \in J$

$d_{ij} \triangleq distance \ from \ GP \ i \in I \ to \ CD \ j \in J$

$h_i \triangleq amount \ of \ homes \ each \ GP \ i \in I \ represents$

Constant values:

$s = 500\,000$ (*fixed setup cost for any CD*)

$ov = 12.5$ (*variable overhead per customer*)

$of = 10\,000$ (*fixed overhead per CD per week*)

$p = 600\,000$ (*purchase price of one truck equivalent*)

$t = 4.90$ (*operating cost per kilometer travelled*)

$m = 0.01$ (*fraction of total population placing an order per week*)

$b = 1920$ (*fixed maximum distance a truck equivalent can travel per week*)

$c = 5$ (*truckload capacity (maximum amount of orders per truckload)*)

$u = 700$ (*maximum number of orders a CD can accommodate*)

$l = 70$ (*minimum number of orders a CD must have to be viable*)

Objective Function:

$$Min(z) = \sum_{j=1}^{J} y_j * (s + of$$
$$+ \sum_{i=1}^{I} \left(h_i * x_{ij} * ov * \mathbf{m}\right) + p * n_j + \sum_{i=1}^{I} (\mathbf{m} * h_i * t * x_{ij} * d_{ij}/c))$$

Constraints:

$$\sum_{i=1}^{I} x_{ij} * h_i * \mathbf{m} \leq u * y_j \quad \forall j \in J$$

$$\sum_{i=1}^{I} x_{ij} * h_i * \mathbf{m} \geq l * y_j \quad \forall j \in J$$

$$\sum_{i=1}^{I} x_{ij} * h_i * d_{ij} * \mathbf{m}/c \leq b * n_j \quad \forall j \in J$$

$$\sum_{j=1}^{J} x_{ij} = 1 \quad \forall i \in I$$

$$x_{ij} = \{0,1\} \quad \forall j \in J, \quad i \in I$$

$$y_j = \{0,1\} \quad \forall j \in J$$

$$n_j \ integer \quad \forall j \in J$$

Appendix E: Cross Docks Data

	Distance (km) from GP(i) to possible CD(j)										
GP	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**No. of homes GP(i) represents**
1	10.6	15.5	15.4	7.7	9.5	22.7	18.6	28.8	34	1.6	3900
3	10.1	14.7	14.6	7.1	8.9	22	17.9	27.8	33.2	0.9	5200
4	9.6	14.2	14	6.5	8.3	21.5	17.4	27.3	32.7	0.4	5200
7	10.4	14.6	13.9	6.3	8.1	21.6	17.4	27.1	33	1.7	1300
8	3.9	7.6	7.2	0.3	1.3	14.7	10.4	27.6	26	7.1	3900
9	2.7	7.1	7	1.8	2.6	14.5	10.2	20.6	25.5	7.4	1300
10	1.9	6.8	6.8	3.6	4.4	14.4	10.1	20.2	25	8.2	3900
11	1.7	6	6.1	4.9	5.7	14.4	9.2	19.8	23.7	9.8	6500
12	0.7	5.5	5.3	3.6	4.4	13.4	8.8	18.5	23.7	9.2	6500
13	2.5	5.5	5.6	6.2	7.0	13	9.1	18.3	22.8	11	5200
14	2.1	4.4	4.7	5.8	6.6	13	7.8	17.7	22	11.4	3900
16	1.2	3.6	3.9	5.0	5.8	10.8	7.1	15.5	21.7	11.1	6500
17	2.8	2	2.3	5.7	6.5	11.2	5.4	14.9	21.6	12.3	3900
18	2.1	3	3	4.4	5.2	9.4	6.2	15.9	20.4	11.4	5200
19	1.5	3.4	5.2	2.3	3.1	10.5	8.4	18.4	23.6	9.1	6500
20	3.7	6.3	5.6	2.1	1.9	12.6	8.9	19.2	24.4	8.4	3900
21	4	2.1	1.4	6.5	6.3	13.1	4.5	14.7	20	13	5200
22	4.6	0	1.8	8.3	8.1	8.7	3.7	13.2	18.6	14.1	6500
23	6.2	1.5	2.3	9.6	9.4	7.8	2.2	11.7	16.9	15.8	6500
24	5.5	2.2	0	8.1	7.9	6.2	3.4	13.4	18.6	14.3	6500
25	6.1	3.6	1.3	7.4	7.2	7	4.4	14.4	19.5	13.7	5200
26	7.3	3.2	2.3	10.1	9.9	8.1	1.4	11.4	16.7	16.6	5200
27	8.6	4.6	2	11	10.8	5.3	1.9	11.4	16.3	17.5	3900
28	11.2	6.4	7.3	14.8	14.6	4	4.2	6.6	12	20.9	3900

Table 15: Distances (km) from each GP to each possible CD site

Appendix F: Tabu Search Algorithm for Cross Docks

```
CDmatrix = %Table 10 data inserted here
[e, f] = size(CDmatrix);
i = e;
j = f-1;

facilset = CDmatrix(1:i,1:j); %may never be changed, may only copy into another matrix
d = facilset; %matrix worked with
open = zeros(i,j);
h = CDmatrix(1:i,f); % = CDmatrix last column = amount of homes GP i represents
n = zeros(1,j); % = amount of truck equivalents required at CD j
y = zeros(1,j); %y = 1 if CD i is opened
x = zeros(i,j); %x = 1 if GP i allocated to CD j
iterations = 0;

s = 500000; %fixed setup cost for any CD
of = 10000; %fixed overhead for any CD per week
ov = 12.5; %variable overhead (dependant on customer orders)
p = 600000; %purchase price per truck
t = 4.9; %operating cost (insurance, depr, licensing, fuel, maint) per km travelled
m = 0.01; %percentage of homes placing an order per week
b = 1920; %maximum distance a truck can travel per week
c = 5; %truckload capacity (max no. of orders)
u = 700; %maximum amount of orders per cd per week;
l = 70; %least amount of orders per week for cd opening to be viable;


%Initial Solution:

for aa = 1:1:i %search for each gp's nearest cd
    min(d(aa,1:j));

    qq = 0;
    do
        qq = qq + 1;
    until d(aa,qq) == min(d(aa,1:j));
    qq;
    open(aa,qq) = h(aa,1)*m; %allocate gp to nearest cd
    x(aa,qq) = 1;
  open(i+1,qq) = sum(open(1:i,qq));
    y(1,qq) = 1;
end

iterations = iterations + 1;
cost = zeros(iterations,j+1);

sum_y = 0;

for bb = 1:1:j %determine cost of this solution
    sum_a = 0;
    sum_b = 0;
    sum_c = 0;
    if y(1,bb) > 0
```

```
            for aa = 1:1:i
                  sum_a = sum_a + x(aa,bb)*h(aa,1)*ov*m; %to be used in determining 'cost'
                  sum_b = sum_b + x(aa,bb)*d(aa,bb)*m*h(aa,1)*t/c; %to be used in determining 'cost'
                  sum_c = sum_c + (x(aa,bb)*d(aa,bb)*h(aa,1)*m/c)/b; %to calculate n(j)
            end
      n(1,bb) = ceil(sum_c); %amount of trucks per CD j
      sum_y = sum_y + y(1,bb)*(s + of + sum_a + p*n(1,bb) + sum_b);
      end
end

cost(iterations,1) = sum_y;
cost(iterations,2:j+1) = y;
bestcost = cost(iterations,1);
bestsol = open;

open = zeros(i,j);
d = facilset;
x = zeros(i,j);
y = zeros(1,j);
n = zeros(1,j);


%Tabu: Determine optimal facilities set

for stage = 9:-1:1 %stage = how many CDs are allowed to be opened
      bestsolchanged = 0;
      stage;
      do %for ww no. of facilities, look for best solutions
            tabu = zeros(i,j);
            randvec = zeros(1,10-stage);
            for aa = 1:1:(10 - stage) %randomly pick (10 - stage) no. of facilities to be closed
                  do
                        randf = ceil(rand*10);
                        tryagain = 0;
                        for bb = 1:aa
                              if randvec(1,bb) == randf
                                    tryagain = tryagain + 1;
                              end
                        end
                  until tryagain == 0;
                  randvec(1,aa) = randf;
            end

            tabu(:,randvec) = facilset(:,randvec); %send closed facilities to tabu list
            d(:,randvec) = 100000; %GPs may not be allocated to closed facilities

            for aa = 1:1:i %search for each gp's nearest open cd
                  min(d(aa,1:j));
                  qq = 0;
                  do
                        qq = qq + 1;
                  until d(aa,qq) == min(d(aa,1:j));
                  qq;
                  open(aa,qq) = h(aa,1)*m; %allocate gp to nearest open cd
                  x(aa,qq) = 1;
                  open(i+1,qq) = sum(open(1:i,qq));
```

```
            y(1,qq) = 1;
        end

        nonfeasible = 0;
        for gg = 1:1:j
            if open(i+1,gg) > u
                nonfeasible = nonfeasible + 1;
            end
        end

        iterations = iterations + 1;
        sum_y = 0;

        for bb = 1:1:j %determine cost of this solution
            sum_a = 0;
            sum_b = 0;
            sum_c = 0;
            if y(1,bb) > 0
                for aa = 1:1:i
                    sum_a = sum_a + x(aa,bb)*h(aa,1)*ov*m; %to be used in determining 'cost'
                    sum_b = sum_b + x(aa,bb)*d(aa,bb)*m*h(aa,1)*t/c; %to be used in determining
    'cost'
                    sum_c = sum_c + (x(aa,bb)*d(aa,bb)*h(aa,1)*m/c)/b; %to calculate n(j)
                end
                n(1,bb) = ceil(sum_c); %amount of trucks per CD j
                sum_y = sum_y + y(1,bb)*(s + of + sum_a + p*n(1,bb) + sum_b);
            end
        end

        cost(iterations,1) = sum_y;
        cost(iterations,2:j+1) = y;
        if cost(iterations,1) < bestcost & nonfeasible == 0 %change best solution if this solution improves the
    previous best
            bestcost = cost(iterations,1);
            bestsol = open;
            bestsolchanged = 0;
            trucks = n;
        else
        bestsolchanged = bestsolchanged + 1;
        end

        open = zeros(i,j);
        d = facilset;
        x = zeros(i,j);
        y = zeros(1,j);
        n = zeros(1,j);
    until bestsolchanged == 15
end

bestcost
bestsol
trucks
```