THE DEVELOPMENT OF A SWARM INTELLIGENT SIMULATION TOOL FOR SUGARCANE TRANSPORT LOGISTICS SYSTEMS

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The undersigned hereby certify that they have read and recommend to the Faculty of Science and Agriculture for acceptance a thesis entitled "**The Development of a Swarm Intelligent Simulation tool for Sugarcane Transport Logistics Systems**" by **Brendon Clyde McDonald** in fulfillment of the requirements for the degree of **Master of Science**.

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Abstract

Transport logistics systems typically evolve as networks over time, which may result in system rigidity and cause changes to become expensive and time consuming. In this study a logistics model, named TranSwarm, was developed to simulate sugarcane harvesting, transport and mill-yard activities for a mill supply area. The aim was to (i) simulate produce flow, and (ii) allow individual working entities to make decisions, driven by rules and protocols, based on their micro-environments. Noodsberg mill was selected as a case study because of low current levels of synchronization. Growers were assumed to operate independent harvesting and transport systems causing inconsistent convergences at the mill. This diverse and fragmented system provided a suitable environment to construct a model that would consider interactions between individual growers and their respective transport systems. Ideally, by assessing the micro-decisions of individuals and how they influence the larger holistic supply chain, TranSwarm quantifies the impacts of different types of transport practices, such as staggering shift changes, transport scheduling, core sampling and consortium-based logistics. TranSwarm is visual, mechanistic and represents key entities, such as roads, farm groupings and the mill. The system uses discrete events to create a dynamic and stochastic environment from which observations and conclusions can be drawn. This approach potentially allows stakeholders to identify key components and interactions that may jeopardize overall efficiency and to use the system to test new working protocols and logistics rules for improving the supply chain.

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Chapter 1

Introduction

1.1 Rationale

In today's modern world of integrated networks and complex system problems, simpler solutions often mean better solutions. On the application of fundamental principles of agent-based modelling, the solution to the heterogeneous sugarcane transport logistics system may present itself with ease. More recently one approach which tracks the principles of agent-based modelling has come from the field of swarm intelligence (SI). SI follows individual behavioral patterns of different entities and how they interact with each other, initially seeming chaotic in nature, but ultimately (when viewed from a global perspective) achieving and accomplishing extremely complex tasks with great simplicity [1]. Some of SI's early and simplest of tasks, namely organization of individual agents, was seen by [2] and [3]. Later [4] developed a more formal understanding/definition to the notion of SI, which highlighted the impact that SI can have in attempting to solve distributed problems inspired by collective behavior of social societies/agents (in our case the sugarcane transport logistics system).

The South African sugar supply chain is currently facing many challenges. The world's sugar price is slowly decreasing while infrastructure and logistical costs are steadily on the rise, thus more focus is moving towards research and development of various components of this supply chain. One such component that immediately identifies itself as an area of great importance is the sugarcane transportation system. South Africa has a typical sugar season composing of millions of tons of sugarcane being cut and transported to the mill. This transportation of sugarcane is a large and extremely complex network of activities in which complex logistical operations are taking place. Sugarcane transportation involves thousands of drivers/workers, vehicles and trailers, thus to avoid wasting these valuable resources, careful planning and coordination is needed. This transportation sector has therefore been identified as a major area where significant cost savings could be materialized. Research has shown [5] that transport management and work protocols can often lead to inefficient systems and that small corrections to these systems could save industries large amounts of money. Already there's been significant progress into improving our understanding of these sugarcane transport systems, which has come in the form of simulation models. These models have been developed [6], [7], [8], [9] and successfully utilized in researching industry operations. Therefore it is not surprising that research and development has now established itself as the international trend among other successful sugar producing countries [10], [11], [12], [13], [14].

The logistical and transportation inefficiencies facing the South African sugar supply chain are not without solutions and possible means for improvement. In fact the potential for decreasing costs and increasing production and efficiencies is enormous.

It is hypothesized that SI-based modelling can be tailored to this problem and implemented appropriately. In other words, if we can take our simple "self organized" agents (vehicles) within our transportation system and apply specific swarm based algorithms for each individual to follow, we may achieve global swarm behavior in which complex tasks can be completed optimally and efficiently. This would potentially result in a system that could correct itself and adjust appropriately when external influences affect the system. One of our goals will be to integrate the ideas and algorithms of swarm intelligence into our agent-based logistics and transportation system, so as to study potential benefits or gains from such a merger.

1.2 Aim and Objectives

The primary aim for this project is the development and implementation of an Agent-based simulation tool for analysis of sugarcane transport logistics systems. This aim is to holistically encapsulate the entire sugarcane transport system within one complete simulation model.

The realization of this aim can only be reached through the development and successful achievement of the following objectives: Firstly conduct a ***"literature review"*** (Chapter 2) on the subject matter and research being carried out, related to our topic. Secondly the development of our ***"model framework"*** (Chapter 3), which identifies our key users of the system, conceptual model and activity diagrams used in constructing our model. The next important objective is constructing a successful ***"methodology-part 1,2"*** (Chapter 4, 5) which involves understanding our region of interest, data collection and simulation scenarios. Following on from this, we will develop a comprehensive summary of the ***"results and discussions"*** (Chapter 6) and finish with ***"conclusions and recommendations"*** (Chapter 7).

1.3 Scope

The scope of this project starts from the ready to harvest sugarcane in the field all the way through to harvested sugarcane arriving (by vehicle) at the mill-yard and being offloaded for crushing. The vehicles will then return to their respective farms and repeat the process of sugarcane transportation. It is assumed that the sugarcane has grown correctly, reached maturity (peek sucrose level) and is always ready for cutting. It is also assumed that the mill is operating correctly and that the vehicles travelling to the mill will always travel on the shortest path.

1.4 Published Work and Contribution

The following publications have resulted from this work:

1.4.1 Conference Papers

- International
    - B.C. McDonald and E. Dube, "Determining the Best Harvesting Practices for the South African Sugar Supply Chain, using Simulation", *International Association of Science and Technology for Development (IASTED), Environmental Modelling and Simulation*, Honolulu, Hawaii, USA, August, 2007, Published.

  - B.C. McDonald and E. Dube, "The Development of a Simulation tool for Analysis of Sugarcane Transport Systems", *International Association of Science and Technology for Development (IASTED), Africa Modelling and Simulation*, Gaborone, Botswana, September, 2008, Accepted.

- Local
  - B.C. McDonald, E. Dube and C.N. Bezuidenhout, "TranSwarm, A Sugarcane Transport Simulation Model based on Behavioral Logistics", *81st Annual South African Sugar Technologists' Association (SASTA) Congress*, Durban, KwaZulu-Natal, South Africa, July, 2008, Accepted.

1.4.2 Contribution

All publications cited above constitutes the author's own work, with the assistance of Mr. Erick Dube. Each paper aimed at tackling and solving different issues, currently being experienced within the South African Sugar Supply chain. These publications have all been subject to a thorough peer-review process after which corrections where made accordingly. Mr. Erick Dube has continually provided advice and guidance where necessary throughout the scope of these publications and my final masters thesis.

Chapter 2

Literature Review

2.1 Introduction

This chapter aims at providing a useful and sound understanding of the necessary information and concepts needed to proceed through this project. In particular the following concepts will be introduced.

- Logistics
- Transportation
- Current Methodologies
  - Top Down (Operations Research)
  - Bottom Up (Agent Based Modelling)
  - Simulations (Discrete Event)
- Swarm Intelligence

A logistics and transportation system is typically made up of a network, comprising of one or more terminals connected by roads. Through this network, commodities will travel from origin to destination. Usually the network in place would have been around for many decades, evolving throughout. Thus it is extremely expensive and time consuming to make radical changes. There are some exceptions such as businesses starting up for the first time that need to construct a new operations network.

In the past, analysis, design and control of transport systems has been carried out by field engineers and Operations Research (OR) scientists. However in recent years there has been a move towards a "descriptive modelling" technique using computer simulation models to replace and/or complement the old conventional models. It has been identified that this new technique is extremely effective in dealing with the impact of dynamic arrival and departure times of vehicles. It also provides an extremely useful visual impact to the analysis of the model [5].

2.2 Logistics

At first sight, "logistics" may seem an easily identifiable concept, however this is a misconception. The broad nature of the word can imply many complex and integrated activities working together. This implication can often lead to a certain loss of precision if one does not understand the complexity of the definition in the context of the domain.

The practice of logistics is essentially derived from the military, where it first meant the movement and supply of troops and equipment. A good example can be seen from the Australian Army Logistics Training Centre (ALTC). ALTC and Simulation

Modelling Services Pty Ltd have worked together, to create a logistical training environment from within ARENA (explained in *Chapter 5*). This virtual simulation environment is for all it's logistics Corps soldiers. They use the system for typical training scenarios that include: the movement of units (personnel and equipment), destination and timing requirements, available transport and routes, to mention but a few. The benefits of such a system have been numerous, e.g decreased learning curves, increased user interaction. The environment enables infinite practice opportunities [15].

The modern definition for logistics is now: *"the detailed coordination of a large and complex operation"* [16]

As businesses develop around the world, one of the determinants for their success will be the degree of management and involvement in their application of logistics. In the context of this project, our working definition of logistics given by [17], is stated below.

Logistics today is closely related to the management of supply chains and involves but is not limited to these features. The logistician plans and controls the movement of goods, services and information to the consumer and in reverse to their point of production or raw material source

The three primary goals of any lean logistical operation is to reduce costs, increase output and improve response times to consumer demand [18], [5]. These goals must be achieved through constant interaction with the system at hand, making subtle changes and adjustments where necessary. In particular, this project will be dealing with the logistics involved in coordinating a successful sugarcane transportation operation. The behavior of vehicle drivers will be analyzed so as to accurately model this transportation system.

2.3 Transportation

With the future of expanding businesses and related complex logistical operations, transportation must be seen as one of the most critical components. Supply chain success, optimizing and efficiencies, reducing costs and increasing output, these are all factors that can attribute themselves to the state of their current transportation system.

In [19] Iannoni presented a discrete simulation model to simulate the reception area processes of a sugarcane plant. Iannoni used a case study of a large Brazilian sugarcane plant located in Sao Paulo State because of its complex transportation network and mill-yard queue structures. The model captured and represented various different vehicle types and focussed on the arrival, waiting and unloading times of these vehicles at the mill. Using the Arena simulation software package Iannoni went on to show how the importance of a coordinated logistics and transportation system (at the mill-yard) can increase efficiency and competitiveness of Brazilian agro industries.

In [20] Chidoma reviewed various different cane haulage problems facing the Hippo Valley Estates in Zimbabwe. Chidoma pointed out that transport problems have been experienced from 2000 to 2005 and that these problems range from longer burn-to-crush delays, increased haulage costs and erratic cane supplies. Chidoma identified the causes of some of these problems to be associated with high level of breakdowns of vehicles and lack of adequate synchronization between cane harvesting, haulage and milling. In other words, with so many diverse transportation methods and coupled with ageing equipment/vehicles, synchronization and efficient cane supply to the mill often breaks down.

Road transportation within the South African sugar industry has always been a complex and integrated set of activities. Within a typical sugar producing area, e.g. Noodsberg, one will find many different and diverse methods of road transportation, from farmer to farmer. Some farmers opt for commercial hauliers to move their cane from farm to mill, while others have their own transportation equipment in place. Typically the transportation of sugarcane will be achieved via trucks, truck and trailer, and/or tractor and trailer; where the trailers are either flat bed or Hilo. Hilos are a basket type of trailer that have chains attached for easy lifting and emptying at the mill-yard [6].

Once a better understanding of what exactly a logistics and transportation system was achieved, all that was left was to provide the necessary background information on the techniques and methodologies available for modelling such a system.

2.4 Current Methodologies

When considering the area of logistics and transportation problems, many different techniques and approaches to solving such problems arose. Of those that were researched, three main techniques and implementations were considered, seen in figure 2.1.

2.4.1 Top Down Approach

Conventionally and for the past few years, researchers and scientists have taken the "top down" approach to solving logistics and transportation problems. This approach entails knowing the problem at hand and being able to set global rules and formulae to which the model will be subject to from the onset. All the individual entities/agents will adhere to these criterion (that is all entities being subject to the same global rules) till a credible solution is found. The "top down" approach entails setting and knowing the global objectives from the start and then working down (breaking the problem up into smaller parts) until the solution is found.

Two of the key fields of study which follow the typical "top down" methodology are Operations Research (OR) and Spreadsheet based analysis (Statistical Approach).

Operations Research

The Operations Research field of study deals with the construction of mathematical models. There is linear programming (LP), integer programming (IP) and mixed integer programming (MIP), which are typically mathematical programs in which the single objective function is to maximize profits or minimize costs. However there are

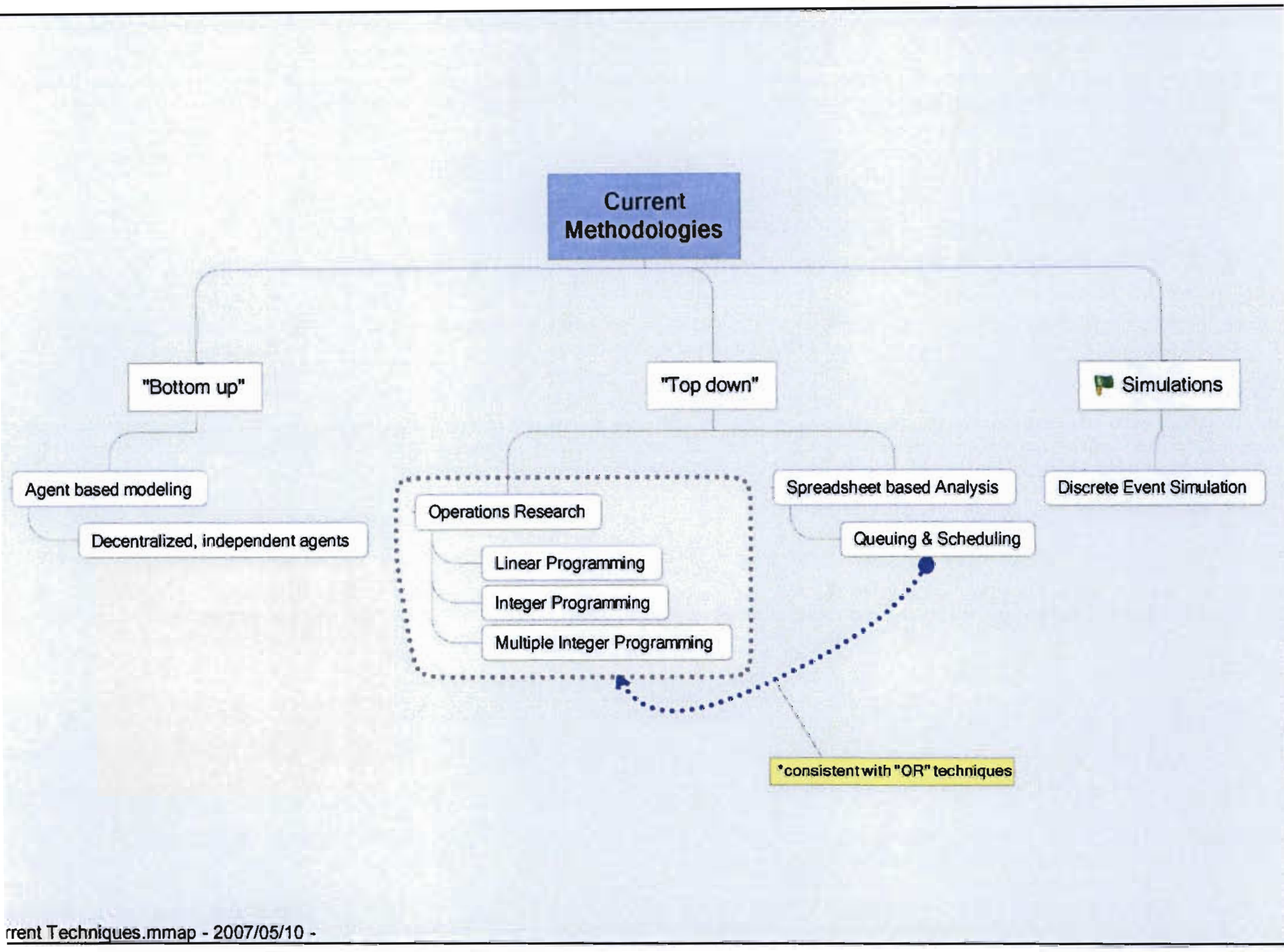


Figure 2.1: Current Methodologies

some subtle differences between LP, IP and MIP models. Within LP, the unknown variables can be in any range (Real, Integer) or data type specific to the problem, but in IP the unknown variables are all required to be integers, thus making most IP problems NP-hard (Nondeterministic Polynomial-time hard) [21]. MIP on the other hand only requires some of the unknown variables to be integers and are also generally considered NP-hard. There are however some subclasses of IP and MIP problems that are efficiently solvable.

Operation Research models has been used successfully in the past to find optimal solutions for decision problems with many variables, although it is restrictive when trying to accurately model and represent dynamic and stochastic real world problems. Ultimately LP, IP and MIP are insufficient at best representing and describing entities such as people, processes and products of complex real world problems.

Some recent work done in this area can be seen in [22], [23] and [24] . In [22], Higgins presents a large-scale integer programming model to optimize sugarcane supply decisions. These decisions are to help in maximizing profitability within a mill region. Higgins points out that there are large differences in sugar yield due to crop age and harvest date and therefore a model was needed to help in decision making. Higgins solves this problem heuristically using a new local search technique, but he also points out that for large scale problems (E.g 4500 farms) there are over 500000 binary variables and the problem is shown to be NP-hard.

In [24] Higgins also developed a model to help with optimizing siding rosters for sugarcane rail transportation. Higgins used operations research techniques to construct this model and shows that, with improved rostering of harvesting groups into sugarcane rail systems, there is scope to reduce transport and harvesting costs.

In [23] Higgins presents a mixed integer programming approach to solving the problem of road vehicle scheduling at a particular sugar mill. Using this approach Higgins sets his objective function to minimize a combination of queue time at the mill and mill idle time. He then goes on to show that the model can reduce vehicle queue times at the mill and be beneficial at assessing the consequences of changes in the harvesting and transport system.

These examples show that Operations Research techniques form an integral part in solving various logistics and transportation problems.

The next field of study that typically follows the "top down" methodology is spreadsheet based analysis (Statistical Approach). This approach utilizes spreadsheet based software like MS EXCEL to create and analyze various static statistical models.

Spreadsheet Based Analysis

Spreadsheet based analysis have been used in the past to solve optimization problems involving scheduling and queuing systems. In [8] the use of spreadsheet based analysis can be seen in development of an integrated sugar supply model, starting from the field to the mill, covering the South African industry. This model, referred to as "CAPCONN" (Capacity Constricted Conveyance), can handle various different harvest scenarios, then bottlenecks can be highlighted and improvements made. The CAPCONN model runs on a weekly basis, producing results and estimations on sugar quality, capacity and costs. These outputs have been compared and measured with those observed in the real world system and the results have been favorable, indicating that CAPCONN can be a suitable diagnostic tool for the future. It is also worth mentioning that the ultimate goal for CAPCONN was to "verify the suitability and feasibility of an integrated supply chain model as a tool for representing supply chain processes and improving efficiencies for the benefit of the supply chain as a single business entity" [8]. This goal, to some degree has been met and the benefits from such a model are many. Already designs and equations from CAPCONN are being used in other areas of supply chain model development.

This spreadsheet based analysis is inappropriate for trying to model and simulate transport and logistical systems because it is mainly a static and deterministic approach, that doesn't consider variations in time or variability of inputs and parameters. As we have seen earlier, our problem involves the modelling of a logistics and transportation network/operation. This, in turn involves many stochastic and dynamic aspects thus indicating that both linear programming techniques and spreadsheets are insufficient for our area of interest. It must also be noted that although scheduling and queuing systems have been mentioned under the title of "Spreadsheet Based Analysis", it can also be found as a sub-class of Operations Research (OR).

2.4.2 Bottom Up Approach

In contrast to the methodologies presented in the top down approach, the "bottom up" approach entails starting at the base of the problem and working your way up to a desired solution. This means breaking the problem up into multiple parts and having each part act on its nearest-neighbor (local) knowledge. Each of these parts will have their own local rules, cooperating or competing with other parts. Then over time, through many interactions and an aggregation of all the parts, a possible solution may arise.

Agent-based modelling

One such field of study that utilizes the "bottom up" approach is agent-based modelling. Agent modelling is based on the idea that a system is made up of individual decentralized agents and that each of these agents will interact with other agents subject to their local neighborhood knowledge. These agents may represent vehicles, drivers or travellers, essentially any entities within your system that can make decisions and contain objectives. Agent modelling presents a relatively new and diverse pattern of thinking which is slowly becoming more popular [25]. The technique offers many advantages when tackling a logistics and transportation problem such as ours. However, there are some limitations, agent modelling may not be appropriate for control problems in which global constraints and objectives have to be satisfied. Another potential draw back is the new idea of delegating tasks to agents, rather than the programmer controlling or having control over the tasks. Further reading and a more detailed report can be seen in [25].

2.4.3 Simulations

The last of the techniques under "Current Methodologies" is a specific field of study found in Computer Science and Industrial Engineering, namely Simulations.

Simulations represent processes that involve many different entities that interact together. In fact, to simulate means: *to imitate or reproduce the appearance, character or conditions of [16].*

The act of simulating, generally entails modelling key behavior or characteristics of a specific system (real or abstract). However more specifically within Computer Science, *"Computer Simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the systems work [26]."*

Some of the advantages of using simulation techniques can be seen in [27] and [28]. Through use of simulations, a model can be built and used to help with understanding and predicting logistics and transportation operations. Simulations can allow the users to run multiple experiments/scenarios and decisions can be made and tested before being implemented in real life. Simulations provide a solution to the challenge of trying to handle stochastic and dynamic events. Real world time (results that would have taken years to see) can be scaled down into simulation time, seeing results in a few seconds [29].

Having reviewed the previous techniques of Operations Research and Agent-based

Modelling we can now utilize certain key aspects of those fields of study and use simulations to bring it all together. Within the scope of simulations we will be focusing on discrete event simulations: this means simulation models that have their state variables change due to events occurring at specific points in time.

For the purpose of this project the techniques of simulations have been chosen, although key methods and ideas may be used from the areas under Operations Research and Agent-based Modelling.

Simulations in Industry

Over the past few years, many sectors of industry have had the benefit of applying simulation models to their various endeavors, such as in [10], [7], [6], [30]:

Cuba is a major competitor in the world market for supplying sugar and recently its government has put focus into the research and development of sugarcane activities to sustain this competitive status. They have identified and tackled the issues of creating efficient and optimized systems specifically within the transportation system. Using the ARENA simulation software tool they have developed a comprehensive model to represent almost all the various activities involved in transporting harvested cane from farm to mill. The benefits of this has been to show them the potential short-falls in their current system [10].

South Africa has also been at the forefront of trying to analyze and detect inefficiencies in it's own sugarcane industry. They have focused on reducing delays within the delivery process of sugarcane, to ultimately decrease deterioration rates and increase sucrose levels in sugarcane. They too have used the benefits that ARENA provides when it comes to implementing user friendly graphical models to represent the transportation system [7], [6].

Transportation is a critical component in any logistics operation and the overall success of business's and industries alike depend on efficient and well designed systems. Areas of Airline transportation logistics and Sea transportation logistics have also been analyzed and modelled successfully using ARENA, thus gaining insight into the subtle inefficiencies that may be present within these [30].

Another exciting area of study that merges simulation, agent-based modelling and various other techniques together, is Swarm Intelligence, which has been noted as being an area from which many new idea's and algorithms can be taken and used within a logistics and transportation system. Therefore, some investigation into the possible benefits of utilizing swarm intelligence has been undertaken.

2.5 Swarm Intelligence

When we think of swarm intelligence, immediately a flock of birds, a school of fish, a swarm of bees or a colony of ants come into most of our minds. Individually these animals/insects are quite simple in nature however, combine them together with more of their own kind and globally they will accomplish tasks of extreme complexity with the greatest of ease [1], [31], [32].

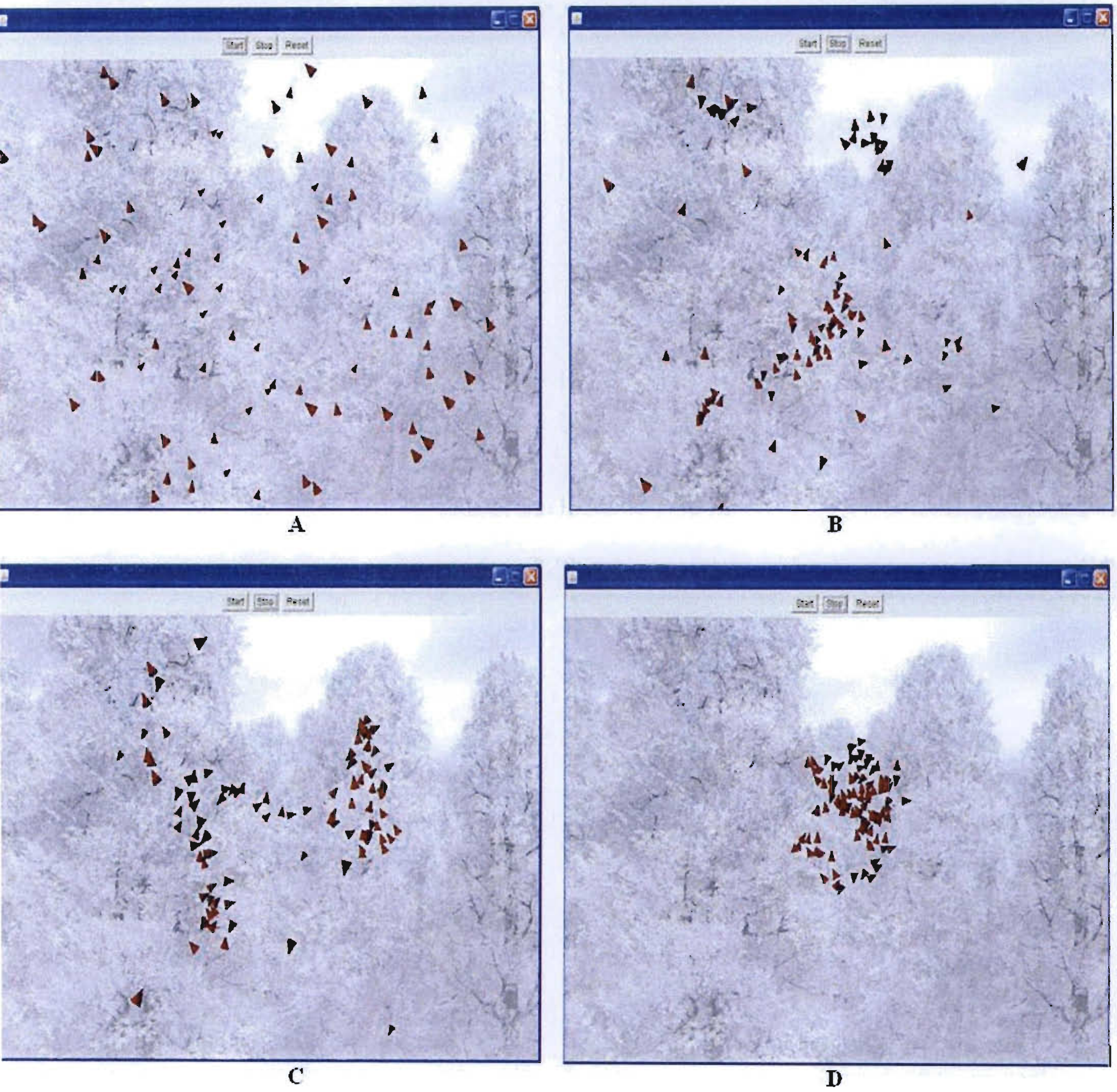


Figure 2.2: Swarm of a 100 "boids"(©B.C. McDonald)

In 1986, Craig Reynolds used the idea of artificial life to create a model, simulating the motion of birds, calling them "boids". Reynolds later went on to prove that flocks of birds base their behavior only on neighboring birds. Each bird follows 3 simple rules, separation (don't collide or get to close to other birds), alignment (fly in the average direction that your neighboring birds are flying in) and cohesion (move towards the average position of your neighboring birds). With each bird following these simple rules, a global swarm is formed. Thus Reynolds pointed out that flocks of birds are essentially "decentralized systems", having no "leader bird" or central controller [3].

In an attempt to explore and understand the algorithms put forward by Reynolds [33], [34], a basic swarm model was developed using Java3D. This Java3D model implements the 3 basic rules/algorithms that boids should follow to mimic swarm behavior. The outcome of this model can be seen in figure 2.2.

In figure 2.2, "A" represents the initial starting conditions of the model, with each boid being assigned a random starting position in 3D coordinates. "B" represents the same model after a few seconds of time has passed, as can be seen, each boid is following it's 3 individual rules, making them slowly begin to form small sub-swarms.

In figure 2.2, "C" shows the model after more time has passed. Now the sub-swarms are beginning to come in contact with each other, thus the boids are all slowly starting to converge on a global swarm. "D" shows the end result of a global swarm having been formed.

The significance of this exploration is that in our case, each boid may represent a vehicle, wanting to move from initial point to end point. The algorithms used in figure 2.2 can be seen in Algorithms 1 and 2.

In 1988, Gerardo Beni first introduced and used the term "swarm intelligence" to describe cellular robotic systems which were simple agents organizing themselves through nearest-neighbor interaction [2].

Later this definition for swarm intelligence was generalized by Bonabeau et al. [4] to mean: *"Swarm intelligence is any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies."*

Algorithm 1 Naive Swarm Algorithm

```
Main()
{
initPostions() //sets random starting positions for each boid
loop
    drawBoids() //display boids on screen
    updateBoids() //move boids
end loop
}

updateBoids()
{
$Vector$ $v1$, $v2$, $v3$
$Boid$ $b$
for all $Boid$ $b$ do
    $v1$ = rule1($b$) //cohesion
    $v2$ = rule2($b$) //separation
    $v3$ = rule3($b$) //alignment
    $b.velocity += v1 + v2 + v3$
end for
}

rule1($Boid$ $b_j$) //move boid towards average position of neighboring boids
{
$Vector$ $pc_j$
for all $Boid$ $b$ do
    if $b \neq b_j$ then
        $pc_j += b.position$
    end if
end for
$pc_j /= N - 1$ //where N is total number of boids
return $(pc_j - b_j.position)/100$ //offset between current boid position and position
it should be in
}
```

Algorithm 2 Naive Swarm Algorithm Continued...

```

rule2($Boid\ b_j$) //don't collide with other boids
{
Vector $c = 0$
for all $Boid\ b$ do
    if $b \neq b_j$ then
        if $|b_j.position - b.position| < 100$ then
            $c- = |b_j.position - b.position|$
        end if
    end if
end for
return $c$
}

rule3($Boid\ b_j$) //fly in average direction and speed of neighboring boids
{
Vector $pv_j$
for all $Boid\ b$ do
    if $b \neq b_j$ then
        $pv_j+ = b.velocity$
    end if
end for
$pv_j/ = N - 1$ //where N is total number of boids
return $(pv_j - b_j.velocity)/8$ //where 8 is an empirically determined constant for
    balancing velocity adjustments
}

```

Chapter 3

Model Framework

3.1 Introducion

One of the most important aspects behind any successful simulation study and model implementation is the design phase [5]. Careful thought needs to go into understanding the vast complexity of your domain. In our case the holistic view of the sugarcane transportation system. To model such a system a few key questions have to be answered, such as: Who are the users of our system, what are the inputs and outputs, which processes need to be identified and how do all these fit into our main conceptual model. These are just some of the questions that have been analyzed and answered below.

3.2 Use Case Diagram

To understand how our sugarcane transportation model should be designed, we first need to identify the potential users involved: this can be seen in figure 3.1. Firstly we have the *Grower* user who will provide various farm, harvest and field transport information. Our system will then utilize this information and eventually produce

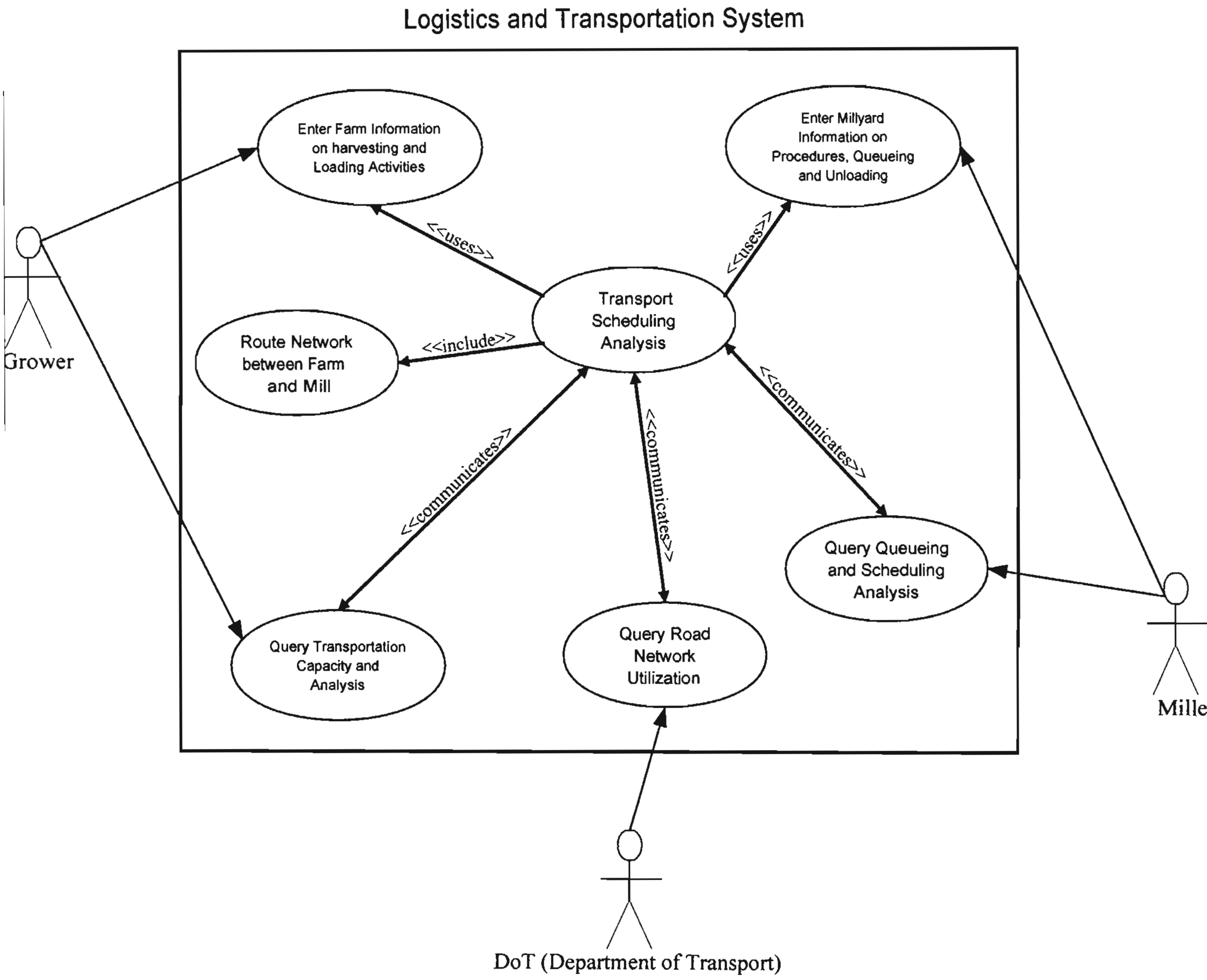


Figure 3.1: Use Case Diagram

a facility whereby the *Grower* can query various details, for example: are his/her resources under-utilized?

Another important user of the system is the *Miller*, the *Miller* will provide various information regarding his/her queueing systems, mill-yard resources and unloading delays. Our system will then once again provide the facility for the *Miller* to query things like: what are the arrival rates of vehicles at the mill gate? How efficiently is their queuing system working?

Lastly we have the *DoT (Department of Transport)* user, who will be expecting a summary/report on what's happening within the road network, i.e. Congestion statistics, traffic flow and density.

3.3 Input/Output Flow

The next important step within our design phase is to identify the input and output flow within our system. This can be seen in figure 3.2. Basically we have the *Growers*, *Millers* and *UKZN (University of KwaZulu-Natal)* (not considered a major user of our system) all providing some kind of input and expecting a subsequent output. Only the *DoT (Department of Transport)* is requiring just output from the model.

Along with the input and output flow being represented in figure 3.2, you can also see all the respective processes (labelled $P_0 \rightarrow P_6$) involved in transferring these inputs and outputs. A more detailed view of the processes can be seen in figure 3.3.

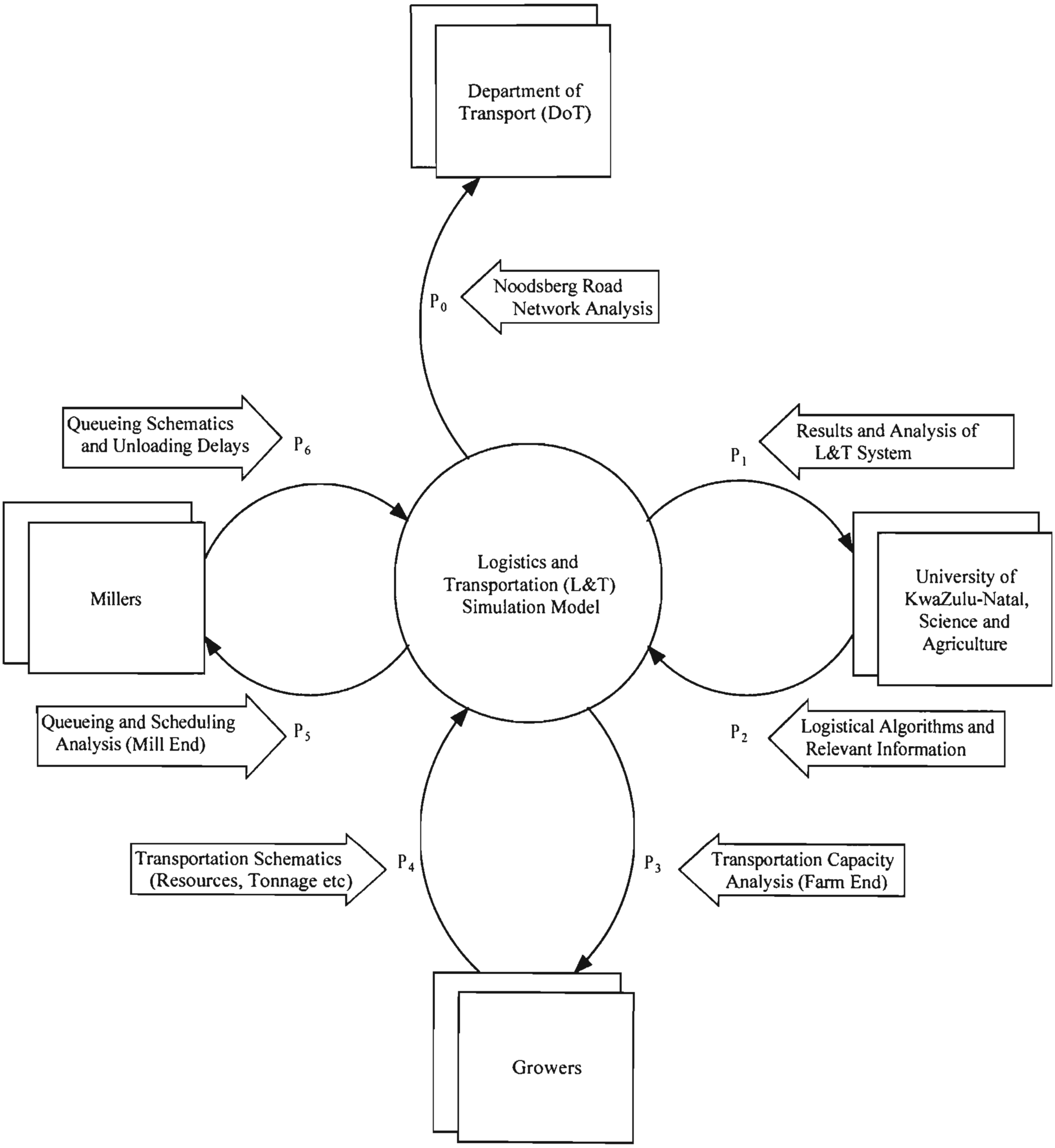


Figure 3.2: Input/Output Flow

3.4 Process identification and definition

The next phase is that of further identification and definition of the processes mentioned in figure 3.2. Note that figure 3.2 and figure 3.3 work in conjunction with one another and reference to figure 3.2 can clarify where certain processes are used. In figure 3.3 we can clearly see those processes which interlink/communicate with each other and those that feed into or out of the model. We start with process P_0 (Road network utilization) which calculates various road statistics and then feeds that information into the sector that will then output this important information to the *DoT*. Then we have P_1 (UKZN output) which simply develops a system report/documentation on production runs for output. P_2 (UKZN input) contributes important logistical information into P_6 (Miller input) and into P_4 (Grower input), these inputs are then collated, fed into the *Transport Scheduling Analysis* System and provide important output information through processes P_5 (Miller output) and P_3 (Grower output) respectively.

3.5 Conceptual Model

Our conceptual model seen in figure 3.4 follows a very logical design, closely related to the flow of the real world system. Note that the model has been divided into two distinct parts, the *Grower/Farm* section and the *Miller/Mill-yard* section, labelled F_0 and M_0 respectively (for a more detailed mathematical representation of our general transportation problem see equation 3.1). The reason for this division of parts is to keep activities related to the party that partakes in them. Thus the grower is responsible for his/her farm (f_0), harvest (h_0) and transport (t_0) activities while the

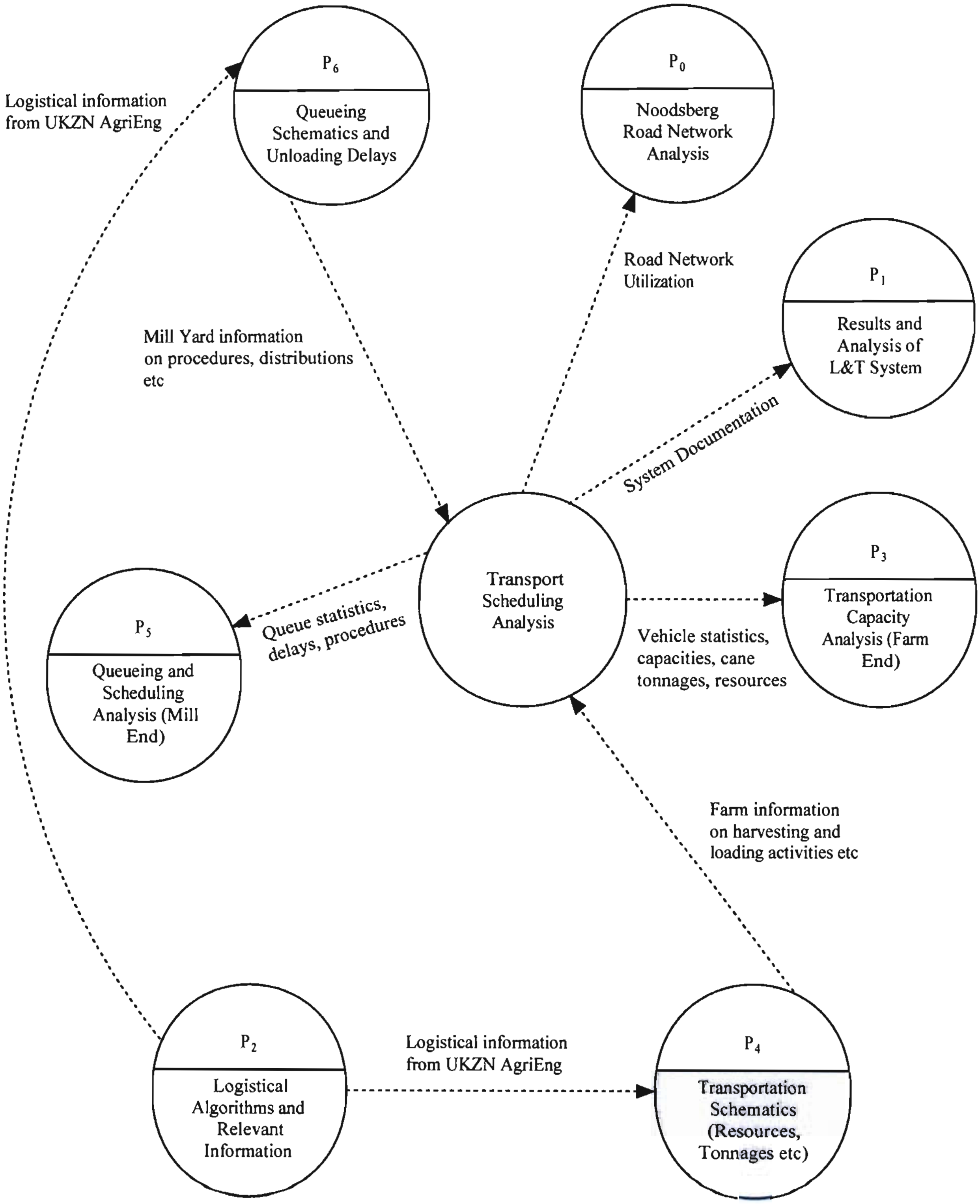


Figure 3.3: Processes

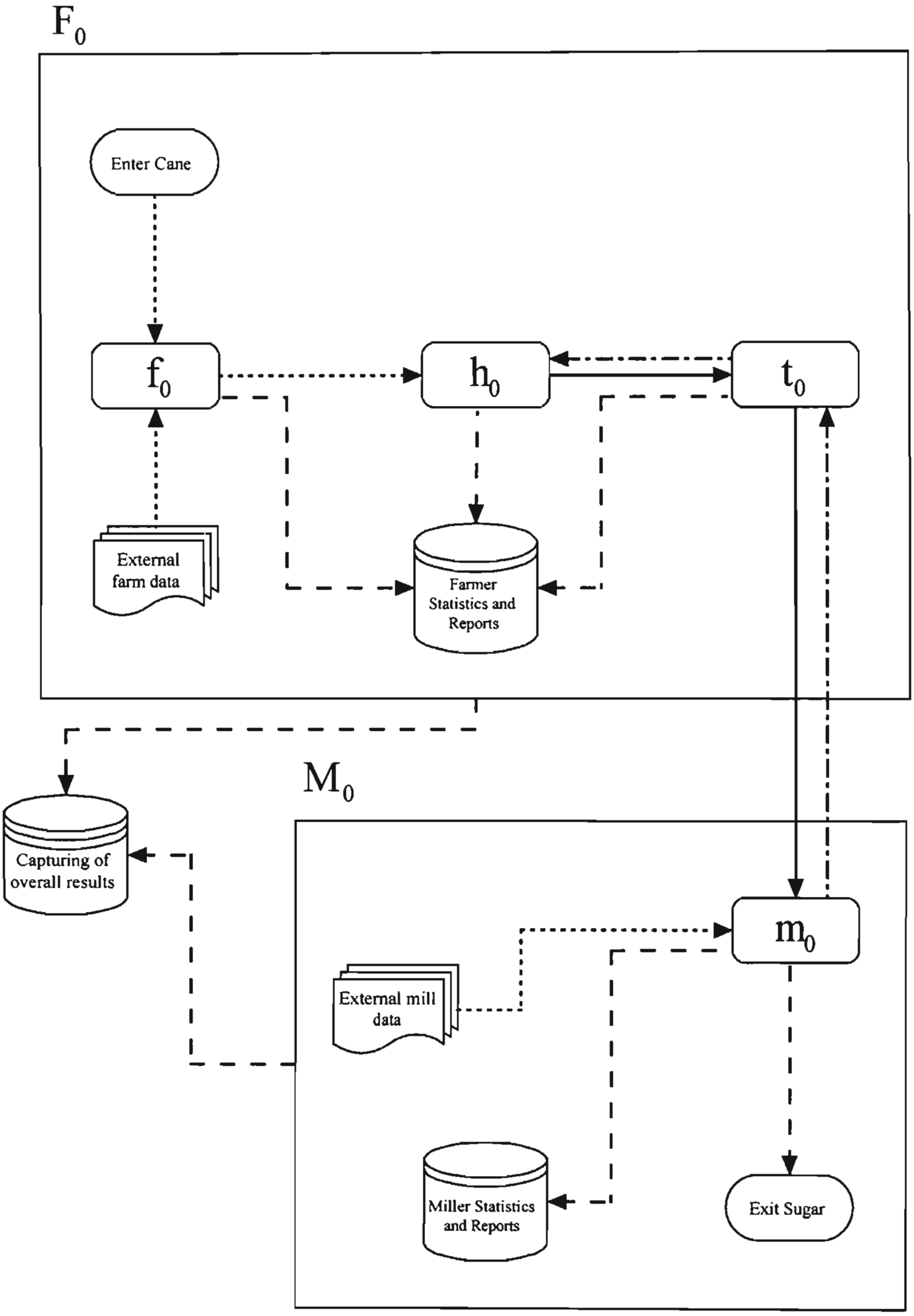


Figure 3.4: Conceptual Model

miller is responsible for his/her mill-yard (m_0).

After understanding the parts involved and how they are separated, one has to continue through the overall flow of the model. When the model is first run, all the various variable values, schedule times and queue structures are initialized appropriately via three simultaneous inputs. These inputs are all contained within a MS Excel spreadsheet and are read into the model through f_0 and m_0. Some of these inputs are: daily sugarcane allocation (for harvest), external farm data (number of vehicles, choppers) and external mill data (number of spiller cranes, hysters). We note that in this case, the term "external" means the data has come from an external source, like interviews with growers/millers and experts in the field.

Once the inputs have been read into the model, the daily allocation of sugarcane (entities) can begin to flow from module to module. First the sugarcane will reach the harvest module (h_0), where the appropriate harvest technique will be chosen and subsequently the cane harvested according to that method. Next the cane will be transported infield to a loading zone and thus enter the transport module (t_0). Here the cane will be loaded onto the correct vehicles and transported to the mill. During the transition through these modules, various facts, statistics and information are gathered and compiled into reports and graphs.

Once the vehicles have left F_0 they enter into the road network where they are assumed to travel the shortest path to the mill and back again. When they reach the mill (M_0) the vehicles will enter the mill-yard (m_0) and offload their respective cane, after which they return to the farm to pick up the next load (continuing this process until all cane has been transported to the mill). Once again it must be noted that various statistics and information are being gathered and reported at the mill end.

- We note that there is a distinct difference between the reference to Farm module F_0 and farm module f_0, the former is a structure composed of f_0, h_0 and t_0, while the latter is just one of the many components that help make up F_0

3.5.1 General mathematical description of a Transportation Problem

Let:

$F \ is \ a \ set \ of \ farms$

$H \ is \ a \ set \ of \ type \ harvest$

$T \ is \ a \ set \ of \ type \ transport$

We define the following Farm module (a Cartesian set product):

$$F_0 = F \times H \times T \ (Supply)$$

Given $M \ a \ set \ of \ mills \ (Demand)$

Let:

$c_{ij} =$ *variable cost* incurred on each unit produced at supply point $i \in F_0$ and shipped to demand point $j \in M_0$

x_{ij} = number of units shipped from supply point $i \in F_0$ to demand point $j \in M_0$

Then the general formulation of our transportation problem is

$$min \sum_{i=1}^{i=F} \sum_{j=1}^{j=M} c_{ij}x_{ij} \tag{3.1}$$

s.t.

$$\sum_{j=1}^{|M|} x_{ij} \leq s_i \; (i = 1, 2, ..., F) \; (Supply\ constraints) \tag{3.2}$$

$$\sum_{i=1}^{|F|} x_{ij} \leq d_j \leq d_{max} \; (j = 1, 2, ..., M) \; (Demand\ constraints) \tag{3.3}$$

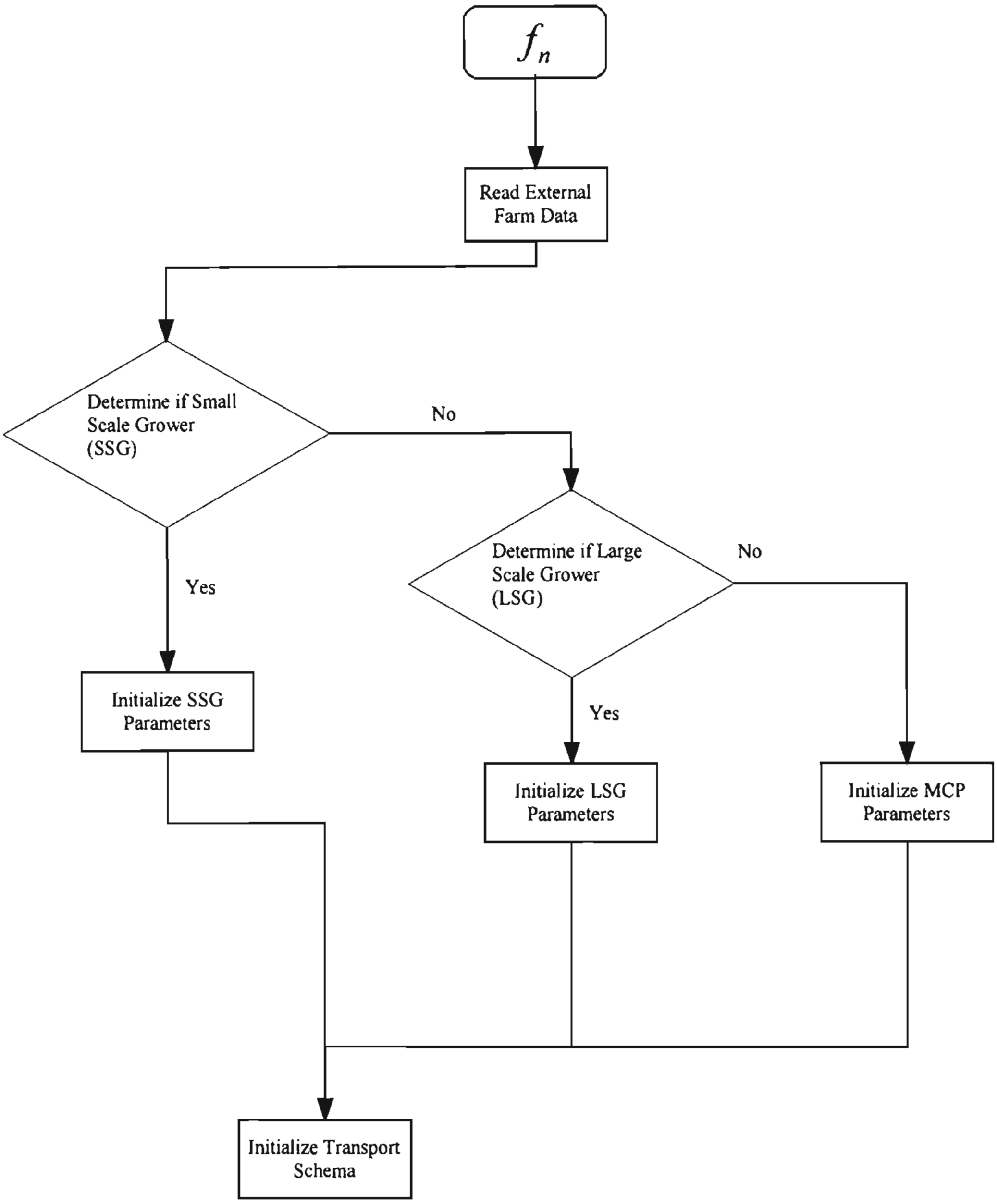
where $x_{ij} \geq 0$ $(i = 1, 2, ..., F;\ j = 1, 2, ..., M)$

3.6 Activity Diagrams

Following on from the conceptual model, each individual module has been further broken up into their representative activity diagrams. These activity diagrams will help in understanding the choices/decisions made as the sugarcane entities pass through the system from harvest to mill-yard.

3.6.1 Farms

In figure 3.5 we start off by having our farm module (f_n) initialized with a certain daily allocation of sugarcane. Then these entities travel through the system and prompt for various external farm data to be read in from MS Excel Spreadsheets. Once that is done the entities will prompt the farm module to determine what type



- Location - Distance to Mill
- Schedules - Day/Night, Duration
- Methods - Truck, Truck & Trailer, Tractor & Trailer, Capacity, Velocity
- Resources - Labor

Figure 3.5: Farm Activity Diagram

of grower this is and initialize the appropriate variables accordingly. Basically all the activities that take place within a farm module are those for defining and initializing a specific farm to match the criteria provided by a real world farm. Below the "Initialize Transport Schema" activity block seen in figure 3.5, are some of the properties that are associated with it.

3.6.2 Harvest and Transportation

The next important activity diagrams to understand are those seen in figure 3.6, the harvest (h_n) and transport (t_n) diagrams. Once all the relevant farm modules have been set up and the cane entities have passed successfully through f_n (see figure 3.5) they then enter the harvest module (h_n). From there all the necessary harvest type decisions will be made, based on research from [9], and the subsequent methods of infield transportation chosen. Once that has been achieved the cane entities will reach the "Initialize Harvest Schema" activity block and the appropriate properties will be initialized. Now the sugarcane is ready to be cut/chopped accordingly.

Next the cane entities are cut/chopped and are then moved into the transport module (t_n). From there, depending on where the vehicles are coming from (i.e. going to the mill, between or returning), the respective activity block ("Farm End Transport", "Routes between Farm and Mill", "Mill End Transport") will be chosen. Each block has similar properties, however they are implemented according to the distinct area they represent.

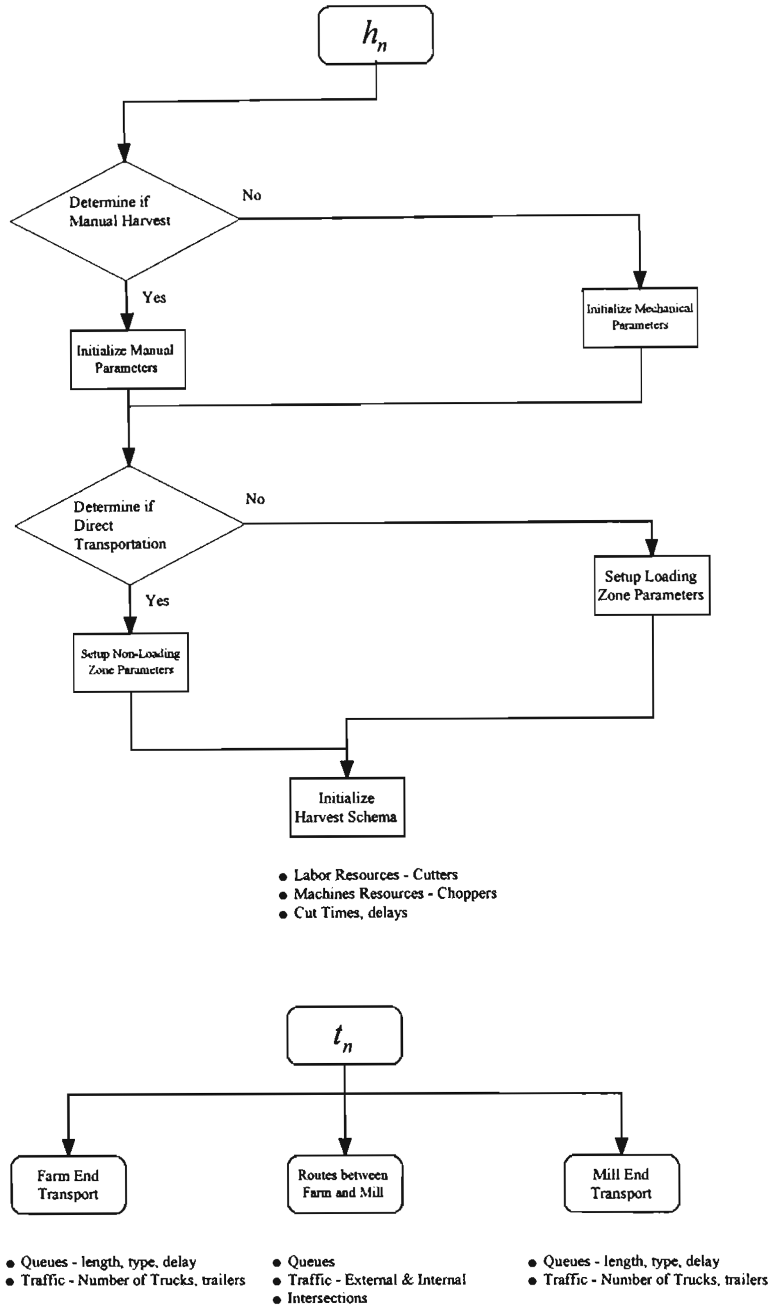


Figure 3.6: Harvest and Transportation Activity Diagram

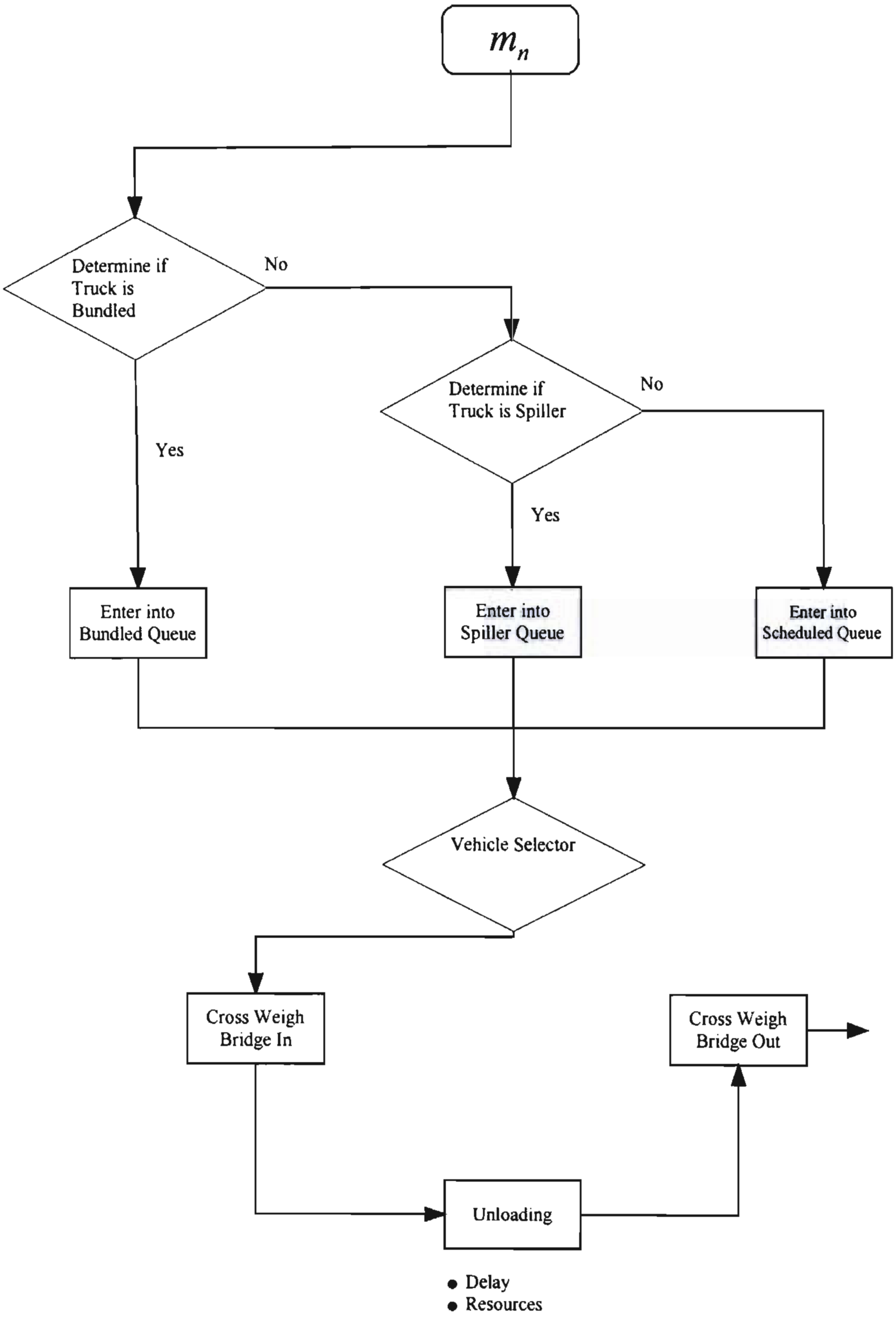


Figure 3.7: Mill-yard Activity Diagram

3.6.3 Mill-yard

Finally there is the mill-yard activity diagram depicted in figure 3.7. Once the vehicles (transporting the sugarcane entities) reach the mill-yard, they'll begin entering into m_n. Here they will trigger the mill-yard to initialize itself correctly and begin setup of it's alternating three queue structure outside the mill gate. The vehicles will then be required to join the appropriate queue based on the type (how the sugarcane was packaged) of sugarcane it's carrying or whether the vehicle has been pre-scheduled with the mill. The latter meaning that the vehicle is in agreement with the miller as to when it will deliver it's cane and thus provided with a specialized queue. Next the vehicles will be selected and pass through the queues and over the weigh bridge one at a time. Finally the vehicles will be offloaded and return to their respective farms to repeat the process.

3.7 Farms Classification

In the previous sections there has been continual reference to the notion of a Farm module and how various variables and activities associated with this Farm module are initialized and operate. There is however one important question that we have not yet answered and that is: how have we decided on which farms to model?

Recall that in the Noodsberg region there are approximately 880 various different sugarcane growers and that trying to model each and every individual farm in this area would be extremely time consuming and difficult. Thus there was a need to develop some sort of generic hierarchical farm grouping structure. Having this sort

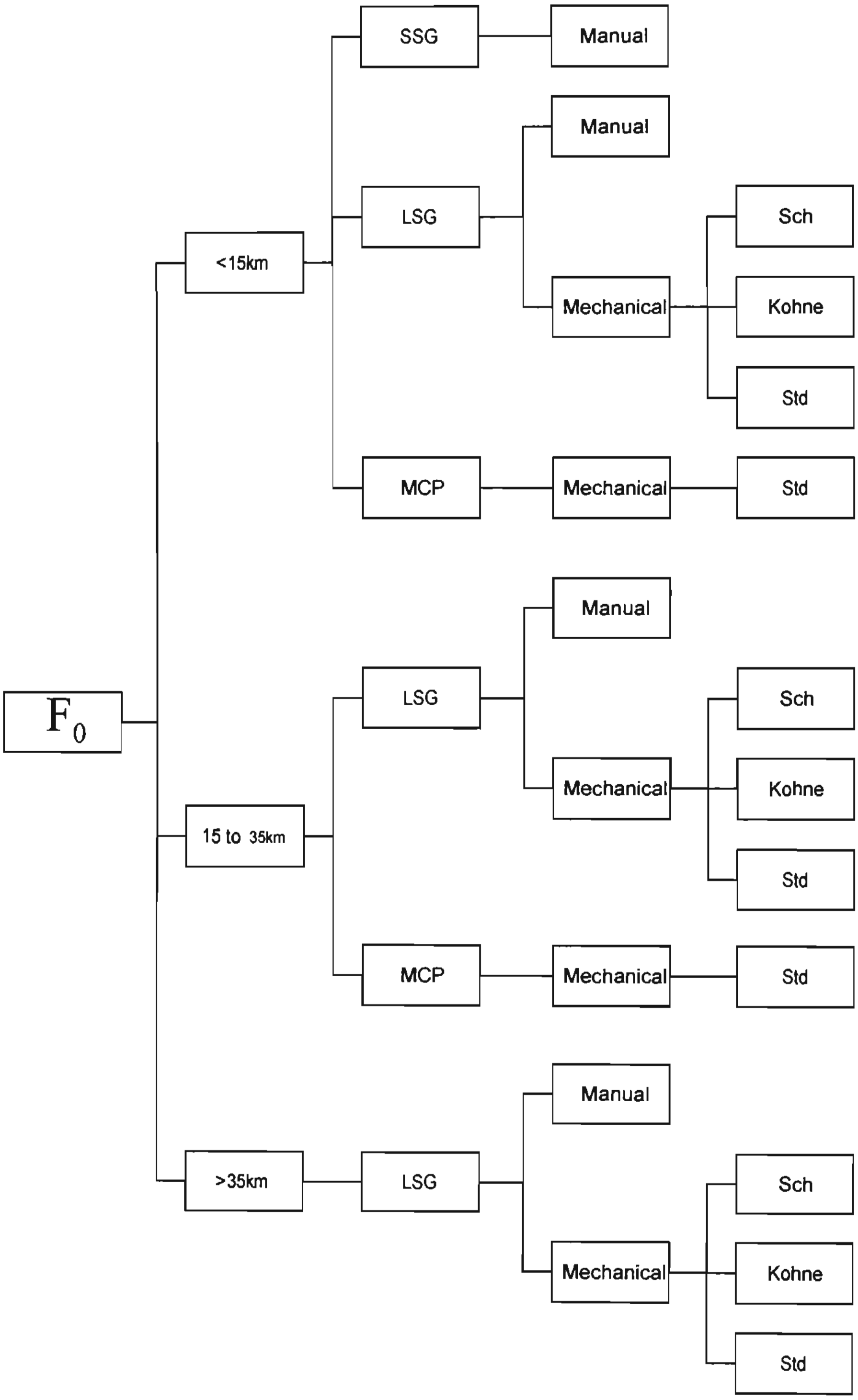


Figure 3.8: Generic Farm Hierarchy/Groupings

of structure would mean simplifying the problem a little, while not losing too much accuracy. An example of this generic farm grouping structure can be seen in figure 3.8. This means that any particular Farm module, in this case F_0, can be one of either 15 generic groupings. These 15 generic farm groupings have been broken up as follows: firstly they are divided by distance to the mill, that being farms located within 15km of the mill, then those that are located between 15km and 35km to the mill and then those that are located greater than 35km to the mill. Next the farms are divided up by grower type, those that are Small Scale Growers (SSG) (simply meaning they produce on average 225 tons RV (recoverable value) or less of sugar), those that are Large Scale Growers (LSG) (they produce on average more than 225 tons RV of sugar) and those that are Miller come planters (MCP) (they are millers that also own farms of LSG size).

It must be pointed out at this point that although there are around 725 SSG's in the Noodsberg region, they only contribute 4% to the total sugarcane provided to the mill seasonally, thus they will all be modelled as one single component. Next it must be mentioned that there are only 2 MCP's contributing about 1% to the seasonal intake of sugarcane at the mill. The remaining 95% of the sugarcane is provided by the 153 LSG's.

Next these grower types are further divided into which harvest techniques they use, i.e. manual or mechanical, this division applies mainly to the LSG's because the majority of SSG's use manual techniques and all MCP's use mechanical techniques.

Lastly the mechanical harvesting farms are further divided up into 1 of 3 main mechanical harvest techniques. Either the *Peter Schroeger* System (Sch), meaning the system entails using a ratio of 1 vehicle (32 tons), 2 trailers (16 tons each) and 1 chopper harvester; there is no infield loading zone (LZ), therefore the vehicle must be at the loading zone for the trailers to be able to empty (delivers during the day). Next we have the *Hugo Kohne* System (Kohne), which is a system that uses a ratio of 1 vehicle (32 tons), 28 bins (8 tons each) and 1 chopper harvester; there is an infield LZ where the bins are stored, therefore the vehicle does not have to continually be at the LZ (delivers at night). Lastly we have the *Standard* System (Std) which is a system that uses a ratio of 1 vehicle (32 tons), 2 trailers (16 tons each) and 1 chopper harvester; all cane is stored in a stock pile at the infield LZ, again this means the vehicle does not have to continually be there (delivers during the day).

Chapter 4

Methodology - Part 1: Model Conceptualization and Data Collection

4.1 Region of Interest

4.1.1 Noodsberg

In some of the previous chapters there has been reference to our region of interest. Now more formally introduced, our region of interest is a small culturally diverse community located just a few kilometers outside of Pietermaritzburg. This area, known as Noodsberg, has sugarcane growing as one of its primary agricultural activities and is fast becoming the center of study for sugarcane research.

Figure 4.1, is a snapshot of the area taken from Google Earth's Satellite imagery. This image shows all major routes/roads in the area, starting with the route *R33* which runs from Pietermaritzburg upwards in a northerly direction, route *M30* also

Noodsberg	MCP	LSG	SSG	Mill Total
Number of Growers	2	153	725	880
Cane Area (ha)	720	30420	1418	32558

Table 4.1: Noodsberg Grower Information *(2006/7 South African Canegrowers Association)*

runs from Pietermaritzburg and then joins up with the route *R614* which continues in a north-easterly direction. The area between these major roads is the greater Noodsberg area, with all subsidiary roads branching off.

To help understand this region further, some of the grower statistics, for the area, can be seen in table 4.1. This information is captured/recorded by the Noodsberg Mill in conjunction with the information provided by South African Canegrowers Association. In other words the number of growers recorded, are those growers which are serviced by the Noodsberg Mill.

To familiarize ourselves with the region of interest, some key questions arose. Firstly is it possible for geospatial information systems (GIS), namely Google Earth and ArcView, to help in mapping this region and secondly is it possible to build our model, overlayed on top of one of these mapping systems? We wanted to create a visually accurate model of the real world area, that growers and millers can immediately relate to. In the sections below we see that with the additional use of a GIS system it has been possible to both accurately map the region and integrate such a map into the model.

Figure 4.2 is a sample output of the area depicting all major road networks and

Figure 4.1: Google Earth Satellite Image of Region

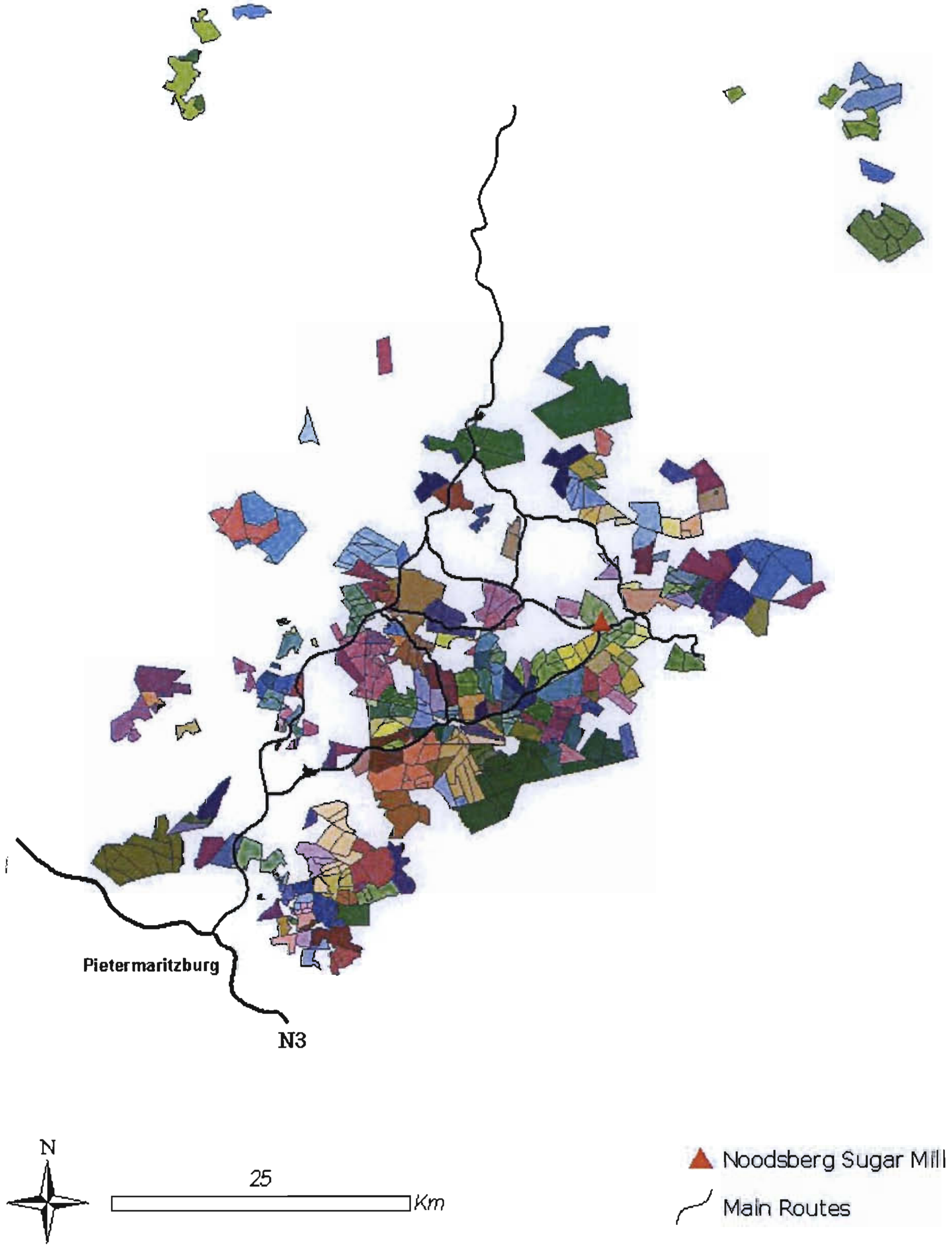


Figure 4.2: GIS Image of Region - Farm Locations

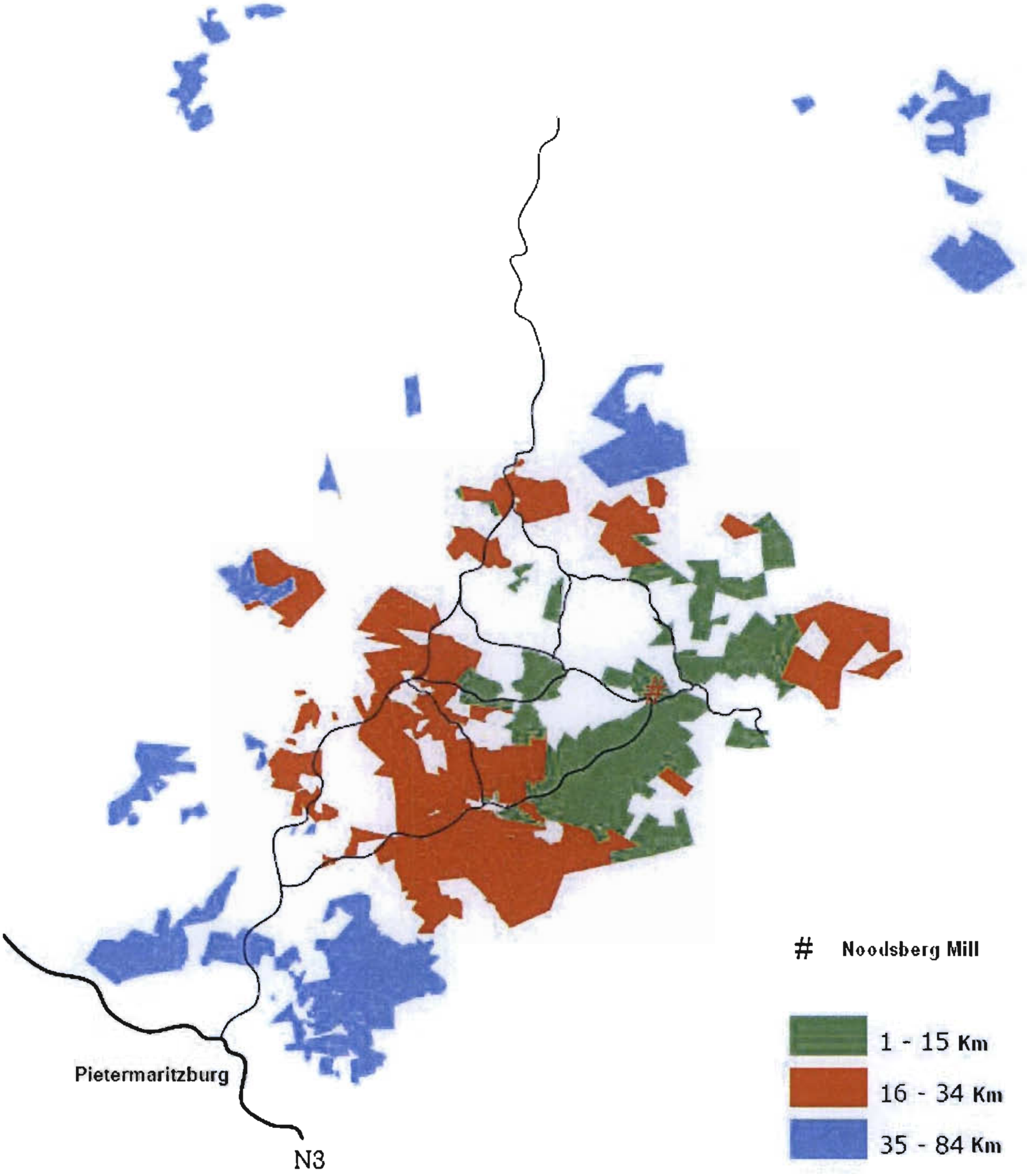


Figure 4.3: GIS Image of Region - Farm Distances to Mill

farm locations in the greater Noodsberg area. Each color block represents a different farm, with some growers owning more than one farm. These routes and farm locations are relatively accurate, developed by the ArcView GIS software package. ArcView is specifically developed for visualizing, managing, creating, and analyzing geographic data. What this means is that there is an accurate, to scale map of the region, showing where the farms are and what possible routes they would travel to reach the mill.

The next GIS image, shown in figure 4.3, depicts how the farms are situated according to the three distance categories (described in ***"Chapter 3, Section - 3.7"***). This now shows exactly how the farms are grouped in accordance with the distance to the mill.

4.1.2 Issues Facing Area

Noodsberg's unique configuration and conservative mind-sets have slowly complicated the areas daily sugarcane operations. Growers prefer to stick with tried and tested family traditions (whether efficient or inefficient), than risk adopting or facilitating the ideas for change. Millers are also following a similar trend and as long as both parties resist potential optimization strategies, the area will continue to fall behind the standards of modern sugarcane practices.

Pressing issues that immediately face this area are: Should growers be moving to mechanization harvest techniques and what are the costs involved [35]? Are there too many transport vehicles in the system and can/should they be reduced [36]?

Where are the vehicles being most affected by delay and can this delay be reduced? Is it possible to better distribute the delivery of sugarcane throughout the day at the mill? Is the mill-yard's three queue structure actually helping to alleviate problems? It must be noted that our project is not aimed at answering all these questions, but rather will shed light on issues (direct and indirect) that will help to answer and solve some of these questions.

4.1.3 Scenario Development

There are many scenarios and different configurations that have been implemented over the course of this project development; however there are two main scenarios that are considered to be vital to the project success. These two scenarios are defined as follows:

1. Develop an industry benchmark configuration. This scenario must model and capture the entire (with some limitations) Noodsberg sugarcane transport and logistics system. Key figures and production measures must be extracted and validated against industry standards. We must confirm the model is working correctly and accurately
2. To investigate the impact of adding to the model, traffic congestion (on road vehicle delay), swarm intelligence (alignment, separation and cohesion rules) and vehicle driver logistics (speeding up/slowing down when close to knock-off time). Each additional feature will be carefully monitored and measured.

4.2 Data Collection

4.2.1 Farm Data

Capturing the relevant data and trying to understand all the different variables involved in making a farm operate has been a crucial stage in this model development [37], [38]. After much interaction with a few specific growers and the help of many agricultural experts on the subject area, a list of the most crucial and dominating variables was drawn up. These variables and subsequent values have been shown below and in further sections to come.

Farm Resources, Capacities and Schedules

Firstly we see in table 4.2, the relevant trailer capacity and speed common to the majority of growers. Then we see in table 4.3 the basic working times of most growers, bearing in mind that currently a select few deliver at night.

Another important table to mention is table 4.4: here we see the relevant rates for the different harvest techniques. Notice the speed difference in tons.hr^{-1} between the manual cutters and the mechanical chopper harvesters while trailer load/unload times are identical.

Trailer	Value
Capacity (tons)	7
Speed (km.hr^{-1})	20

Table 4.2: Grower Trailer Information

Schedule	Duration
Day	07:00 - 17:00
Night	18:00 - 23:00

Table 4.3: Grower Work Schedules

Delays/Rates	Value
Chopper Harvester (tons.hr^{-1})	60
Cutter (tons.hr^{-1})	0.8
Trailer Load Time (mins)	7
Trailer Unload Time (mins)	7

Table 4.4: Grower Delays/Rates

Tables 4.5, 4.6 and 4.7 are all relatively similar, showing the general ratios of capital/resources for the different grower types within the area.

- We note that all these figure's are representative of the global/average trends within the Noodsberg region. Data provided from various grower interviews/surveys.

Daily Sugarcane Allocations

One of the most important inputs into our model is that of daily sugarcane allocations for each respective grower. In other words how much cane will be cut/chopped by each grower on each day, bearing in mind that at the beginning of a milling season (roughly April to December), each grower must establish an agreement with the mill as to how much cane it will deliver to the mill each week. This schedule/agreement must be kept by the grower to the best of its ability, thus theoretically and ideally both parties would like these daily deliveries to follow a relatively uniform distribution. The idea is to keep the mill happy with constant and steady supply of sugarcane

LSG Capacity Ratios	Manual	Mechanical
Chopper Harvesters	0	1
Cutters	20	0
Trailers	2	2
Trucks	1	1

Table 4.5: LSG Grower Capacity Ratios

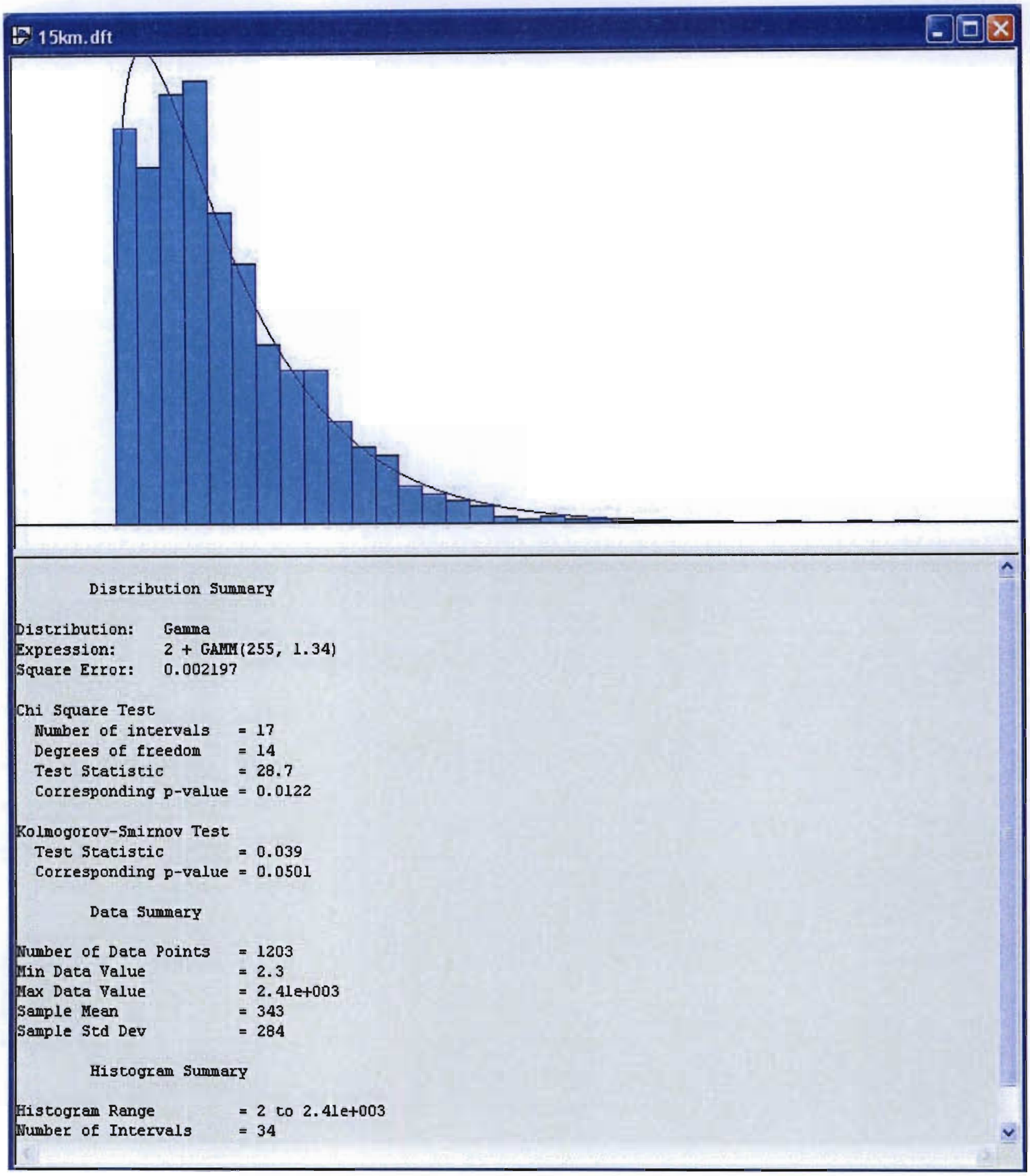
SSG Capacity Ratios	Manual
Cutters	10
Trailers	1
Trucks	1

Table 4.6: SSG Grower Capacity Ratios

and the growers happy that all their cane will hopefully reach the mill within the season. However as with most applications, the real world practices always tend to differ greatly from the way it should operate theoretically.

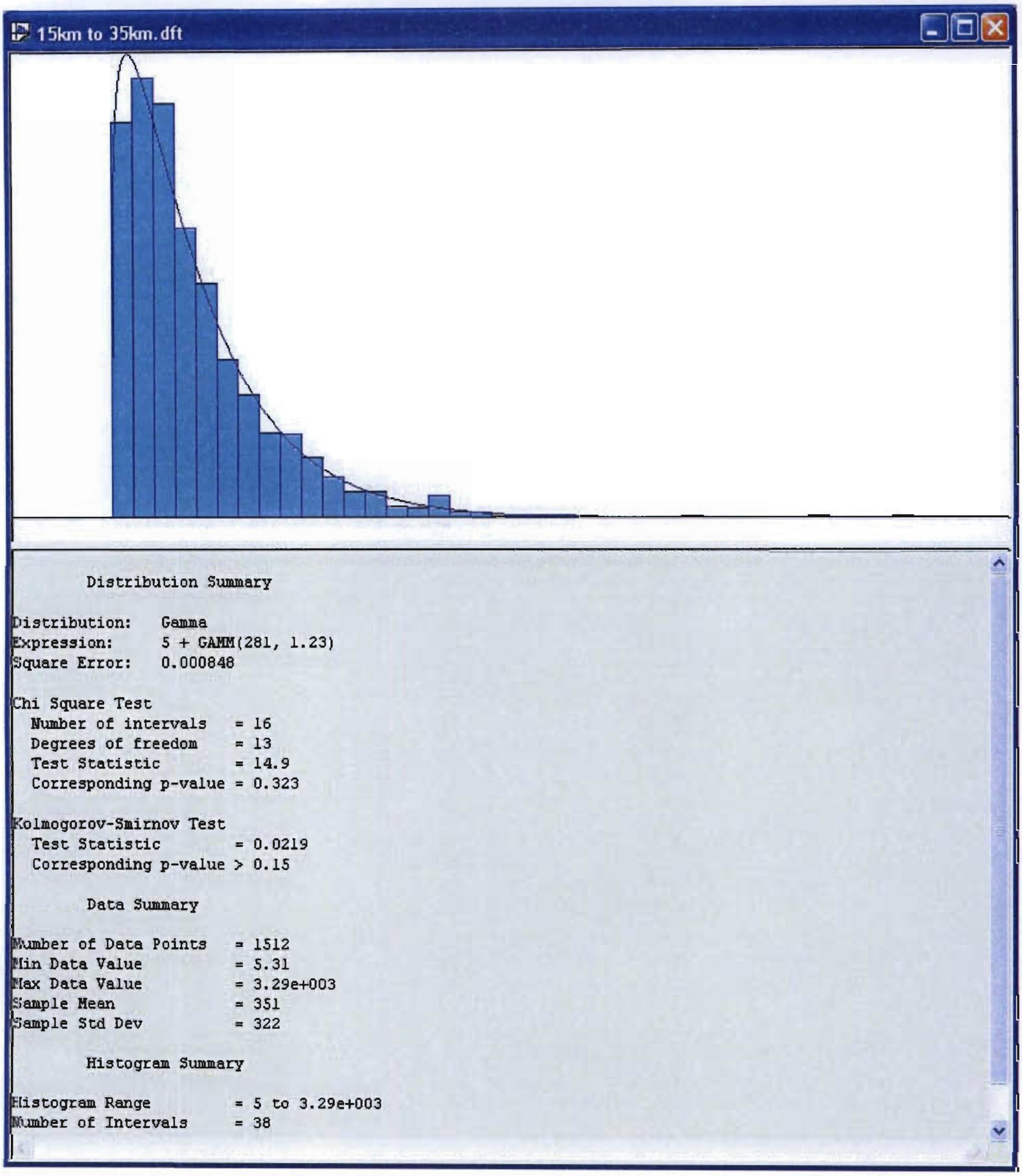
Table 4.8 shows the LSG statistics for each grower group located within a certain distance category from the mill. The importance of table 4.8 is that it shows how much cane each LSG area contributes relative to the total average season intake. It must be pointed out that these figures are representative of the 2006 South African Sugarcane Research Institute (SASRI) data for the Noodsberg area in which only data for the LSG's (major contributors) was provided.

Rockwell Arena's Input Analyzer tool (a complete statistics software package) was used. We loaded the survey data into it and produced meaningful distributions and accurate parameters for the different LSG area's, thus giving an indication as to how



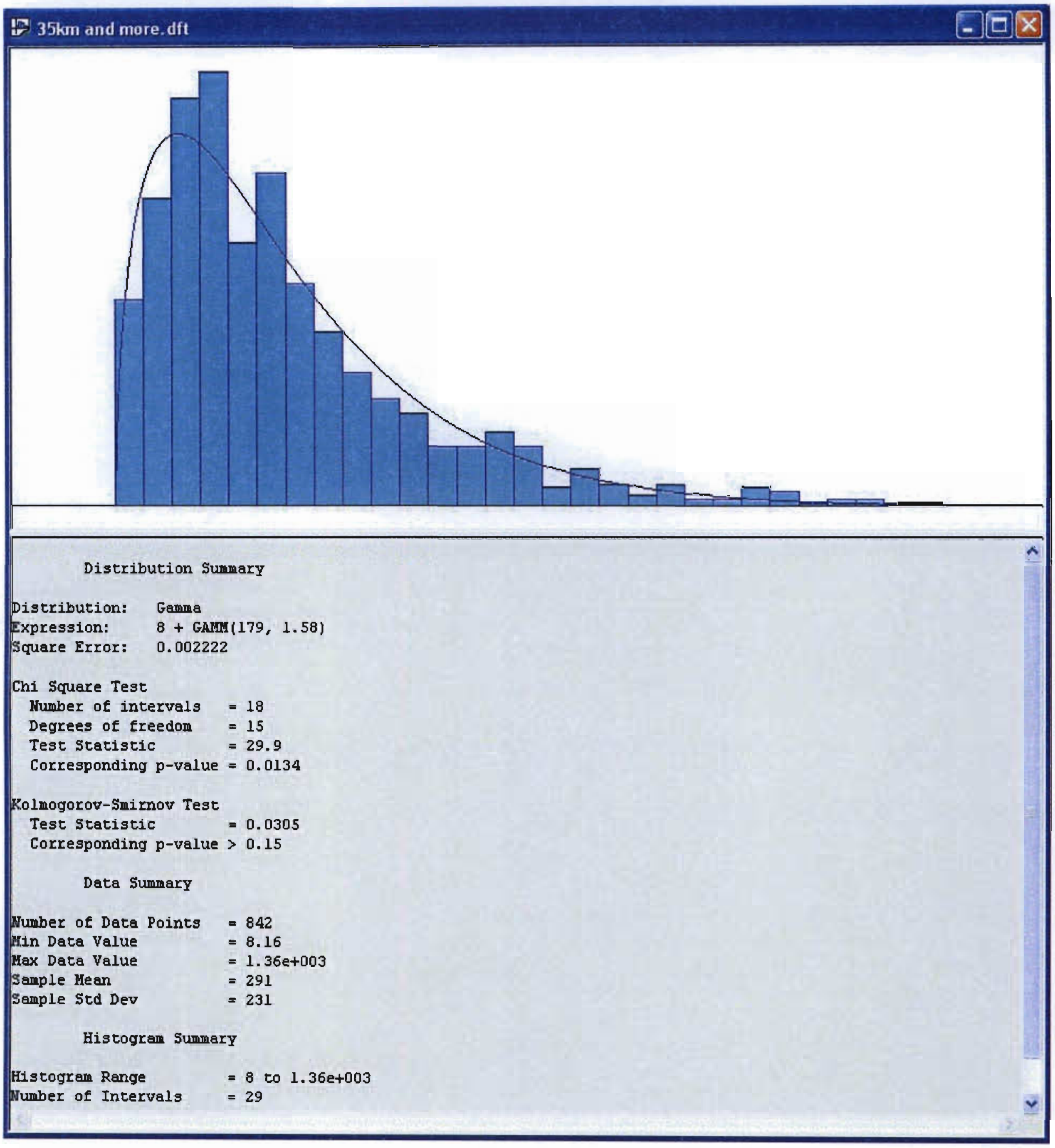
```
        Distribution Summary

Distribution:   Gamma
Expression:     2 + GAMM(255, 1.34)
Square Error:   0.002197

Chi Square Test
  Number of intervals   = 17
  Degrees of freedom    = 14
  Test Statistic        = 28.7
  Corresponding p-value = 0.0122

Kolmogorov-Smirnov Test
  Test Statistic        = 0.039
  Corresponding p-value = 0.0501

        Data Summary

Number of Data Points   = 1203
Min Data Value          = 2.3
Max Data Value          = 2.41e+003
Sample Mean             = 343
Sample Std Dev          = 284

        Histogram Summary

Histogram Range         = 2 to 2.41e+003
Number of Intervals     = 34
```

Figure 4.4: Gamma distribution representing sugarcane deliveries of farms located within 15km of the mill



```
        Distribution Summary

Distribution:    Gamma
Expression:      5 + GAMM(281, 1.23)
Square Error:    0.000848

Chi Square Test
  Number of intervals    = 16
  Degrees of freedom     = 13
  Test Statistic         = 14.9
  Corresponding p-value  = 0.323

Kolmogorov-Smirnov Test
  Test Statistic         = 0.0219
  Corresponding p-value  > 0.15

        Data Summary

Number of Data Points    = 1512
Min Data Value           = 5.31
Max Data Value           = 3.29e+003
Sample Mean              = 351
Sample Std Dev           = 322

        Histogram Summary

Histogram Range          = 5 to 3.29e+003
Number of Intervals      = 38
```

Figure 4.5: Gamma distribution representing sugarcane deliveries of farms located between 15km and 35km of the mill



```
        Distribution Summary

Distribution:   Gamma
Expression:     8 + GAMM(179, 1.58)
Square Error:   0.002222

Chi Square Test
  Number of intervals   = 18
  Degrees of freedom    = 15
  Test Statistic        = 29.9
  Corresponding p-value = 0.0134

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0305
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 842
Min Data Value          = 8.16
Max Data Value          = 1.36e+003
Sample Mean             = 291
Sample Std Dev          = 231

        Histogram Summary

Histogram Range         = 8 to 1.36e+003
Number of Intervals     = 29
```

Figure 4.6: Gamma distribution representing sugarcane deliveries of farms located greater than 35km of the mill

With the matching distributions for the delivery data now provided, a further summary of those results can be seen in table 4.9. Table 4.9 shows the matching distribution for each LSG area's sugarcane deliveries for the 2006 season. It also shows the exact distribution expression which happens to be a Gamma distribution in all cases (just varying on parameters) and how well this distribution curve fits the data, seen by the mean square error value (in all cases this error value being smaller than 0.003, i.e. an almost perfect fit to the data). For convenience, the definition of a Gamma distribution is stated below:

A random variable X is gamma distributed with scale θ and shape k is denoted:

$$X \sim \Gamma(k, \theta) \text{ or } X \sim \text{Gamma}(k, \theta) \tag{4.1}$$

The probability density function of the gamma distribution can then be expressed in terms of the gamma function:

$$f(x; k, \theta) = x^{k-1} \frac{e^{-x/\theta}}{\theta^k \Gamma(k)} \text{ for } x > 0 \text{ and } k, \theta > 0 \tag{4.2}$$

We note at this point that although there is sufficient information to obtain parameters for a Gamma distribution for daily cane allocations, the model is not without limitations. Firstly the data used did not distinguish between growers that are manual and those that are mechanical, the latter having in most cases larger delivery amounts. The data also represents a weekly delivery rate, when actually what is needed is a daily delivery rate. From known bounds on a manual and mechanical harvest, we could now estimate a respective weekly delivery amount from the relevant Gamma distribution and then scale that value down into a daily amount that falls within manual or mechanical harvest bounds (depending on grower).

Farm Scalability

One issue that has been discussed in some of the previous sections/chapters is that of farm modelling and representation. It was said that farms would be classified according to certain characteristics and thus modelled accordingly (refer back to ***"Chapter 3: Farm Hierarchy"***). To elaborate on this point further, each farm grouping will actually represent a collection of farms that all fit the general characteristics of that particular group. Therefore our farms have the ability/functionality to be scaled according to the number of farms they represent, this scalability option is represented on input and once a group of farms have been chosen to be scaled up/down (i.e. ratio *1:N*), all subsequent properties of that farm group will also be scaled accordingly (i.e. number of vehicles, trailers and daily cane allocation).

The reason for this additional functionality is that the area of Noodsberg is a rapidly expanding community and each year more farmers may come to grow sugarcane, thus our model can now adapt to these changes and scale itself appropriately. Another important reason is to allow for different scenarios to be modelled based on the number of farmers/growers within certain areas. Success of such scalability can be seen in [9].

Figure 4.7, shows exactly how the region has been divided up to represent all

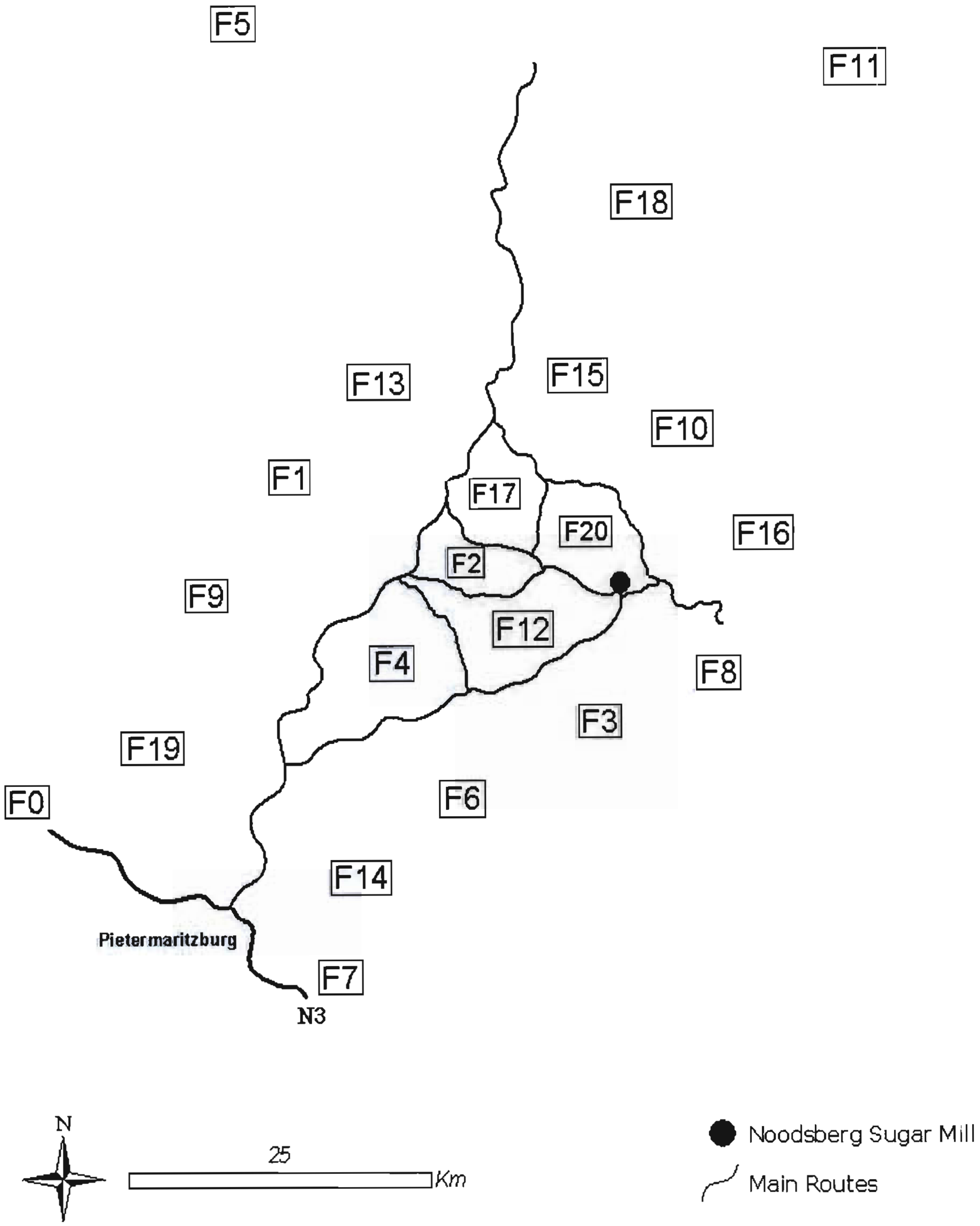


Figure 4.7: GIS Image of Region - Major Farm Groupings

significant farm locations/groupings. Each respective Farm module (*F0-F20*) can been seen in figure 4.7 and a sample of the properties associated with some of these Farm modules can be seen in table 4.10.

F_N	Num Farms	Cane Amt	Cane Type	Num Trucks	Num Trailers	Num Choppers
F3	2	180 (tons.day^{-1})	Spiller	4	56	2

Table 4.10: Sample of the properties associated with Farm module F3, which is a collection of mechanical harvesting farms

A few details need to be explained here. The *"Num Farms"* variable, is our scale factor and all subsequent variables that follow are scaled by this number. Next recall that our variable values for each farm adhere to a certain ratio of resources, according to what type of farm it is. This ratio is then proportionally scaled by the scale factor. Lastly along with farm type, there's also a *"Cane Type"* which represents the way the cane has been packaged (i.e. spiller cane = loosely packaged cane within a trailer/truck, while bundled cane = small bundles of cane strapped together with chains within a trailer/truck).

4.2.2 Transport and Road Network Data

Within the Noodsberg area there are various means of transportation and along with that a well defined road network (albeit some are dirt roads). Therefore determining which vehicles to model and what routes they should take had to be based on some sort of survey, showing at least the proportion of total deliveries (%) for each vehicle type.

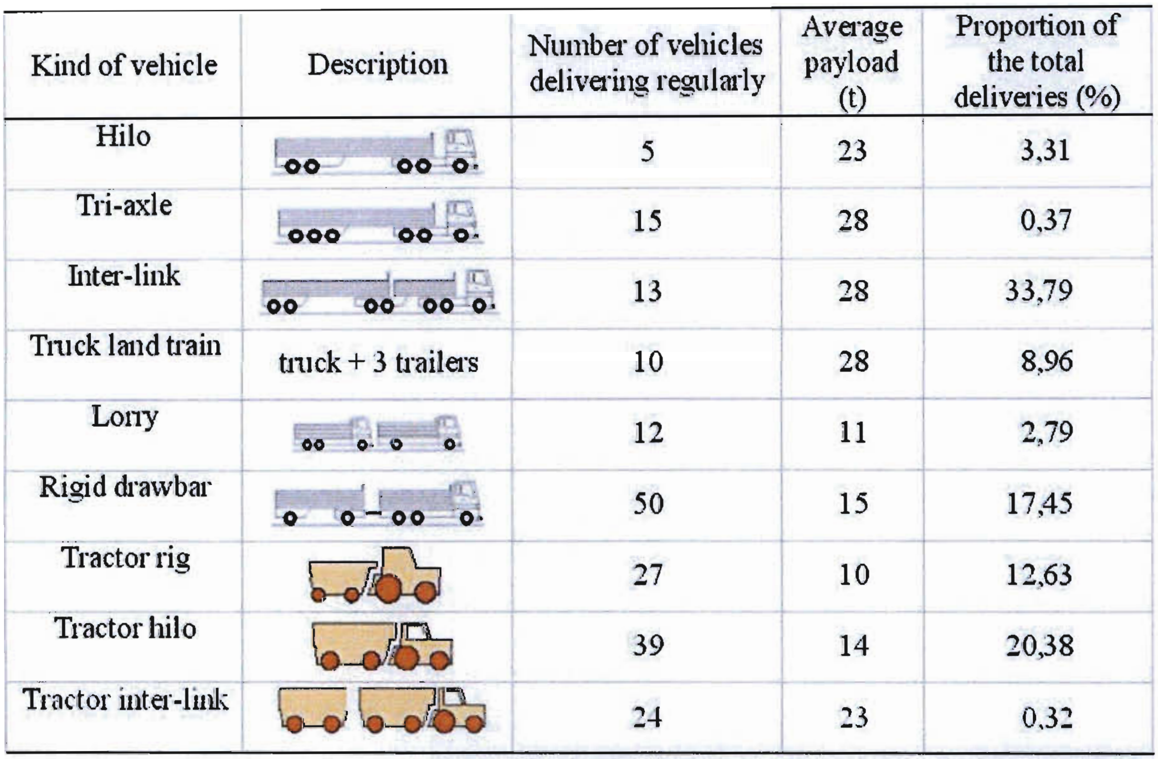
Transportation

Figure 4.8 is a summary of all the major vehicle types that deliver to the Noodsberg mill, as well as the proportion of total deliveries (%). From this information it can be seen that the *"Inter-link (28 ton average payload)"* vehicles contribute the highest proportion of total deliveries standing at 33.79% and the *"Tractor hilo (14 ton average payload)"* vehicles contribute the second highest proportion of total deliveries standing at 20.38%. Therefore those two main classes of vehicle have been chosen for modelling transportation activities.

The next important information is that of average vehicle speeds, this information was provided and stands at $40\ km.hr^{-1}$ for fully loaded vehicles and $60\ km.hr^{-1}$ for empty vehicles. Lastly Noodsberg currently has *105* of these vehicles transporting sugarcane to it's mill.

4.2.3 Route Data

Routing in this project has been simplified by the assumption that all growers will transport their vehicles via the shortest path possible and that there is only one demand point (i.e. only one Mill that these vehicles supply to). In figure 4.9 we see a snapshot of our initial stage simulation model that has been built on top of the GIS map provided. This snapshot shows various supply points (i.e. farms) that have their vehicles currently on route and delivering to the mill. The vehicles that are solid colored are vehicles that are in transit, while the non colored vehicles are currently idle.



Kind of vehicle	Description	Number of vehicles delivering regularly	Average payload (t)	Proportion of the total deliveries (%)
Hilo		5	23	3,31
Tri-axle		15	28	0,37
Inter-link		13	28	33,79
Truck land train	truck + 3 trailers	10	28	8,96
Lorry		12	11	2,79
Rigid drawbar		50	15	17,45
Tractor rig		27	10	12,63
Tractor hilo		39	14	20,38
Tractor inter-link		24	23	0,32

Source : South African Sugar Association 2005 – Cane Testing Service.

Figure 4.8: Various vehicle types used to transport cane at Noodsberg mill

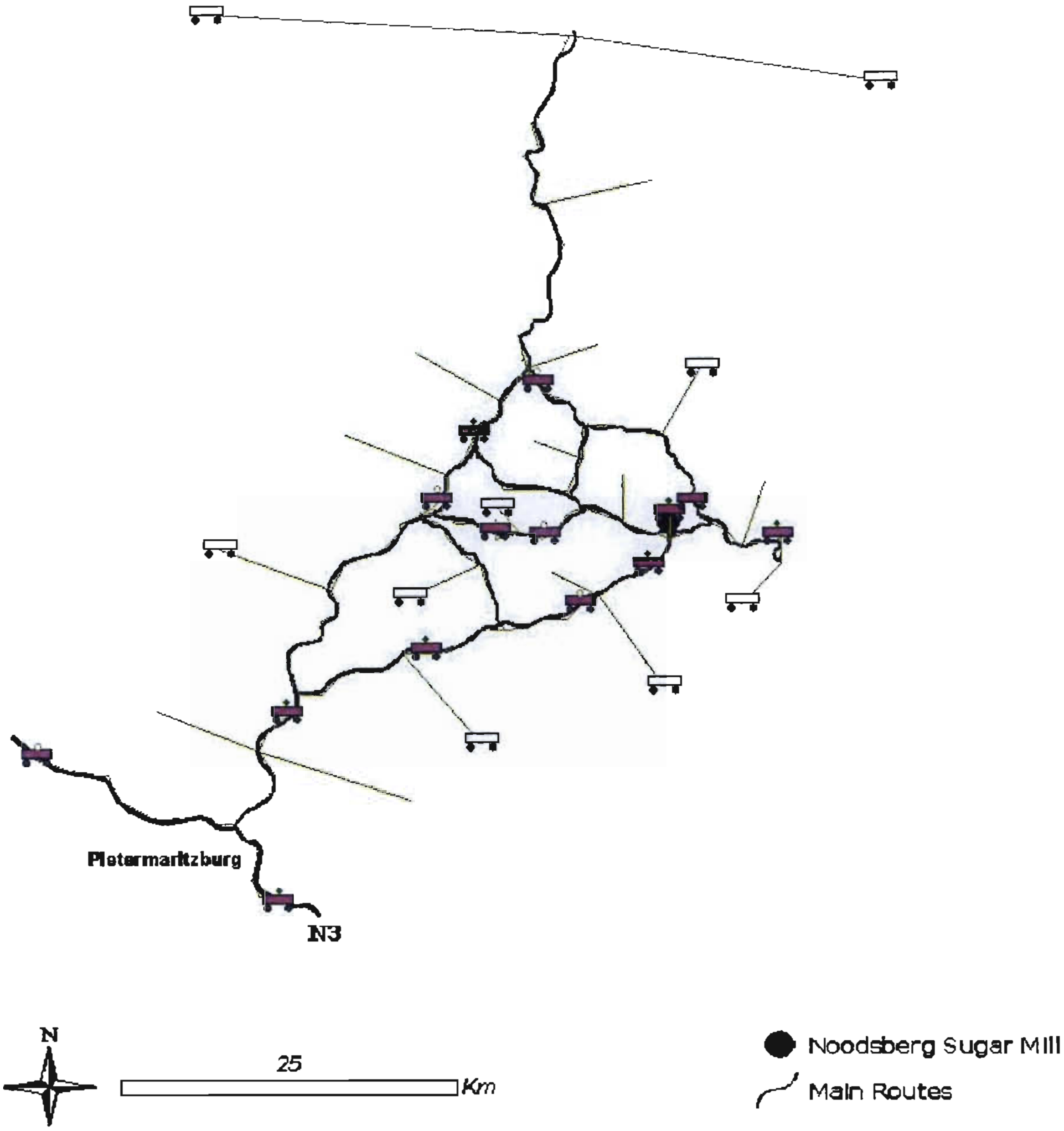


Figure 4.9: GIS map, overlayed on top of our simulation model - showing loaded and empty vehicles (shaded and unshaded, respective) on route to various pickup and drop off points

An important point to mention here is that there are various control points along every main route, these control points are specifically situated at all the intersections and at the median of every route. Although invisible to the viewer, control points are a key design technique, developed to have a firm degree of control over the vehicles, their speeds and various traffic statistics throughout the model.

Traffic Measures

In the initial stages of this project we identified three main users of our system, namely the *Growers*, *Millers* and various *DoT* members. This section deals with the various measures of traffic and road network utilization that the *Department of Transport* would be interested in.

Equations 4.3 and 4.4 are self explanatory, however we do need to elaborate a little more on equation 4.5. Traffic congestion [39] can be an extremely difficult variable to measure, due to the fact that peoples views on how to measure it differ greatly. Along with that you also have the added problems of what exactly causes and contributes to traffic congestion.

For these reasons we have taken a relatively conservative approach to measuring it, seen in equation 4.5. The way it works is we take the reference velocity, which is the velocity the truck would travel at if there were no other vehicles obstructing it on the road (i.e. maximum speed limit allowed for that road stretch) and we subtract from it, the actual velocity the truck is currently going. This will then give a velocity difference from which we can work out the delay, scaled down to seconds lost per kilometer that a truck incurs while on route.

The obvious question that arises now is how do we influence or rather keep track of its actual velocity. Well this means predetermining whether a stretch of road is currently in a state of varied congestion. In other words as our vehicles travel on route, they will reach and pass through various check points. At these check/control points the system will check the next stretch of road ahead for the vehicle and determine whether that stretch is congested (to some degree) or not.

The next important question was, what conditions are necessary for varied congestion, well this can be seen by table 4.11. What this means is that at each control point, the traffic density variable for the next stretch of road is checked and measured against this chart/table 4.11. For example if there are more than 30 vehicles on the next stretch of road then that stretch is considered to be in a state of extreme congestion, therefore the velocity for a fully loaded vehicle must be decreased to 28km.hr^{-1} and the velocity for a empty loaded vehicle must be decreased to 48km.hr^{-1}.

This now brings up the next question, on how we decided upon these different congestion categories. This is derived from traffic density theory [40], that states: if vehicles have a length L (or average length, in our case 18 meters) and a separator distance d (or good average separator distance, in our case 7 meters) between them, then the vehicles will take up $L + d$ units of road. Therefore there is $\frac{1}{L+d}$ vehicles present per unit length of road. For example if the current road stretch is 1km long then: $\frac{1000(meters)}{18+7} = 40$, therefore you can only fit a maximum of 40 vehicles on that unit length of road. Now add in the potential for other external traffic vehicles to be present on the road and you can work out a potentially viable congestion chart.

$$Traffic\ Density\ (\rho) = \frac{NumVehicles_{Route}}{Distance_{Route}} \tag{4.3}$$

$$Traffic\ Flow\ (q) = \rho \times u \tag{4.4}$$

$$Traffic\ Congestion\ (c) = u_{Ref} - u_{Actual}, \tag{4.5}$$

$Where\ u = Velocity,\ u_{Ref} = Reference\ Velocity\ or\ Free\ Flow\ Velocity,$

$And\ u_{Actual} = Actual\ Velocity\ (Velocity\ based\ on\ \rho\ of\ road\ stretch)$([40], [41])

	Extreme	Severe	Heavy	Moderate	Free Flow
ρ (veh.km^{-1})	$\rho \geq 30$	$20 < \rho < 30$	$10 \leq \rho \leq 20$	$4 \leq \rho < 10$	$\rho < 4$
$u_{fullLoad}$ (km.hr^{-1})	28	31	34	37	40
$u_{emptyLoad}$ (km.hr^{-1})	48	51	54	57	60

Table 4.11: Congestion Chart for modifying u_{Actual}

4.2.4 Mill-yard Data

One of the final stages of our data collection process is the understanding and collection of data for the Noodsberg mill-yard. In figure 4.10 we see a Google Earth Satellite view of the entire Noodsberg Mill area, along with that you can see the large queues (selected within a rectangular box) outside the mill gate which are already well developed. As already known, huge amounts of time are loss by Growers when their vehicles become tied up in large mill-yard queues.

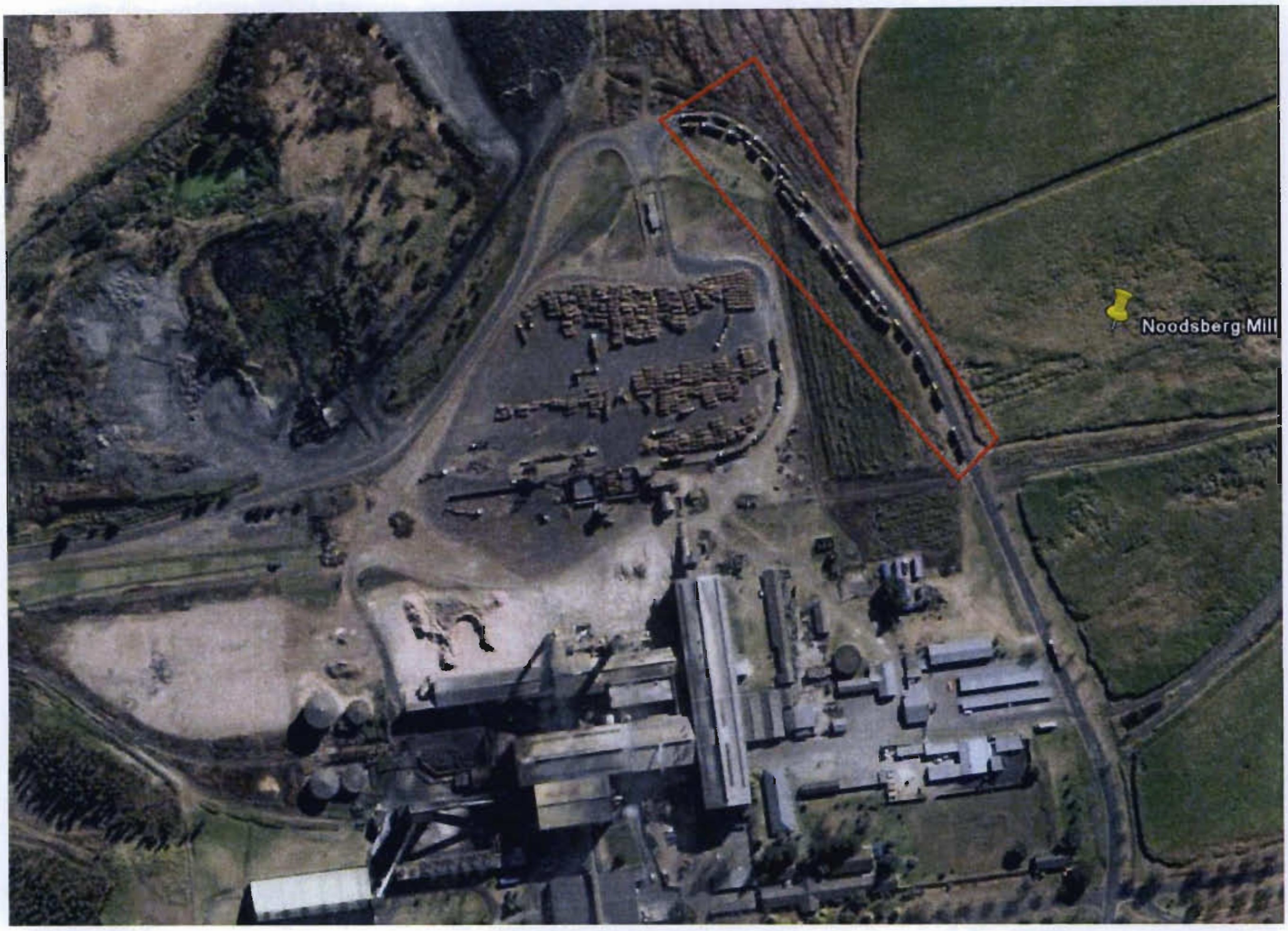


Figure 4.10: Google Earth Satellite image of the Noodsberg Mill area - Rectangular box highlights extreme queues outside mill-yard

Noodsberg uses a 3 queue structure, with each queue following a first-in-first-out (FIFO) policy, however there are additional properties such as the vehicles in front of each queue must alternate between each other as to who goes in first, with immediate preference always going to the vehicles in the scheduled queue first.

Most the mill-yard resources that have been modelled can be seen in table 4.12.

Variable	Value
Queues outside Mill-yard	3 (FIFO alternating queue structure)
Weigh Bridge	4 mins (2 mins Crossing In, 2 mins Crossing Out)
Spiller Cranes	1
Spiller Crane Unload time	15 mins
Bundled Hysters	5
Bundled Hyster Unload time	10 mins
Vehicles allowed in Mill-yard	17 (10 Bundled, 7 Spiller)

Table 4.12: Mill-yard variables and resources

Of those properties, the maximum vehicles allowed in the mill-yard at any particular point in time, is of particular concern. What this means is that at any point in time there can be only 17 vehicles inside the mill-yard, of that 10 must be bundled and 7 spiller. If this case is ever reached then the next vehicle to go inside the mill-yard must be from the same queue that the departing (exiting) vehicle came from (i.e. if a spiller truck leaves then only a spiller truck can enter). Lastly only one vehicle/truck can cross the weigh bridge at a time.

4.3 Simulation Configurations

The development and careful configuration of numerous simulation scenarios have been vital to the success of empirically determining the best simulation model setup [42]. As mentioned earlier (***"Chapter 4: Part 1, 4.1.3, Scenario Development"***) two specific model scenarios have been implemented and will now be discussed below.

Firstly, **configuration one** aimed at developing an industry benchmark system. This

Configuration 1	Simulation Value	Industry Value
Number Farms	96	153
Number Vehicles	105	105
Bundled/Spiller Ratio (%)	44:56	44:56
Mech/Man Ratio (%)	42:58	40:60
Total Daily Cane (tons)	7980	6000–8000
Vehicle Shortest Path	Enabled	Enabled
Road Traffic Congestion	**Disabled**	Enabled
Subtle Driver Logistics	**Disabled**	Enabled
Swarm Manipulation (Experimental)	**Disabled**	Enabled

Table 4.13: Simulation Configuration Setup 1

meant adapting and adjusting our model to best represent the current real world system based on industry recorded inputs which feed into the model at runtime. The empirical nature of this process involved many re-runs and fine tuning of the system because inputs and outputs had to be carefully measured and constantly compared to the specific real world production measures set. A global summary (for a more detailed summary refer to Appendix A, figure A.1 and ***"Chapter 4: Part 1, Farm Scalability, figure 4.10"***) of the key inputs can be seen in table 4.13. Here we compare the input values chosen for simulation versus the real world industry inputs given, however before we discuss the inputs further, it must be pointed out that table 4.13 has been divided into two distinct parts. The top half of the table represents the global inputs, while the bottom half represents additional functionality that the model can incorporate (this functionality can be enabled or disabled). For the purpose of a default configuration scenario this additional functionality (excluding "Vehicle Shortest Path") has been disabled.

As can be seen in table 4.13, there are subtle differences in the inputs used in the simulation compared with those ranges given by industry (*provided by the Noodsberg Cane Growers Association, 2008*). Perhaps the main discrepancy within the inputs is that of "Number of Farms" which needs further explanation. This large discrepancy exists because in industry some farmers do not own their own transportation systems, but rather out-source from other farmers or transportation companies. Therefore this presented a small but challenging design decision. Should the model be expanded to fit those small groupings of farmers who out-source their transportation needs or should the model assume those farms represented are only the ones which have their own transportation systems in place? Bear in mind that our main design goal was to have an accurate representation of the number of vehicles in the system, regardless of the number of farms representing them. Further supporting this simplification, it follows that if the number of vehicles in the system is accurate then the subsequent components which make up the model will still operate correctly e.g mill-yard queues, road traffic. Thus this discrepancy between number of farms used in the simulation versus the number of farms used in the industry standard has been set aside as a potential goal for future work. This decision has been further supported by discussions with various key industry representatives.

Secondly, **configuration two** was to further investigate the impact of adding/enabling the functionality of traffic congestion (road vehicle delay - on specific main routes), swarm intelligence (alignment, separation and cohesion rules) and subtle vehicle driver logistics (speeding up/slowing down when close to knock-off time) into **configuration one**. Some of the main questions presented here, were: will the addition of these features have much effect on the model and if so to what degree? Another extremely

Configuration 2	Simulation Value	Industry Value
Number Farms	96	153
Number Vehicles	105	105
Bundled/Spiller Ratio (%)	44:56	44:56
Mech/Man Ratio (%)	42:58	40:60
Total Daily Cane (tons)	7980	6000–8000
Vehicle Shortest Path	Enabled	Enabled
Road Traffic Congestion	**Enabled**	Enabled
Subtle Driver Logistics	**Enabled**	Enabled
Swarm Manipulation (Experimental)	**Enabled**	Enabled

Table 4.14: Simulation Configuration Setup 2

important objective was to accurately measure and monitor these features.

Tables 4.13 and 4.14 are almost identical, except in terms of additional functionality. Table 4.14 has all the additional functionality enabled with the purpose of comparison with the default, **configuration one**. Further clarification on the specifics of each additional function can be seen below:

- **Vehicle Shortest Path** - all sugarcane vehicles are assumed to follow the shortest path to and from the mill. This meant utilizing a built-in feature of Arena (specifically Dijkstra's algorithm), which involved the creation and definition of various nodes (vertices) throughout the route network, therefore creating a matrix consisting of path distances (costs) between nodes. This allows the simulation entity travelling through the network to lookup in the matrix and evaluated the shortest path

- **Road Traffic Congestion** - throughout the simulation runtime (6 days, Monday to Saturday), there is a continual process of updating the road traffic density variables associated with specific main routes. Therefore as vehicles enter those specific road stretches (checkpoints are located at strategically selected points along route), they adjust their velocities accordingly (based on current traffic density for the next stretch of road)

- **Subtle Driver Logistics** - the idea behind subtle driver logistics is that vehicle drivers make seemingly small decisions according to the relation between their knock-off times and the current time. Take for example a vehicle busy being loaded infield at the farm. If the current time is close to his lunch (12:00 - 13:00) time or finish (17:00 - 18:00) time, he may decide to slow down and/or come to a complete stop. These decisions which occur on a daily basis and between so many vehicle drivers can affect the greater sugarcane supply chain schedule greatly. Thus an investigation was carried out to see the effect of such decisions on the simulation model results

- **Swarm Manipulation** - following the basic swarm algorithm shown in ***"Chapter 2: Section 2.5"***, we now discuss how this experimental concept was applied to the simulation model. Recall that for a group or collection of entities to exhibit swarm behavior, it should follow the three basic rules of alignment, separation and cohesion. Now in terms of the simulation design and functionality, the alignment rule and separation rule has already been implicitly implemented, those being that vehicles know the route to and from their start and end points (alignment) and vehicles will never collide with one another and are free to overtake (separation). This means that only the cohesion rule had to be explicitly implemented. Recall that cohesion is the movement of boids towards the average position of its neighboring boids. In this system cohesion was achieved by inducing drivers to think that their centroid is positioned at the mill site and that the length of the shortest path between the driver and mill was used as the distance measure for computing the swarm centroid. This meant that cohesion within the system was implemented from a mill-yard perspective. The reason for this is that the mill-yard is noted as being the pull factor or demand point of our model. Therefore throughout the days of the week, the mill-yard will pull and demand supply from vehicles and as the current mill-yard capacity rises or falls so too will the cohesive state of the model change accordingly. Vehicles will be remotely communicated to by the mill-yard and told to either speed up (strong cohesion) or slow down (weak cohesion) supply to the mill

We note that the reason for enabling all additional features at once in ***configuration two*** *and not sequentially (i.e. having multiple configurations), is due to the fact that measuring and recording the interaction of all these features together (at once) was more important than tracking the sequential and marginal influence of each additional feature added one at a time*

Chapter 5

Methodology - Part 2: Software Solution

5.1 Software Solution

The simulation software package of choice, used to implement our model, is Rockwell Arena v11.0 (Full Academic License). To appreciate this choice a brief overview of some of the many other simulation tools/libraries available was carried out. Interested readers can find more information in [43].

- Software Libraries (containing basic distribution functionality/calculations)
  - C++SIM
    "This an object-oriented simulation package written in C++. It provides discrete event process-based simulation similar to SIMULA's simulation class and libraries [44]."
  - JavaSIM
    "This is a set of Java packages for building discrete event process-based

  simulation, similar to that in SIMULA and C++SIM (from which JavaSim is derived) [45].”

  - DSOL

    “This is an open source, java based, suite for continuous and discrete event simulation [46].”

- Simulation Tool of Industrial Processes
  - Rockwell ARENA

    Arena has advanced features for modelling complex systems, for example; (i) It is a flexible high-level simulation language. (ii) It provides a framework in which the user can develop a wide variety of simulation models [47]. (iii) Arena can model complex systems quickly and accurately, it gives the user control over time variants and interaction with objects. (iv) It has a well developed graphical user interface for essential visual confirmation when modelling real-world systems. (v) The package accommodates entities, attributes, variables, resources, queues, events and statistical accumulators for to support realistic modelling. (vi) Finally, Arena uses discrete event-driven simulation (a successful simulation technique [19], [48], [49]) with an advanced event calendar to process changes at specific points in time.

For the purpose of this project, we were looking for a simulation software tool that would provide an accurate, visual and reliable simulation environment in which to create our working model. Thus the libraries that were reviewed (although helpful), had particular shortcomings in creating such a graphical model.

5.1.1 Implementation

The implementation of our model within the Arena simulation platform followed the key design principles developed in our conceptual model (see figure 3.4). Arena facilitates a flowchart type methodology when building components of your system, thus the components found within our conceptual model could be represented accordingly. Using the logical structures and predefined control blocks, that Arena provides, we have constructed a generic sugarcane transport logistics system, named ***TranSwarm***. ***TranSwarm*** allows entities, which in our case represent our sugarcane, to move through our system from farm to mill, following the core conceptual model flow process. Subsequently appropriate design rules and decision based protocols are acted upon as entities reach certain control points throughout the model. This Arena based model has been implemented/designed with modularity in mind, allowing for further additional constructs to easily be added or alternatively removed, whenever a user so wishes. Perhaps one of the key implementation features, is that of the user interface and ease of use. Users simply click the ***"run"*** button and the model initializes and executes itself appropriately and correctly.

To give one a brief understanding of the way Arena allows the programmer to model logical constructs and manipulate entity flow, see figure 5.1, which shows a sample

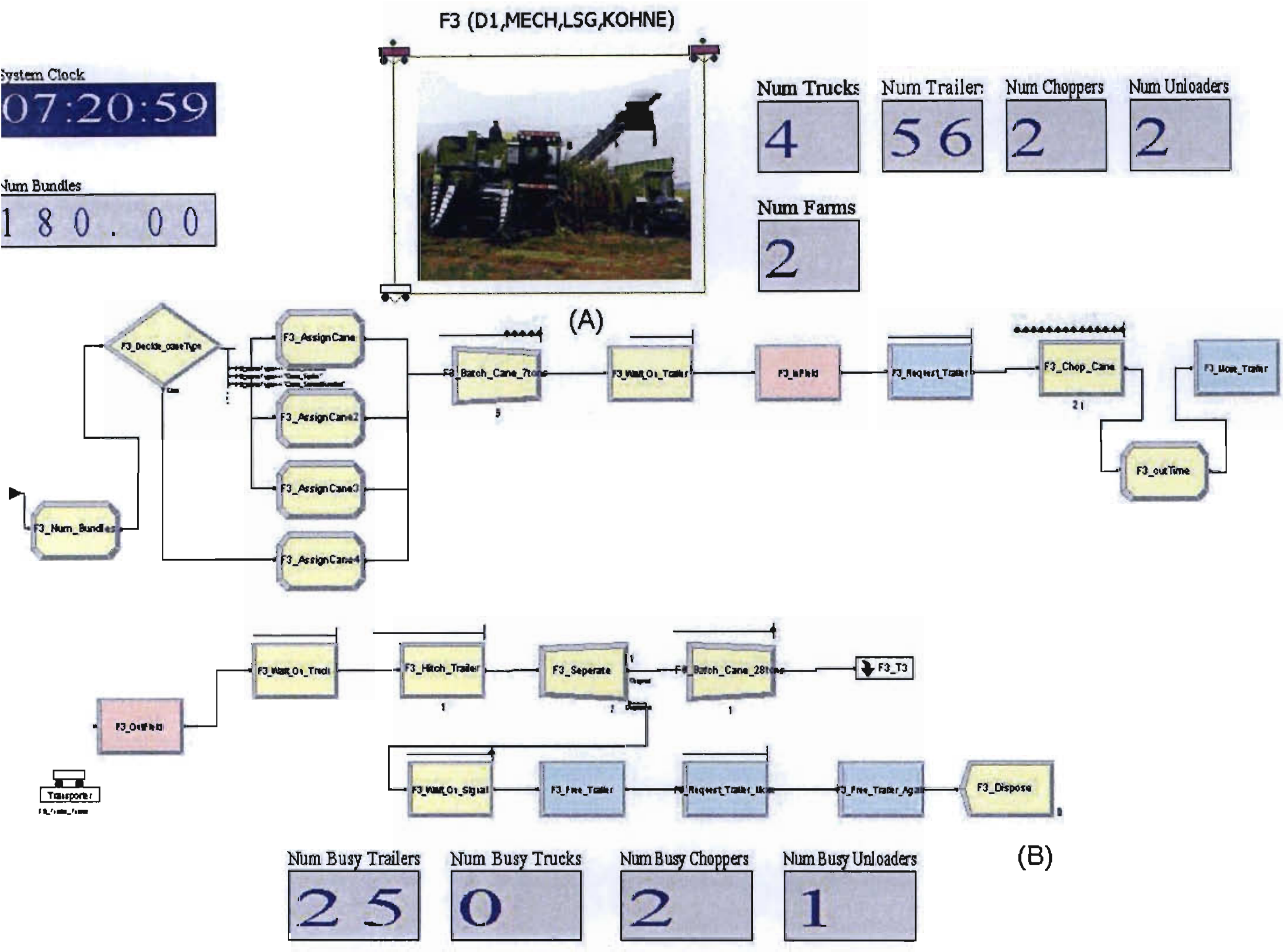
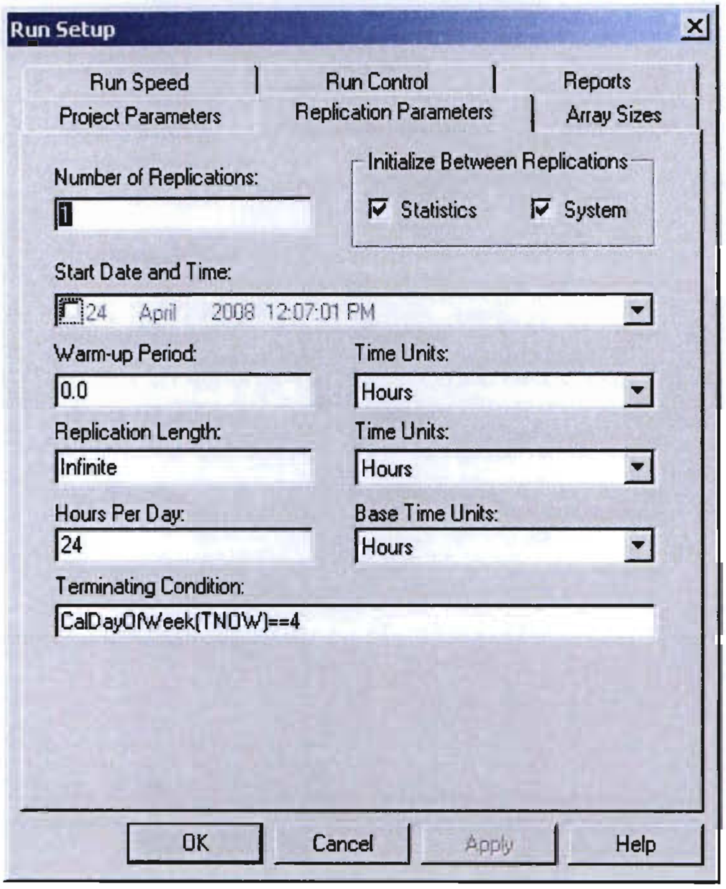


Figure 5.1: Farm Module Sample - *(A) Graphical view of harvest, showing infield to outfield transportation, (B) Arena implementation of the Farm Module*

coding construct (implementation) of one of the many farms modelled within our system. Each block represents a logical construct containing various different properties/variables that can be manipulated to function as the programmer wishes. These blocks are then connected together to provide an interaction and flow methodology for the entities that will pass through them. Additionally, as seen in figure 5.1, each farm is tagged for easy identification, seen by **F3(D1,MECH,LSG,KOHNE)**. This means that this particular farm is from farm grouping **F3** (see Appendix A, figure A.1 for farm properties), is found within distance category **D1** from the mill, uses **mechanical** harvest techniques, is a **large scale grower** and follows the **Kohne** harvest-transportation system.

5.1.2 User Interface and Capabilities

TranSwarm was developed as a simulation model representing the Noodsberg sugarcane transport logistics system. This simulation model has been developed with three key users in mind, recall, the farmers/growers, the millers and the department of transport (DoT). Therefore a relatively simple graphical user interface (GUI) has been designed for ease of use. Arena catered for this by allowing models of great complexity to be built and hidden behind the Arena software interface. Thereby abstracting the complexities of the model from the end user and simply providing them with a play/pause, fast-foreword/rewind and simulation setup control feature. This advantage does however come with a disadvantage and that is, end-users must have the original Arena software already installed to be able to run the simulation model project files. Figure 5.2 shows the simulation model ***TranSwarm*** lying within the Arena software interface. Within this interface the users will be able run and control



Number of Replications: 1

Initialize Between Replications: ☑ Statistics ☑ System

Start Date and Time: ☐ 24 April 2008 12:07:01 PM

Warm-up Period: 0.0 Time Units: Hours

Replication Length: Infinite Time Units: Hours

Hours Per Day: 24 Base Time Units: Hours

Terminating Condition: CalDayOfWeek(TNOW)==4

Figure 5.3: TranSwarm - Run Control Dialog Box

the setup of ***TranSwarm*** and subsequently watch the real time graphical simulation as it is executed. Additionally users can traverse through each part of the graphical simulation model simply by clicking on the relative components, this will then navigate the user to the inner workings of that specific sub-model, showing it's graphical simulation.

Figure 5.3 depicts the parameter controls that a user may wish to set before the runtime occurs. This allows users to alter the amount of simulation replications that occur as well as many other additional features. Once the simulation model has run to completion a set of reports and graphs will be shown, see ***"Chapter 6"***.

5.2 Verification and Validation

One of the key steps in any simulation study and development is the verification and validation phase. These sections indicate whether the model is operating as intended (verification) and how it fairs in comparison with the real world system (validation).

5.2.1 Verification

This particular step poses two main questions, those being:

- has the model been built correctly
- does the model operate as intended

In terms of making sure the model has been built correctly, it is imperative that the model design has been accurately captured and that when implementing this design the right simulation techniques are used. This meant following a discrete event driven simulation approach so that different system components can represent their real world counterparts and perhaps even more beneficial is that debugging tasks are simplified. Potential errors and runtime inaccuracies were easily identified and linked to their specific system component, therefore eliminating these errors were easy.

The model is operating as intended, with a steady flow of information from harvest to mill and back again. The results are then displayed and captured for further user analysis.

5.2.2 Validation

The validation phase poses three main questions, those being:

- does the model adequately represent the real world model
- does the behaviorial data from both models correlate
- does the simulation model's ultimate user have confidence in the system

Does this logistics and transportation simulation model adequately represent the real world model, yes it does. In the real world model there is a natural flow to the transportation of sugarcane, that is, sugarcane is harvested (in small segments) and then slowly transported from farm to mill. During this time there are various logistical,

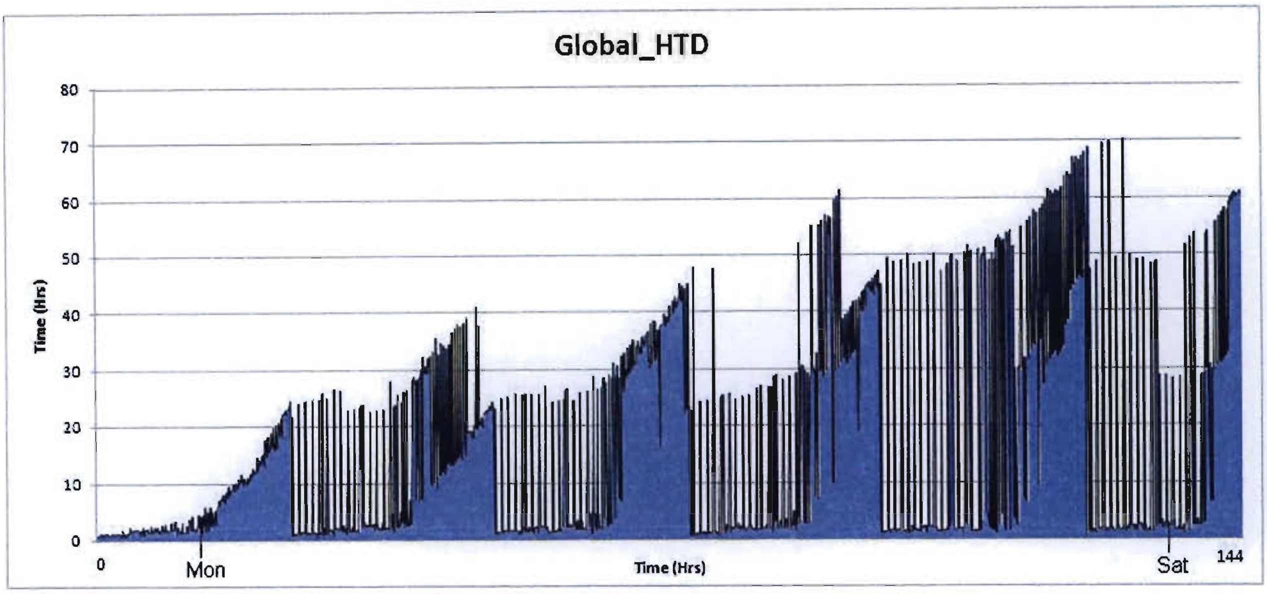


Figure 5.4: Global Harvest to Drop off (HTD)

transportation and management constraints that affect the movement of this sugarcane. These range from limited resources (number of vehicles, number of chopper harvesters) to routing and traffic problems (congestion, density, flow) and finally to mill-yard issues (queuing structure, number hysters). Now having reviewed how the basic real world system operates (logistics and transportation system), this *(TranSwarm)* is an accurate simulation model to represent it.

Next, does the behaviorial data from both systems correlate, yes there is a strong correlation between the two systems (Real World Vs. Logistics and Transportation Simulation System). Figure 5.4 represents a sample of the global harvest to drop off results captured from the simulation setup **configuration one**. The "global harvest to drop off" (HTD) graph shows the time it takes each farmer to move their sugarcane from harvest point to inside the mill-yard. This is an extremely important validation graph as there are numerous external and internal operations that affect this curve. In other words, in order for this value to be reasonably accurate, it would mean that all other system components must be operating within acceptable limits. Figure 5.4 shows along the *y axis* the HTD time (hrs) for each farmer and along the *x axis* the simulation runtime (run over six days, Monday to Saturday, measured in hours). The global (all farmers) average HTD time for this graph is *16.4 hrs* and the industry figure stands at about 16hrs. For a more detailed comparison and analysis of results from each simulation scenario/configuration, please refer to ***"Chapter 6: Results and Discussion"***.

Lastly does the ultimate end user have confidence in the system, yes there is a degree of confidence from the end user. After numerous visits to the Noodsberg area and consultations with a few specific farmers in the area, it was determined that the output of *TranSwarm* is in accordance with the current operations on the roads. Specific mention must be given to *SASRI* (South African Sugarcane Research Institute) expert Prof. Peter Lyne and Prof. Carel Bezuidenhout (School of Bioresources Engineering and Environmental Hydrology) for their efforts in making sure this application followed the current transportation practices used today.

Chapter 6

Results and Discussion

6.1 Results

For convenience the following results have been categorized according to the three main components that make up the system, those being the *farm area*, *road network* and *mill-yard*. In each area of investigation the results from both *configuration one (default scenario)* and *configuration two (additional features enabled - road traffic congestion, driver logistics and swarm manipulation)* are compared and contrasted. Along with this the results are also measured against the industry figures where known. Lastly it must be noted that these results are based on a case study of the Noodsberg region.

6.1.1 Farm Analysis

When measuring and monitoring the various farm areas, five specific performance measures were taken into account, these can be seen in table 6.1. The results produced from **Config 1** and **Config 2** are very similar indicating that the additional features from **Config 2** had little effect on improving the performance of the global

Variable	**Config 1**	**Config 2**	**Industry Value**
Avg Tons in Network	1109	**1179**	Unknown
Avg Vehicles in Network	46	**50**	Unknown
Avg Material Flow (Tons.hr^{-1}.veh^{-1})	9.76	**9.85**	≈7
Avg Tons.veh^{-1}	24.10	**23.58**	≈24
Avg HTD (hrs)	16.48	**16.10**	≈16

Table 6.1: Farm Analysis - Bolded values represent system improvement

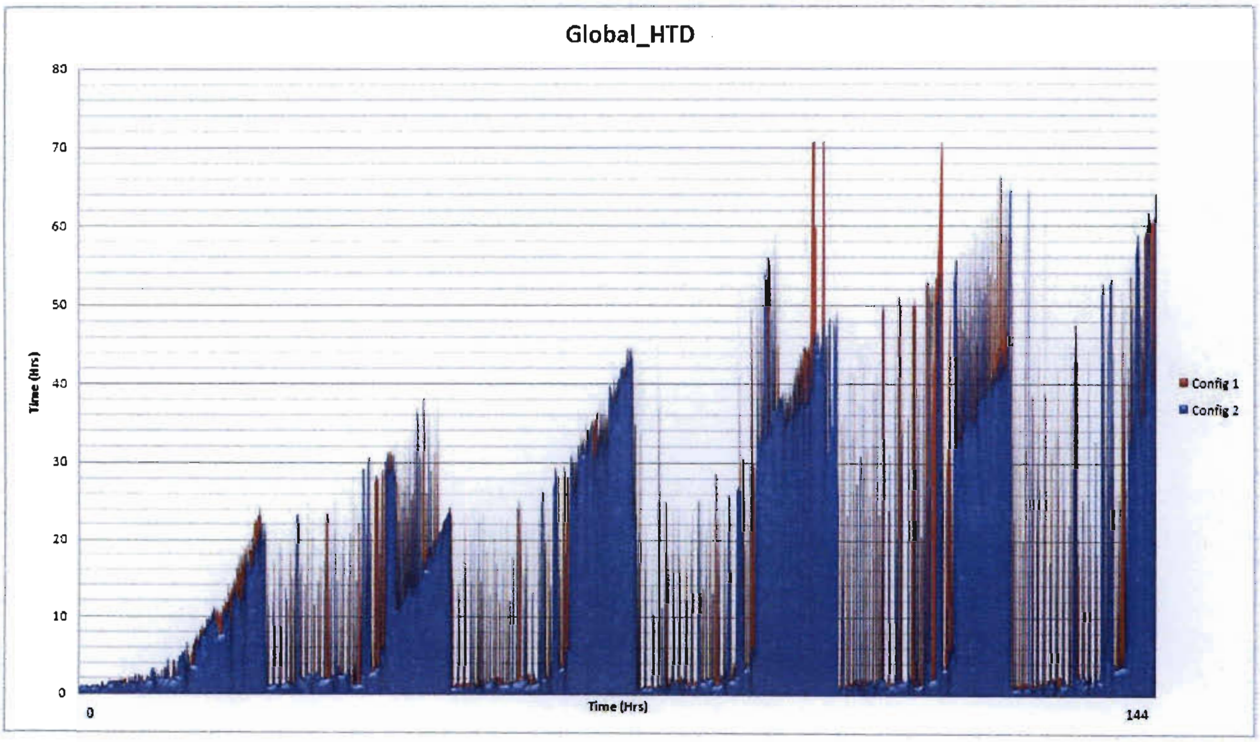


Figure 6.1: Global Harvest to Drop off (HTD) - Config 1 (Red) Vs. Config 2 (Blue)

farm area. In other words the addition of swarm intelligence (pushing and pulling the demand of sugarcane from the mill-yard) in **Config 2** did subtly improve the movement and output of sugarcane from the various farm areas however, this experimental technique's performance was further reduced by the additions of driver logistics and traffic congestion.

The two main global farm area performance measures are that of *material flow* and *HTD* (Harvest to Drop off). These measures performed extremely well, falling within acceptable limits of the industry known values. In fact the *average material flow* (average sugarcane flow per vehicle throughout the system) in both configurations was favorably higher than the industry value, indicating that the model may be slightly more efficient than it's real world counterpart. The *HTD* figures are perhaps the most important farm performance measures as they are influenced by most of the key system components. In table 6.1 **Config 2** has an *average HTD* of 16.10 (hrs) while **Config 1** is 16.48 (hrs), this improvement from **Config 2** must be attributed to the implementation of swarm intelligence as it is the only performance enhancing feature added.

The harvest to drop off graphs for each simulation configuration can be seen in figure 6.1. Here we can clearly see where **Config 2** performed better than **Config 1**. This graph has been mapped over a one week simulation run, Monday to Saturday.

Variable	Config 1	Config 2	Industry Value
Avg Traffic Density (Veh.km^{-1})	Disabled	**3.02**	Unknown
Avg Traffic Flow (Veh.hr^{-1})	Disabled	**109**	Unknown
Avg Congestion [Delay(secs).km^{-1}]	Disabled	**8.07**	Unknown
Avg Travel Rate Index ($\frac{PeakPeriod_{velocity}}{FreeFlow_{velocity}}$)	Disabled	**1.17**	Unknown

Table 6.2: Traffic Analysis - Bolded values represent system improvement

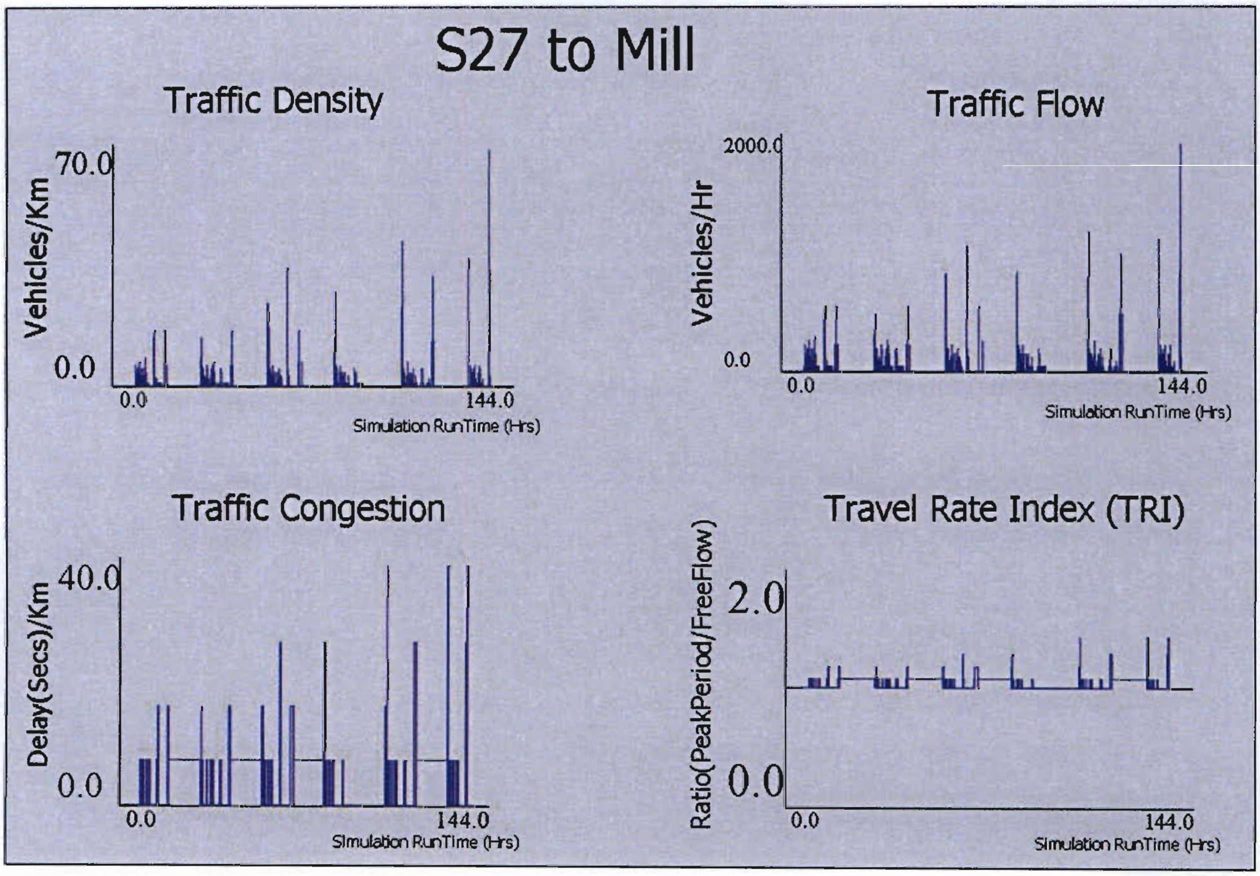


Figure 6.2: Road Network Statistics - Config 2

6.1.2 Road Network Analysis

Tracking and measuring the road network throughout our system was carried out on a few specific main routes. A summary of the results from one particular main route, that being station 27 to the mill (which is the stretch of road all vehicles must converge on before entering the mill-yard area and exit out on when leaving the mill-yard area - this includes vehicles currently waiting in the mill-yard queues), can be seen in table 6.2 and figure 6.2. One particular reason for choosing this specific route for analysis is that when the vehicles outside the mill-yard begin to queue, they will queue within a specific three queue structure on this route and thus will subsequently influence the traffic flow, density and congestion greatly. This route can be seen in - recall figure 4.10 from ***"Chapter 4: Section 4.2.4"***.

Four key traffic measurement variables were recorded and these figures seemed to fit the general traffic trends seen by industry. Firstly looking again at figure 6.2 we see how the general trend of traffic density, flow and congestion rises steadily throughout the week. This occurrence is synonymous with the delivery pattern of farmers as they try to deliver and complete their weekly sugarcane allocations with the mill (farmers will start off slowly at the beginning of the week and steadily increase sugarcane supply as the week ends). In table 6.2 we see the average recorded values for each of those traffic measures however, along with these we must point out that traffic density (min and max omitted) rose to a peak of 44 veh.km^{-1} (compared to the average of 3.02 veh.km^{-1}) and that traffic congestion rose to a peak of 38.57 (secs) delay.km^{-1} (compared to the average of 8.01 (secs) delay.km^{-1}). This shows that although the ***average*** traffic trends were not too bad along that route, there were

Variable	Config 1	Config 2	Industry Value
Avg Tons.hr^{-1}	265.74	**273.25**	≈280
Avg Mill-yard Arrival Times (24:00 hrs)	10:36	**10:57**	Unknown
Avg Mill-yard Turnaround Times (mins)	**168.63**	180.12	≈120
Avg Vehicle Time in Mill-yard (mins)	**40.15**	41.75	≈36
Avg Mill-yard Capacity (%)	46.23	**52.77**	Unknown

Table 6.3: Mill-yard Analysis - Bolded values represent system improvement

points throughout the week when that route became extremely congested and the mill-yard queues over populated. Now bearing in mind that this simulation system does not stochastically simulate mill break downs (out of this projects scope), if a break down or system delay had to occur at the mill end, then this global system would suffer greatly.

It must be noted that in **Config 1** no additional features were enabled therefore, various traffic statistics were not required for documentation. Another important point is that there were no recorded traffic statistics provided from industry either. Although there were not any benchmark figures to compare against, at least we have now provided some insight into the influences of traffic on the current road network.

6.1.3 Mill-yard Analysis

The mill-yard is the central hub of the system, being the demand point it will pull and push away vehicles as it tries to create a uniform operation and delivery pattern. Once again the results from both configuration scenarios can be seen in table 6.3 along with the industry known values. Five performance measures have been taken into account and in this case **Config 2** does not always out perform **Config 1**. In fact these differences can be directly attributed, once again, to the implementation

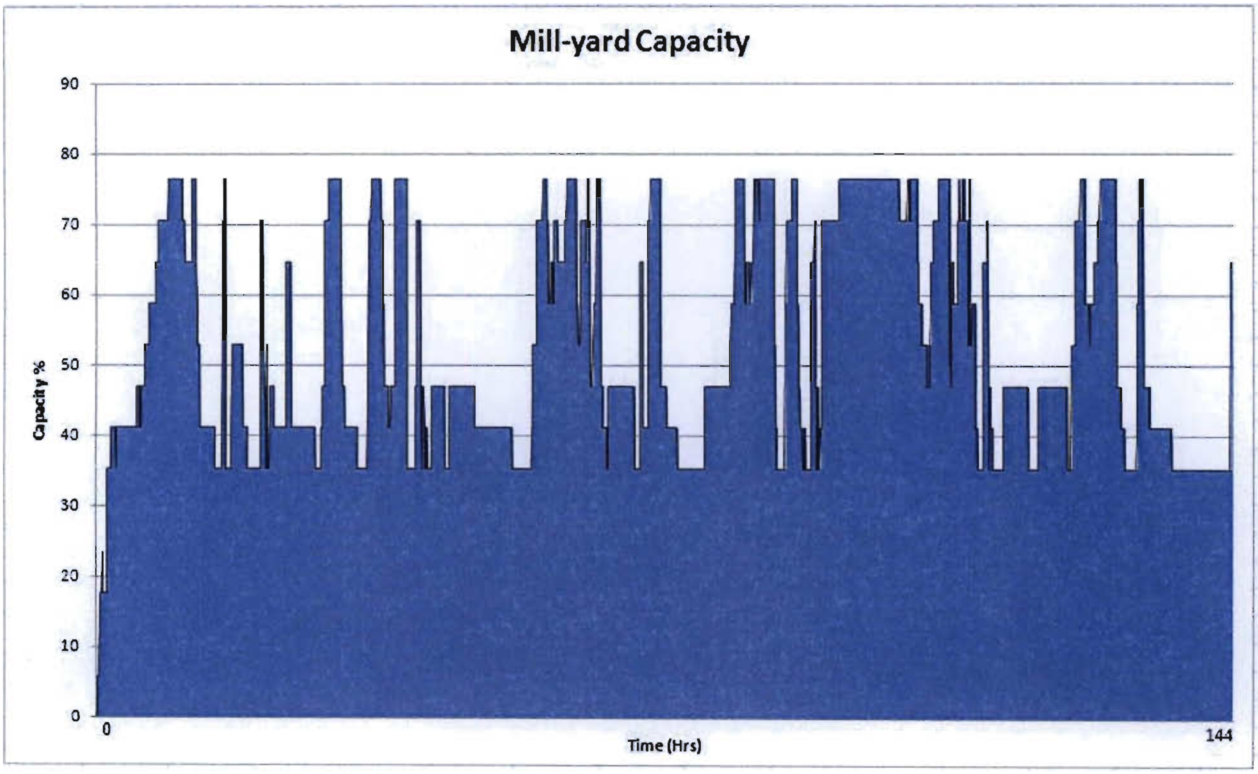


Figure 6.3: Mill-yard Capacity - Config 2

Figure 6.4: Vehicle Time in Mill-yard - Config 1 (Red) Vs. Config 2 (Blue)

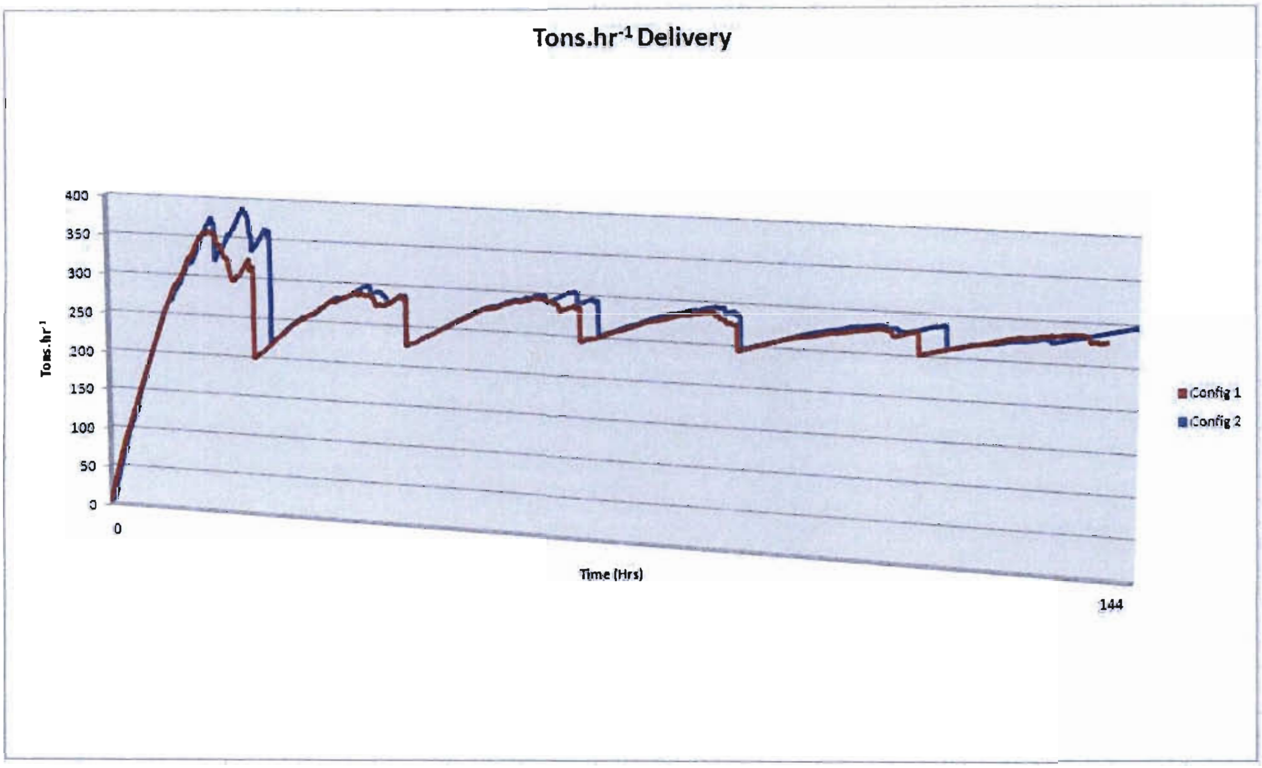


Figure 6.5: Mill-yard Delivery amounts - Config 1 (Red) Vs. Config 2 (Blue)

of swarm intelligence. Firstly the *average* $tons.hr^{-1}$ delivery of sugarcane at the mill-yard and the *average mill-yard capacity (%)* in **Config 2** are higher than **Config 1**. This is because with swarm intelligence enabled, change in mill-yard capacity triggers the cohesive functions of swarm intelligence, either pushing vehicles away or pulling them towards the mill-yard. This average increase in mill-yard capacity has however, actually worsened the mill-yard turnaround times and time vehicles spend in the mill-yard, this is because with swarm intelligence activated the mill-yard wants to continually keep it's capacity at a uniformly high percentage. Thus the default **Config 1** performs better in those areas.

The comparison of the simulation results and those of the industry, seen in table 6.3 need further explanation. There were some cases where industry was unable to supply a required parameter and parameters that were available were difficult to confirm in the literature. Therefore the approximate industry values shown are those provided verbally by industry experts and must be considered with reasonable (larger) limits in mind.

Of the five main mill-yard performance measures, three have been graphically depicted contrasting **Config 1** and **Config 2** results. These can been seen in figures 6.3, 6.4 and 6.5. Figure 6.3 was taken from **Config 2** results, showing the impact of swarm intelligence and the other additional features. One can see how the graph distributes itself uniformly.

Figure 6.4 shows how **Config 1** was subtly better than **Config 2** for vehicle times spent in mill-yard, performing better without the impact of the additional features. While figure 6.5 shows how **Config 2** performed better than **Config 1** because the swarm rules and additional features promoted a better push-pull system between the mill-yard (demand) and farms (supply).

6.2 Achievements

In this work we have accomplished the following:

- The successful development and implementation of an agent-based simulation tool for analysis of sugarcane transport logistics systems
- A holistic encapsulation of the entire sugarcane transport system within one complete simulation model
- Accurate measurement and monitoring of key system components
- Successful implementation of additional features - Swarm Intelligence, Traffic Congestion and Subtle Driver Logistics
- Confidence by industry in the system (verified and validated)
- Successful and meaningful case study of the Noodsberg Region
- Published work

6.3 Difficulties and Limitations

Some of the difficulties experienced during this project were:

- Arena's time slice denominations and event generator caused some events to be missed or duplicated
- Arena lacked some functionality in performing simpler tasks
- Arena imposed some design constraints due to the nature of its implementation
- Industry data and information was often badly or not documented at all
- Due to the system size and requirements, performance may vary from computer to computer

6.4 Extension

The current simulation system provides road network statistics for only certain stretches of road (main routes), therefore future work must be done to capture all route statistics within the network. Various mill-yard and farm components have also been simplified, leaving room for future improvement. The current system scope is from harvest to mill-yard, possible work could be done to extend this scope to include planting activities and mill crush activities.

Chapter 7

Conclusion and Recommendations

7.1 Recommendations

The importance of this simulation tool for industry has been to assess and identify the performance of certain key variable measures. This system has provided the platform from which various sugarcane transport components can easily be analyzed. The results previously shown can and have already highlighted the values of these key performance measures and it is now up to industry to take action where necessary on variables/components that are under performing. Along with this the experimental techniques of swarm intelligence has proven to be advantageous in certain areas and although it may seem impracticable (purely academic), if all vehicles could communicate with one another and have the mill-yard as the central dispatcher, we could see the benefits of subtle swarm intelligence coming through. Further, with communication techniques such as MANETS the industry could soon realize the benefits of swarm intelligence.

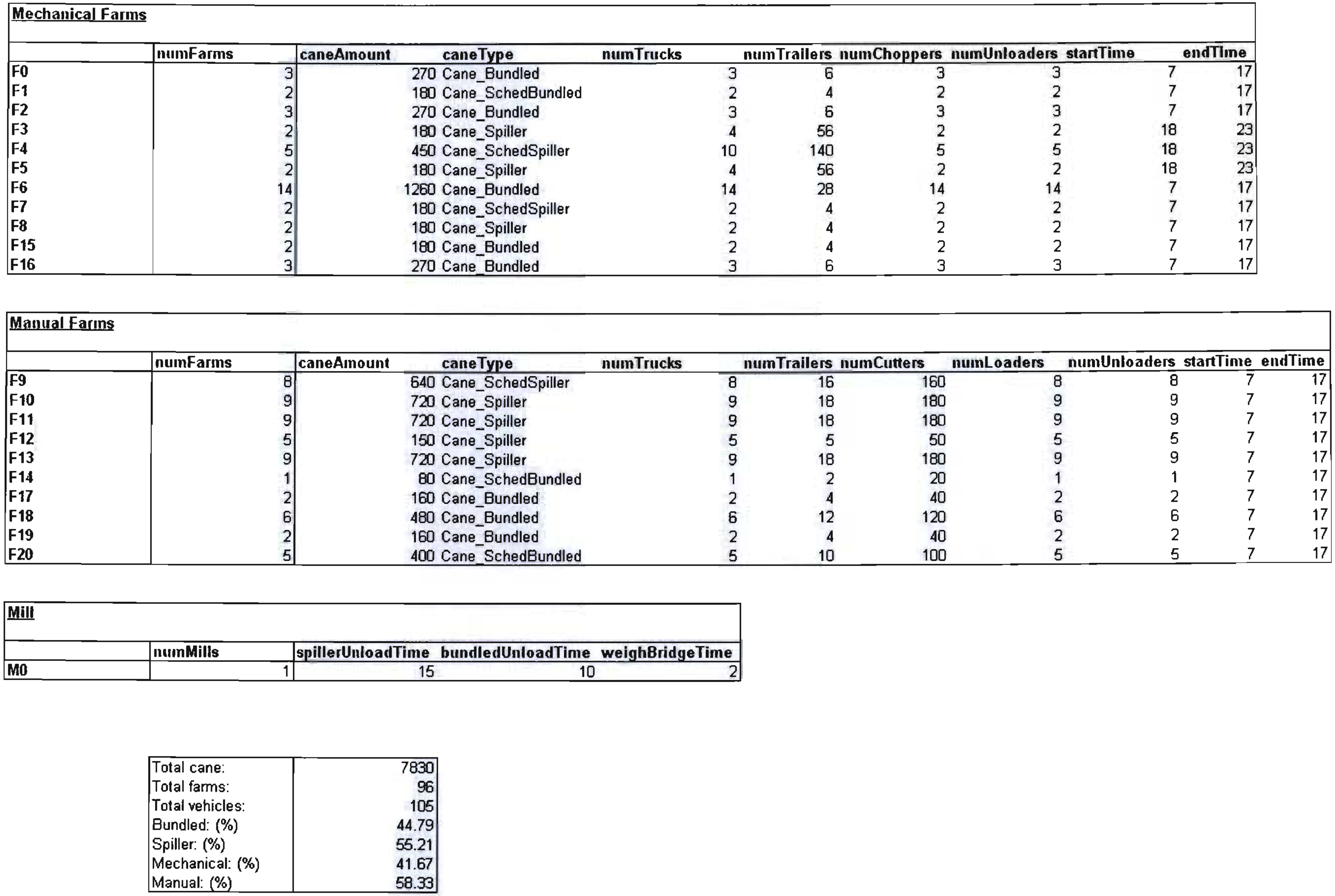
7.2 Conclusion

This transport system simulation model, has been verified and validated against the industry standards. It has also achieved it's primary aim of being an agent-based simulation tool for analysis of sugarcane transport logistics systems. It is ultimately a simulation model where transportation rules can be quantified and assessed. The hardest obstacle experienced throughout this model development was the ability to gain the trust of the community that it represents. As more members of this transport system buy into the usefulness of this evaluation tool, so the model will refine itself further by establishing additional measurement variables and key indicators. This will ultimately produce a truly dynamic and reliable system.

Appendix A

Simulation Input Charts

A.1 Sample Input Spreadsheet



Mechanical Farms

	numFarms	caneAmount	caneType	numTrucks	numTrailers	numChoppers	numUnloaders	startTime	endTime
F0	3	270	Cane_Bundled	3	6	3	3	7	17
F1	2	180	Cane_SchedBundled	2	4	2	2	7	17
F2	3	270	Cane_Bundled	3	6	3	3	7	17
F3	2	180	Cane_Spiller	4	56	2	2	18	23
F4	5	450	Cane_SchedSpiller	10	140	5	5	18	23
F5	2	180	Cane_Spiller	4	56	2	2	18	23
F6	14	1260	Cane_Bundled	14	28	14	14	7	17
F7	2	180	Cane_SchedSpiller	2	4	2	2	7	17
F8	2	180	Cane_Spiller	2	4	2	2	7	17
F15	2	180	Cane_Bundled	2	4	2	2	7	17
F16	3	270	Cane_Bundled	3	6	3	3	7	17

Manual Farms

	numFarms	caneAmount	caneType	numTrucks	numTrailers	numCutters	numLoaders	numUnloaders	startTime	endTime
F9	8	640	Cane_SchedSpiller	8	16	160	8	8	7	17
F10	9	720	Cane_Spiller	9	18	180	9	9	7	17
F11	9	720	Cane_Spiller	9	18	180	9	9	7	17
F12	5	150	Cane_Spiller	5	5	50	5	5	7	17
F13	9	720	Cane_Spiller	9	18	180	9	9	7	17
F14	1	80	Cane_SchedBundled	1	2	20	1	1	7	17
F17	2	160	Cane_Bundled	2	4	40	2	2	7	17
F18	6	480	Cane_Bundled	6	12	120	6	6	7	17
F19	2	160	Cane_Bundled	2	4	40	2	2	7	17
F20	5	400	Cane_SchedBundled	5	10	100	5	5	7	17

Mill

	numMills	spillerUnloadTime	bundledUnloadTime	weighBridgeTime
M0	1	15	10	2

Total cane:	7830
Total farms:	96
Total vehicles:	105
Bundled: (%)	44.79
Spiller: (%)	55.21
Mechanical: (%)	41.67
Manual: (%)	58.33

Figure A.1: Sample Input Spreadsheet

Appendix B

Case Study: Noodsberg Region

B.1 Sample Images

Figure B.1: Noodsberg Farms

Figure B.2: Noodsberg Mechanical Harvesting

Figure B.3: Noodsberg Infield Loading

Figure B.4: Noodsberg Transportation

Figure B.5: Noodsberg Unloading

Figure B.6: Noodsberg Mill

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