1 INTRODUCTION

Supply planning and traffic flow planning are major activities in the automotive manufacturing environment worldwide. Supply planning directly influences the traffic within a manufacturing plant. The impact of supply planning strategies like JIT, JIS and DS on plant traffic is rarely considered, as supply and traffic flow planning are traditionally seen as separate activities.

BMW is one of the leading international automotive manufacturers. BMW Plant 9.2 in Rosslyn, South Africa, are planning to switch production from the E46 (current 3-series) model to the E90 (new 3-series) model in 2005. Major changes influencing logistic planning will include:

- Increased electronic complexity
- Changes to imported and local content
- Vehicle is 14% bigger
- Production volume will be 200 to 250 units per day
- A new Preparation Plant will be required
- New part families will be introduced
- Increased returnable packaging
- A new comfort track will be required
- A new body shop will be required
- 3 new JIS modules will be introduced

Logistic supply planning for the new E90 model was recently started and is still at a stage where it is relatively open and flexible to justifiable suggested changes.

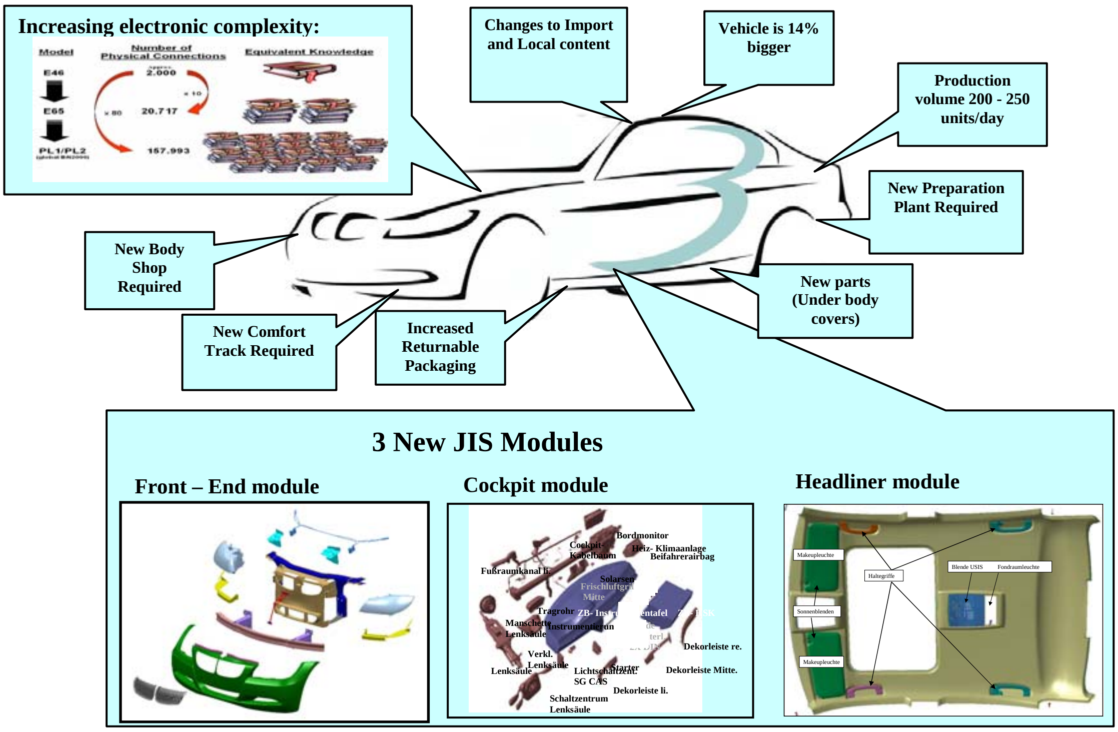


Figure 1: Major E90 changes influencing logistics

2 PROBLEM STATEMENT

BMW SA and other automotive manufacturers are facing various specific problems relating to supply and traffic flow planning. One of these problems is in selecting the best supplier transportation medium among various alternatives for the supply of each part family, taking into account the effects on plant traffic. Several variables have to be considered during this decision making process and no concrete decision support tool exists at present.

Another specific problem faced by automotive manufacturers today lies in accessing the impact of physical relocation decisions on plant traffic. Several proposed plant layout changes and changes to the location of supplier delivery points exist for BMW Plant 9. These proposed changes will imply large relocation expenses and will inevitably have a major impact on the traffic flow within the plant. The respective impact of these proposed layout changes have to be investigated, analysed and compared.

BMW Plant 9 is already running at a 100% traffic capacity with the current E46 model. They are anticipating a 20-30% increase in traffic within the plant with the introduction of the E90 model. The traffic situation in Plant 9 will have to be investigated and analysed further. New solutions will have to be found in order to handle the anticipated increase in traffic. Figure 2 shows snapshots of the current traffic flow situation.

Figure 2: Current traffic flow situation at BMW Rosslyn

3 RESEARCH PROJECT APPROACH

3.1 Scope of the research project

The research has been done in the field of supply and traffic flow planning in the automotive manufacturing environment. The study only included automotive OEMs (e.g. Nissan, Ford, BMW) and their first tier suppliers, as indicated in the figure below.

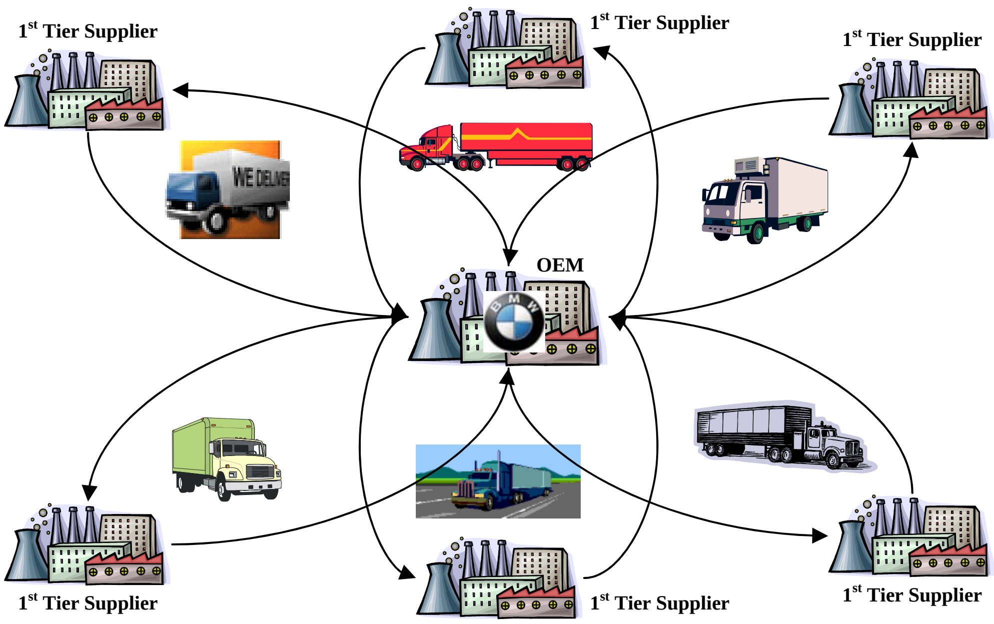


Figure 3: Environment of the research project

3.2 Project Deliverables

The first deliverable is a ***decision support tool*** that can assist automotive manufacturers in selecting the best supplier transportation medium among various alternatives for the supply of each part family.

The recommendations provided by this tool are, however, only based on deterministic calculations at this stage.

The second deliverable is a comprehensive ***traffic flow simulation*** model of BMW Plant 9. The model focuses on the traffic found within the plant boundaries, but outside plant buildings (thus, traffic flow in the streets within the plant). An overview of the traffic flow simulation concept is shown in Figure 4.

By using both of these deliverables together, it is possible to dynamically analyse and compare both the effect of selecting various combinations of supplier transportation vehicles on plant traffic and the respective impacts of proposed layout changes and changes to the location of supplier delivery points on plant traffic.

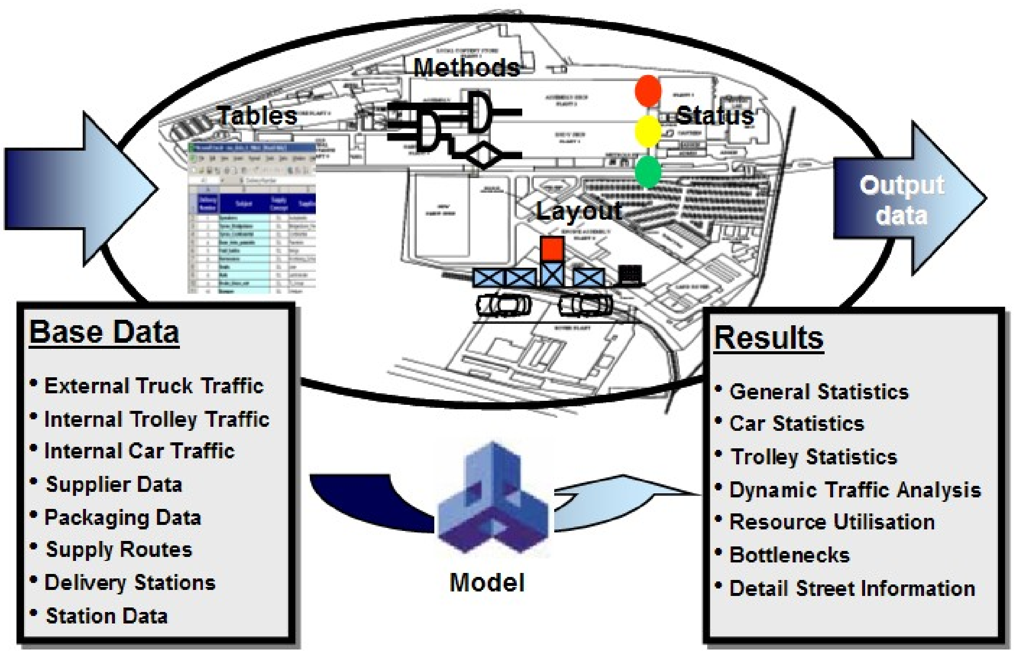


Figure 4: Traffic flow simulation concept

3.3 Project Execution

After the need for the *supply medium decision support tool* was established, the next steps were:

- To clearly define the user requirements for the tool
- To identify and investigate all the variables that need to be taken into account during the supply medium selection process
- Development of a decision support tool in MS-Excel that incorporates all variables in the supply medium selection process
- To make the implementation and use of this tool as fast, efficient and user friendly as possible
- To translate the tool calculation functions from MS-Excel into Visual Basic code in order for it to be easily integrated with existing software in use by automotive manufacturers
- To set up a sustainable user manual for the independent implementation and use of the tool
- To translate both the tool and user manual into German, as the tool will be distributed to and used by automotive manufacturers in South Africa and Germany

In terms of the *traffic flow simulation*, the steps taken were:

- To clearly define the customer requirements for the simulation
- To identify and acquire all the necessary information needed to construct the models. This information includes:
  - Plant layout and supplier delivery points for each part family
  - Supplier delivery- frequency and schedules

- Supplier delivery vehicle information (Type, geometry, average travelling speed within plant, unloading method, unloading time, loading capacity, etc.)
- Supplier delivery routes (entrance and exit possibilities from 5 different gates in plant to- / from the respective delivery points)
- Properties of all roads within the plant (lengths, width, one/two directional, speed restrictions etc.)

- To construct the models in eM-Plant 6.0, using the acquired information
- To verify and validate the models, in terms of the information input, model logic and –functionality, and simulation results
- To generate and present the simulation results in a graphical, easily interpretable format in order to be able to compare the different scenarios quickly and intuitively

3.4 Project Document Overview

Following is an overview of the respective chapters in this project document:

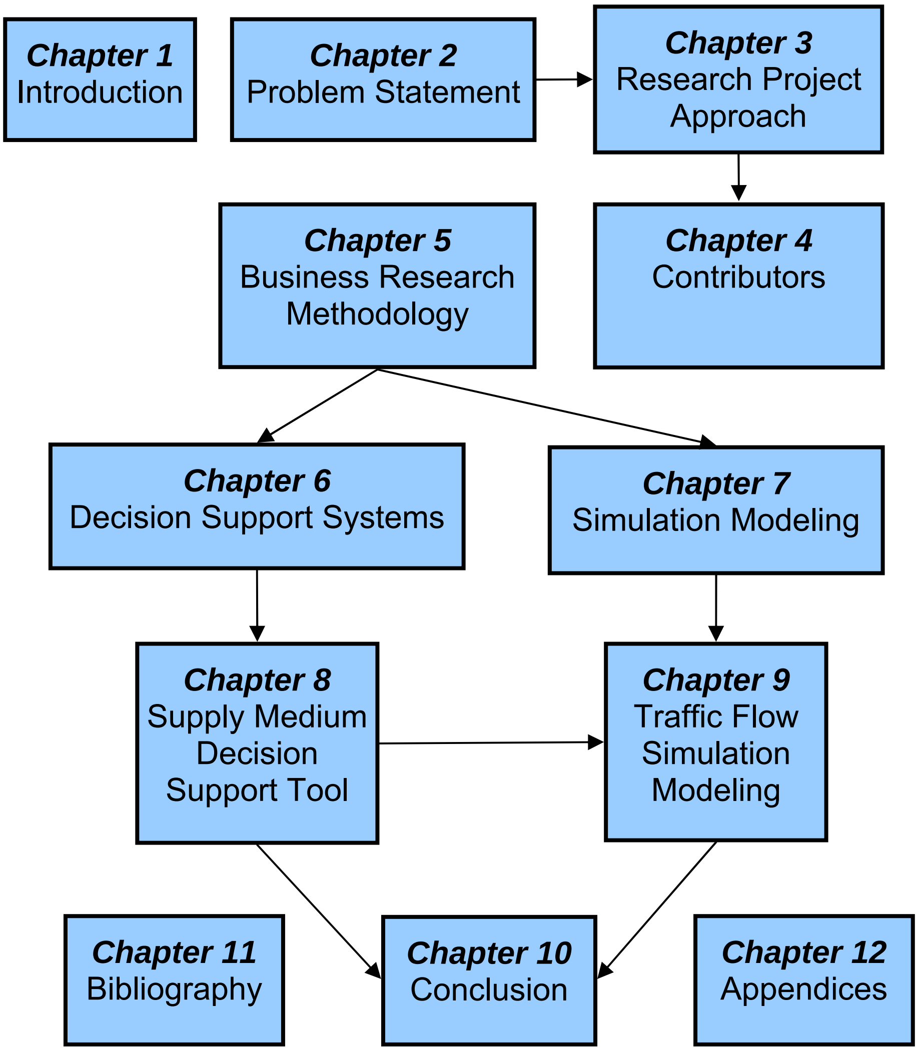


Figure 5: Project Document Overview

4 CONTRIBUTORS

AIDC, BMW SA (Pty) Ltd., Fraunhofer IPA and the Industrial Engineering Department of the University of Pretoria (UP) were all contributors to this research project (see Figure 6 and 7).

Fraunhofer IPA contributed their knowledge and experience in applied research, product development and simulation modeling
www.fraunhofer.de

AIDC contributed their knowledge and experience in the South African automotive industry
www.aidc.co.za

Plant Rosslyn

The developed systems have initially been implemented at BMW SA (Pty) Ltd Plant 9 in Rosslyn
www.bmw.co.za

The dissertation was conducted in the Industrial Engineering Department of the University of Pretoria
www.up.ac.za

Figure 6: Resource contributing groups

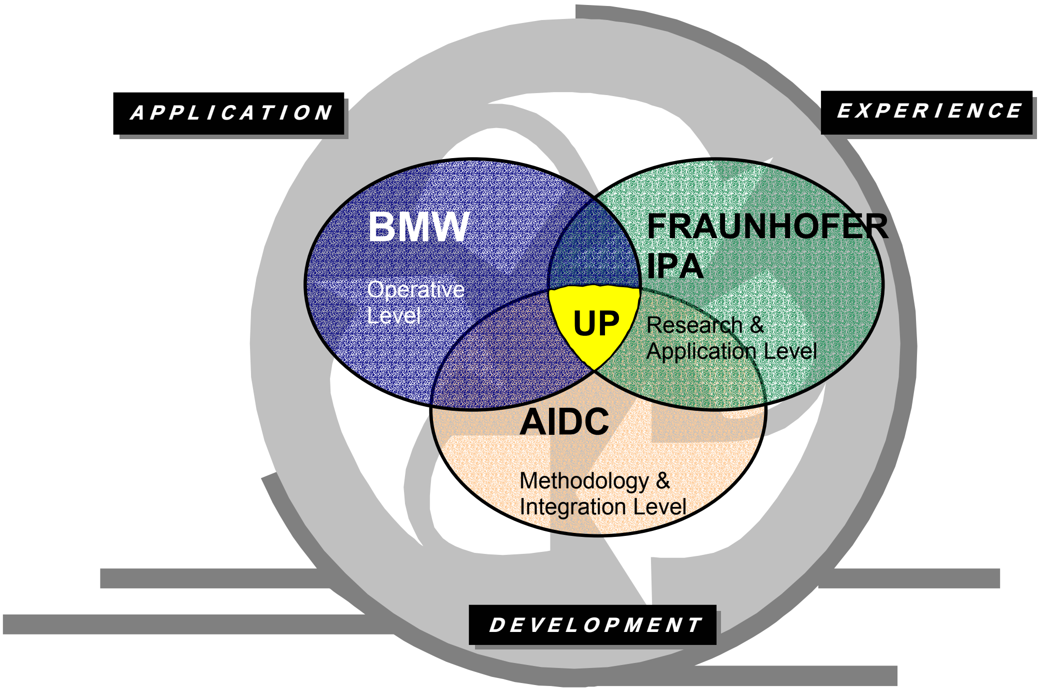


Figure 7: Resource contributing groups in context

The research project was conducted over a period of 13 months (February 2003 to March 2004)

5 BUSINESS RESEARCH METHODOLOGY

5.1 Introduction

Scientific research can be defined as "an endeavour to discover new or collate old facts etc. by the scientific study of a subject or by a course of critical investigation"[20], or as the "systematic, controlled, empirical, and critical investigation of hypothetical propositions about the presumed relations among phenomena".[14]

Business research is the systematic and objective process of gathering, recording, and analysing data for aid in making business decisions. It is a controlled, empirical and critical investigation of phenomena of interest to managerial decision making.[4] Most business research is applied research.

A distinction can be made between basic research and applied research.[28] **Basic research** (also referred to as pure research) attempts to expand the limits of knowledge. It does not directly involve the solution to a particular, pragmatic problem, and its findings can generally not be immediately implemented. Basic research is conducted to verify the acceptability of a given theory or to discover more about a certain concept. **Applied research** is conducted when a decision must be made about a specific real-life problem. Applied research encompasses those studies undertaken to answer questions about specific problems or to make decisions about a particular course of action or policy. For example, an organisation contemplating a paperless office and a networking system for the company's personal computers may conduct research to learn the amount of time its employees spend at personal computers in an average week.

Procedures and techniques utilised by basic and applied research do not, however, differ substantially. Both employ the **scientific method** in answering the questions at hand. Broadly characterised, the scientific method refers to techniques and procedures that help the researcher to know and understand real-world phenomena. The scientific method requires systematic analysis and logical interpretation of empirical evidence (facts from observation or experimentation) to confirm or disprove prior conceptions.

5.2 Types of Research

Research can be classified by means of various criteria, like the method of the research, the goal of the research or distinguishing between basic research and applied research. Common classes of research methods are:[18]

Descriptive research

Descriptive or "case study" research is research in which a specific situation is studied either to see if it gives rise to any general theories or to see if existing general theories are borne out of the specific situation. An example of this is Mead's anthropological studies of isolated cultures to see whether pervasive social organisations are essential features of humankind.[16]

Ex post facto research

In experimental research similar groups are exposed to different treatments to observe the effect of the treatments (moving from cause to effect). In ex post facto research, on the other hand, one looks back at the effect and try from there to deduce the cause. For ex post facto research to be valid, one must eliminate all other possible causes. Ex post facto means "from after the fact", and typically occurs when data is available which could not be generated by experimental research. The relationship between road development in an area and its current population would be an example. Even though this could be experimentally tested, few researchers have the funds to build road systems or the time to see the effect of this over 20 years.

Experimental research

In experimental research one is primarily concerned with cause and effect. Researchers identify the variables of interest and seek to determine if changes in one variable (called the independent variable, or cause) result in changes in another (called the dependent variable, or effect).

Creative research

Creative research involves the development of new theories, procedures and inventions. It is much less structured than experimental research and can not always be pre-planned.

Creative research includes both practical and theoretical research. Practical creative research involves the design of physical things (artefacts) or the development of real-world processes. Theoretical creative research involves the discovery or creation of new models, theorems, algorithms, etc.

Action research

According to Kurt Lewis, "There's nothing as practical as a good theory".[3] This idea formed the basis of his research approach which has become known as "action research". As an example, if a company has a problem then the steps in action research would be:

1. The expert gathers data from both the specific problem (from the company) and the general topic (from a literature study).
2. The expert recommends changes and these are implemented by the company.
3. After a suitable time period, research is conducted to determine the effectiveness of the changes.

This can be an extremely useful form of applied research if all the steps are followed objectively and scientifically.

Historical research

Studies of the past to find cause-effect patterns are known as historical research. Such research commonly use past events to examine current situations and to predict future situations, like for example in stock-market forecasting.

Expository research

Expository research is purely based on existing information and normally results in "review"-type reports. By reading widely on a field and then comparing, contrasting, analysing, and synthesising all points of views, the researcher can often make important new insights.

5.3 Stages in the research process

According to Zikmund[28], business research often follows a general pattern. The stages are:

1. Defining the problem
2. Planning the research design
3. Planning the sample
4. Collecting data
5. Processing and analysing the data
6. Formulating the conclusion and preparing the report

Defining the problem

"The formulation of a problem is often more essential than its solution."
– Albert Einstein

This research task may be to clarify a problem, to evaluate a program, or to define an opportunity. Often, the researcher may not have a clear-cut statement of the problem at the outset of the research process, and the initial stage is actually problem discovery, rather than problem definition. Thus, the problem statement is often made only in general terms, what is to be investigated is not yet specifically defined.

The adage "a problem well defined is a problem half solved" is worth remembering. This adage emphasises that an orderly definition of the research problem gives a sense of direction to the investigation. Careful attention to the problem definition allows a researcher to set proper research objectives, improving the chances of collecting the necessary and relevant information (and not collecting surplus information). The formal quantitative research process should not begin until the problem has been clearly defined.

Planning the research design

After the research problem has been formulated, the research design must be developed. A research design is a master plan specifying the methods and procedures for collecting and analysing the needed information. The sources of information, the research method or technique (survey, experiment, secondary data study, or observation), the sampling methodology, and the schedule and cost of the research must also be specified. The objectives of the research methods, the available data sources, the urgency of the decision, and the cost of obtaining the data will determine which method is chosen.

Planning the sample

Sampling involves any procedure that uses a small number of items or a portion of a population to make a conclusion regarding the whole population. If, for example, you take your first bite of a steak and conclude that it needs salt, you have just conducted a sample. Defining the population, determining the sample units within the population, determining the sample size, and deciding on how to sampling units are to be selected are tasks of the researcher during this stage.

Collecting data

Once the research design (including the sampling plan) has been formalised, the process of gathering information may begin. Often there are two phases to the process of data collection: pre-testing and the main study. A pre-testing phase, using a small sub-sample, may determine whether the data collection plan is an appropriate procedure for the main study.

Processing and analysing the data

Once the fieldwork has been completed, the data must be converted into a format that will answer the decision maker’s questions, and analysed. Analysis is the application of reasoning to understand and interpret the data that have been collected. The appropriate analytical tool technique for data analysis will be determined by management’s information requirements, the characteristics of the research design, and the nature of the data collected.

Formulating the conclusion and preparing the report

As mentioned before, most business research is applied research, with the purpose of providing information for making decisions. The final stage of the research process is to interpret the information and draw conclusions relevant to managerial decisions. Making recommendations is often a part of this process. This topic is discussed in the next section.

5.4 Research Reporting

The end product of the research process is the written research report. It is a formal statement of the background of the problem being investigated, the nature of the study itself, and the relevant findings and conclusions drawn from the research process. It is critically important to generate an effective report once the research is completed.

According to Davis[4], the following five guidelines are critical in the development of first class research reports:

Know your audience: A research report is a communication device. If you fail to consider the audience to whom you are writing, the information contained in the report will not be used to the best advantage. For example, highly statistical treatments of results simply confuse many managers. The report should be presented with the reader in mind.

Organise the report logically: A poorly organised report can render the information within it useless. A well-organised report helps the reader follow the logic of the investigation and the conclusions. The flow of the report should be logically outlined before the writing begins, to ensure that the information is presented in an easy-to-follow fashion. Different organisational styles are preferred by various research organisations. Make sure the one you choose to follow presents the results logically.

Watch your writing style: A research report that is written poorly and has gross grammatical errors, misspelled words, and typographical errors is a disgrace. It not only displays a lack of care on the side of the researcher, but it also makes the reader suspect the quality of the research results. Even though software writing aids can be of tremendous help in improving one's writing style, it is still, however, up to the writer to produce the best document possible. The researcher must make intelligent decisions about writing style that are consistent with the goals and purpose of the study.

Note the limitations of the study: A good research report notes the study's limitations. It just makes good sense for limitations to be expressly stated. It is good for the researchers because it protects against the improper use or application of the study's findings. It is also good for managers because it allows them to see the imperfections or inadequacies of the results. In essence, it serves to protect both parties in the use of research for decision-making purposes.

Be succinct and visual: A succinct report is always desirable over a long and wordy presentation. It is important to stress that presentations should be easy to understand and are accompanied by conclusions that make sense. Usually, managers are bombarded with all types of data. The shorter and more powerful the written presentation, the better. Similarly, the saying: "A picture is worth a thousand words" also holds true in formal research reports. Use visuals and graphics, if appropriate, to convey important information to the reader.

5.5 Ethical issues in research

Business research ethics is the proper conduct of the business research process.[4] Research carries with it responsibility. Just like there are ethical issues in all human interventions, there are ethical questions in business research. The two fundamental ethical questions in research are:[18]

- What are morally acceptable research topics?

- What are morally acceptable methods of researching a particular topic?

Both questions, as with most moral issues, have been and still are the subject of considerable debate. Law usually sets the background and limits in ethical conduct.

There are three concerned parties in business research situations: the researcher, the sponsoring client (user), and the respondent (subject).[28] Each party has certain rights and obligations. The respondent's rights include:

- the right to privacy
- the right to be informed about all aspects of the research

His or her main obligation is to give honest answers to research questions. The researcher is expected to:

- adhere to the purpose of the research
- maintain objectivity
- avoid misrepresenting research findings
- protect subjects' and clients' right to confidentiality
- avoid shading research conclusions

The client is obligated to:

- observe general business ethics when dealing with research suppliers
- avoid misusing the research findings to support its aims
- respect research respondents' privacy
- be open about the intentions to conduct research and about the business problem to be investigated

Ethics should always be considered before and during the research process, as it has a significant impact on public acceptance and participation in the research, as well as the quality of the data obtained from the research process.[4]

6 DECISION SUPPORT SYSTEMS

6.1 Introduction

Since developing a Decision Support System (DSS) is one of the primary objectives of this dissertation, it is appropriate to discuss various aspects of DSS here. Main points of discussion are decision making and management issues, followed by design and implementation considerations, and lastly benefits brought about by DSS.

6.1.1 Making decisions

Decision-making is a process of choosing among alternatives courses of action for the purpose of attaining a set of goals.

According to Simon[23], decision-making processes fall into a continuum that ranges from highly structured (sometimes referred to as programmed) to highly unstructured (non-programmed) decisions. **Structured** processes refer to routine and repetitive problems for which standard solutions exist. **Unstructured** processes are “fuzzy”, complex problems for which there are no cut-and-dried solutions. Simon describes the decision making process as a three-phase process:

- Intelligence: searching for conditions that call for decisions
- Design: inventing, developing and analysing possible courses of action

- Choice: selecting a course of action from those available

An unstructured problem is one in which none of the three phases are structured. Decisions where some, but not all, of the phases are structured are referred to as **semi-structured**.

6.1.2 Decision support systems

"Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer based support system for management decision makers who deal with semi-structured problems". [12]

Decision support systems (DSS) should not be confused with Management Information Systems (MIS), Management Support Systems (MSS), or Expert Systems, even though there are undoubtedly some similarities between them.

DSS are used for decisions in which there are sufficient structure for computer and analytical aid to be of value but where managers' judgements are essential. The aim is in creating a supportive tool for management, under their own control, that does not attempt to automate the decision process, predefine objectives, or impose solutions. It should serve as an extension of the user's problem solving capabilities.

6.2 Management support systems

6.2.1 Management defined

Management is a process by which certain goals are achieved through the use of resources (people, money, energy, materials, space, and time). These resources are the inputs to the process, and the attainment of the goals can be viewed as the output of the process (see Figure 8).

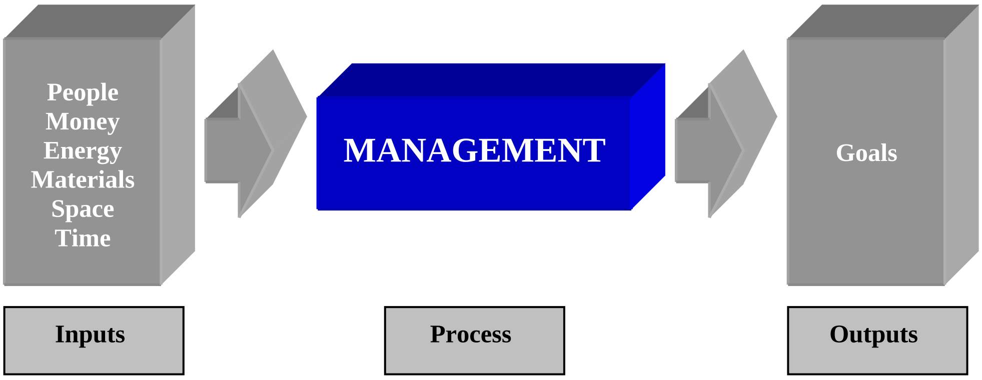


Figure 8: Management defined

The level of a manager's success is often measured in terms of productivity, which is the ratio between outputs (products, services) over inputs (resources). Managers are engaged in a continuous process of decision making to carry out critical functions like planning, organising, directing and controlling. All managerial activities revolve around decision-making.

6.2.2 The need for management support

In the past, managers have considered decision-making a pure art and talent acquired over time through experience. In actual business practise, the same type of managerial problem could be approached and successfully solved through different managerial styles. Mostly, these managerial styles were based on creativity, judgement, intuition and experience, rather than on systematic quantitative methods based on a scientific approach.

The environment in which managers must operate in is changing very rapidly, and the trend is towards increased complexity. Because of improved technology and communication systems, the number of alternatives to consider during decision-making is much higher. Also, the potential effect that decisions can have on an organisation is increasing.

Today, management is seen as a science. Traditional trial-and-error approaches to management are no longer sufficient. Systematic quantitative methods based on a scientific approach are necessary in order to accommodate the dynamic decisions that need to be taken. Managers must become more sophisticated and learn how to use new tools and techniques developed in their field.

6.3 Management science

According to Turban[26], the management science approach adopts the view that managers can follow a fairly systematic process for decision-making. Therefore, it is possible to use a scientific approach to managerial decision-making. This approach involves the following steps:

1. Defining the problem (a decision situation which may deal with some trouble or with an opportunity)
2. Classifying the problem into a standard category
3. Constructing a mathematical model that describes the real life problem
4. Finding potential solutions to the modelled problem and evaluating them
5. Choosing and recommending a solution to the problem. This process is centred around modeling

Modeling involves the transformation of the real-world problem into the prototype structure.

6.4 Data management

6.4.1 Data collection

In many cases, data has to be extracted from the various available sources to a specific database for use by the specific DSS application. Sometimes it is even necessary to collect raw data in the field, by methods like:

- Time studies (during observations)
- Surveys (using questionnaires)
- Observation (e.g. using video cameras)
- Soliciting information from experts (e.g. interviews)

Whatever the case may be, input data to the DSS always need to be validated on a continuous basis.

6.4.2 Data problems

The following table summarises the major data problems in DSS (source: Alter[1], p.30)

Table 1: Data problems

Problem	Typical Cause	Possible Solution
Data is not correct.	Raw data was entered inaccurately. Data derived by an individual was derived carelessly.	Develop a systematic way to ensure the accuracy of raw data. Whenever derived data is submitted, carefully monitor both the data values and the manner in which the data was generated.
Data is not timely.	The method for generating the data is not rapid enough to meet the need for the data.	Modify the system for generating the data.
Data is not measured or indexed properly.	Raw data is gathered according to a logic or periodicity that is not consistent with the purposes of the analysis.	Develop a system for rescaling or recombining the improperly indexed data.
Too much data is needed.	A great deal of raw data is needed to calculate the coefficients in a detailed model. A detailed model contains so many coefficients that it is difficult to develop and maintain.	Develop efficient ways of extracting and combining data from large-scale data processing systems. Develop simpler or more highly aggregated models.
Needed data simply does not exist.	No one ever stored data needed now. Required data never existed.	Whether or not it is useful now, store data for future use. (This may be impractical because of the cost of storing and maintaining data. Furthermore the data may not be found when needed). Make an effort to generate the data or to estimate it if it concerns the future.

6.5 User interface

6.5.1 Definition

The *user interface*, also referred to as the *dialog generation and management system (DGMS)* or *user interface management system (UIMS),* facilitates the link between the system user and the DSS. The primary purpose of the user interface is to enhance the ability of the system user to utilise and benefit from the DSS. One of the keys to the successful use of a DSS by decision makers is the user interface.

6.5.2 Objectives

Schneidman[22] has identified eight primary objectives (often called the "golden rules for dialog design") for user interface design:

- Strive for consistency of terminology, menus, prompts, commands and help screens
- Enable frequent user to user shortcuts that take advantage of their experiential familiarity with the computer system
- Offer informative feedback for every operator action that is proportional to the significance of the action
- Design dialogs to yield closure such that the system user is aware that specific actions have been concluded and that planning for the next set of activities may now take place
- Offer simple error handling so that, to the extent possible, the user is unable to make a mistake. Even when mistakes are made, the user should not have to, for example, retype an entire command entry line but, rather, just edit the incorrect portion

- Permit easy reversal of action so that the user is able to interrupt wrong commands rather than having to wait for them to be fully executed
- Support internal locus of control such that users are always the initiators of actions rather than the reactors to computer actions
- Reduce short-term memory load so that users are able to master the dialog activities that they perform

The quality of the interface, from the user's perspective, depends on what the user sees (or senses), the required user knowledge (what the user must know to understand what is sensed), and what action the user can (or must) take to obtain needed results.

6.5.3 Graphics

One of the most important factors influencing the decision-making capability of a manager is the way in which information is presented. By presenting information graphically in an easily interpretable format, its meaning can be better conveyed to managers, permitting them to "visualise" critical data and relationships.

6.6 Implementation

Implementation is an ongoing process of preparing an organisation for the new system and introducing the system in such a way as to help assure its success.

6.6.1 Integration

Integration of computer-based systems refers to the integration of the systems into a single facility rather than having separate hardware, software and communications components for each independent system. Various applications may even be linked, allowing them to communicate with- and interact with each other.

Even though the integration of a DSS with existing systems may have many benefits, such as increasing the quality and efficiency of the total system, it may not be desirable. A comprehensive feasibility study would be required in order to establish whether or not the derived benefits justify the cost and time implications of integration.

6.6.2 Resistance to change

Introducing new technologies or systems into an organisation will almost always result in some change. Introducing a new DSS could mean a change in the manner that decisions are made, communications are transmitted, control is exercised or power is distributed. Behavioural problems related to such changes will most probably develop, together with some kind of dysfunction.

It is common to encounter resistance to change within an organisation, mainly because of the *perceived* threats accompanying these changes. It is essential for the system introducer to address and eliminate these perceived threats (see Hultman[9] and Judson[11]).

Change management deals with resistance to change and its many dimensions. It is emerging as an important discipline, especially in technology-oriented organisations (see Anderson[2]).

6.6.3 User involvement

Participation in the system development process by users or representatives of the user groups is a crucial condition for successful development of a DSS. User involvement is advocated throughout the development process with a considerable amount of direct management participation.

It may be required to train users in using the DSS. This may be done through formal training courses, workshops, online training facilities or/and through the provision of a user manual, depending on the type, intensity, complexity and user knowledge requirements of the training needed.[21]

6.6.4 Management support

It has long been recognised that top management support is one of the most important ingredients necessary for the introduction of any organisational change. The chances of successful implementation are greatly enhanced by top management's commitment to advocating and devoting full attention and support to a system.[12]

6.7 Benefits

The major benefits brought about by a DSS are the:[26]

- Ability to support the solution of complex problems
- Fast response to unexpected situations that result in changed conditions. A DSS enables a thorough, quantitative analysis in a

very short time. Even frequent changes in a scenario can be evaluated objectively in a timely manner

- Ability to try several different strategies under different configurations, quickly and objectively
- New insights and learning. The user can be exposed to new insights through the composition of the model and an extensive sensitivity "what-if" analysis. The new insights can help in training experienced managers and other employees as well
- Facilitated communication. Data collection and model construction experimentation are being executed with active users' participation, thus greatly facilitating communication among managers. The decision process can make employees more supportive of organisational decisions. The "what-if" analysis can be used to satisfy sceptics, in turn improving teamwork
- Improved management control and performance. DSS can increase management control over expenditure and improve performance of the organisation
- Cost savings. Routine application of a DSS may result in considerable cost reduction, or in reducing (eliminating) the cost of wrong decisions
- Objective decisions. The decisions derived from a DSS are more consistent and objective than decisions made intuitively
- Improving managerial effectiveness, allowing managers to perform a task in less time and/or with less effort. The DSS provides managers with more "quality" time for analysis, planning and implementation

6.8 DSS Generators

A DSS generator is an integrated package of software that provides a set of capabilities to build a specific DSS quickly, inexpensively and easily. One of the most common generators is a spreadsheet.

Spreadsheets have become a powerful tool in modeling in recent years. Some of the reasons for its growing importance are:

- Data is often submitted to the modeller in a spreadsheet
- Data can easily be turned into information on the spreadsheet using formulas, embedded functions, and statistical or optimisation subroutines
- Data and information can easily be turned into informative visual displays using spreadsheet charting and graphing functions

Refer to Hesse[8] for in-depth information on spreadsheet modeling and analysis.

6.9 Selecting Appropriate Software

There are many spreadsheet packages commercially available, including:

- Quattro Pro
- Lotus 1-2-3
- Microsoft Works
- Microsoft Excel

Microsoft Excel will be used in the development of the supply medium decision support tool in this project because:

- It is by far the most generally accepted, -available and -used spreadsheet available on the market. Using this software will ensure the most efficient distribution, implementation and use of the developed DSS
- There are no additional purchasing- or installation costs associated with acquiring the software (the software has already been purchased and installed by all four of the resource contributing organisations as described in chapter 4)
- No training is required in the use the software (all relevant program developers and -users are proficient in the use of the software)

In cases where there are more than one candidate software package that can be used in a project, and it is uncertain which package will be most beneficial to the specific application, it is necessary to perform a structured evaluation of the alternatives. The weighted-score approach, as described in section 7.8, is an effective way to evaluate alternative software.

7 SIMULATION MODELING

7.1 Introduction

Simulation refers to a broad collection of methods and applications to mimic the behaviour of real systems, usually on a computer with appropriate software. According to McLeod[17], "Simulation is the use of a model (not necessarily a computer model) to conduct experiments which, by inference, convey an understanding of the behaviour of the system modelled."

Computer simulation refers to methods for studying a wide variety of models of real-world systems by numerical evaluation using software designed to imitate the system's operations or characteristics, often over time, for the purpose of gaining a better understanding of the behaviour of the system for a given set of conditions.[13] It utilises people, equipment, methods and material to evaluate alternative courses of action in terms of performance criteria. This is summarised in Figure 9.

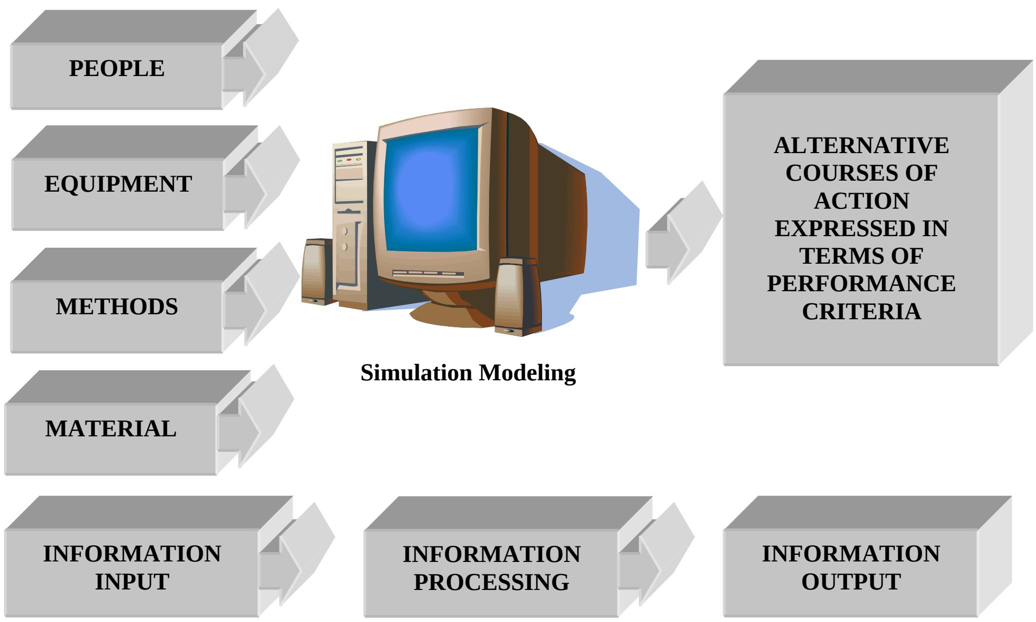


Figure 9: Overview of Computer Simulation[6]

7.2 History of Simulation

Computer simulation modeling came to age in the late 1950's, within the domain of operations research and management sciences. The simulation process was usually very time consuming and required large budgets for lengthy computer processing time, and was therefore only used as a last resort when a complex system could not be studied in any other manner. Output reports were often difficult to interpret and communicate. Simulation users required a strong computer programming background. As seen in the figure below, approximately 40% or more of the simulation effort was consumed by programming related tasks. Model verification and validation typically demanded exhausting hours interpreting endless pages of computer coding and output. The time spent experimenting with a model was normally limited due to the costs associated with making changes.

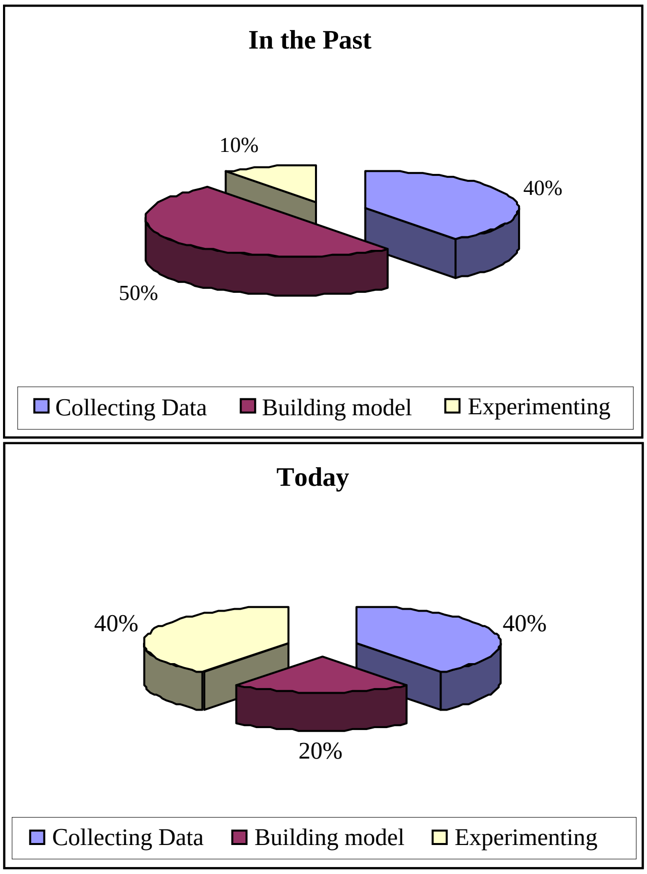


Figure 10: Simulation Modeling Time Allocation[6]

The programming effort required during the model building process has been significantly reduced in modern simulation tools. Computer programming skills, although beneficial, are no longer mandatory. Model verification has been made much simpler by graphical animation features. Changes can be incorporated in models relatively fast and easily. More time can be allocated to experimenting with “what-if” scenarios.

Simulation has become a critical part of solving both everyday and complex, dynamic problems in a large field of application areas which is continuing to expand.

7.3 Simulation Terminology

7.3.1 Static vs. Dynamic Models

A model that is not influenced by time is called a *static model*. Time does not play a natural role in the model, and there is no “simulation clock" involved. A classic example of a static simulation is the experiment described by George Louis Leclerc around 1733, known as the *Buffon Needle Problem*, to estimate the value of π. During this experiment, it was found that if a needle of length L is tossed onto a table painted with parallel lines spaced d apart ($d \geq L$), the needle will cross a line with probability $p = 2L/(\pi d)$. (See Kelton[13], p.10). A model that is influenced by time is called a *dynamic model*. The state of the model evolves over simulated time, which is tracked by a mathematical clock.
An example of a dynamic simulation is a model representing a production line with multiple workstations and parts moving between the workstations.

7.3.2 Deterministic vs. Stochastic Models

Any model that does not contain random variables as input is referred to as a *deterministic model*. Every specific set of input conditions for a deterministic model produces one, and only one, unambiguous set of results. Probability does not influence the results produced by such a model. A doctor's strict appointment-book operation with fixed service times would be an example. A model containing processes controlled by random variables as input is referred to as a *stochastic model*. These variables do not have a specific value, but rather a range of values which can change with no particular pattern, like a bank with randomly arriving customers requiring varying service times. It is possible to have both deterministic and stochastic inputs in different components of the same model.

7.3.3 Continuous vs. Discrete Event Models

In a *continuous model*, changes to the state of the system can occur continuously over time; an example would be the level in a reservoir as water flows in and is let out, and as precipitation and evaporation occur. In a *discrete model*, though, changes to the state of the system can only occur at discrete and usually separated points in time, such as a manufacturing system with parts arriving and leaving at specific times, machines going down and coming back up at specific times, and breaks for workers. *Mixed continuous-discrete models* have elements of both continuous and discrete change in the same model; an example might be a refinery with continuous changing pressure inside vessels and discretely occurring shutdowns.

7.3.4 Terminating vs. Steady-State Simulations

A *terminating simulation* is one in which the model dictates specific starting and stopping conditions as a natural reflection of how the target system actually operates. As the name suggests, the simulation will terminate according to some model-specified rule or condition. An example would be a store that opens at 8am with no customers present, closes its doors at 5pm, and continues operation until all customers (already inside and waiting for service) have been serviced. A *steady-state simulation*, on the other hand, is one in which the real-world system is simulated over a theoretically infinite time frame. For example, a paediatric emergency room operating 24 hours a day, 7 days a week, 365 days a year, can be represented by a steady-state simulation.[13]

7.3.5 Steady State

This state of a simulation model is achieved (usually after running the model for a sufficient time period) when successive model performance measurements are statistically indistinguishable over time (see figure 11).

7.3.6 Warm-Up Period

It is often the case that there exists a time period when initialising a model that is unrepresentative of steady state. This problem is overcome by letting the model “warm up” and run for a time period until steady state is achieved, before gathering statistics data used for analysis. This time period is known as the warm up period (see figure 11).

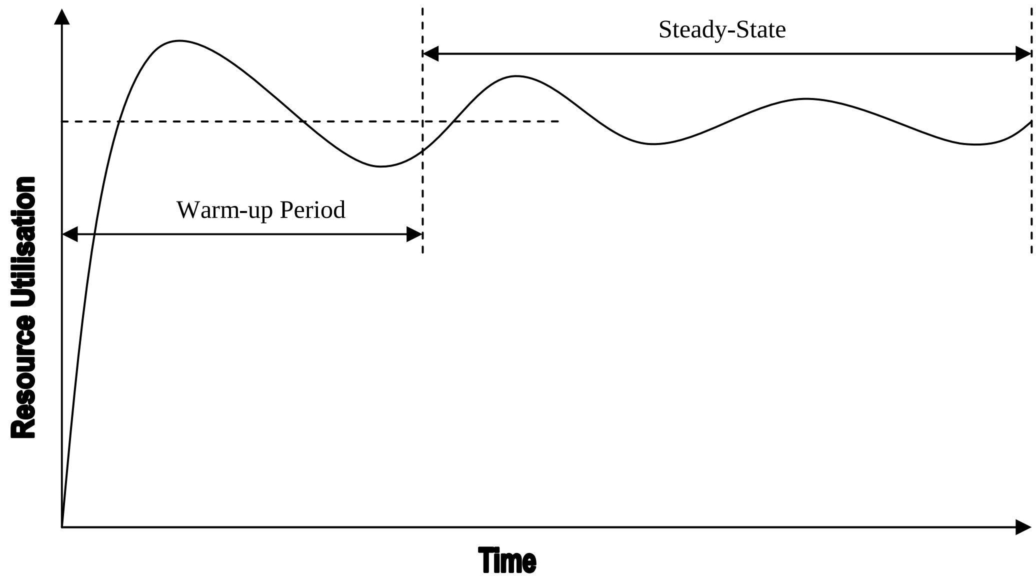


Figure 11: Illustration of warm-up period and steady state[7]

7.3.7 Verification and Validation

Verification is the process of investigating the model's functional and computational proficiencies, with the purpose of ensuring that the model is operating in the intended manner according to the modeling assumptions made, that is, as the user intended it to operate. This can be accomplished most effectively by doing a complete *walk-through* of the model, verifying that it works correctly. *Validation* is the process of ensuring that the model represents reality, that is, that the model behaves the same as the system being simulated. It is important that both the simulation model and the real-world system be measured and compared on the same criteria, in order to determine the degree to which they correspond. This can be achieved by examining and comparing the model structure (i.e., the algorithms and relationships) and output results and comparing them to reality. For models having complex logic, animation can be a useful validation tool.

7.4 Probability Distributions

A set of values or measurements which represent the relative frequency with which an event occurs or is likely to occur is called a *probability distribution*. In general, a probability distribution can be used to represent an event in a process that repetitively produces outcomes that vary per iteration.

7.4.1 Continuous and Discrete Probability Distributions

A distribution that describes an infinite number (uncountable) of possible outcomes of a phenomenon (say x) is called a *continuous distribution*. The lognormal distribution is an example of a continuous probability distribution (see Figure 12). A distribution that describes a finite number of possible outcomes of a phenomenon, on the other hand, is called a *discrete distribution*. The binomial distribution is an example of a discrete probability distribution. (see Figure 13).

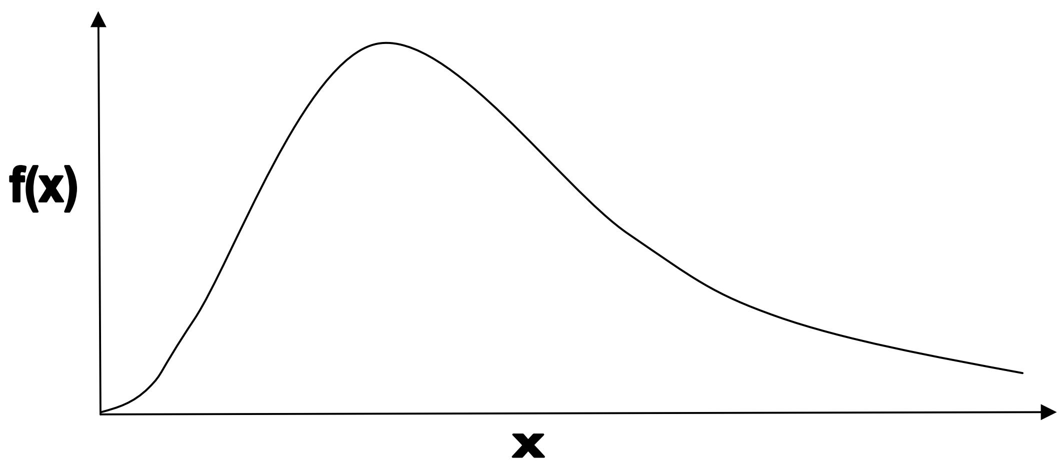


Figure 12: Continuous probability distribution: Lognormal

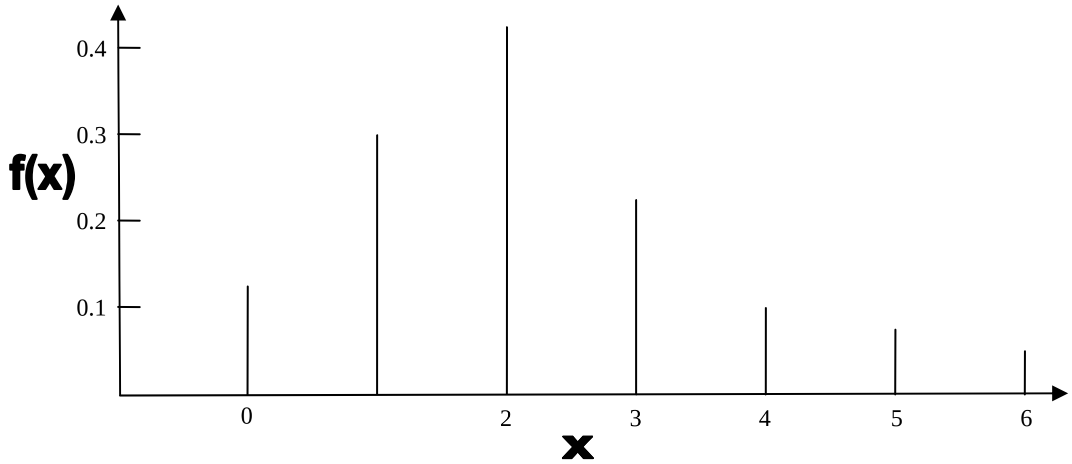


Figure 13: Discrete probability distribution: Binomial

7.4.2 Mean, Variance and Standard Deviation

The *mean* of a probability distribution measures its centre in the sense of an average, or better, in the sense of centre of gravity. It is the weighted average of all the possible values in the distribution's population. The degree of change between the random variable values and the mean of the probability distribution is called the *variance* of the distribution. The square root of the variances is called the *standard deviation*, and is a measure of the spread of the sample values around the mean value. (For more on this topic, refer to Harrington[7] p.180-186).

7.5 Common Probability Distributions

Theoretical probability distributions are used to represent empirical data, because they help to "level out" data irregularities. Empirical data is often collected over short time intervals, therefore extreme values (tail values in a distribution) may not be recorded in these intervals.

It is critical for model builders to understand the key characteristics and typical uses for standard probability distributions in order for them to find representative distributions for empirical data, and for processes for which no historical data exists.

7.5.1 Common Standard Continuous Probability Distributions

Some of the most common standard continuous probability distributions and their respective most common uses in simulations are:[6]

Exponential: Widespread use in queuing systems, utilised to generate random values for the time between arrivals of "customers" into a system. Other possible applications are the time to complete and the time until failure for electronic components.

Gamma: Can be used to represent the time needed to complete a task or group of tasks. Suppose that the time to complete a given task is represented by the exponential distribution, then the gamma distribution can be employed to generate values representing the total time required to complete *n* independent performances of that task.

Normal: Often utilised to represent process times for machines and in measuring various types of error.

Uniform: The Uniform distribution is a continuous distribution used to define values that are equally likely to fall anywhere within a specific range. Over the range of zero to one, it is used as the basis for generating values from the standard probability distributions. It can also be utilised to represent the time duration of a task if minimal information is known about the task, and the time to complete the task is believed to vary randomly and evenly between two values.

Weibull: Reliability issues are often represented with a Weibull distribution, for instance to generate values for the time to failure on a piece of equipment or the average life of an electronic component.

Triangular: Is particularly useful for situations where only three pieces of information are known about a task. Very often, when asking people the time for a specific task, they can only tell you that "most of the time it's "a", but it ranges between "b" and "c". These values can be used as the parameters of the triangular distribution.

Lognormal**:** Can be used to represent the time to perform certain tasks.

Erlang: Frequently used in queuing systems to represent service time distributions for various tasks.

Beta: Particularly useful in representing phenomena pertaining to proportions. The proportion of defective items found in a given lot size could be described by this distribution.

7.5.2 Common Standard Discrete Probability Distributions

Some of the most common standard discrete probability distributions and their respective most common uses in simulations are:[7]

Poisson: The Poisson distribution is usually associated with arrival rates. It reflects the probability associated with a finite number of successes (arrivals) occurring in a given arrival time interval or specified area. The arrival rate of customers into a system or the number of phone calls arriving at a switchboard each hour might be represented by this distribution.

Bernoulli: This distribution applies to situations where there are only two possible states, (e.g. success or failure). The output of a process that can only be *defective* or *non-defective* can be represented by this distribution.

Binomial: Expresses the number of outcomes in *N* trails. The number of defective items in a batch of size *N* is sometimes represented by this distribution.

7.6 Successful Modeling

7.6.1 Good Practices

According to Gogg and Mott[6], the first and utmost step in any problem-solving process is defining the problem. The ***problem statement*** should be clearly defined and known by all the members of the project team. If there are uncertainties to what exactly the problem is, it is very difficult to solve the problem. The following step is to determine exactly where you are and where you want to be.

Objectives are one of the primary design factors in a simulation model. It is something that one's efforts are intended to attain and accomplish. Management and all members of the project team should clearly understand the stated objectives before and during the simulation project.

It is important to note that, even though sometimes unavoidable, it is important not to divide the main problem into too many ***sub-problems*** to be solved separately, as this may likely result in ineffective total solutions.

Criteria also need to be established prior to building a simulation model. It is a standard of judgement, sometimes referred to as a performance index, telling you how an alternative's effectiveness will be evaluated. Equipment / labour utilisation, queuing times, WIP levels and throughput are often used as criteria, but the most universal criterion is probably money.

The necessity of making ***assumptions*** during the construction of a simulation model is almost inevitable. It can be defined as a judgement, estimate or opinion taken to be true without any proof. Like criteria, all assumptions must be documented and agreed upon at the start of the project. Even though assumptions can simplify the model building process, they can also influence the results produced by it. It is better to start with many assumptions and to reduce them at a later time when deemed necessary. An assumption holds good until it is established that it significantly influences the simulation results. It becomes obligatory to re-evaluate the assumption when this occurs.

Animation, graphical icons and background layouts can significantly enhance a model's ability to communicate. It is a vital element in every simulation analysis to communicate model logic and results. A model's credibility is influenced by its ability to express itself. On-screen animation can be a helpful means of identifying problem areas and highlight the effects of different alternatives. The data will, however, have to be analysed more thoroughly in order to understand the magnitude of these problem areas, and to make recommendations for improvements. In the absence of on-screen animation, the simulation user should rely primarily on charts, graphs and tables as communication media. It is important to note, though, that the purpose of animation is for communication, not for making conclusions. The information needed to analyse the magnitude of problem areas and their effects is contained in the statistical reports produced by the simulation. Conclusions based solely on animation can be misleading.

7.6.2 Replications

The ***results*** from a single replication of a stochastic simulation are themselves stochastic, and represent one possible outcome from an infinite number of possibilities. Therefore, it is important to note that in order to make valid conclusions, multiple and independent model runs and statistical analysis of the output generated by them are required with stochastic simulations.

Depending on the degree of precision required in the output, it might be desirable to determine a degree of confidence for the output, a range within which one can have a certain level of confidence that the true mean falls. For example, for a given confidence level or probability, say 0.90 or 90%, a confidence interval for the average throughput rate of a system might be determined to be between 45.5 and 50.8 units per hour. It can then be said that there is a 90% probability that the true mean throughput of the model (not of the actual process) lies between 45.5 and 50.8 units per hour.

The design of the simulation runs directly determines the reliability of the simulation results. Two important factors to consider is the *run length* (time measure of a single simulation run) and the *number of replications* (number of cycles through the simulation model during a simulation run).

For steady-state simulations (see *7.3.4 Terminating vs. Steady-State Simulations*), determining a sufficient run-length can be difficult. A good approach is to define a warm-up period (see *7.3.6 Warm-up period*) and then run the model long enough to gather sufficient statistical data after it has reached a steady-state (see *7.3.5 Steady-state*). With this approach, a single, relatively long simulation run will be sufficient.

For terminating simulations (see *7.3.4 Terminating vs. Steady-State Simulations*), however, deciding on the simulation run length is easy: it is the period during which you wish to analyse the process. As for the number of replications, the following formula works well for establishing a statistically valid number of replications[10 & 7].

$$n = (Z^2_{\alpha/2}.\sigma^2)/d^2$$

In this formula, *n* is the minimum number of desired replications, *d* is the accuracy expressed in the same unit as those of the performance measurement, *z* is the critical value from the standard normal table for a desired confidence level, 1*α*, and *σ* is the standard deviation of the parameter under study. To be able to use this formula, *α*, *d*, and *σ* must be known. For the latter, it is often necessary to substitute an estimate based on prior data of a similar kind (or, if necessary, a good guess).[10]

Using this formula and assuming a confidence level of 95%, standard deviation of 8 units per hour and accuracy of 5 units per hour, the minimum number of desired replications for the traffic-flow simulation model is calculated to be

$$n = (Z^2_{\alpha/2}.\sigma^2)/d^2$$
$$n = (Z^2_{0.05}.8^2)/5^2$$
$$n = 9.83$$

or 10 if rounded up to the nearest integer. Thus, by doing 10 replications we are able to construct a confidence interval that covers the true mean with probability of 95%

7.7 Benefits of Simulation

Simulation modeling is most useful in cases where alternative solutions become too complex (sometimes impossible) or costly. Harrington and Tumay[7] list the benefits brought about by simulation:

Simulation can assist in creative problem solving: Fear of failure prevents people from coming up with new ideas. Simulation allows creative experimentation and testing and then selling the idea to management, thus encouraging an optimistic "Let's try it" attitude. Thus simulation provides a means for creative problem solving.

Simulation can predict outcomes: Simulation educates people on how a system might respond to changes. For example, simulation could help in predicting response to market demands placed on a business system. This allows for analysing whether the existing infrastructure can handle a new demand placed on it. Simulation can thus help determine how resources may be effectively utilised. Simulation thus helps in predicting outcomes for various changes to system inputs.

Simulation can account for system variances: Conventional analytical methods, such as statistical mathematical models, do not effectively address variance as calculations are derived from constant values. Simulation takes variance in account, in a system incorporating interdependence, interaction among components, and time. This approach allows for examining variation in a broader perspective.

Simulation promotes total solutions: Simulation allows modeling entire systems, therefore promoting total solutions. Simulation models provide insights into the impact that process changes will have on input to and output from the system as well as system capabilities. Simulation models can be designed to provide an understanding of the system-wide impact of various process changes.

Simulation can be cost effective: As organisations try to respond quickly to changes in their markets, a validated simulation model can be an excellent tool for evaluating rapid responses. For example, a sudden change in market demand for a product can be modeled using a validated system model to determine whether the existing system can cater to this need. Additionally, simulation modeling provides for experimenting with system parameters without having to tamper with the real system. Simulation provides more alternatives, lowers the risk, increases the probability of success, and provides information for decision support without the cost of experimenting with the real system. Simulation thus provides a cost-effective way to rapidly test and evaluate various solutions to respond to market demands.

Simulation can help quantify performance metrics: Simulation can help quantify performance measures for a system. For example, the aim of the system may be to satisfy the customer. Using a simulation model, this requirement could be translated into time to respond to a customer's request, which can then be designated as the performance measure for customer satisfaction.

Simulation serves as a means of communication: A simulation model can be used to communicate the new or reengineered process in a dynamic and animated fashion. This provides a powerful means of communicating the function of various components to those who will use the new system, helping them understand how it works.

7.8 Selecting Simulation Software

Selecting the most appropriate software for a simulation project is critical to the success of the project. The weighted-score selection method will be used to evaluate the alternative products available. This approach provides an effective evaluation of alternative products by assigning weights to the evaluation criteria and comparing alternatives on the basis of their weighted scores. The steps involved in the procedure are essentially as follows:[7]

1. Identify and list the criteria to be used for making the product selection
2. Weight each criterion in terms of its relative importance (e.g., 1 = unimportant, 2 = nice to have, 3 = desired, 4 = needed, 5 = must have)
3. Define a scale for scoring each product against each criterion (1 = does not comply with requirements; 4 = complies fully with requirements)
4. Score the features of each candidate software package and supplier using the scale and weight factor
5. Conduct a sensitivity analysis on the results of the software evaluation
6. Select the software with the highest weighted score

7.8.1 Software Evaluation Criteria

The Software Engineering Institute (SEI)[29] and ISO 9000 provide excellent guidelines for software evaluation techniques and criteria. Simulation software can be evaluated on the following criteria:

Functionality: This can be evaluated in terms of five functions:

1. ***Process Mapping:*** The ability to create a model conveniently, easily and with logical hierarchy decomposition from predefined elements.
2. ***Modeling:*** A measure of the modeling functions and flexibility for representing various types of behaviours in a model, like scheduling entities or resources; to model activities such as branching, splitting, and joining; to assign resources to activities; and to model complex rules and routing.
3. ***Simulation and animation:*** A measure of the visual approach to defining a process, its workflow, and its resources, as well as dynamically updating animations and graphs.
4. ***Analysis:*** The ability to collect and analyse data for model input, as well as the ability to measure the performance of model output.
5. ***Input and output:*** The ability to interface with other software applications for input / output data exchange.

Usability: A measure of how easy it is to learn how to use-, and then to use the software. General specific features to look for that make simulation software easy to use include:

- Modeling constructs that are intuitive and descriptive
- Model-building procedure that is simple and straightforward
- Use of graphical input wherever possible

- Input prompts that are clear and easy to follow
- Context-sensitive help
- Simplified data entry and modification.
- Automatic gathering of key performance measures
- Debugging and trace features
- Output reports that are easy to read and understand

Reliability: Reliability of simulation software is perhaps the most difficult criterion to asses. In addition to normal software bugs that may be caused by a graphical user interface (GUI), operating system (OS) or device drivers, simulation tools may suffer from reliability problems that are unique to discrete-event simulation. Some of the questions to consider when evaluating reliability are:

- How robust is the underlying technology used in the simulation software?
- What is the process for fixing bugs? How is the fix provided to users?
- What testing procedures are in place to ensure that no new bugs are introduced in the fixing process?
- Is the vendor ISO 9000-certified?
- Are the bugs related to GUI, OS, device drivers, or animation? Or are the bugs in the simulation engine or reporting?

Maintainability: There are four aspects to consider when evaluating maintainability:

1. ***Security:*** Simulation vendors typically make use of two types of security modes in order to protect their software from illegal duplication and use: software keys and hardware keys (dongles). These keys enable the user to launch the software, and the software cannot be used without it. These security measures cause a certain inconvenience and annoyance, but are unavoidable.

2. ***Documentation:*** Both the on-line documentation and printed manuals should be carefully reviewed for each product. The care and interest put into the documentation is often a reflection of the vendor's interest in providing quality software and services.
3. ***Hardware and other software requirements:*** Basic questions affecting the hardware and other software configuration required include:
   - Does the software run under multiple operating systems?
   - Does the software require special graphics cards or drivers?
   - Can the software be used on a network?
   - Can the software print or plot model layouts, model data files, output statistics or graphs?
   - Does the software require special compilers?
   - How much memory (RAM) is needed to run the software?

4. ***Upgrades and enhancements:*** Software is one of the most rapidly changing commodities on the market today. If a simulation vendor doesn't have an aggressive R&D program, its products will quickly become outdated. Specific questions to ask are:
   - How often does the vendor provide new releases?
   - Is the software vendor up to date with the latest developments in software technology?
   - Is the vendor involved in industry standards committees?
   - Are the new releases compatible with the old ones?

Scalability: This is a measure of the ability of the simulation software to serve as a modeling tool at multiple levels of detail for various skill levels. Typically, simulation software allow for modeling on various levels of detail. On a high modeling level, predefined building blocks provide simplicity and reduced modeling time, while requiring a lower skill level. On a low modeling level, elements and programming language functions provide for detailed modeling and flexibility, while requiring a higher skill level.

Vendor quality: The quality and reputation of the software supplier should be measured. It is important to make sure that the tool is fully supported by the supplier. In selecting a supplier, it is worthwhile to ask the following questions:

- How long has the supplier been in business? What is the company's installed user base?
- What is the supplier's financial status?
- Who are the supplier's key reference accounts, and how long have they been customers?
- What is the business focus of the company? What percentage of its revenue comes from products?
- How many employees does the company have, and how does this number break down by R&D, Marketing / Sales, and Customer Service?

Vendor services: Customer service provided by the software suppliers can be evaluated in terms of:

1. ***Technical Support:*** Technical support may be required for problems as simple as software installations or as complex as a software crash during a simulation run. Questions that should be asked for assessing the level of technical support are:
   - How does the vendor provide technical support (e.g., phone, bulletin board, user groups)?

- What percentage of the total staff is dedicated to customer services?
- Are the developers of the product willing to talk to the end users?
- How responsive is the vendor to user deadlines?
- How close is the nearest authorised representative? How competent is the representative?

2. ***Training:*** Training on using the simulation software may vary from standard training programs / courses to customized on-site training. Users should verify that the appropriate levels of training required by them are available.
3. ***Modeling Services:*** A vendor may offer in-house modeling services of their customers. This differs from consulting services in the sense that they may be very competent to build a model based on a specification, but may not have the expertise to make system design decisions.
4. ***Other Services:*** Vendors may offer other services in addition to normal customer services that are expected, that may be beneficial to the user (e.g., Internet news groups where users can exchange ideas, newsletters, case studies and user group meetings).

Cost of ownership: When evaluating software products on their cost, the entire cost of doing simulation projects with the particular product must be considered. Cost factors like installation cost, cost of training, labour cost during projects, etc. should be included in the calculation.

7.8.2 Simulation Software Available

A vast number of simulation software packages are available on the market today. Following from the fifth biennial survey of simulation software for discrete event systems simulation and related products on forty seven leading products [Swain, 1999][25], four candidate products were identified for use in the traffic flow simulation:

Table 2: Candidate simulation software

Vendor	Product	Website
Rockwell Software	Arena	www.arenasimulation.com
Tecnomatix	eM-Plant	www.tecnomatix.com
Enterprise Dynamics	Enterprise Dynamics	www.enterprisedynamics.com
CACI Products Company	SimProcess	www.simprocess.com

7.8.3 Weighted-Score Selection Method Results

The weighted-score selection method was applied to evaluate the alternative products, as described earlier in this chapter. Fraunhofer IPA provided input to this exercise (see chapter *4 Contributors*). The results follow:

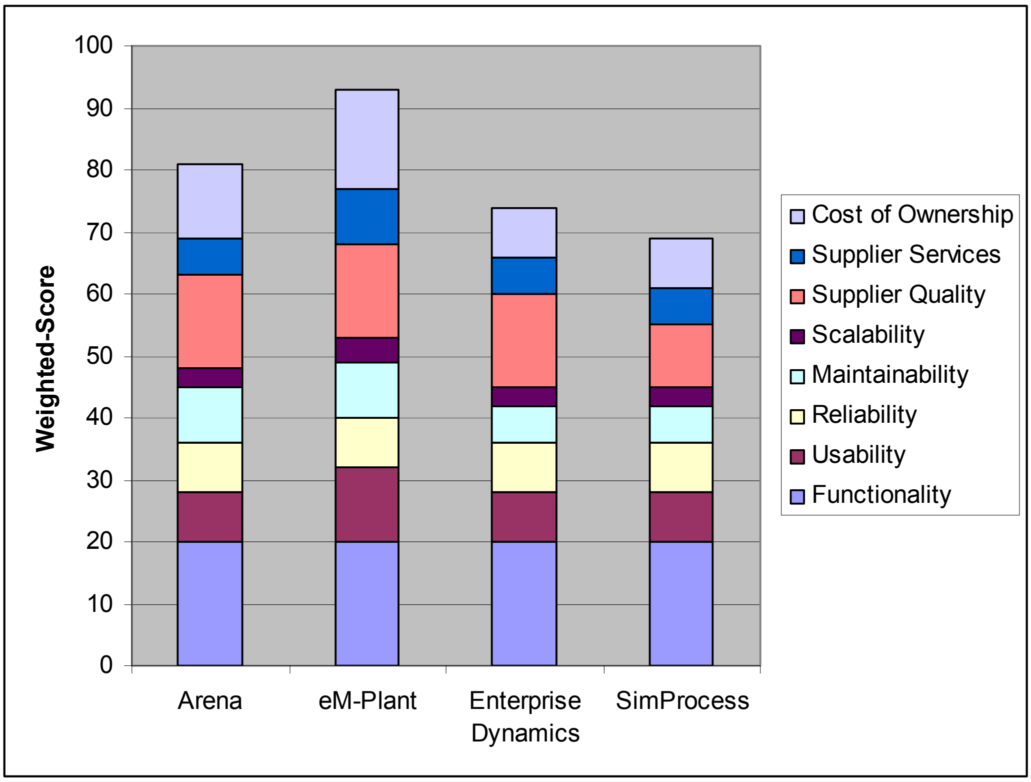


Figure 14: Weighted-score selection method results graph

Table 3: Weighted-score selection method results table

		Arena		**eM-Plant**		**Enterprise Dynamics**		**SimProcess**	
Criteria	Weight	Raw Score	Arena	Raw Score	eM-Plant	Raw Score	Enterprise Dynamics	Raw Score	SimProcess
Functionality	5	4	20	4	20	4	20	4	20
Usability	4	2	8	3	12	2	8	2	8
Reliability	4	2	8	2	8	2	8	2	8
Maintainability	3	3	9	3	9	2	6	2	6
Scalability	1	3	3	4	4	3	3	3	3
Supplier Quality	5	3	15	3	15	3	15	2	10
Supplier Services	3	2	6	3	9	2	6	2	6
Cost of Ownership	4	3	12	4	16	2	8	2	8
Total			81		93		74		69

The result of the evaluation performed clearly indicates that eM-Plant is the most preferable software for the traffic flow simulation.

8 SUPPLY MEDIUM DECISION SUPPORT TOOL

8.1 Introduction

As described in chapter 2, BMW SA and other automotive manufacturers are facing various specific problems relating to supply- and traffic flow planning. One of these problems is selecting the best supplier transportation medium among various alternatives for the supply of each part family, taking into account the effects on plant traffic. Several variables have to be considered during this decision making process, and no decision support tool exists at present for this purpose.

As mentioned in paragraph 6.1.2, *"Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer based support system for management decision makers who deal with semi-structured problems".*[12] DSS are used in making decisions where sufficient structure exists for computer and analytical aids to be of value but where human judgements are essential. The aim when developing a DSS is creating a supportive tool for management use that does not attempt to automate the decision process, predefine objectives, or impose solutions. It should serve as an extension of the user's problem solving capabilities.

A **decision support tool** will be developed to assist automotive manufacturers in making the supply planning decisions as described in chapter *2 Problem Statement* (see Figure 15).

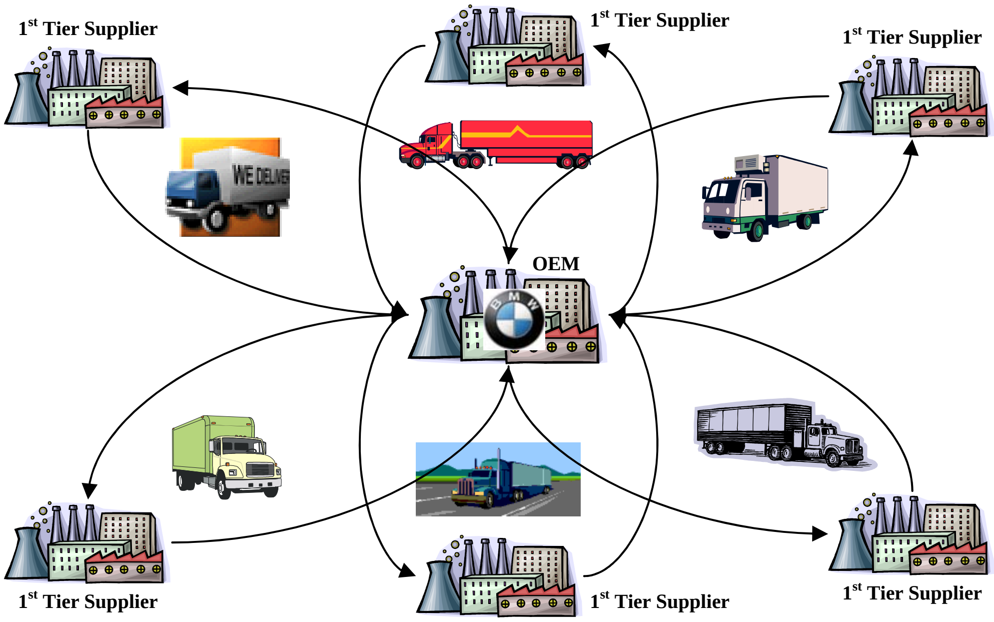


Figure 15: Environment of the decision support tool

8.2 User Requirements Specification

An investigation was conducted in order to determine the user requirements for the supply medium DST. The investigation revealed the following user requirements:

The tool should:

- be fast, efficient and user friendly to implement and use
- incorporate all variables influencing the supply medium selection process
- be easily integrated with existing software and applications in use by automotive manufacturers
- be flexible enough to allow for easy updating or addition of data
- calculate and compare the number of deliveries required per day for all JIT / JIS deliveries for use as input to a traffic flow simulation model.

- have a User Manual assisting the implementation and use of the tool
- be available in English and German, as it will be distributed to and used by automotive manufacturers in South Africa and Germany

It has also been established that the need for such a tool only exists for assisting in the planning of JIT and JIS deliveries, because:

  - these deliveries are made directly to their required areas in the assembly plant and only minimal line-side stock of these parts are kept as a production buffer
  - these deliveries have been identified as the main cause of traffic in the plant's known high traffic flow areas

- warehouse deliveries are done by standard sized trucks and containers, always delivering fluctuating consolidated loads (mixed part families) as required to replenish used warehouse stock.

8.3 Identifying Input Variables

The variables that need to be taken into account during the supply medium selection process are:

- Truck information
  - Truck types available
  - Dimensions of loading area for each truck type
  - Load restrictions for each truck type
  - Cost per day for each truck type
- Supplier information
  - All JIT / JIS suppliers
  - Delivery cycle time for each supplier

- JIT / JIS delivered part family information
  - All JIT / JIS delivered parts
  - Part weight
  - Parts required per final product
  - Stillage dimensions
  - Stillage weight
  - Parts per stillage

8.4 Developing the DST in MS-Excel

Following paragraph 6.9, Microsoft Excel was used for development of the supply medium decision support tool in this project.

The tool consists of three main components, namely:

1. ***Input data sheets:*** These three sheets (namely the **Boundary Conditions-**, **Part Families-** and **Delivery Cycle Times** sheet) contain all the data as listed in section 8.3. The user can view and update this data conveniently while using the tool (see chapter 3 of the User Manual in Appendix A)
2. ***Main sheet:*** This sheet serves as the main user interface (see Figure *18 Main Sheet,* p.81). As described in chapter 3 of the User Manual (see Appendix A), the user can set the following criteria in the tool:
   - **Part family to be analysed:** selected from a drop-down list on the main sheet.
   - **Offloading device:** the user can specify whether a forklift or stacker will be used to offload the parts from the delivery vehicle. This has an influence on the maximum height that parts can be stacked on the delivery vehicle in later calculations.
   - **Manner of offloading:** the user can specify whether the parts will be offloaded from the side or back of the delivery vehicle.

This has an influence on the way the parts will be packed on the delivery vehicle.

- **Stackability:** the user can specify whether the stillages may be stacked on top of one another or not when packed on the delivery vehicle.

3. ***Visual Basic for Applications module:*** This module contains the code for all the calculations made by the tool. All necessary data are extracted from the *input data sheets* and *main sheet* into the VBA module, calculations are made (see *8.4.1 Calculations in VBA*) and results are displayed in the main sheet (see Figure *18 Main Sheet,* p.81).

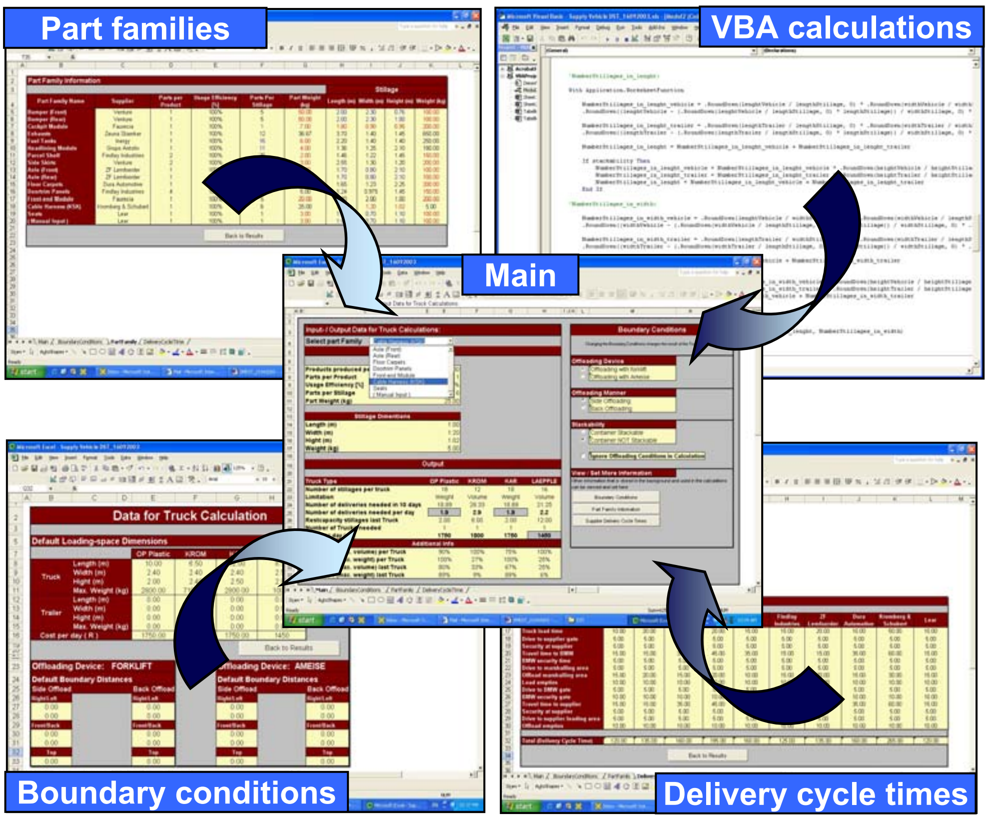


Figure 16: Components of the SMDST

8.4.1 Calculations in VBA

All calculations enabling the tool were translated from MS-Excel formulas into Visual Basic code in order for it to be easily integrated with existing software and applications in use by automotive manufacturers.[I] A part of the visual basic code can be seen in Figure 17 below (refer to Appendix B for the complete code).

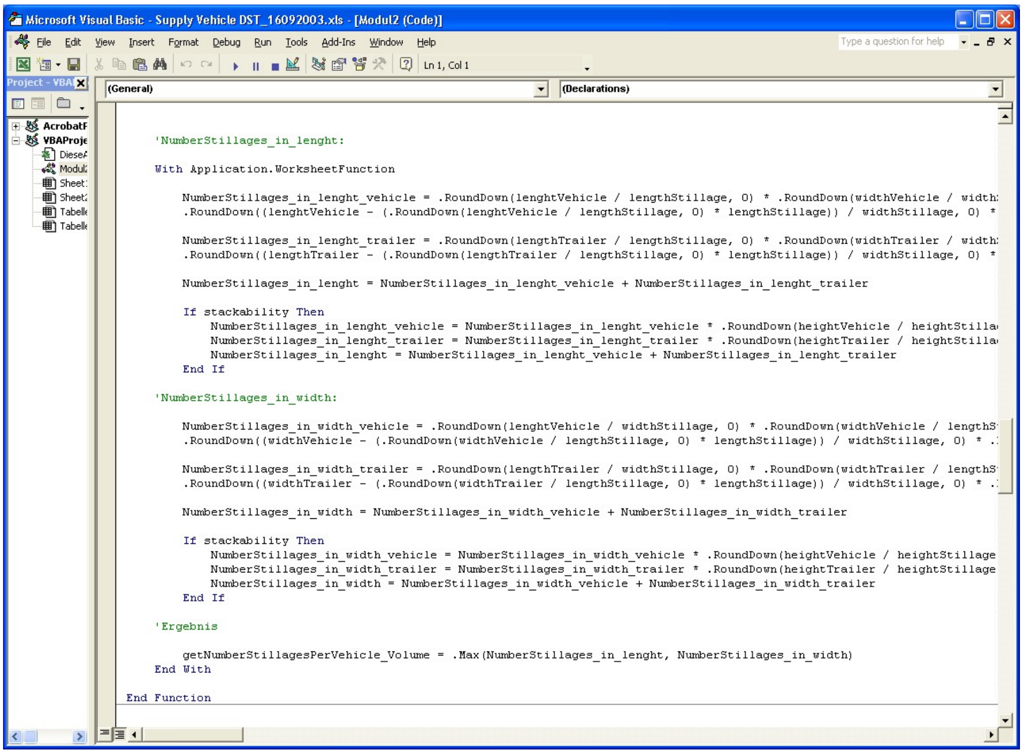


Figure 17: Calculations made in VBA

Variables have been declared in VBA to be used during calculations. All variables have been declared as one of the following four types:

- ***Integer:*** a whole number (not a fractional number) that can be positive, negative, or zero (maximum size 2^{16}-1)

[I] EM-Planner is a good example of such an application. It's "API" function allows for easy integration of VBA programs into its models. Refer to www.tecnomatix.com for more on this application.

- ***Double:*** also known as type *"Real"*, which can be any value (whole or fractional) in the infinitely divisible range of values between positive and negative infinity
- ***String:*** also known as type *"text"*, containing any combination of text
- ***Boolean:*** equal to one of two values: *true* or *false*

Following is a list of variables that have been declared in VBA and a description of the logic behind the VBA calculations. Values are read from the main- and input data sheets and the appropriate variables (in VBA) set equal to these values every time any variable is changed in the input data sheets or main sheet by the user.

- **products_produced_per_day** (as type Integer): the number of cars produced in the plant per day, value read from *Main* sheet
- **parts_per_Product** (as type Integer): the number of part of the specific part family required per car produced, value read from *Part Families* sheet
- **efficiency** (as type Double): measure of the usage efficiency of the specific part family, calculated as: 100% - percentage (%) scraped, value read from *Part Families* sheet
- **parts_per_Stillage** (as type Integer): the number of parts that are packed in a single stillage, value read from *Part Families* sheet
- **partWeight** (as type Double): the weight of a single part of the specific part family, value read from *Part Families* sheet
- **lengthStillage** (as type Double): the length of the stillage used for the specific part family, value read from *Part Families* sheet
- **widthStillage** (as type Double): the width of the stillage used for the specific part family, value read from *Part Families* sheet
- **heightStillage** (as type Double): the height of the stillage used for the specific part family, value read from *Part Families* sheet

- **offloadingDevice** (as type String): an indication of whether a *forklift* or *stacker* will be used to offload the stillages from the delivery vehicle, read from *Main* sheet
- **offloadingManner** (as type String): an indication of whether the stillages will be offloaded from the *side* or *back* of the delivery vehicle, read from *Main* sheet
- **stackability** (as type Boolean): an indication of whether the stillages may be stacked on top of one another or not when packed on the delivery vehicle, read from *Main* sheet
- **maxWeightVehicle** (as type Double): the load weight restriction of the vehicle under consideration, value read from *Boundary Conditions* sheet
- **maxWeightTrailer** (as type Double): the load weight restriction of the vehicle's trailer under consideration, value read from *Boundary Conditions* sheet
- **stillageWeight** (as type Double): the weight of the stillage used for the specific part family, value read from *Part Families* sheet
- **lenghtVehicle** (as type Double): the length of the vehicle's *carrying space*[II] under consideration, value read from *Boundary Conditions* sheet
- **widthVehicle** (as type Double): the width of the vehicle's carrying space under consideration, value read from *Boundary Conditions* sheet
- **heightVehicle** (as type Double): the height of the vehicle's carrying space under consideration, value read from *Boundary Conditions* sheet
- **lengthTrailer** (as type Double): the length of the vehicle's trailer's carrying space under consideration, value read from *Boundary Conditions* sheet

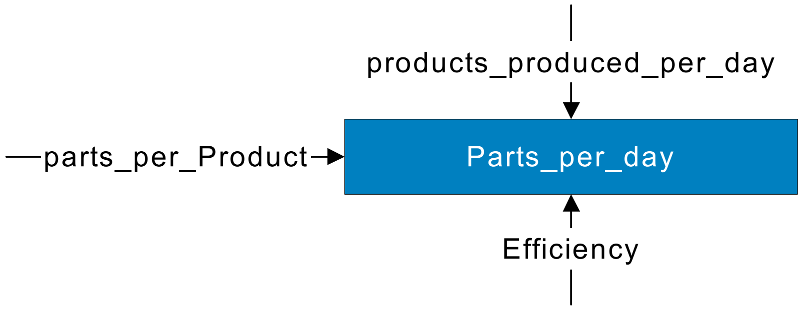
[II] Defined as the space that can be utilised for packing stillages in / on the vehicle, and ***not*** the dimensions of the entire vehicle

- **widthTrailer** (as type Double): the width of the vehicle's trailer's carrying space under consideration, value read from *Boundary Conditions* sheet
- **heightTrailer** (as type Double): the height of the vehicle's trailer's carrying space under consideration, value read from *Boundary Conditions* sheet
- **boundaryDistanceRight** (as type Double): the *boundary distance*[III] on the vehicle's right side, value read from *Boundary Conditions* sheet
- **boundaryDistanceLeft** (as type Double): the boundary distance on the vehicle's left side, value read from *Boundary Conditions* sheet
- **boundaryDistanceFront** (as type Double): the boundary distance on the vehicle's front, value read from *Boundary Conditions* sheet
- **boundaryDistanceBack** (as type Double): the boundary distance on the vehicle's back, value read from *Boundary Conditions* sheet
- **boundaryDistanceTop** (as type Double): the boundary distance on the vehicle's top, value read from *Boundary Conditions* sheet

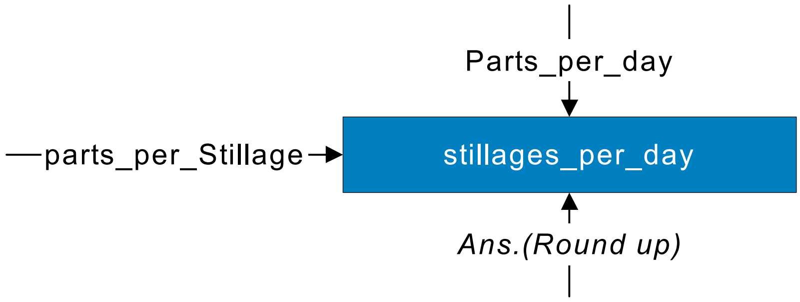
With these variables set, VBA continues by making the following calculations for the remaining variables:

- **Parts_per_day** (as type Double): the number of part of the specific part family required per day, calculated from:

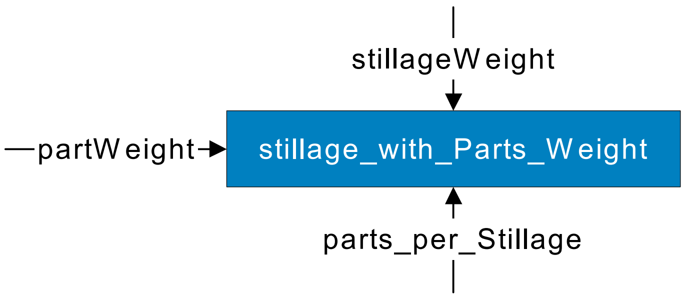
[III] Defined as the distance on a specific side of a vehicle than cannot be utilised as carrying space, due to restrictions of the offloading device used



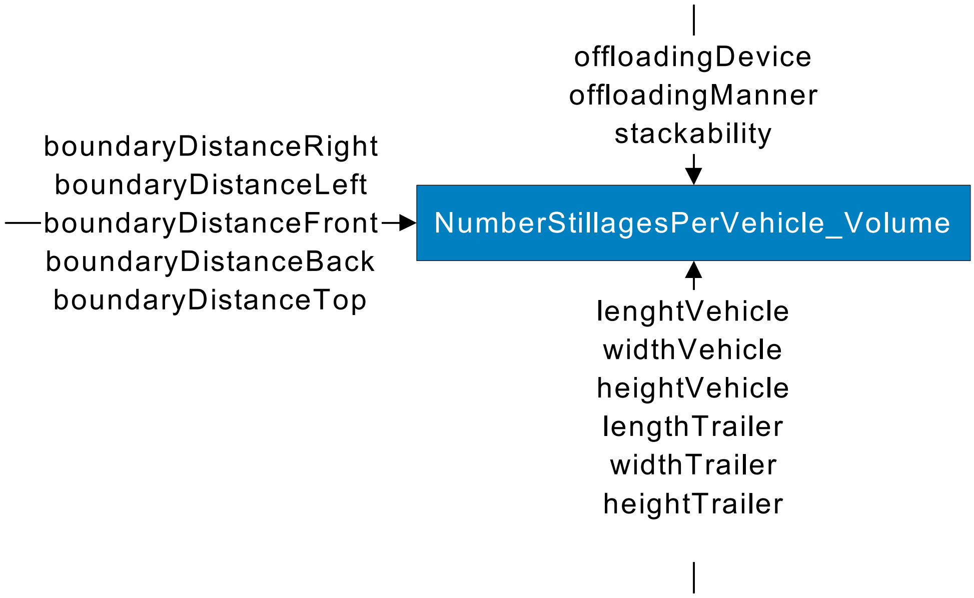
- **Stillages_per_day** (as type Integer): the number of stillages of the specific part family required per day, calculated from:



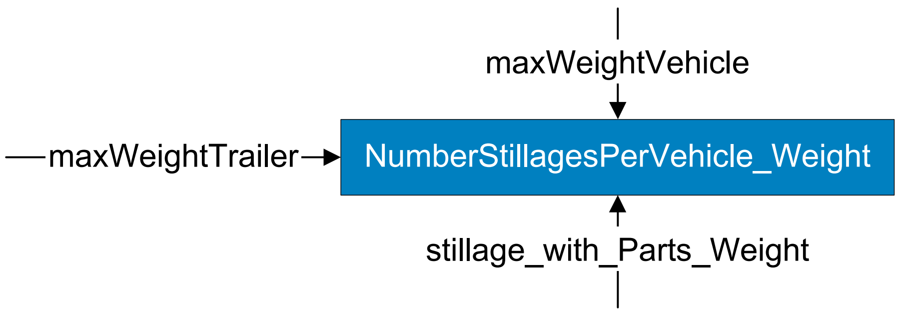
- **stillage_with_Parts_Weight** (as type Double): the weight of a full stillage (stillage carrying parts), calculated from:



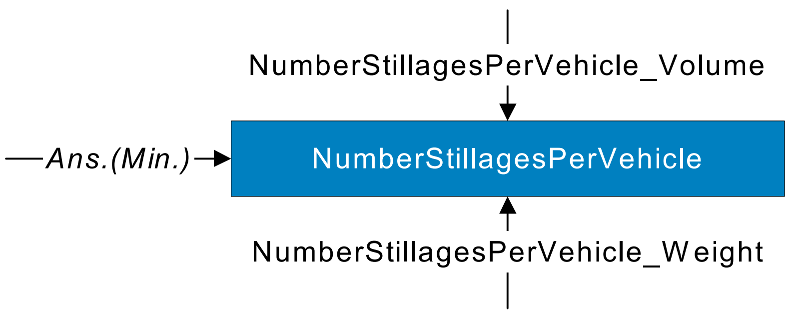
- **NumberStillagesPerVehicle_Volume** (as type Integer): the maximum number of stillages of a specific part family that fits into the vehicle's carrying space, calculated from:



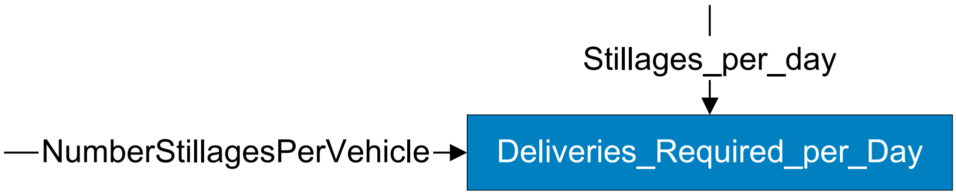
- **NumberStillagesPerVehicle_Weight** (as type Integer): the maximum number of stillages of a specific part family that can (theoretically) be packed on a vehicle before the vehicle reaches its weight restriction calculated from:



- **NumberStillagesPerVehicle** (as type Integer): the maximum number of stillages of a specific part family that can be packed on a vehicle calculated from:

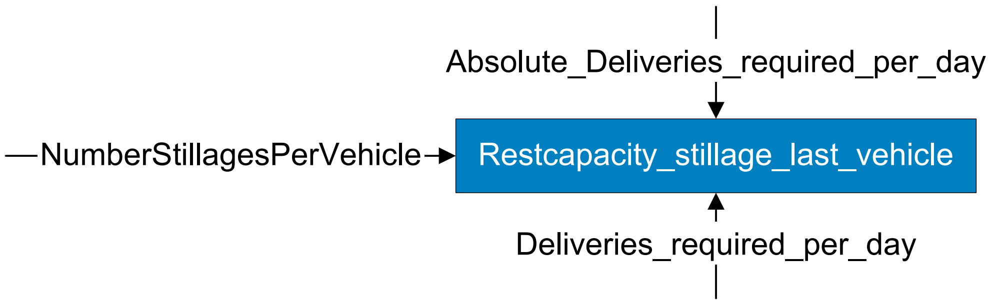


- **Deliveries_required_per_day** (as type Double): the number of deliveries of the specific part family required per day, calculated from:



- **Absolute_Deliveries_required_per_day** (as type Integer): the absolute number of deliveries of the specific part family required per day, calculated from:

- **Restcapacity_stillage_last_vehicle** (as type Integer) calculated from:



8.4.2 Information Output

The calculation outputs are displayed on the main sheet of the tool's user interface (see *Figure 18,* p.81). Both the vehicle yielding the *lowest number of deliveries required per day* and the vehicle resulting in the *lowest cost per day* are automatically highlighted for easy identification (ref. 1 in *Figure 18,* p.81).

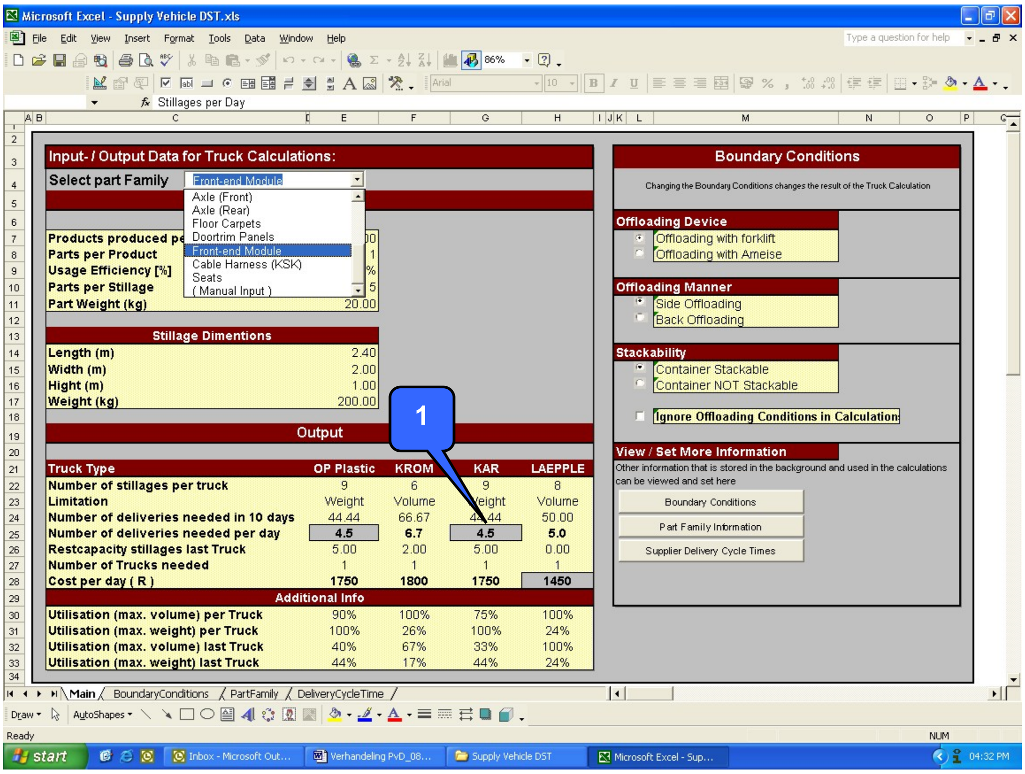


Figure 18: Main sheet

8.4.3 Output example

To illustrate both the sensitivity of the calculation output to parameter changes and the capability of the tool in terms of calculation speed and usage efficiency, a simple example follows:

The output shown in *Figure 18: Main Sheet* clearly indicates that (for the selected part family and settings):

- both the "OP Plastic" and "KAR" vehicles are the most favourable in terms of the number of deliveries required per day (4.5 deliveries required per day, on average)
- the "Leapple" vehicle is the most favourable in terms of the daily cost implication (R1450 per day, on average)

By changing only one variable in the calculation, namely the *stackability*[IV] of the container (ref. 1 in *Figure 19*), the calculation output changes considerably (see *Figure 19: Capability example*).

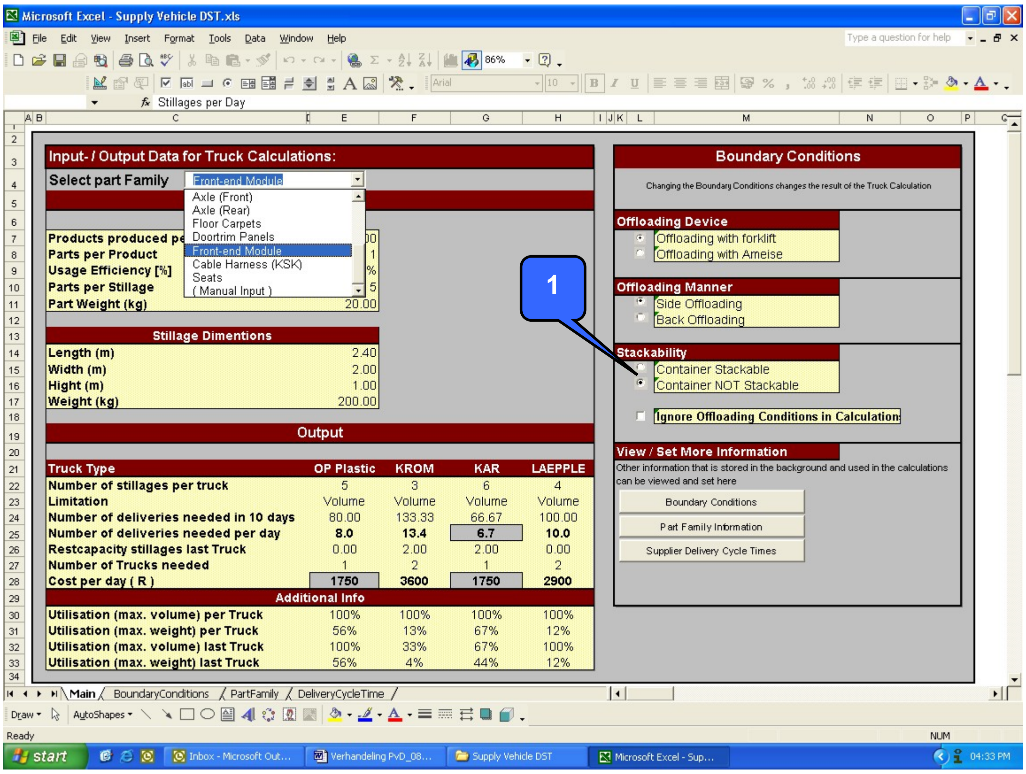


Figure 19: Capability example

The calculation output now indicates that:

- the “KAR” vehicle is (alone) the most favourable in terms of the number of deliveries required per day (6.7 deliveries required per day, on average)
- both the “OP Plastic” and “KAR” vehicles are the most favourable in terms of the daily cost implication (R1750 per day, on average)

[IV] An indication of whether the stillages may be stacked on top of one another or not when packed on the delivery vehicle

8.5 Implementation and Use

As one of the specified user requirements, the implementation and use of the tool had to be as fast, efficient and user friendly as possible. As the tool was developed in MS-Excel, it can be used on any device that has MS-Excel installed on it. Even though the use of the tool is relatively intuitive, a user manual is available to guide the user in the use of the tool.

8.5.1 User Manual

A user manual was developed to assist the user during the set-up and use of the tool. The User Manual addresses the following points (as seen in its table of contents):

Figure 20: User Manual table of contents

Both the tool and User Manual were translated into German, as the tool will be distributed to and used by automotive manufacturers in Germany.

The English and German versions of the *supply medium decision support tool* and User Manual are all located on the supplementary CD[V]

[V] A supplementary CD was submitted together with this dissertation (see Appendix C). To obtain this CD, contact the Industrial Engineering Department of the University of Pretoria through the following website: http://ie.up.ac.za/

in the “SMDST” folder. The User Manuals are also included in Appendix A of this document.

9 TRAFFIC FLOW SIMULATION MODELING

9.1 Introduction

One of the problems faced by automotive manufacturers today is assessing the impact of various combinations of supplier transportation vehicles as well as the physical routing decisions on plant traffic.

Several proposed changes to the plant layout, changes to the location of supplier delivery points and changes to supplier delivery vehicle types for several part families have to be evaluated for the BMW Plant in Rosslyn. These proposed changes will imply large relocation expenses and will inevitably have a major impact on the traffic flow within the plant. The impact of these proposed changes can effectively be analysed, evaluated and compared by means of simulation modeling (see Figure 21).

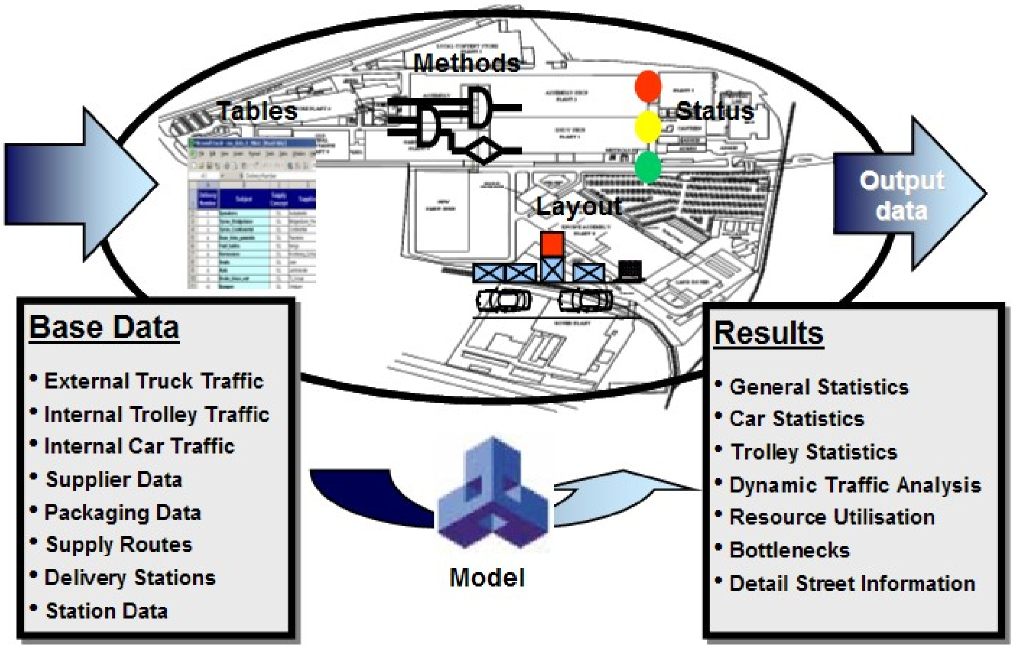


Figure 21: Traffic flow simulation concept

9.2 User Requirements Specification

A comprehensive *traffic flow simulation model* of the BMW Plant in Rosslyn is required, simulating the traffic movement within the plant boundaries but outside plant buildings - thus, traffic flow in the streets within the plant.

The final deliverable should be a tool capable of assessing the impact of proposed changes to the plant layout, location of supplier delivery points within the plant and different supplier delivery vehicles for several part families.

The scenario representing the current situation of the current production scenario (where the E46 models are manufactured) should initially be developed, to serve both as a means of validating the functionality and accuracy of the model and as a basis model for future scenarios. This model would have to be easily adaptable to incorporate suggested changes in the future.

It is essential that both the model's *input data* and *simulation results* can be viewed and manipulated by users with relatively low computer skills and possibly no simulation skills, independent of the simulation model and -software.

The generated simulation results have to be presented in a graphical, easily interpretable format in order to compare various scenarios quickly and intuitively and to communicate the results effectively across all organisational levels.

9.3 Identifying and Acquiring Critical Information

Information critical to the development and use of the simulation model was identified and collected. The information was either:

- of a logical nature, necessary to understand the operational logic and functionality of the environment being simulated, or
- of a quantitative data nature, required as input to the simulation model.

9.3.1 Traffic Sources

Logical information was collected on the sources of traffic within the plant. There are four different types of vehicles causing traffic within the plant:

- **Trucks / Supplier delivery vehicles** (The delivery of all material, parts, components or subassemblies to the plant by external supplier vehicles). Supplier trucks deliver to- and move within the plant between 7am and 11pm daily (see Figure 22).

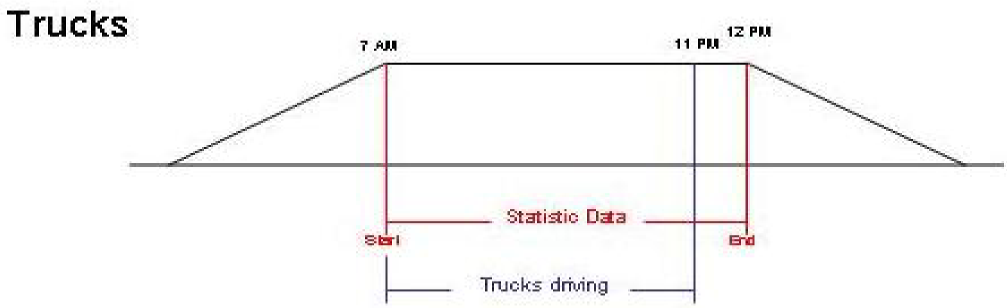


Figure 22: Movement of trucks within the plant

- **Forklifts and trolleys** enter the Plant between 6am and 7am and drive to their "home" stations. They circulate between two stations within the plant from 7am until 11pm and leave the plant thereafter (see Figure 23).

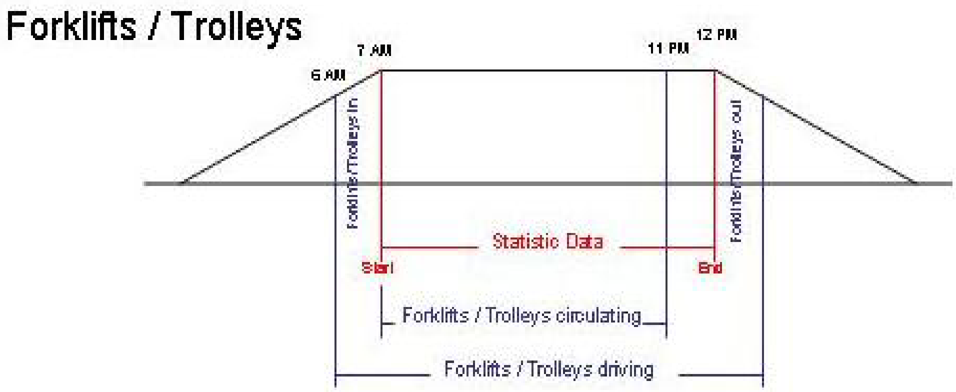


Figure 23: Movement of forklifts and trolleys within the plant

- **Cars** are work in progress (Nearly finished products manufactured in the plant). They have reached the production stage where all of the manufacturing tasks have been completed and need only to be driven to a few locations within the plant where functional and performance checks can be performed before exiting the plant. Cars move within the plant between 7am and 12pm (see Figure 24).

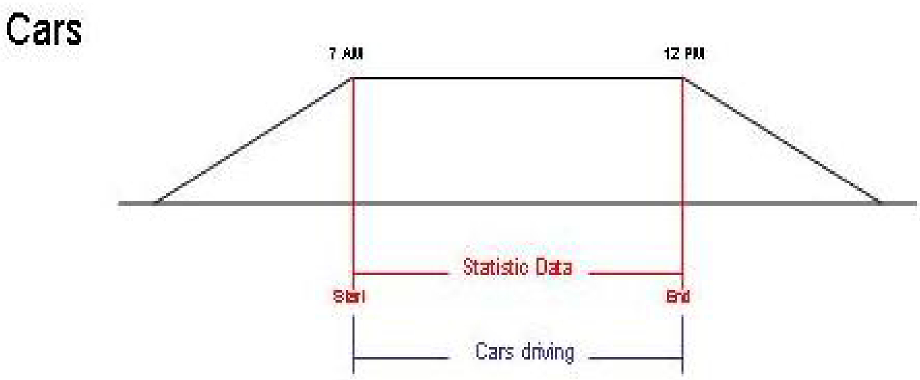
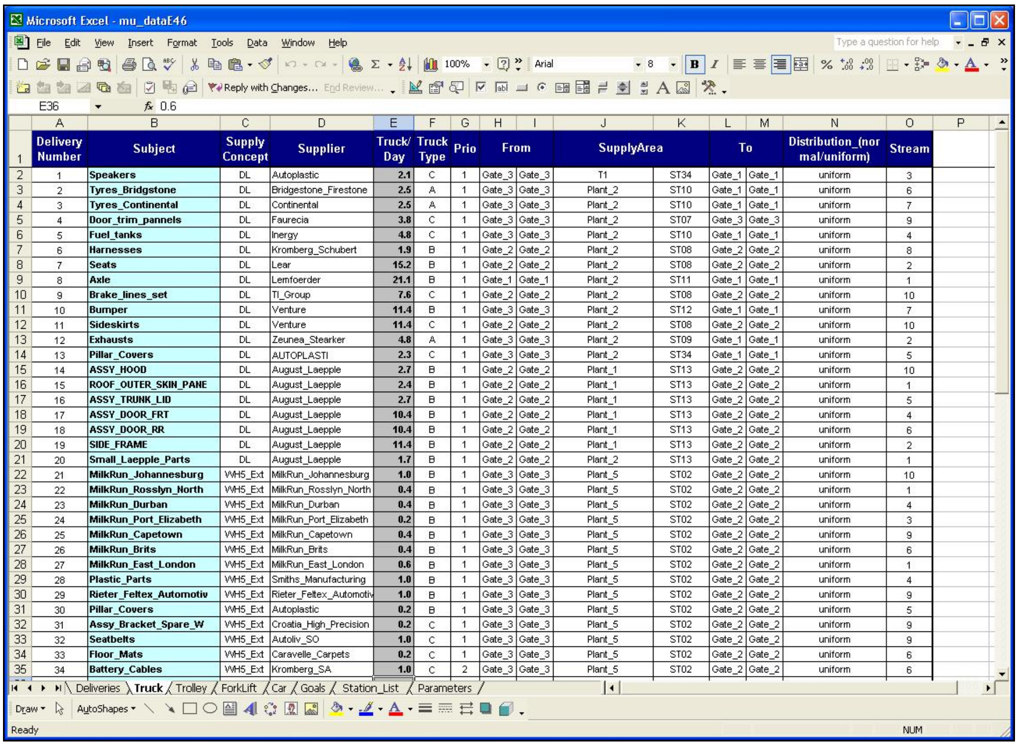


Figure 24: Movement of cars within the plant

9.3.2 Excel: Input data

- The following data was collected for analysis to determine input to the simulation model and entered into a pre-configured Excel spreadsheet named “MU_Data” (see Figure 25 and Appendix C):



	Delivery Number	Subject	Supply Concept	Supplier	Truck/ Day	Truck Type	Prio	From		SupplyArea		To		Distribution_(normal/uniform)	Stream
2	1	Speakers	DL	Autoplastic	2.1	C	1	Gate_3	Gate_3	T1	ST34	Gate_1	Gate_1	uniform	3
3	2	Tyres_Bridgstone	DL	Bridgestone_Firestone	2.5	A	1	Gate_3	Gate_3	Plant_2	ST10	Gate_1	Gate_1	uniform	6
4	3	Tyres_Continental	DL	Continental	2.5	A	1	Gate_3	Gate_3	Plant_2	ST10	Gate_1	Gate_1	uniform	7
5	4	Door_trim_pannels	DL	Faurecia	3.8	C	1	Gate_3	Gate_3	Plant_2	ST07	Gate_3	Gate_3	uniform	9
6	5	Fuel_tanks	DL	Inergy	4.8	C	1	Gate_3	Gate_3	Plant_2	ST10	Gate_1	Gate_1	uniform	4
7	6	Harnesses	DL	Kromberg_Schubert	1.9	B	1	Gate_2	Gate_2	Plant_2	ST08	Gate_2	Gate_2	uniform	8
8	7	Seats	DL	Lear	15.2	B	1	Gate_2	Gate_2	Plant_2	ST08	Gate_2	Gate_2	uniform	2
9	8	Axle	DL	Lemfoerder	21.1	B	1	Gate_1	Gate_1	Plant_2	ST11	Gate_1	Gate_1	uniform	1
10	9	Brake_lines_set	DL	TI_Group	7.6	C	1	Gate_2	Gate_2	Plant_2	ST08	Gate_2	Gate_2	uniform	10
11	10	Bumper	DL	Venture	11.4	B	1	Gate_3	Gate_3	Plant_2	ST12	Gate_1	Gate_1	uniform	7
12	11	Sideskirts	DL	Venture	11.4	C	1	Gate_2	Gate_2	Plant_2	ST08	Gate_2	Gate_2	uniform	10
13	12	Exhausts	DL	Zeunea_Stearker	4.8	A	1	Gate_3	Gate_3	Plant_2	ST09	Gate_1	Gate_1	uniform	2
14	13	Pillar_Covers	DL	AUTOPLASTI	2.3	C	1	Gate_3	Gate_3	Plant_2	ST34	Gate_1	Gate_1	uniform	5
15	14	ASSY_HOOD	DL	August_Laepple	2.7	B	1	Gate_2	Gate_2	Plant_1	ST13	Gate_2	Gate_2	uniform	10
16	15	ROOF_OUTER_SKIN_PANE	DL	August_Laepple	2.4	B	1	Gate_2	Gate_2	Plant_1	ST13	Gate_2	Gate_2	uniform	1
17	16	ASSY_TRUNK_LID	DL	August_Laepple	2.7	B	1	Gate_2	Gate_2	Plant_1	ST13	Gate_2	Gate_2	uniform	5
18	17	ASSY_DOOR_FRT	DL	August_Laepple	10.4	B	1	Gate_2	Gate_2	Plant_1	ST13	Gate_2	Gate_2	uniform	4
19	18	ASSY_DOOR_RR	DL	August_Laepple	10.4	B	1	Gate_2	Gate_2	Plant_1	ST13	Gate_2	Gate_2	uniform	6
20	19	SIDE_FRAME	DL	August_Laepple	11.4	B	1	Gate_2	Gate_2	Plant_1	ST13	Gate_2	Gate_2	uniform	2
21	20	Small_Laepple_Parts	DL	August_Laepple	1.7	B	1	Gate_2	Gate_2	Plant_2	ST13	Gate_2	Gate_2	uniform	1
22	21	MilkRun_Johannesburg	WH5_Ext	MilkRun_Johannesburg	1.0	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	10
23	22	MilkRun_Rosslyn_North	WH5_Ext	MilkRun_Rosslyn_North	0.4	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	1
24	23	MilkRun_Durban	WH5_Ext	MilkRun_Durban	0.4	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	4
25	24	MilkRun_Port_Elizabeth	WH5_Ext	MilkRun_Port_Elizabeth	0.2	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	3
26	25	MilkRun_Capetown	WH5_Ext	MilkRun_Capetown	0.4	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	9
27	26	MilkRun_Brits	WH5_Ext	MilkRun_Brits	0.4	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	6
28	27	MilkRun_East_London	WH5_Ext	MilkRun_East_London	0.6	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	1
29	28	Plastic_Parts	WH5_Ext	Smiths_Manufacturing	1.0	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	4
30	29	Rieter_Feltex_Automotiv	WH5_Ext	Rieter_Feltex_Automotiv	1.0	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	9
31	30	Pillar_Covers	WH5_Ext	Autoplastic	0.2	B	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	5
32	31	Assy_Bracket_Spare_W	WH5_Ext	Croatia_High_Precision	0.2	C	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	9
33	32	Seatbelts	WH5_Ext	Autoliv_SO	1.0	C	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	9
34	33	Floor_Mats	WH5_Ext	Caravelle_Carpets	0.2	C	1	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	6
35	34	Battery_Cables	WH5_Ext	Kromberg_SA	1.0	C	2	Gate_3	Gate_3	Plant_5	ST02	Gate_2	Gate_2	uniform	6

Figure 25: MU_data_E46.xls - screenshot

- **All truck deliveries to the plant:** A list of names of all the deliveries made to the plant by trucks (supplier delivery vehicles) was set up and entered into the "Subject" column of the "Truck" sheet in the "MU_Data" spreadsheet.
- **All trolley rotations within the plant:** A list of names of all the trolleys regularly moving between two stations within the plant was set up and entered into the "Subject" column of the "Trolley" sheet in the "MU_Data" spreadsheet.
- **All forklift rotations within the plant:** A list of names of all the forklifts regularly moving between two stations within the plant was set up and entered into the "Subject" column of the "Forklift" sheet in the "MU_Data" spreadsheet.
- **Number of cars produced per day:** The average daily production volume was calculated (taken as the average over the last 6 months of production) and entered into the "Cars / Day" cell in the "MU_Data" spreadsheet[VI]
- **Car routing logic within the plant:** a List containing all the stations within the plant that a car may have to visit, all the following stations that the car may visit from that station, as well as the probability of a car visiting a following station from its current station (see Figure 41, p.111)
- **Delivery frequency of every truck delivery:** The average number of deliveries per day was calculated (taken as the average over the last six months of production) for every truck delivery made to the plant and entered into the "Trucks / Day" column of the "Truck" sheet in the "MU_Data" spreadsheet.
- **Number of rotations per day made by every forklift and trolley:** The average number of rotations made per day between the two rotation stations (taken as the average over the last six months of production) for every trolley / forklift and entered into

[VI] It is possible to rename any cell within a sheet of an Excel spreadsheet. This is done mainly for easier referencing to the specific cell during calculations and reading and writing data to and from the cell from external applications at a later stage the "Trucks / Day" column of the "Truck" sheet in the "MU_Data" spreadsheet (see *9.6.3 Routing Trolleys and Forklifts*).

- **Delivery route of every truck delivery:** Defined by three attributes, namely the delivery's:

  - Entry gate
  - Delivery point
  - Exit gate

  (see Figure 41, p.112) and respectively entered into the "From", "Supply Area" and "To" columns of the "Truck" sheet in the "MU_Data" spreadsheet.
- **Rotation route of every trolley and forklift:** Defined by the 2 stations within the plant that the trolleys / forklifts rotate between and respectively entered into the "Supply Area 1" and "Supply Area 2" columns of the "Trolley" sheet in the "MU_Data" spreadsheet (see Figure 42, p.113)
- **Plant opening hour:** The time of day that the first production shift starts within the plant, entered into the "Opening Hour" cell in the "MU_Data" spreadsheet
- **Plant closing hour:** The time of day that the last production shift ends within the plant, entered into the "Closing Hour" cell in the "MU_Data" spreadsheet
- **Plant warm-up period:** The period of time between the plant opening time and the time the gates are opened to receive truck deliveries to the plant, entered into the "Warm-Up Period" cell in the "MU_Data" spreadsheet
- **Plant cool-down period:** The period of time between the time that the gates are closed to truck deliveries to the plant and the plant closing time, entered into the "Cool-Down Period" cell in the "MU_Data" spreadsheet

Other data and information were also collected to assist model development. These included:

- **Plant layout:** Information about the location of all gates and delivery points within the plant (see Figure 26, p.93)
- **Properties of all roads within the plant:** (length, width, one/two directional, speed restrictions) (see *9.4.4 Model building Blocks / Road*)
- **Properties of all delivery points / stations within the plant:** (number of marshalling zones per station, number of buffer places per station, operating schedule per station) (see *9.4.4 Model Building Blocks / Station*)

Even though most of the above mentioned data was available in the BMW SAP system, extracting the data from the SAP database into the pre-defined input data Excel spreadsheet "MU_Data" still required a considerable amount of manual data processing. However, once this data has been entered into the input data spreadsheet, it can be used for as many simulation replications as required. Separate, unique input data spreadsheets will have to be created for every scenario to be simulated in the future.

If a simulation scenario is created to represent a possible future scenario in the plant, calculations and estimations will have to be made (based on the most recent planning data) for most of these variables in the input data spreadsheet.

9.4 Developing the Model in eM-Plant

9.4.1 Modeling with eM-Plant Objects

eM-Plant provides a number of predefined objects for simulating the activities and logic in a typical manufacturing environment. There are five types of objects available:

- ***Control Objects:*** Objects inherently necessary for controlling the logic and functionality of the simulation model
- ***Material flow objects:*** Objects used to represent stationary processes and resources that process moving objects
- ***Information flow objects:*** Objects used to record information and distribute information among objects in the model
- ***Moving Objects:*** Objects used to represent mobile material, people and vehicles in the simulation model and that are processed by material flow objects. Moving objects are more commonly referred to as MUs (moving units)
- ***Display and User Interface Objects:*** Objects used to display and communicate information to the user and to prompt the user to provide inputs at any time during a simulation run

Objects' variables can either be set manually before the start of each simulation run, or set dynamically during a simulation run with the use of methods and SimTalk commands.

9.4.2 Modeling with eM-Plant Methods and SimTalk

SimTalk is a programming language similar to programming languages like Turbo Pascal and Visual Basic for Applications, with the exception that it was specifically developed for application in eM-Plant models.

EM-Plant's *method* objects are used to dynamically control and manipulate models. SimTalk programmes are written inside *method* objects and executed every time the *method* is called during a simulation run.

9.4.3 Modeling levels

The model was constructed on various eM-Plant levels to ensure a logical structure. The logic behind using eM-Plant levels is similar to using Microsoft Windows Explorer. By opening a "folder" that is on a higher modeling level, it is possible to view its content on a lower level. The models' highest modeling level is called the "plant layout level", shown in Figure 26.

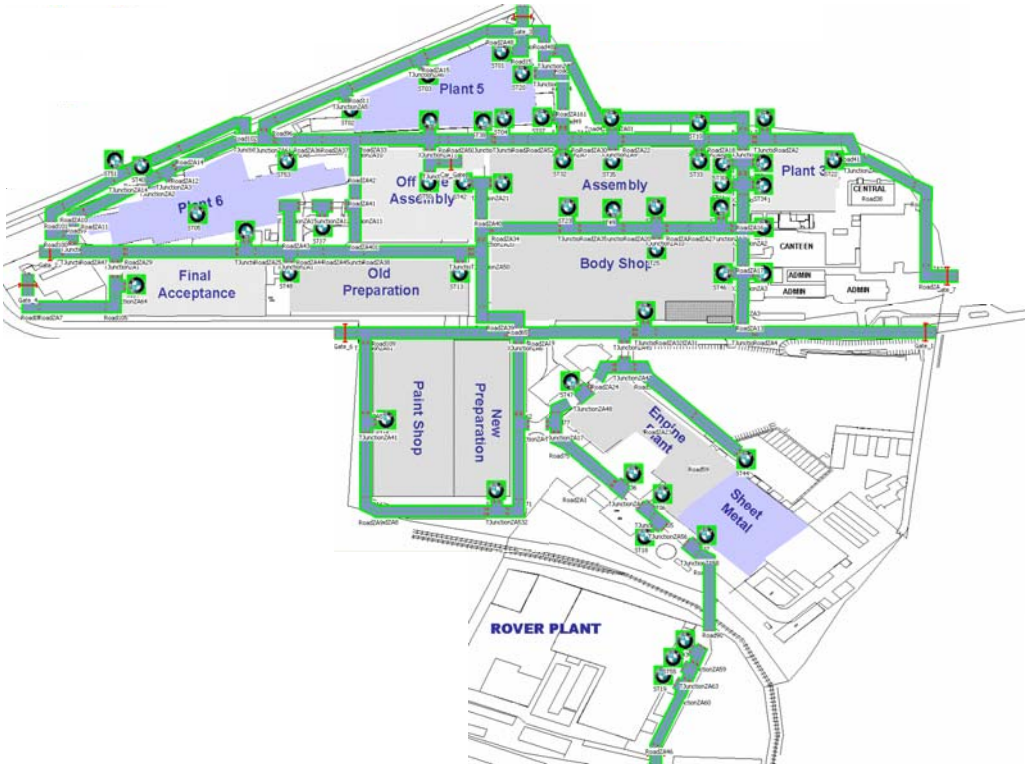


Figure 26: Plant layout modeling level

The next lower-detail modeling level is the building blocks, as described in the following section.

9.4.4 Model Building Blocks

The model was constructed by first developing five intelligent *building blocks*. These allow the user to construct his own plant layout by simply adding the required pre-developed building blocks into the model and connecting them appropriately, almost like building a puzzle.

Every time the model is initialised, changes made to the layout are automatically identified and updated in the rest of the model.

The defined building blocks are as follows:

Station: The *station building block* represents a loading / offloading point within the plant. All trucks / supplier delivery vehicles entering the plant drive to a specific station within the plant, parks in a designated parking space within the station, waits while being serviced (usually by a forklift, first offloading full stillages from the truck and then loading empty stillages back onto the truck), and then leaves the station. On the plant layout level, a *station building block* is represented by the following symbol:

Figure 27: Station symbol

On the station layout level, a *station building block* consists of a network of objects and methods as seen in Figure 28 below.

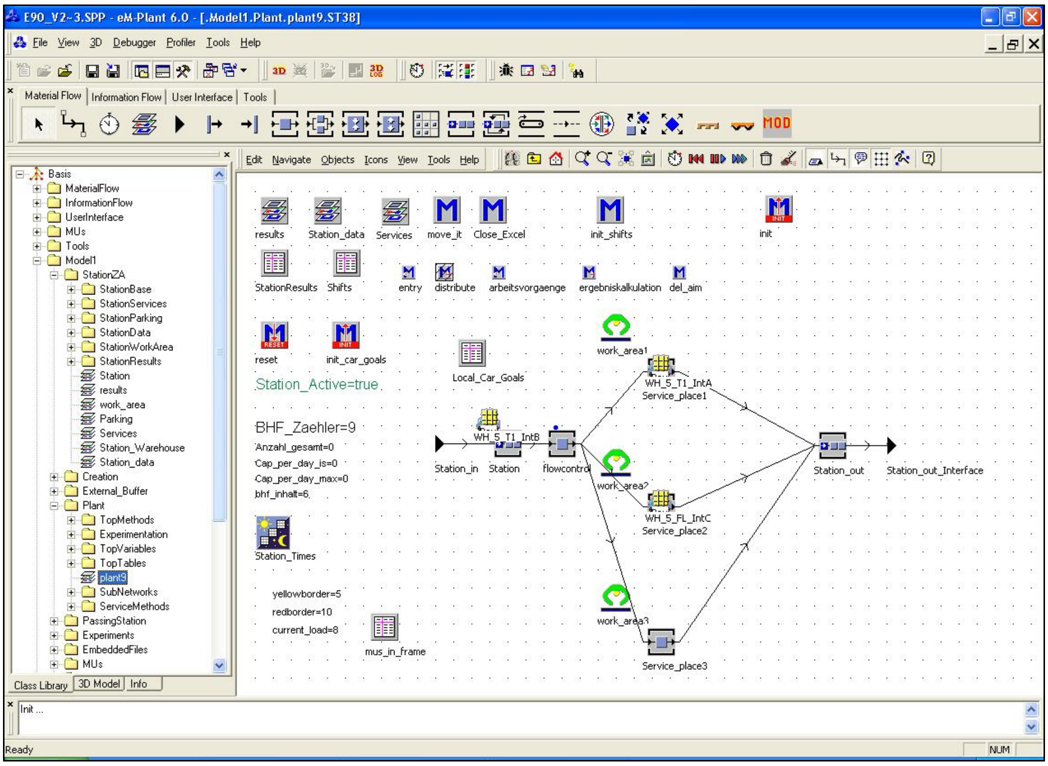


Figure 28: Station building block

In essence, a service station consists of marshalling zones and buffer places. A marshalling zone represents a space where an MU (*moving unit: can be a truck, trolley, forklift or car*) can park while being serviced at the station. A buffer place represents a space where an MU can park while waiting for service at a station.

Each station has a unique Microsoft Excel Spreadsheet called "Station_Data" embedded[VII] into it. This input file contains the following station information:

- Number of marshalling zones (The number of units that can be serviced at the station in parallel)
- Number of buffer places (The number of units that can wait for service at the station)

[VII] This is an eM-Plant specific term and means that the file is directly linked to the station and will be saved together with the model.

- Service time (The time it takes (on average, in minutes) to serve an MU that arrives at the station. This value is used as a basis when setting the parameters of the probability distribution representing the service times at a station (see point 3 of the *station logic* below)
- Planned working schedule of the station (start time, break times and –intervals, closing time)

Each station's parameters can be edited / changed in its "Station_Data" file. This information is automatically read from the "Station_Data" file and updated into the model every time a station is reset and initialised.

Station Logic: Following is a brief description of the logic used to simulate the activities at a station building block.

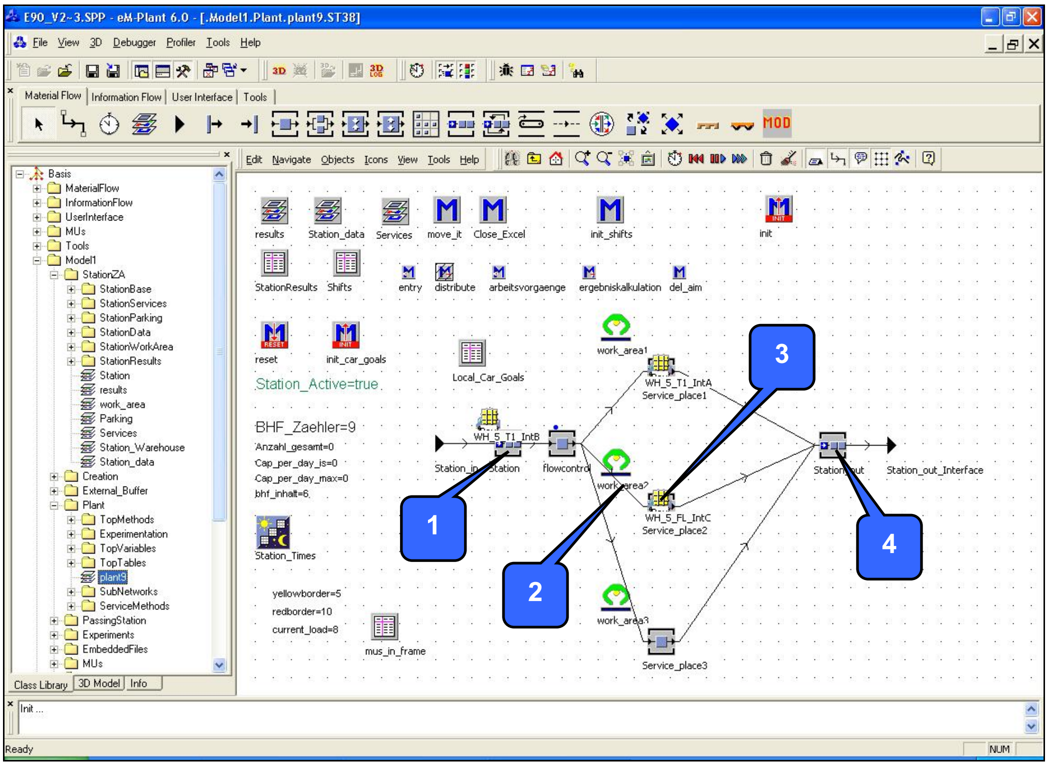


Figure 29: Station Logic

1. As an MU arrives at a station, it checks whether the station has any unoccupied buffer places. If so, it moves to the first

unoccupied buffer space. Otherwise, it remains outside of the station - blocking the way for other MUs to pass - until a buffer place becomes available within the station (ref. 1 in Figure 29).

2. As an MU occupies a buffer space within the station, it checks whether the station has any unoccupied marshalling zones. If so, it moves to the first unoccupied marshalling zone. Otherwise, it remains in the buffer until a marshalling zone becomes available within the station (ref. 2 in Figure 29).

3. As an MU occupies a marshalling zone within the station, a random observation is drawn from a normal distribution (see *7.4 Probability Distributions*) with mean equal to the station's specified service time, standard deviation equal to ¼ of the station's specified expected service time, lower boundary equal to ½ of the station's specified service time, upper boundary equal to 2 times the station's specified service time, and set as the service time for the MU (ref. 3 in Figure 29).

4. The MU waits on the marshalling zone until the service time has elapsed before it moves to the station's exit. As the MU passes the station's exit, its information is collected and stored in a table for statistical use at a later stage. Thereafter it immediately leaves the station towards its next destination (ref. 4 in Figure 29).

Gate: The *gate building block* represents a gate within the plant. All MUs have to enter and leave the plant through a gate. On the plant layout level, a *gate building block* is represented by the following symbol:

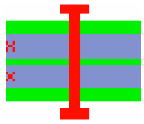


Figure 30: Gate symbol

On the gate layout level, a *gate building block* consists of a network of objects and methods as seen in Figure 31 below.

Gate Logic: Following is a brief description of the logic used to simulate the activities at a gate building block.

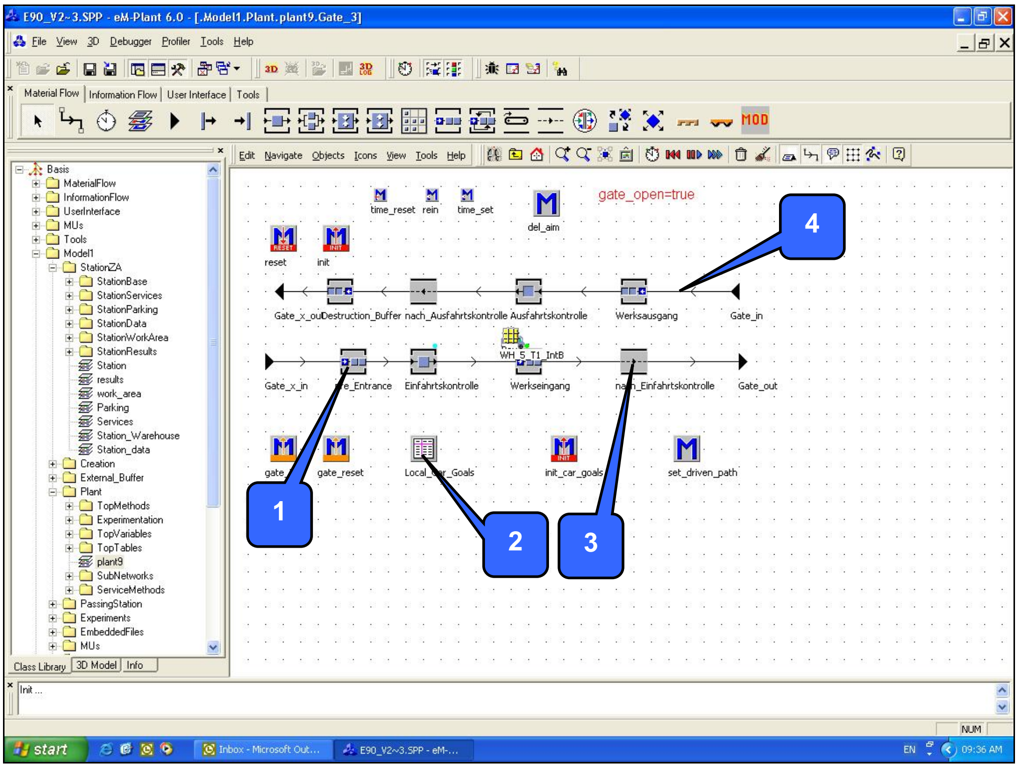


Figure 31: Gate building block

1. As an MU is created during a simulation run, it is first directed to the correct gate where it is to *enter* the plant and enters the gate (ref. 1 in Figure 31). Once an MU has entered the plant through a gate it becomes part of the active simulation model.

2. As the MU travels through the gate, its information is collected and stored in a table for statistical use at a later stage (ref. 2 in Figure 31). Thereafter it immediately leaves the gate towards its next destination (ref. 3 in Figure 31).

3. As an MU *leaves* the plant through a gate (ref. 4 in Figure 31), its information is first updated in the various tables before it is deleted so that it is no longer part of the active simulation model.

Road: The *road building block* represents a road / street within the plant. On the plant layout level, a *road building block* is represented by the following symbol:

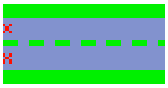


Figure 32: Road symbol

On the road layout level, a *road building block* consists of a network of objects and methods as seen in Figure 33 below.

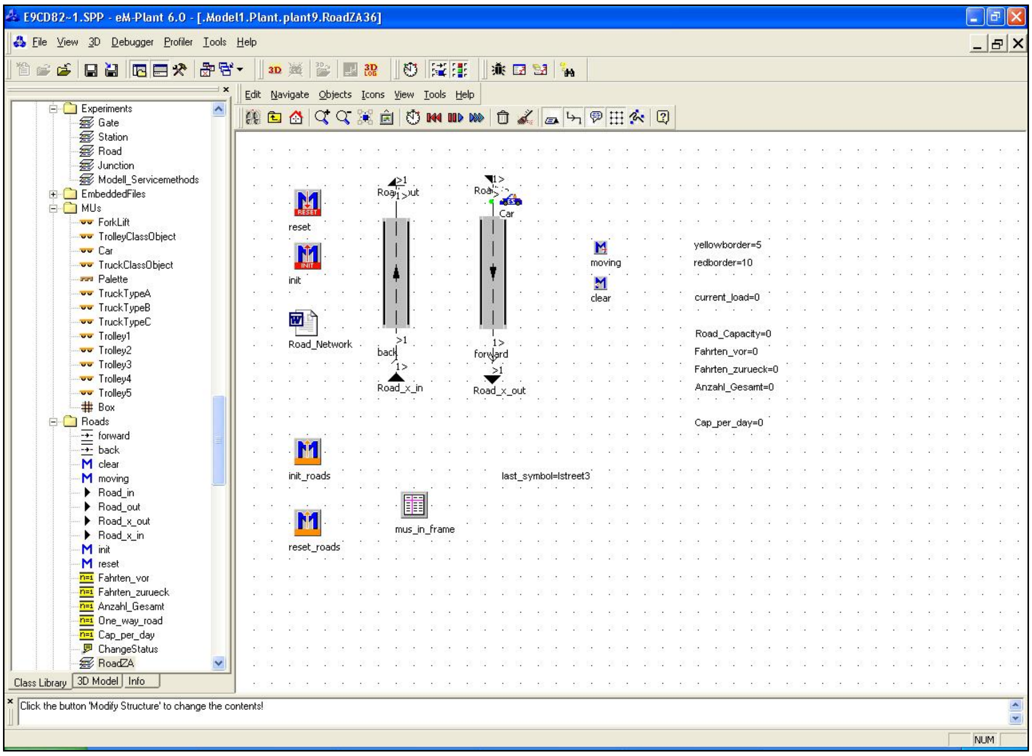


Figure 33: Road building block

The road building block provides:

- a two-way connection between any of the other building blocks
- tracks (travelling means) for all MUs
- the ability to set the capacity of a road (this allows the user to specify the maximum number of MUs that can be located on the section of road at any given time)
- the ability to set the length of a road (this information is necessary to track the distances that MUs travel, used for calculations at a later stage and presented in the "Traffic_Results.xls" file (see paragraph 9.5.2))
- the ability to monitor and record information on the MUs using a road

T-Junction: The *T-junction building block* represents a T-junction within the plant. On the plant layout level, a *T-junction building block* is represented by the following symbol:

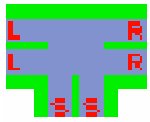


Figure 34: T-Junction symbol

On the T-junction layout level, a *T-junction building block* consists of a network of objects and methods as seen in Figure 35 below.

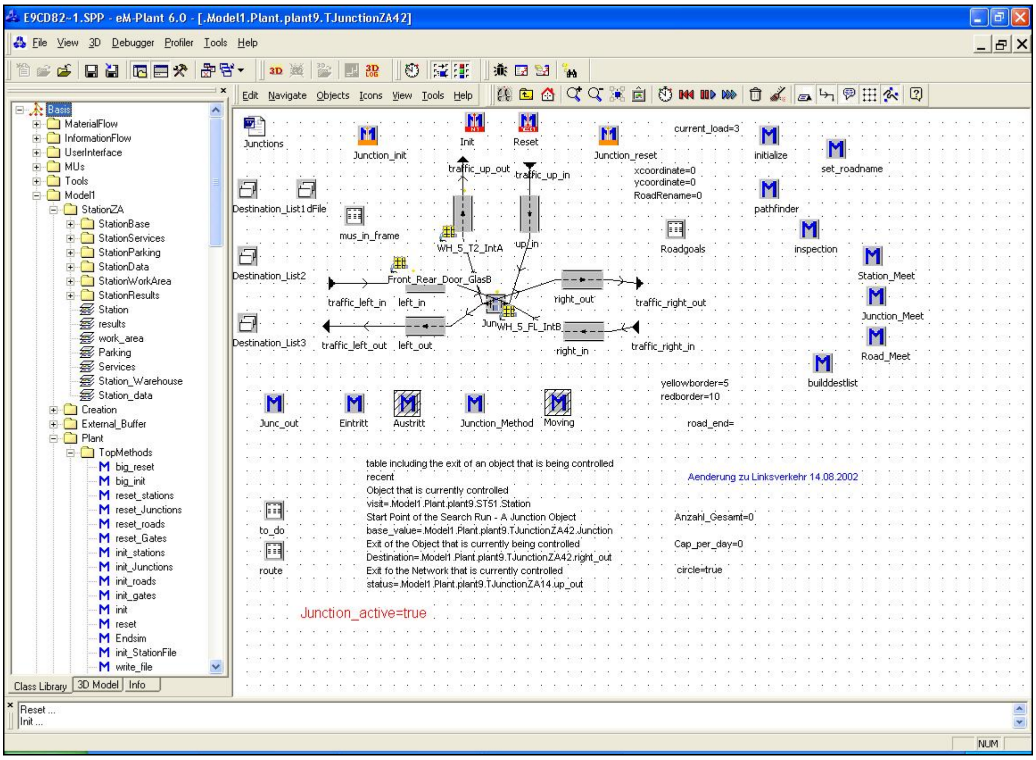


Figure 35: T-Junction building block

The T-junction building block provides:

- a three-way connection between any other building blocks
- tracks (travelling means) for all MUs

- the ability to set the capacity of the tracks within a T-junction (this allows the user to specify the maximum number of MUs that can be located on each section of the T-junction at any given time)
- the ability to set the lengths of the tracks within a T-junction (this information is necessary to track the distances that MUs travel, used for calculations at a later stage and presented in the "Traffic_Results.xls" file (see paragraph 9.5.2))
- the ability to monitor and record information on the MUs using a T-junction

X-Junction: The *X-junction building block* represents an X-junction within the plant. On the plant layout level, an *X-junction building block* is represented by the following symbol:

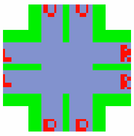


Figure 36: X-Junction symbol

On the X-junction layout level, an *X-junction building block* consists of a network of objects and methods as seen in Figure 37 below.

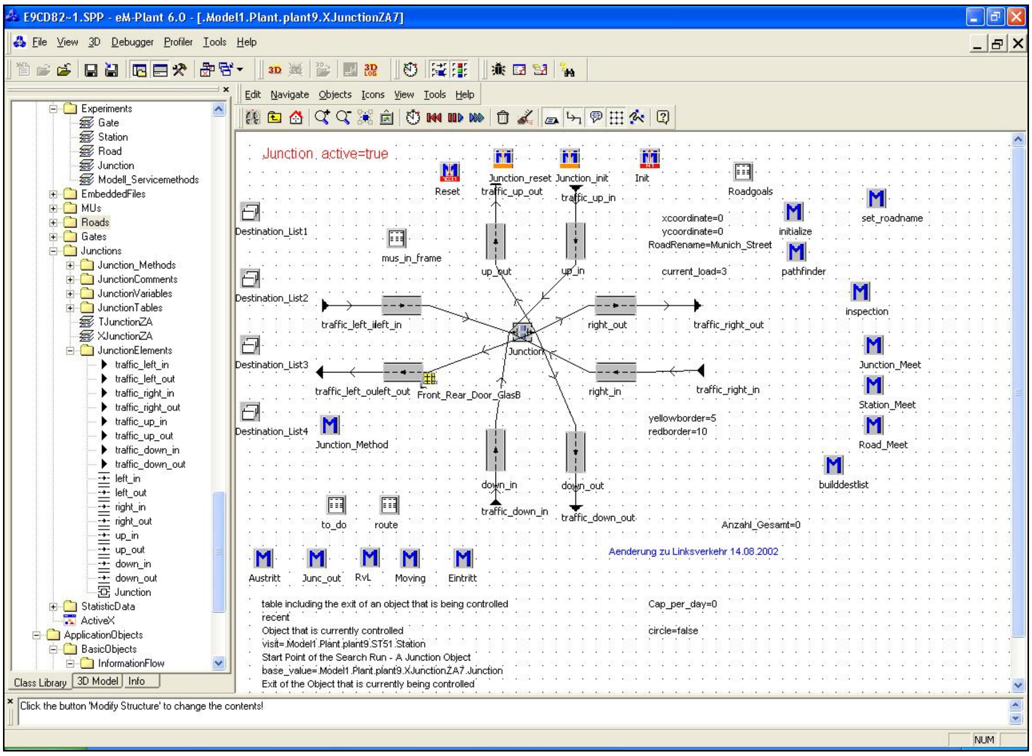


Figure 37: X-Junction building block

The X-junction building block provides:

- a four-way connection between any other building blocks
- “tracks” (travelling means) for all MUs
- the ability to set the capacity of the tracks within a X-junction (this allows the user to specify the maximum number of MUs that can be located on each section of the X-junction at any given time)
- the ability to set the lengths of the tracks within a X-junction (this information is necessary to track the distances that MUs travel, used for calculations at a later stage and presented in the “Traffic_Results.xls” file (see paragraph 9.5.2))
- the ability to monitor and record information on the MUs using a X-junction

9.4.5 Assumptions made

The following assumptions were made during the modeling process:

Assumption: all road capacities were set to be “1”. This means that no MU (moving unit) can pass another MU on a road.
Justification: The reason for this assumption is that as a rule, no vehicle may ever stop to offload while it is on a road. It may only stop in the dedicated parking / offloading areas next to the roads to offload. Even though it is physically possible for one vehicle to pass another on a road within the plant, this is generally not allowed because of plant safety restrictions. In light of this, this is a valid assumption.

Assumption: The *traffic levels* in the plant are measured as the number of MUs moving on a road at a specific time. Therefore, only moving MUs (MUs on the roads), in both direction on a road, are seen as traffic. MUs that have entered a station and are either waiting to be serviced or are already being serviced are not seen/measured as traffic.
Justification: one of the main objectives of the simulation model is to monitor the *expected* traffic flow levels and the traffic congestion / problem areas on the roads within the plant over time. Vehicles parked on a designated area within a station do not influence traffic flow in nearby roads. In light of this, this is a valid assumption.

9.5 Excel / eM-Plant Interface

As stated in the user requirement specification, it is essential that both the model’s *input data* and *simulation results* can be viewed and manipulated by users with relatively low computer skills and possibly no simulation skills, independent of the eM-Plant model and -software.

For this reason, both the input data and simulation results are captured in Microsoft Excel spreadsheets. The spreadsheet format and layout are predefined and cannot be changed by the user. The user is restricted to changing the values within each "cell" within the spreadsheets only. Predefining the spreadsheet format and layout is a prerequisite for the functionality of the interface between the Excel spreadsheets and the eM-Plant model.

Data transfer between Microsoft Excel and eM-Plant is enabled through eM-Plant's "activeX" interface. The "activeX" interface allows data to be read and exchanged between Excel spreadsheets and eM-Plant models (see Figure 38).

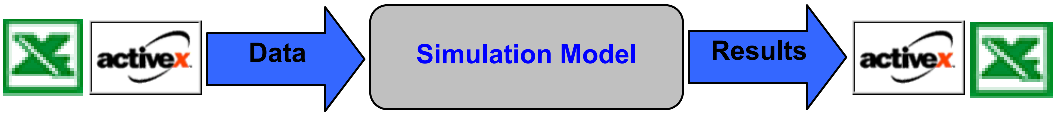


Figure 38: Excel / eM-Plant Interface

9.5.1 Importing Input Data

As explained in paragraph 9.3.2, data was collected for use as input to the simulation model and entered into the pre-configured Excel spreadsheet "MU_Data" (see Figure 25 and Appendix C).

The data is converted from Excel format into eM-Plant tables with eM-Plant's "activeX" interface every time the model is reset and initialised as follows:

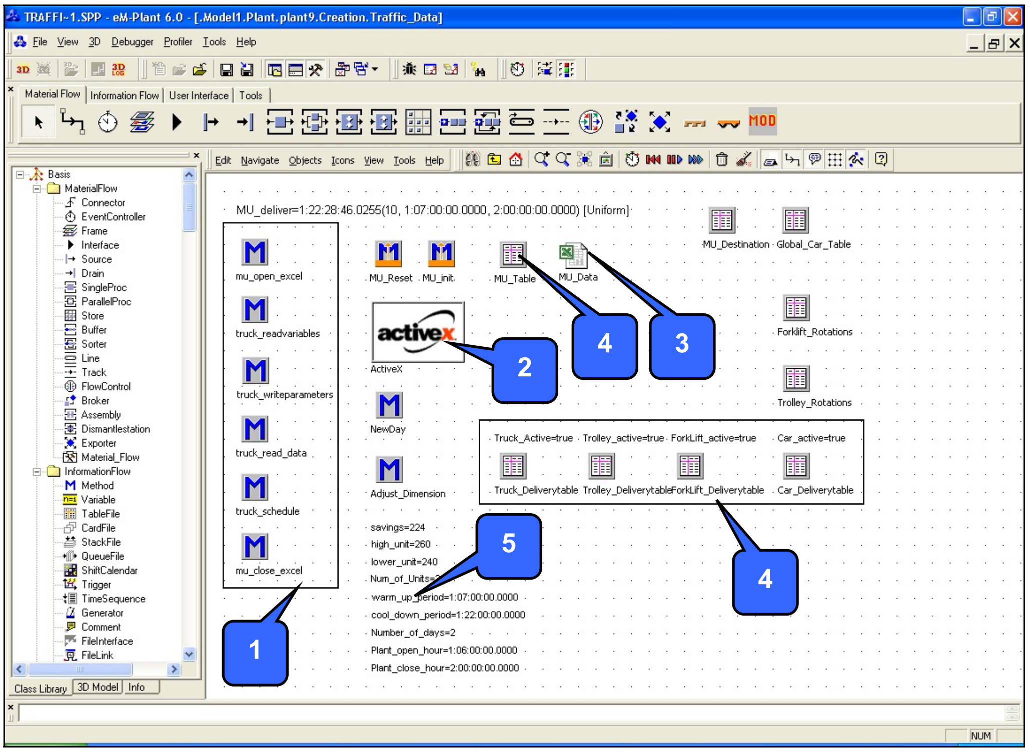


Figure 39: Importing Input Data

As the model is initialised, the respective methods (ref. 1 in Figure 39) containing *SimTalk* code and commands (see paragraph 9.4.2) are called and executed. They firstly use eM-Plant's *activeX* interface (ref. 2 in Figure 39) to establish a link for data exchange between the model and the Excel spreadsheet "MU_Data" (ref. 3 in Figure 39). Data is then read from the spreadsheet and written into the appropriate eM-Plant tables (ref. 4 in Figure 39) as explained in more detail in *"9.6.1 Creating MUs"*. All relevant model variables (ref. 5 in Figure 39) are set in accordance to the values specified in the spreadsheet. Once all relevant data have been transferred into the eM-Plant model, the *activeX* established link is disabled. This data can now be easily read and manipulated by other objects in the model.

9.5.2 Exporting Results

When running the simulation, data is collected in several eM-Plant tables. Once the simulation run has reached the end of an operational day (i.e. the end of a replication), this data is exported from the eM-Plant tables into the pre-defined Excel spreadsheet “Traffic_Results.xls” and saved as follows:

- The first time a replication is completed, the folder “c:/trafficsimulation” is created on the computer’s local hard drive.
- After every replication, a unique folder is created on the computer’s local hard drive within the “c:/trafficsimulation” folder and an internal counter in the model is incremented. The name of this created folder is “Simulation_Run_#”, with # being the number of the model’s internal counter.
- The predefined Excel spreadsheet is filled with actual data after every simulated operational day and saved under the corresponding “Simulation_Run_#” folder under a unique name referring to the “replication number” of the particular run.

As calculated earlier (see *7.6.2 Replications*), a minimum of 10 replications need to be done within every simulation run in order for the statistical results to comply with the desired confidence interval. After the 10th replication has been completed (resulting in a unique “Traffic_Results.xls” file being created for each replication), an extra “Traffic_Results.xls” file is created. The average values over the 10 replications are written to this file and stored under the name “Results_Run_#”, with # being the number of the model’s internal counter.

An example of the “Traffic_Results.xls” file is shown in Figure 40 and in Appendix C.

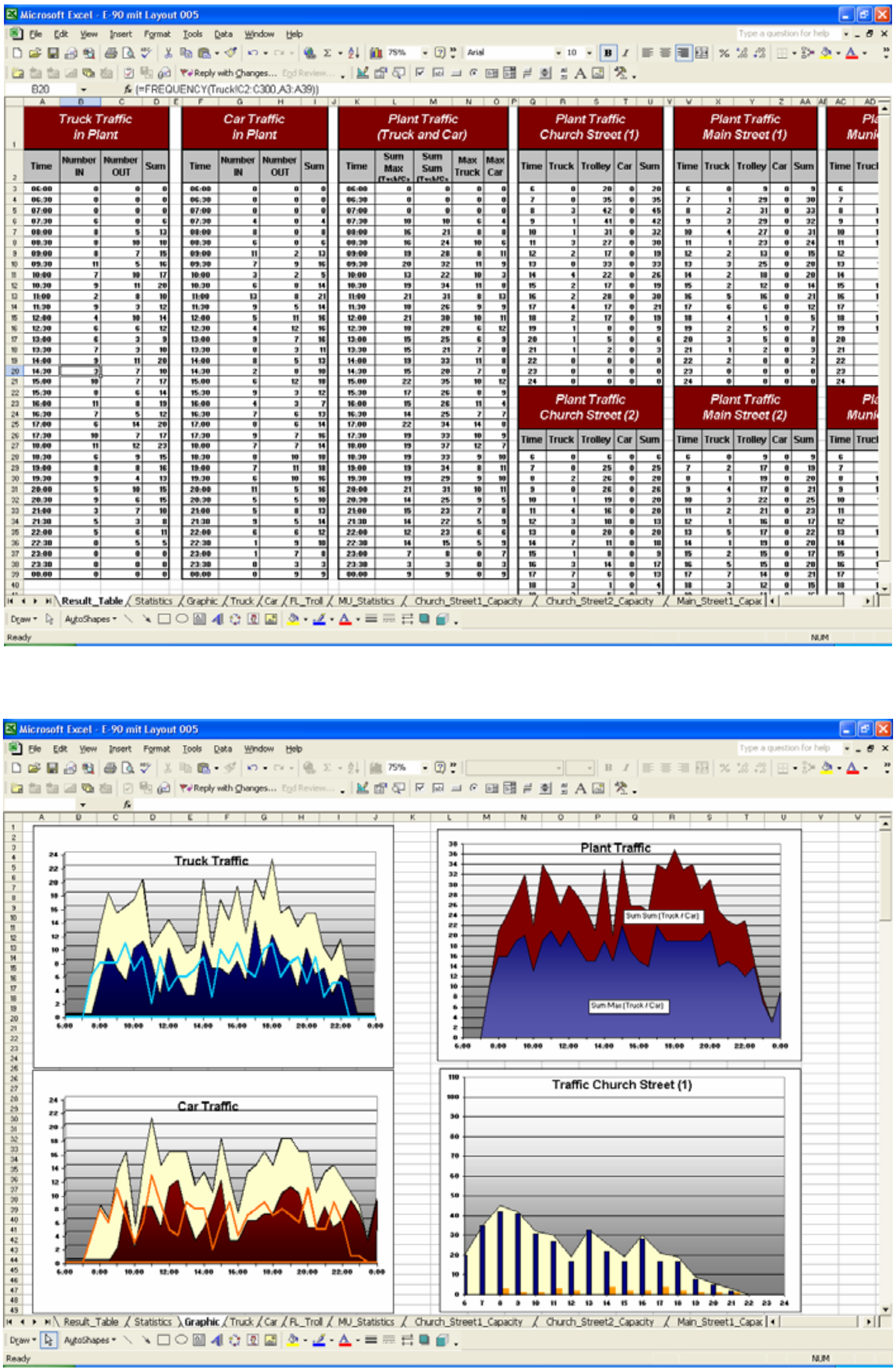


Figure 40: Simulation results: Traffic_Data.xls file

9.6 Routing MUs through the Model

The four different types of vehicles found within the plant (see *9.3.1 Traffic Sources*) are represented by four types of MUs (moving units), namely the *truck, trolley, forklift* and *car* type MU.

9.6.1 Creating MUs

As the input data file "MU_Data.xls" is converted and imported into the appropriate tables in the simulation model (as explained in paragraph *9.5.1 Importing Input Data*), a "creation list" specifying all MUs to be created during the simulation run is created in the eM-Plant tables (ref. 4 in Figure 39) as follows:

- The number of MUs of type *truck* equal to the specified "Trucks / Day" field is created for every entry in the Excel spreadsheet's "Trucks" sheet (e.g. the following entry in the Excel spreadsheet's "Trucks" sheet will result in 12 MUs of type *truck* to be created and added to the creation list:

Table 4: Example of entry in "Trucks" sheet

Delivery Number	Subject	SupplyConcept	Supplier	Trucks/ Day
14	**Cockpit_Module**	JIT	Faurecia	**12**

- The number of MUs of type *car* created during a simulation run is set equal to a sample drawn from a normal probability distribution with mean equal to the specified "Cars produced per day" cell, lower border equal to the specified "Lower production border" cell and upper border equal to the specified "Upper production border" cell in the Excel spreadsheet's "Parameters" sheet.
- One MU of type *trolley* is created for every entry in the Excel spreadsheet's "Trolleys" sheet.

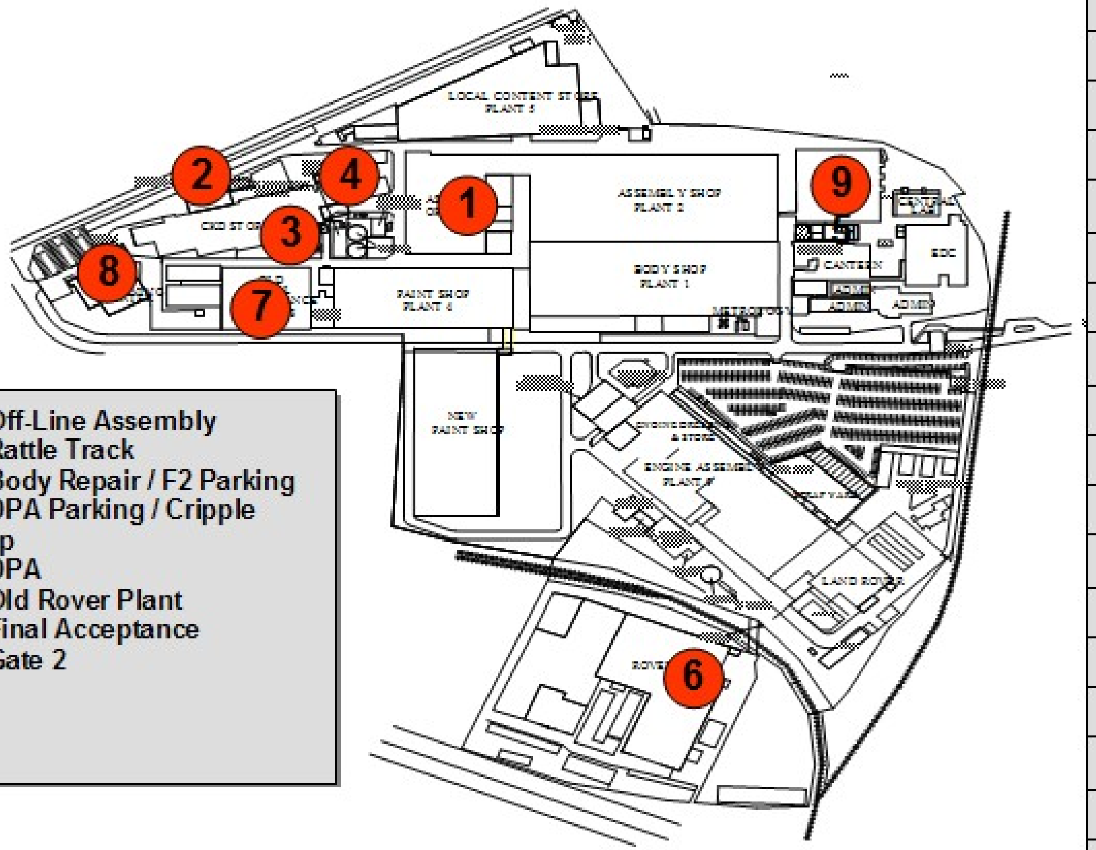
- One MU of type *forklift* is created for every entry in the Excel spreadsheet's "Forklifts" sheet.

All the MU's' information as specified in the Excel spreadsheet is attached as attributes to every entry in the *creation list.* As MUs are created from the *creation list* during the simulation run, the following attributes are also created and attached to them:

- Name (the delivery name as specified in the "subject" column in the Excel spreadsheet)
- Type (the MU type identifying it as a truck, trolley, forklift or car)
- Number of this type (the number of the specific type of MU to be created in the current simulation run)
- Distance travelled (variable keeping track of the distance the MU travels within the plant)
- Destination table (table containing information on the route the MU is to take within the plant as specified in the Excel spreadsheet, only created for- and attached to trucks, trolleys and forklifts)

Also read from the input data file "MU_Data.xls" and converted into an eM-Plant table is the *car-routing probability table*, containing a list of all the stations within the plant that a car may visit, all the following stations that the car may visit from that station, as well as the probability of a car visiting a following station from its current station[VIII] (see Figure 41 on next page).

[VIII] This probability table was set up from historical car routing information as found on the BMW SAP system. The system stores historical routing information on every car manufactured in the plant.



1 – Off-Line Assembly
2 – Rattle Track
3 – Body Repair / F2 Parking
4 – DPA Parking / Cripple Camp
5 – DPA
6 – Old Rover Plant
7 – Final Acceptance
8 – Gate 2

From	To	%
1	2	60
1	3	5
1	4	20
1	6	15
2	1	40
2	4	10
2	5	50
3	1	80
3	7	20
4	1	10
4	5	50
4	7	40
5	1	10
5	2	10
5	7	80
6	1	100
7	8	100

Figure 41: Car routing probability

9.6.2 Routing Trucks

Truck type MUs have a simple destination table as an attribute, containing its routing information (this includes the names of its entrance gate, destination station and exit gate). As a truck is created, it is directed to its "entrance gate", enters the model through this gate, moves via streets (roads, t-junctions and x-junctions) to reach and enter its destination station, is processed by the station, leaves the station, moves via streets to reach and enter its exit gate and exits the model through this gate (see Figure 42 below).

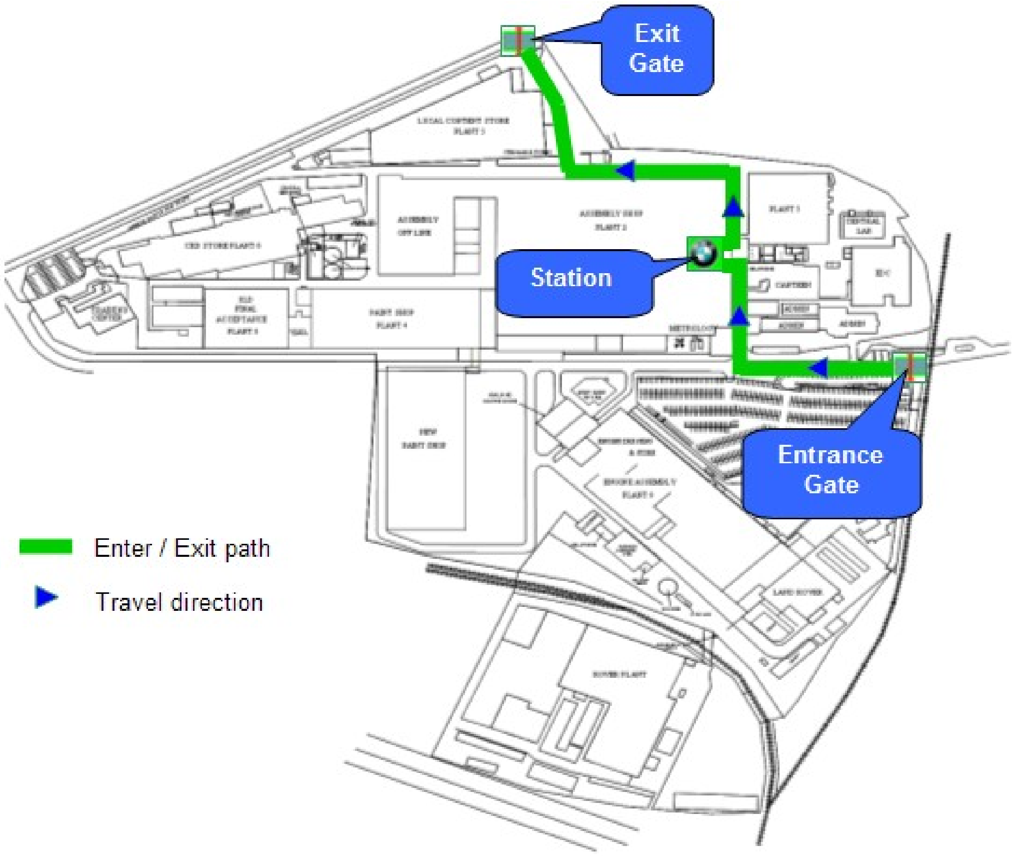


Figure 41: Example of a truck's route through the model

9.6.3 Routing Trolleys and Forklifts

Trolley- and forklift type MUs are routed through the model with similar logic. Each MU has a simple destination table as an attribute, containing its routing information (this includes the names of its entrance gate and two *rotation stations* (the two stations within the plant between which it should travel)). The number of rotations that the MU has to make between its rotation stations is also specified as one of its attributes. As a trolley or forklift is created, it is directed to its "entrance gate", enters the model through this gate, moves via streets (roads, t-junctions and x-junctions) to reach and enter the first of its rotation stations, moves between its rotation stations on streets for the number of times necessary (being processed by the stations every time it reaches them), then move via streets to reach and enter its exit gate and exits the model through this gate (see Figure 43 below).

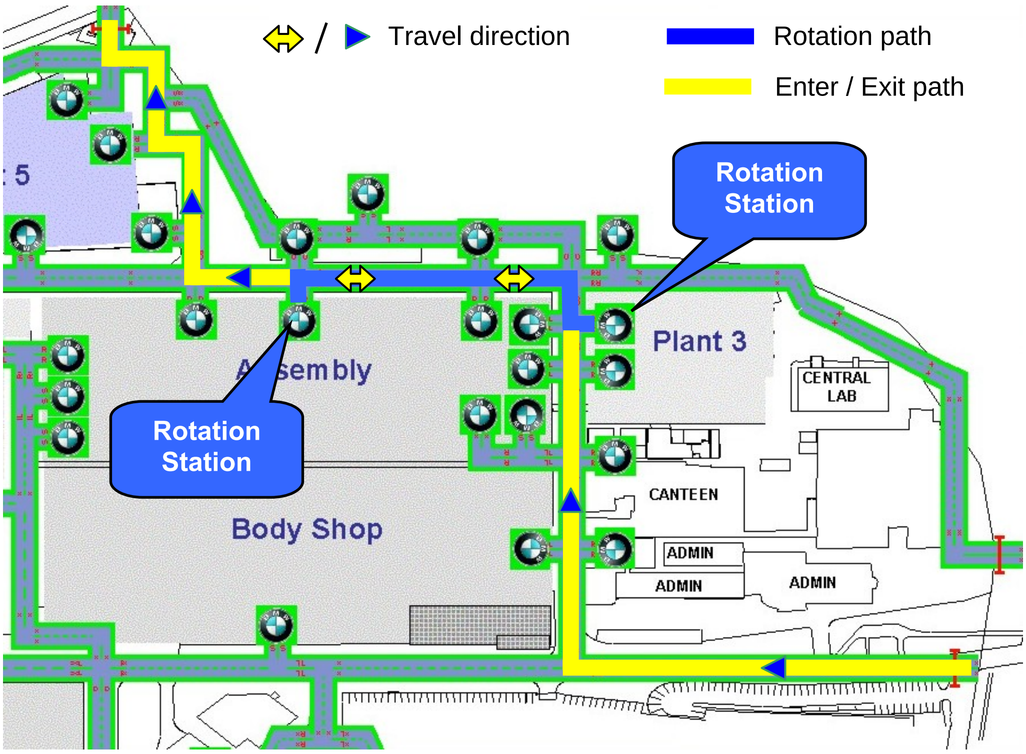


Figure 42: Example of a trolley / forklift's route through the model

9.6.4 Routing Cars

Car type MUs do not have a destination table as an attribute containing its routing information. Instead, the *car-routing probability table* (see Figure 41 and paragraph 9.6.1) is used to direct cars through the model. As a car is created, it is directed to the "car gate" (located at the end of the manufacturing assembly line) through which it enters the model. From here it moves via streets (roads, t-junctions and x-junctions) to reach and enter its destination stations. As the car leaves a particular station, its next destination is determined through the *car-routing probability table* and it moves to that destination until it eventually leaves the plant through its exit gate.

9.7 Simulation Output

As one of the user requirements specifications, the generated simulation output / results had to be presented in a graphical, easily interpreted format in order to compare the different scenarios quickly and intuitively and to communicate the results effectively across all organisational levels.

It is clear from both the simulation results and the current actual traffic flow situation within the plant that there are three areas within the plant where the traffic flow levels can be classified as *critical – being at or exceeding a capacity of 100%.* These areas are "Church-", "Main-" and "Munich street", as shown in the figure below. As a result, monitoring of the traffic flow will be focused on these three critical traffic flow areas.

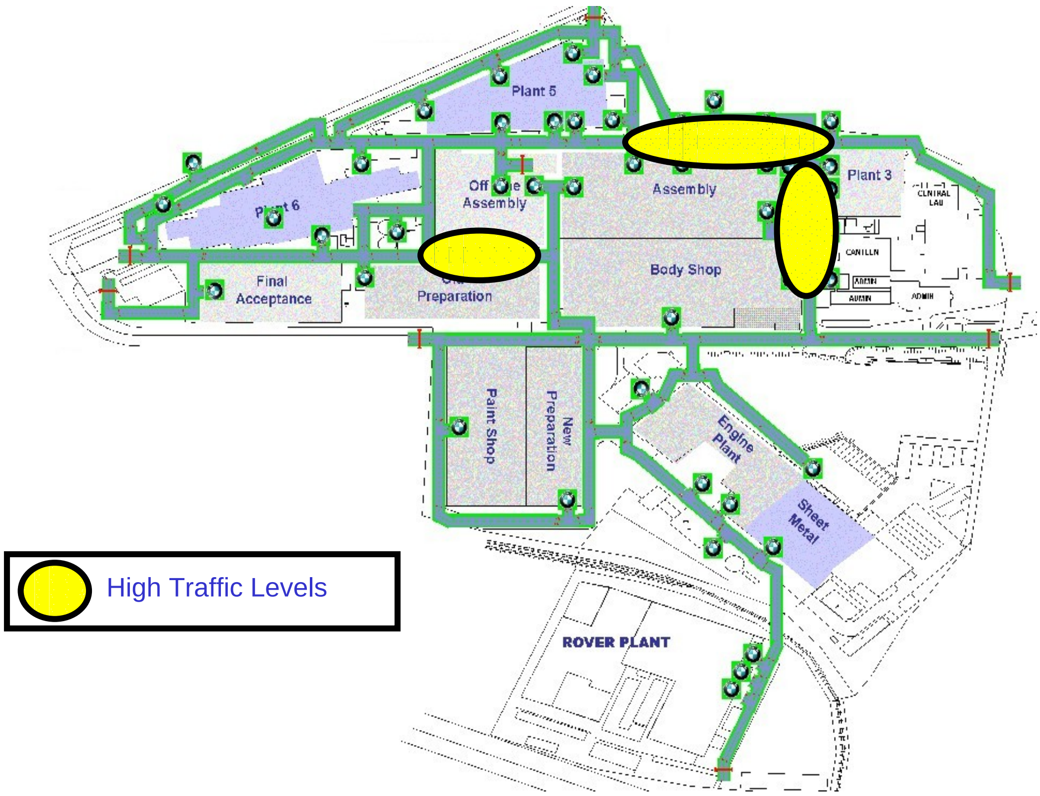


Figure 43: Critical traffic flow areas

The simulation results represent the expected current traffic flow levels (measured as the amount of MUs moving over a section of road, in any direction, on average per hour over the 10 simulation replications (see *7.6.2 Replications*)) on the *critical* roads within the plant, and are summarised in Figure 44 and Table 5.

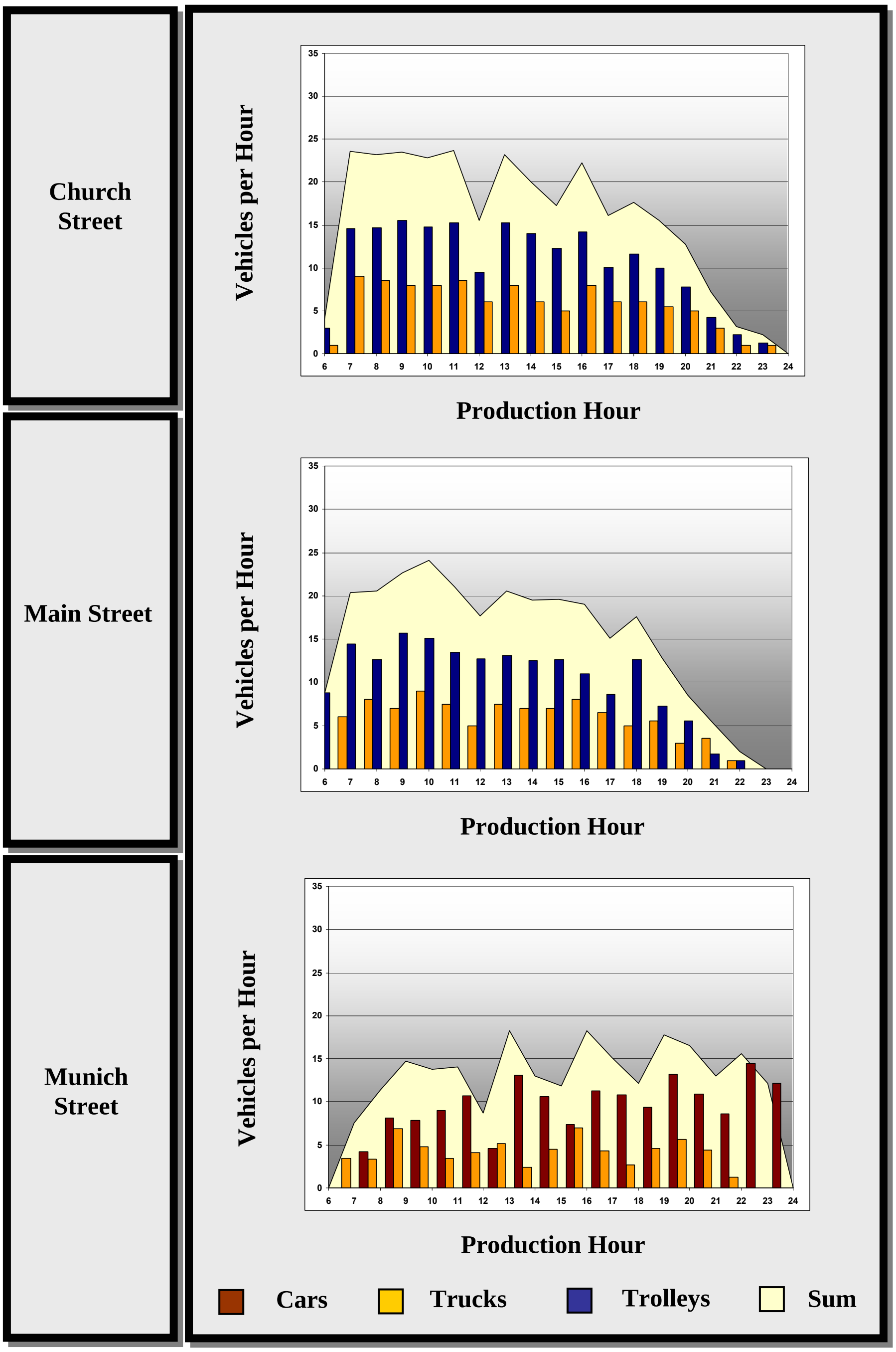


Figure 44: Current Scenario: Traffic Flow Levels

Table 5: Current Scenario: Statistics

General Statistics	MUs In Plant
	Sim. Model
# Trucks	246.90
# Trolley (Rotations)	240.20
# Cars (left the Plant)	215.50

Car Statistics	Off-Line Assembly
	Sim. Model
Max Process Time	06:09:40
Ave Process Time	02:06:50
Max Driven Km	8.06
Ave Driven Km	1.94

Trolley Statistics	Supply Routes
	Sim. Model
Max Supply Route (All) Km	16.39
Ave Supply Route (All) Km	7.65
Max Supply Route (Single)	2.22
Ave Supply Route (Single)	1.21

Truck Statistics	Supply Routes
	Sim. Model
Max Process Time	01:57:14
Ave Process Time	00:30:13
Max Driven Km	1.22
Ave Driven Km	0.74

These are the figures and table as found in the “Traffic_Result.xls” file. The complete “Traffic_Result.xls” file is shown in Appendix C. The statistical outputs to a simulation run are:

General statistics

- **# Trucks:** the number of trucks that left the plant during a simulation replication (averaged over all replications. See *9.6.2 Routing Trucks)*

- **# Trolley/Forklift (Rotations):** the number of completed trolley and forklift rotations (see *9.6.3 Routing Trolleys and Forklifts)* during a simulation replication (averaged over all replications)
- **# Cars (left the plant):** the number of cars that left the plant during a simulation replication (averaged over all replications. See *9.6.4 Routing Cars)*

Car Statistics

- **Max Process Time:** The longest time that any car was processed before leaving the plant (maximum over all replications)
- **Ave Process Time:** The average time that every car was processed before leaving the plant (average over all replications)
- **Max Driven km:** The furthest distance that any car drove within the plant before leaving the plant (maximum over all replications)
- **Ave Driven km:** The average distance that every car drove within the plant before leaving the plant (averaged over all replications)

Trolley/Forklift Statistics

- **Max Supply Route (All) km:** The furthest total distance that any trolley/forklift drove within the plant during a replication (maximum over all replications)
- **Ave Supply Route (All) km:** The average total distance that every trolley/forklift drove within the plant during a replication (average over all replications)
- **Max Supply Route (Single) km:** The furthest distance that any trolley/forklift drove within the plant for a single rotation (see *9.6.3 Routing Trolleys and Forklifts)* during a replication (maximum over all replications)
- **Ave Supply Route (Single) km:** The average distance that every trolley/forklift drove within the plant for a single rotation

(see *9.6.3 Routing Trolleys and Forklifts)* during a replication (average over all replications)

Truck Statistics

- **Max Process Time:** The longest time that any truck spent within the plant (maximum over all replications)
- **Ave process Time:** The average time that every truck spent within the plant (average over all replications)
- **Max Driven km:** The furthest distance that any truck drove within the plant (maximum over all replications)
- **Ave Driven km:** The average distance that every truck drove within the plant (average over all replications)

9.8 Model Verification and Validation

Before the model can be accepted as a valid representation of the real-world system being simulated, all aspects of the model must first be verified and validated (see paragraph 7.3.7 for definitions of verification and validation). The model was verified and validated by:

- Doing a "walk through" of the entire model, verifying that it operates in the intended manner according to the modeling assumptions made and programming logic used. This was done by using:
    - animation as a tool to "track" individual MUs through the model, verifying that it is directed through the model in the expected and intended manner
    - eM-Plant's *debugger* function to follow and view the logic of each *SimTalk* command within each method in the model as it is executed in real-time during a simulation run (see paragraph *9.4.2 Modeling with eM-Plant Methods and SimTalk*)

- Verifying the validity of all assumptions made (see paragraph *9.4.5 Assumptions made*) by consulting individuals experienced in simulation modeling with eM-Plant simulation software
- Comparing the simulation results of the model of the as-is situation (the base case) with actual information from the real world system. Hypothesis test were conducted to determine if there is a statistically significant difference between the model and the real-world system (see Figure 46, Figure 47 and Table 6)

The hypothesis tests were performed following the guidelines provided by Johnson[10], as follows:

Firstly, by formulating a null hypothesis and an appropriate alternative hypothesis for every statistical output that had to be evaluated. In each case the null hypothesis was formulated as *μ = actual value* (see Table 6), and the two-sided alternative hypothesis was in turn formulated as *μ ≠ actual value.* The alternative hypothesis is two-sided because one would want to reject the null hypothesis if the mean of the *simulated values* is significantly less than or significantly greater than the *actual values*.

Secondly, by specifying the level of significance. In each case this was set at $\alpha = 0.05$.

Thirdly, by calculating the criterion Z (assuming the results are approximately normally distributed due to the central limit theorem), on which the outcome of the test will be based, as:

$$Z = \frac{\overline{\chi} - \mu_o}{\frac{\sigma}{\sqrt{n}}}$$

with n (the number of replications performed) equal to 10 (following the calculation in *7.6.2 Replications*). For $\alpha = 0.05$, the dividing lines (or critical values) of the criteria are -1.96 and 1.96 for the two-sided alternative hypothesis (Johnson[10], p.240). This means that the null hypothesis will be rejected if Z < -1.96 or Z > 1.96.

The calculations were done in MS-Excel and the results are shown in Table 6. Following the outcome of the hypothesis tests, it is concluded that there is no significant difference between the simulation model's results and the actual values / reality. Thus, the simulation model represents reality sufficiently.

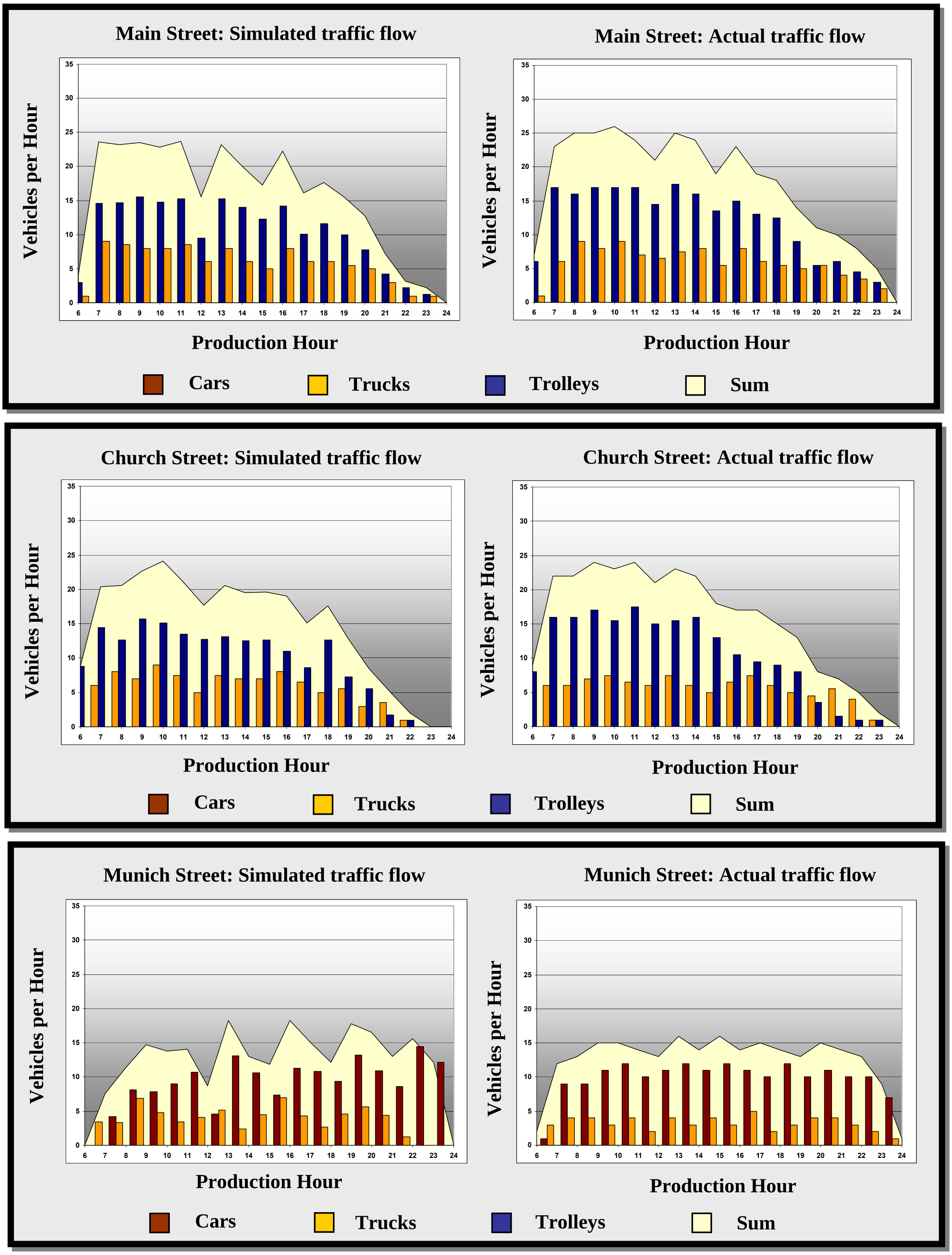


Figure 45: Comparing simulated- and actual traffic flow

The minimum, maximum and average values of the simulation results are displayed over time in Figure 47, providing a good indication of the variability between the replications (see *7.6.2 Replications*):

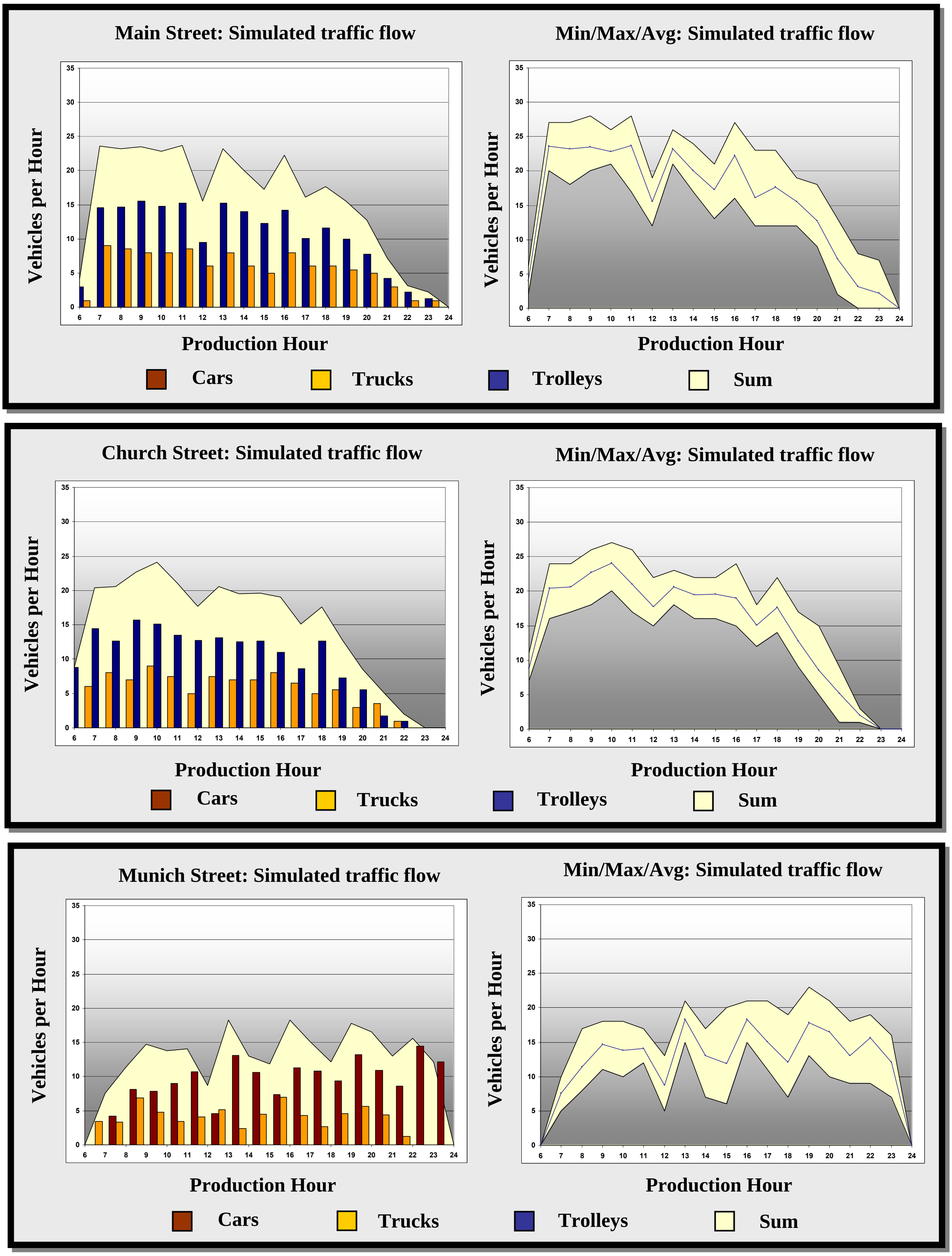


Figure 46: Evaluation of simulated traffic-flow spread

Table 6: Comparing simulated- and actual statistics

General Statistics	***MUs In Plant***		***Null Hypothesis: μ =***	$\hat{\sigma}$	***Z***	***Hypothesis Test Result: Reject Null Hypothesis if Z < -1.96 or Z > 1.96***
	Sim. Model	**Actual**				
# Trucks	**246.90**	**247.00**	**247.00**	**0.316**	**-1.000**	**Do not reject**
# Trolley (Rotations)	**240.20**	**238.00**	**238.00**	**9.438**	**0.737**	**Do not reject**
# Cars (left the Plant)	**215.50**	**220.00**	**220.00**	**7.934**	**-1.794**	**Do not reject**
Car Statistics	***Off-Line Assembly***					
	Sim. Model	**Actual**				
Max Process Time	**06:09:40**	**06:32:00**	**06:32:00**	**00:49:03**	**-1.440**	**Do not reject**
Ave Process Time	**02:06:50**	**02:05:00**	**02:05:00**	**00:04:01**	**1.447**	**Do not reject**
Max Driven Km	**8.06**	**7.50**	**7.50**	**1.951**	**0.900**	**Do not reject**
Ave Driven Km	**1.94**	**1.90**	**1.90**	**0.094**	**1.450**	**Do not reject**
Trolley Statistics	***Supply Routes***					
	Sim. Model	**Actual**				
Max Supply Route (All) Km	**16.39**	**16.50**	**16.50**	**1.521**	**-0.227**	**Do not reject**
Ave Supply Route (All) Km	**7.65**	**7.80**	**7.80**	**0.399**	**-1.192**	**Do not reject**
Max Supply Route (Single)	**2.22**	**2.25**	**2.25**	**0.084**	**-1.017**	**Do not reject**
Ave Supply Route (Single)	**1.21**	**1.24**	**1.24**	**0.073**	**-1.270**	**Do not reject**
Truck Statistics	***Supply Routes***					
	Sim. Model	**Actual**				
Max Process Time	**01:57:14**	**01:50:00**	**01:50:00**	**00:29:03**	**0.788**	**Do not reject**
Ave Process Time	**00:30:13**	**00:29:00**	**00:29:00**	**00:02:04**	**1.864**	**Do not reject**
Max Driven Km	**1.22**	**1.23**	**1.23**	**0.030**	**-1.044**	**Do not reject**
Ave Driven Km	**0.74**	**0.75**	**0.75**	**0.012**	**-1.722**	**Do not reject**

9.9 Modeling Different Scenarios

Now that the simulation model has been set-up, verified and validated, it is possible to adapt the model to represent various different scenarios. The effects of the various alternatives considered during the supply planning process (as described in *Chapter 2: Problem Statement*) and its impact on plant traffic can now be systematically evaluated:

- Firstly: by means of the SMDST, which provides critical information about the cost implication and number of deliveries required for all possible combinations of part families and delivery vehicles used (see appendix *A: SMDST User Manual*)
- Secondly: the simulation model's input data file can easily be updated in accordance to the SMDST's information in preparation of a new simulation experiment (see *9.3.2. Excel: Input Data)*
- Thirdly: the traffic flow simulation model can be run. The model will automatically use the updated input data file and create unique results files for the scenario currently under analysis
- Fourthly: the simulation model's results files can be viewed and compared to those of previous scenarios (see *9.7 Simulation Output*)

Each scenario will consist of a unique set of data files, as shown in Table 7:

Table 7: Files for each scenario

Description	File Name	File Type
Simulation model	e.g. E46_current scenario	eM-Plant model (.ssp)
Input data	MU_Data	Microsoft Excel Spreadsheet (.xls)
Results	Traffic_Results	Microsoft Excel Spreadsheet (.xls)
Station Files	ST01 – ST54	Microsoft Excel Spreadsheet (.xls)

These files have been completed for the current scenario at BMW Plant 9.2 in Rosslyn and can be viewed in Appendix C. (In future, this scenario will be referred to as the **base** scenario).

To illustrate the capability and use of the tools developed during this project, one of the various changes considered for BMW Plant 9.2 was evaluated and compared to the base scenario. The complete exercise is shown in Appendix D.

10 CONCLUSION

BMW SA and other automotive manufacturers are facing various specific problems relating to supply- and traffic flow planning. Two of these specific problems lie in:

- selecting the best supplier transportation medium among various alternatives for the supply of each part family, taking into account the effect on plant traffic. Several variables have to be considered during this decision making process, and no concrete decision support tool existed to assist during this process

- accessing the impact of physical relocation decisions and changes to the location of delivery areas within the plant on plant traffic

BMW Plant 9.2 in Rosslyn are planning to switch production from the E46 (current 3-series) model to the E90 (new 3-series) model in 2005 (see chapter *1 Introduction*). Several proposed plant layout changes and changes to the location of supplier delivery points exist for the E90 scenario (see chapter *2 Problem Statement*). These proposed changes will imply large relocation expenses and will inevitably have a major impact on the traffic flow within the plant.

Tools developed during this study will assist automotive manufacturers during the supply planning phase of their logistics planning process. The respective impact of these proposed changes can now be investigated, analysed and compared by means of these tools. Even though the tools can function independently, their real value is only realised once they are used in conjunction with each other as a Decision Support System (DSS) (see *chapter 6 Decision Support Systems).* In essence, this DSS consists of a Supply Medium Decision Support Tool (SMDST) and a traffic flow simulation model.

The effects of various decisions considered during the supply planning process (as described in *Chapter 2: Problem Statement*) and the impact of these decisions on plant traffic can now be systematically evaluated (see Figure 48 and *9.9 Modeling Different Scenarios*):

- Firstly: by means of the SMDST, which provides critical information about the cost implication and number of deliveries required for all possible combinations of part families and delivery vehicles used

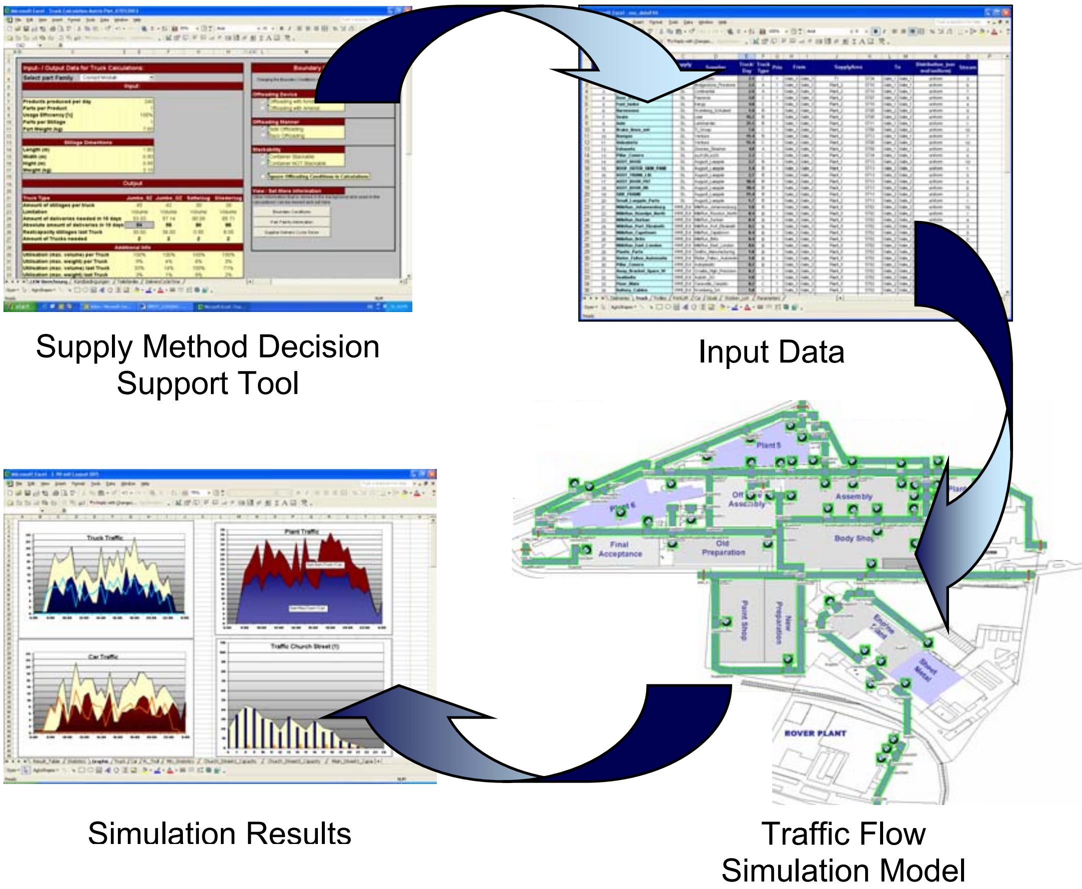


Figure 48: Overview of supply and traffic flow Decision Support System (DSS)

- Secondly: the simulation model's input data file can easily be updated in accordance to the SMDST's information in preparation of a new simulation experiment
- Thirdly: the traffic flow simulation model can be run. The model will automatically use the updated input data file and create unique results files for the scenario currently under analysis
- Fourthly: the simulation model's results files can be viewed and compared to those of previous scenarios

All the user requirements as stated in the user requirements specifications (sections 8.2 and 9.2) have been met. Every component of the DSS was developed generically as far as possible, allowing the user to adapt it to other similar manufacturing plants with relative ease.

By utilising this DSS, scenarios can be evaluated and compared faster, more efficiently and by means of more quantitative measures than before, considerably reducing uncertainty and risk of planning (as demonstrated in the application example in *Appendix D*).

Certainly, this system will not only give BMW SA a competitive edge in preparing for the launch of the E90, but can also support other automotive manufacturers in their quest towards manufacturing excellence in an ever-increasing internationally competitive and complex environment.

11 BIBLIOGRAPHY

1. Alter, S.L., *Decision Support Systems: Current Practices and Continuing Challenges*. Reading, MA: Addison-Wesley, 1980
2. Anderson, D., *Beyond change management,* Pfeiffer, 2001
3. Baron, R.A., Byrne, D., *Social Psychology: Understanding Human Interaction*, seventh edition, Boston: Allyn and Bacon, 1994
4. Davis, D., *Business Research for Decision Making*, fifth edition, Duxbury, 2000
5. Fitzpatrick, J., Secrist, J., Wright, D. J., *Secrets for a successful dissertation*, Sage Publications, 1998
6. Gogg, T. J., Mott, J. R. A., *Improve quality and productivity with simulation,* 1992
7. Harrington, H. J., Tumay, K., *Simulation Modeling Methods*, McGraw-Hill, 2000
8. Hesse, R., *Managerial spreadsheet modeling and analysis,* Irwin, 1997
9. Hultman, K., *Making change irresistible : overcoming resistance to change in your organization,* Davies-Black, 1998
10. Johnson, R. A., *Miller and Freud's Probability and Statistics for Engineers*, fifth edition, Prentice-Hall, 1994
11. Judson, A. S., *Changing behavior in organizations : minimizing resistance to change,* Blackwell Business, 1991
12. Keen, P.G.W., and M.S. Scott-Morton. *Decision Support Systems, An Organizational Perspective*. Reading, MA: Addison-Wesley, 1978
13. Kelton, W. D., Sadowski, R. P., Sadowski, D. A., *Simulation with Arena*, p.176, 1998
14. Kerlinger, F. N., *Foundations of Behavior Research*, third edition, New York, 1986, p.10
15. Krick, E., *An Introduction To Engineering Concepts*, *Methods And Issues*, New York, John Wiley & Sons, Inc., 1974
16. Louw, D.A., *Human Development*, Pretoria: HAUM, 1991
17. McLeod, J., *Simulation*, Volume 51, Number 4, October, Simulation Councils, Inc., 1988
18. Melville S, Goddard W, *Research Methodology*, Juta & Co Ltd, 1996
19. Mouton, J., *How to succeed in your Master's and Doctoral Studies*, Van Schaik, 2001
20. Oxford, *The Oxford Encyclopaedic English Dictionary*, Oxford University Press, New York, 1991
21. Sage, A.P., *Decision Support Systems Engineering*, John Wiley & Sons, Inc. 1991

22. Schneidman, B., *Designing the User Interface: Strategies for Effective Human Computer Interface,* Addison-Wesley, Reading, MA, 1987
23. Simon, H. *The New Science of Management Decision*. Englewood Cliffs, NJ: Prentice-Hall, 1977
24. Sprague, R. H., Jr., Watson H. J., *Decision Support Systems: Putting Theory into Practice,* Prentice-Hall, 1993
25. Swain, J. J., "Imagine New Worlds" *OR/MS Today,* February 1999, pp. 38-41
26. Turban, E. *Decision support and Expert Systems: Management Support Systems,* third edition, Macmillan, 1993
27. Whicker, M. J., Sigelman, L., *Computer Simulation Applications: An Introduction*, Sage Publications, 1991
28. Zikmund, W. G., *Business Research Methods*, South-Western, 2003
29. www.sei.cmu.edu