STUDIES USING COMPUTER SIMULATION MODELS TO SOLVE PROBLEMS RELATED TO LOGISTICS TERMINALS

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BY

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CERTIFICATE

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DECLARATION

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ABSTRACT

Keywords: *Simulation, Logistics Terminals, Performance Improvement, Conceptual modelling.*

This thesis deals with the use of simulation as a problem-solving tool to solve a few logistic system related problems. More specifically it relates to studies on transport terminals. Transport terminals are key elements in the supply chains of industrial systems. One of the problems related to use of simulation is that of the multiplicity of models needed to study different problems. There is a need for development of methodologies related to conceptual modelling which will help reduce the number of models needed. Three different logistic terminal systems Viz. a railway yard, container terminal of apart and airport terminal were selected as cases for this study. The standard methodology for simulation development consisting of system study and data collection, conceptual model design, detailed model design and development, model verification and validation, experimentation, and analysis of results, reporting of finding were carried out.

We found that models could be classified into tightly pre-scheduled, moderately pre-scheduled and unscheduled systems. Three types simulation models(called TYPE 1, TYPE 2 and TYPE 3) of various terminal operations were developed in the simulation package Extend. All models were of the type discrete-event simulation. Simulation models were successfully used to help solve strategic, tactical and operational problems related to three important logistic terminals as set in our objectives. From the point of contribution to conceptual modelling we have demonstrated that clubbing problems into operational, tactical and strategic and matching them with tightly pre-scheduled, moderately pre-scheduled and unscheduled systems is a good workable approach which reduces the number of models needed to study different terminal related problems.

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CHAPTER ONE

INTRODUCTION AND RESEARCH FRAMEWORK

1.1. INTRODUCTION

This thesis deals with the study of use of simulation as a problem-solving tool to solve a few logistic system related problems. Transport systems involve multiple entities and getting good performance from such complex system is found to be a difficult exercise. Decision making in such systems are done with analytical, mathematical and heuristics based models. Simulation is also becoming a favorite tool in this area especially due to the common use of computers in problem solving and the availability of good simulation packages and trained personnel.

1.1.1. Logistics

Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third-party logistics services providers. To varying degrees, the logistics function also includes sourcing, procurement, production planning, scheduling, packaging, assembly and customer service. It is involved in all levels of planning and execution--strategic, operational and tactical. Logistics management is an integrating function, which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology[1].

Logistics management takes into consideration every facility that has an impact on cost. It plays an important role in making the product conform to customer

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[1] Council of Logistics Management, http://www.cscmp.org/Website/AboutCSCMP/Definitions/Definitions.asp (12 June 2007)

requirements. Also it involves efficient integration of suppliers, manufacturers, warehouses and stores and encompasses the firms' activities at many levels, from the strategic level through the tactical to the operational level.

Logistics is a challenging and important activity because it serves as an integrating or boundary spanning function. It links suppliers with customers and it integrates functional entities across a company. With the ever-growing competition in today's market place it becomes necessary for a firm to use its resources to focus on strategic opportunities. This is where the concept of logistics plays a major role, i.e. it helps to leverage certain advantages the firm has in the marketplace.

The logistics network, consists of suppliers, manufacturing centers, warehouses, distribution centers and retail outlets, as well as raw materials, work-in-process inventory and finished products that flow between the facilities as illustrated in Figure1.1.

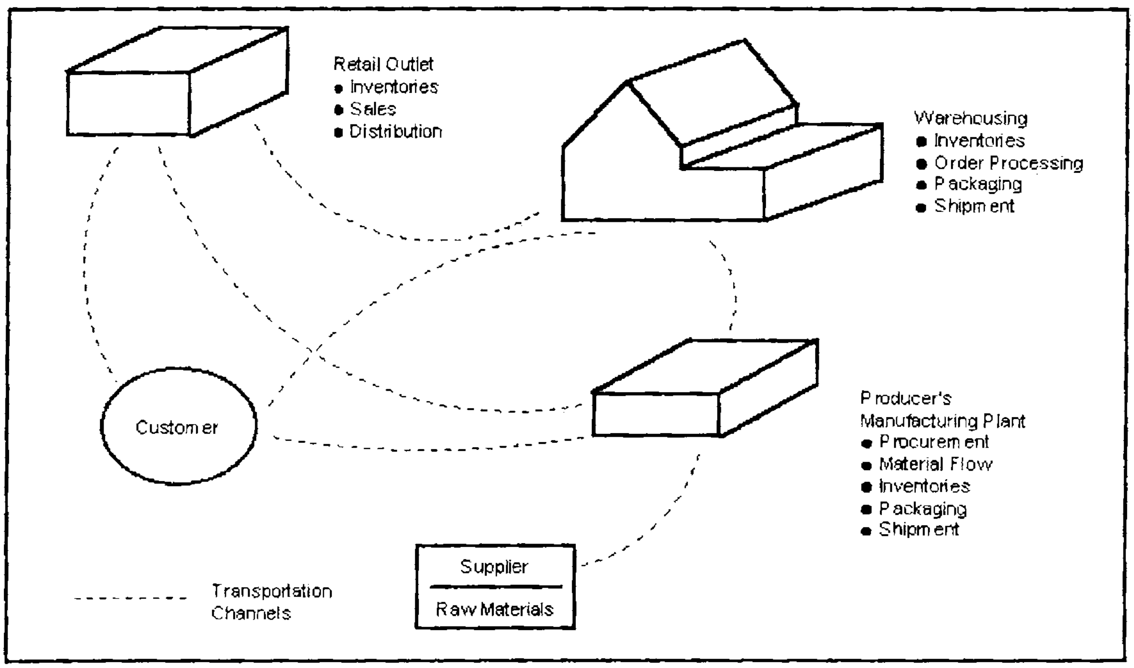

Figure 1.1: Elements of Industrial Logistics

(Figure Source: Blanchard, B. S., *Logistics Engineering and Management)*

McGinnis (1998) categorize logistics activities into the following distinct groups,

Transportation: transporting a package or unit load from a specific origin to a specific destination.

Distribution: use of a warehouse as a staging point for satisfying customer orders together with transportation to the customer.

Manufacturing: all the material handling and control within a factory.

1.1.2. Supply chains

Researchers and practitioners have several definitions for the supply chain. Each definition contains common key words such as logistics network, supplier, end-customer, raw material, information, goods/products, services, and facilities. From a management view, Tan (1998) defines a supply chain as encompassing material/supply management from the supply of basic raw materials to final product; it also focuses on how firms utilize their suppliers, processes, technology and capability to enhance competitive advantage. From a logistics view, Saunders (1997) defines a supply chain as an external chain that is the total chain of exchange from original source of raw material, through the various firms involved in extracting and processing raw materials, manufacturing, assembling, distributing and retailing to ultimate end customers. Ellram (1991) defines a supply chain as a network of firms interacting to deliver product or service to end customer, linking flows from raw material supply to final delivery. Business concerns recognize the need to invest in and focus on supply chains. The growth in telecommunication and transportation technologies has led to further growth of the supply chain.

One of the great strengths of simulation modelling is the ability to model and analyze the dynamical behavior of a system. This makes simulation an ideal tool for analyzing supply chains because supply chains can exhibit very complex dynamical behavior.

1.1.3. Transport Terminals

A terminal is a node in a transport network between the supplier and the customer, it binds together transport modes with different characteristics into a transport chain in order to meet the supplier's and the customer's demand for frequency and capacity in the flow. The activities in a terminal will consequently be connected to problems created from differences, since varying structure between customers and suppliers as well as between different means of transportation must be overcome. This, among other things, leads to the fact that the problems are of a very varying sort depending on if they regard the operative activities or new constructions and/or expansion (Lumsden, 2002).

1.1.4. Managerial decision making.

The level or hierarchy of management involved in the decision making is dependent on the type of problem. Three types of problem categorization are common.

Strategic level: Strategic level problems consider long-term decisions that involve large capital expenditures.

Tactical level: Tactical level decisions affect operations over the course of year or so, and are often made by middle managers.

Operational level: Operational level problems deal with day-to-day decision issues. Operational decisions follow guidelines set during tactical planning.

1.2. THE PROBLEM AND OBJECTIVES OF STUDY

Transport terminals are key elements in the supply chains of industrial systems. Ideally, a terminal must be planned so as to ensure an acceptable level of service in terms of waiting time for transport means and goods/passengers. Insufficiency of capacity of infrastructure, and unpredictable problems (such as delay in ship arrival, variability in container numbers, breakdowns, etc.), reduce the level of service in terminal systems. There are basically two ways to face this situation: either to improve operational methods, and/or to invest in new facilities. The second solution is usually much more expensive, so the analysis should begin by exhausting the first option. If the desired performance is not achieved, then the investment in new facilities should be considered. Simulation models and analytical models are used to solve a large number of such problems. The types of problems that can be studied by a model differ according to the flexibility of the model.

Air, sea, road and rail are the transport modes used to carry bulk cargo. It is to be noted that large terminal facilities exist mostly in the case of air, sea and rail and it is at these terminals that most delays and inefficiencies are present. Terminal operations are therefore key to improving these transport systems.

In this thesis we have studied the following three systems:

1. A Container terminal for a port
2. A railway marshalling yard for passenger trains
3. An Airport terminal

The basic purpose of any simulation model is to address the problem/problems of real world systems. Model(s) may be developed to solve a single problem or multiple problems. Usually a single model will not be able to solve many other problems. When many problems are to be solved many different models (these models need not be very different) are usually developed. Figure 1.2 illustrates this concept. Problems at hand may be similar or dissimilar. For example when a system runs on time schedules (e.g. an airport), problems like shift timing, fixing additional schedules, are similar. But a problem like design of system capacity is not similar to schedule related problems. There is a need for creating separate models for each of above problems. Single or multiple models of a system could be developed to tackle problems in four different ways as depicted in Figure 1.2. *It is not economical to build a new simulation model of a system each time a new problem is to be solved. A flexible modelling framework which addresses different categories of problem should be envisaged at the time of conceptual modelling.* If we could develop techniques of categorizing problems and systems modelled, so that problems in the same category, can be solved using the same or very similar model, it would be a great contribution to development and use of simulation. This issue has been focused on in this work with respect to terminal system characteristics.

The motivation for this research is the apparent lack of modelling studies related to terminal systems together even though there exist several models of each of individual types of terminal systems. Commonalities or differences in characteristics related to modelling, facility design, operational planning and problem solving remain relatively less researched. Another motivation was the fact that even though, Kerala State has some large terminal systems in and around Kochi, hardly any simulation modeling based studies have been reported.

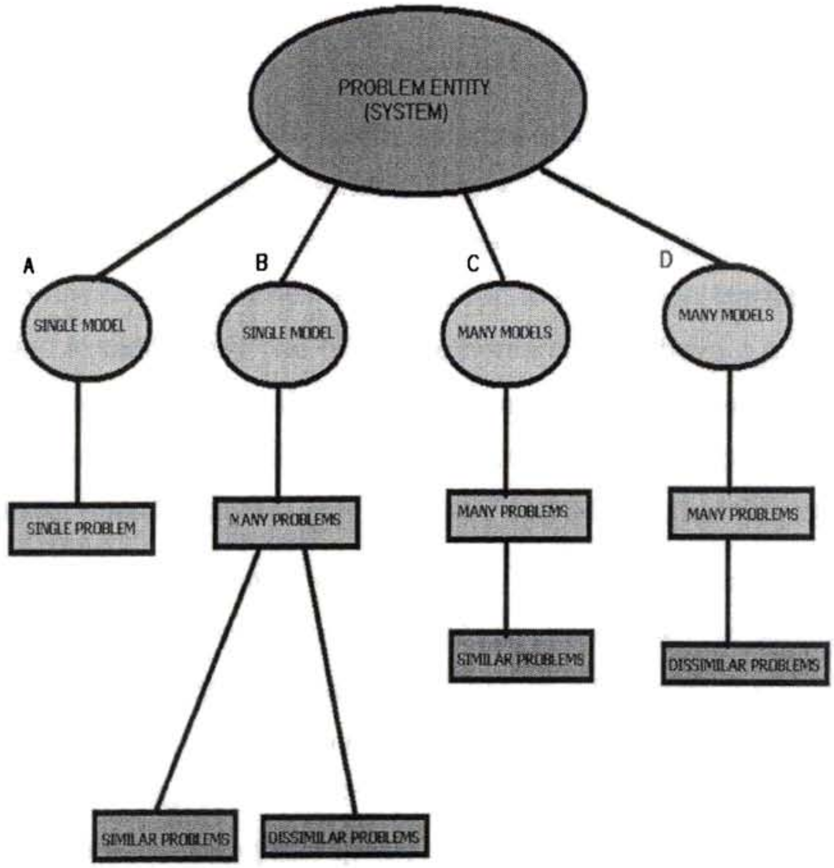

Figure 1.2: Single or multiple models of a system

The objectives of this study were

1 To develop and use simulation models to help solve some problems of a container terminal of a seaport.

2 To develop and use simulation models to help solve some problems of a passenger rail yard.

3 To develop and use simulation models to help solve some problems of an airport.

4 Based on the above experience to develop a flexible modelling framework, which addresses different categories of problem so that problems in the same category can be solved using the same or very similar model.

1.3. METHODOLOGY

When using simulation issues such as conceptual model building, model validation, and experiments on model, interpretation of results, and adopting corrective measures become important. Research is being done in all these areas. There are two approaches that are seen to be used in literature. The first approach tries to tackle only one of the problems stated above e.g.: research to find out best ways of model building. The second approach combines more than one issue discusses above and try to present tools and methodology for all of the issues taken for specific cases. Later approach was adopted in this work.

Simulation modelling approach was used in this study. The steps involved simulation modelling studies described in all common books on simulation (see Law and Kelton, 1991; Banks et al, 1995). Figure 1.3 shows a schematic of a simulation study (Maria, 1997). The iterative nature of the process is indicated by the system under study becoming the altered system which then becomes the system under study and the cycle repeats.

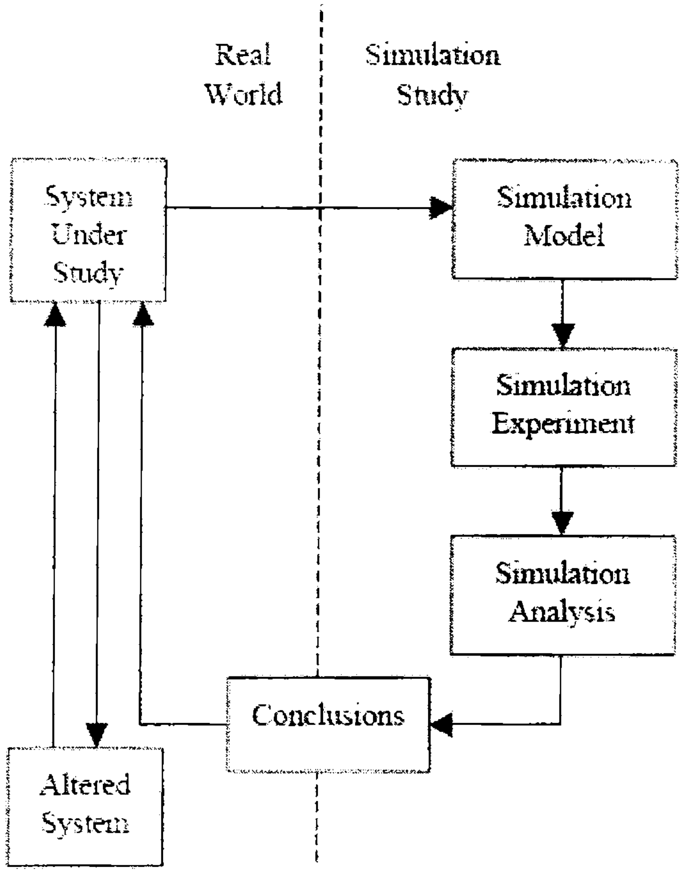

Figure 1.3: A schematic of a simulation study

Conceptual modelling involves abstraction of a model from a real or proposed system. Robinson (2004) defined the conceptual model as a "*non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model*".

There are four basic steps (Pace, 2000) in the development of a simulation conceptual model. The first step is collection of authoritative information about the intended application domain that will comprise the simulation context. Development of the simulation concept and collection of authoritative information for the simulation context are likely to occur iteratively as the entities and processes to be represented in the simulation are more clearly defined. As depicted in Figure 1.4, next step is development of simulation elements. The fourth step addresses relationships among simulation elements to ensure that constraints and boundary conditions imposed by the simulation context are accommodated.

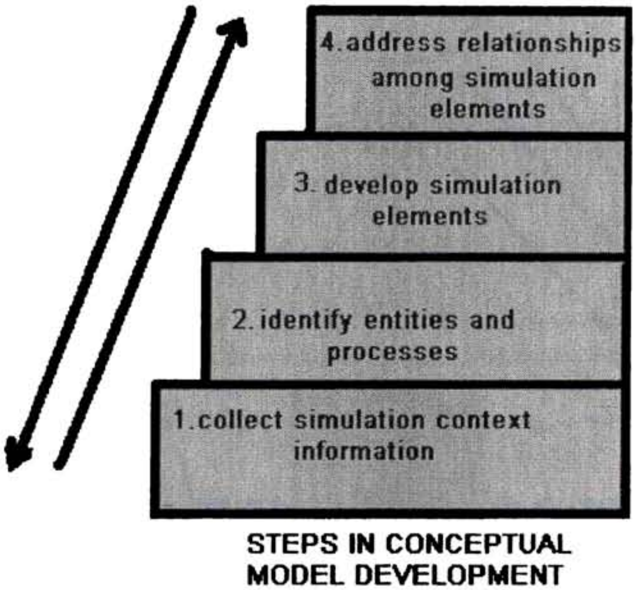

Figure 1.4: Conceptual Model Development

Before developing simulation models, the ways of clustering problems and systems modelled were considered. In this case after considering different ways of catagorising problems we found that clubbing problems on the basis of whether they were operational, tactical or strategic was found to be a good method. This was done because in the case of transport terminals we found that models, could be classified into tightly pre-scheduled, moderately pre-scheduled and unscheduled systems. This gave us a match between tightly prescheduled models and their use for solving operational type problems. Moderately prescheduled models found their match with Tactical type problems, and there was a match between unscheduled models and strategic problems. This pairing of model type and problem type makes it easier to develop models that can be used to solve similar type problems (See Figure1.5). This approach has been used by us to solve problems related to transport terminals such as Railway yard, Airport and Container terminal of a port.

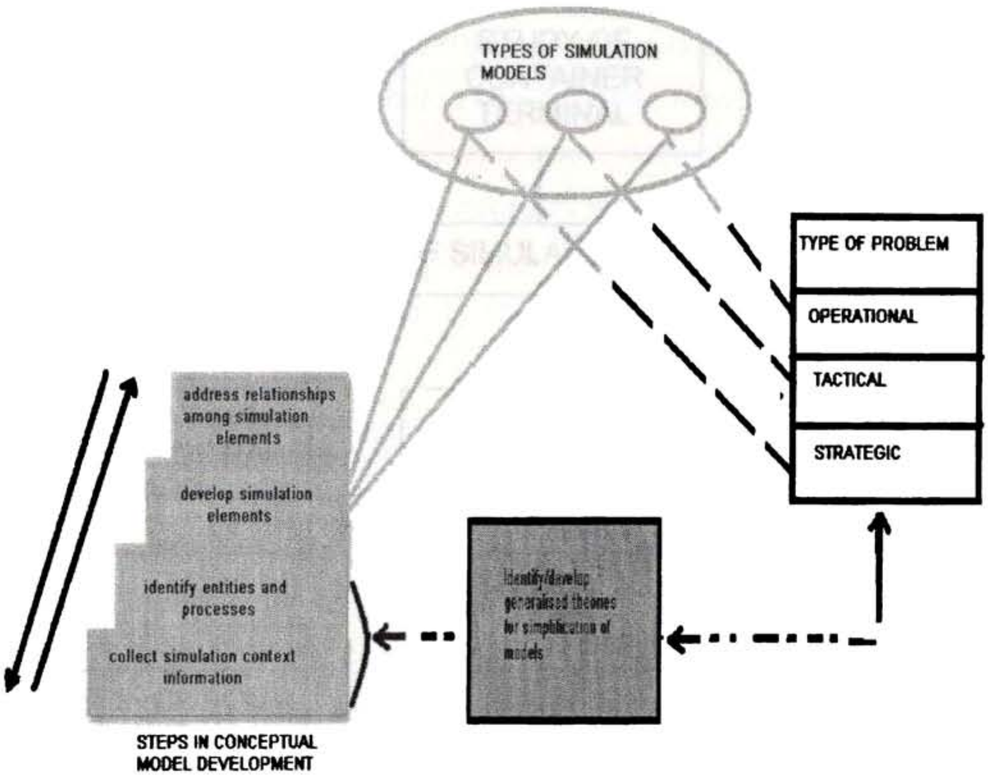

Figure 1.5: Pairing of model type and problem type

The methodological framework of our research is summarized in Figure 1.6. The approach starts with study of each of terminal system, selection of a simulation tool, conceptual modelling and development of the model into simulation models of each type of terminal. The simulation models were then verified and validated and then used for experiments. As a conclusion, commonalities and differences between the models are discussed and inferences regarding a framework for conceptual modeling to be used for terminal system modeling are given.

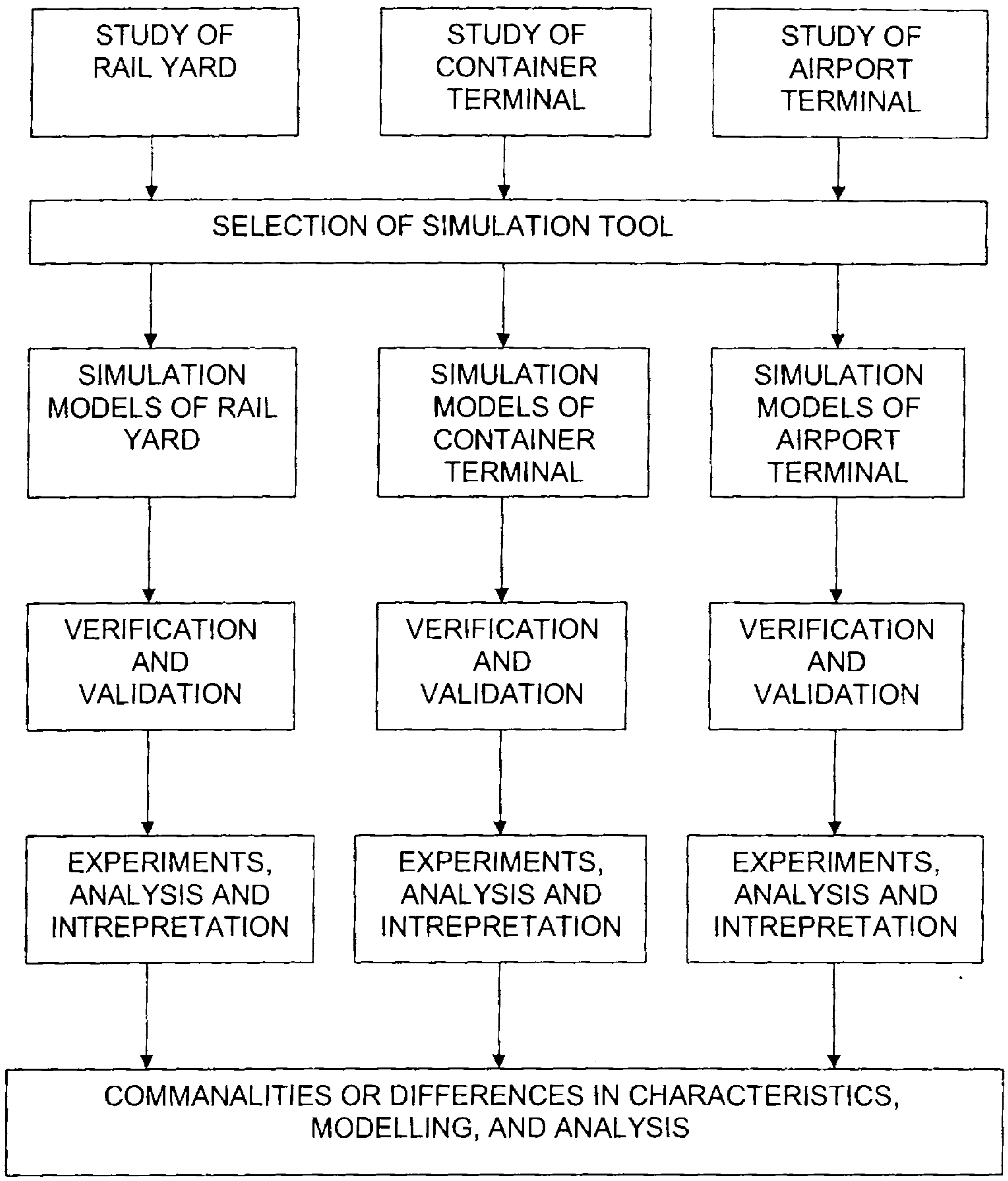

Figure 1.6: Methodological framework of research

1.4. ORGANISATION OF THESIS

In this chapter we have provided an introduction to Logistics and enumerated the objectives of the study and explained the methodology adopted. In chapter two, a detailed review of literature related to basics of simulation and use of simulation in design and improvement of terminal systems is given. In chapters three, four and five the study of three different transport terminals using simulation models are presented. Chapter three deals with the case of a Container Terminal. Chapter four is devoted to the study of a Railway Yard. In chapter five, study related to an Airport is presented. The sixth chapter brings out the limitations of the thesis, and presents our conclusions and scope of future work.

Two appendices are given at the end. Appendix I gives a listing of various popular simulation language with the desirable features required for our type of modelling and analysis. A list of various features available in these languages is also given. In Appendix II a brief description of various features available in Extend Simulation Language is given.

CHAPTER TWO

LITERATURE REVIEW

2.1. INTRODUCTION

Simulation is a powerful tool available to decision-makers responsible for the design and operation of complex processes and systems. It makes possible the study, analysis and evaluation of situations that would not be otherwise possible. In this chapter we review the basics of simulation, tools for performance improvement by simulations, basics of logistics and terminal systems. We also present a detailed review of relevant literature related to container terminals, rail yards and airport terminal systems.

2.2. BASICS OF SIMULATION

Law and Kelton(1991), Banks et al(1995) give good introduction to the art and science of simulation. According to Shannon(1998) simulation is defined as *the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and /or evaluating various strategies for the operation of the system.* Thus it is critical that the model be designed in such a way that the model behavior mimics the response behavior of the real system to events that take place over time.

The term's *model* and *system* are key components of our definition of simulation. By a *model* we mean a representation of a group of objects or ideas in some form other than that of the entity itself. By a *system* we mean a group or collection of interrelated elements that cooperate to accomplish some stated objective. One of the real strengths of simulation is the fact that we can simulate systems that already exist as well as those that are capable of being brought into existence, i.e. those in the preliminary or planning stage of development.

2.2.1. Advantages and Disadvantages

Simulation has a number of advantages over analytical or mathematical models for analyzing systems. The basic concept of simulation is easy to comprehend and hence often easier to justify to management or customers than some of the analytical models. In addition, a simulation model may be more credible because its behavior has been compared to that of the real system or because it requires fewer simplifying assumptions and hence captures more of the true characteristics of the system under study.

Other advantages include:

- We can test new designs, layouts, etc. without committing resources to their implementation.
- It can be used to explore new staffing policies, operating procedures, decision rules, organizational structures, information flows, etc. without disrupting the ongoing operations.
- Simulation allows us to identify bottlenecks in information, material and product flows and test options for increasing the flow rates.
- It allows us to test hypothesis about how or why certain phenomena occur in the system.
- Simulation allows us to control time. Thus we can operate the system for several months or years of experience in a matter of seconds allowing us to quickly look at long time horizons or we can slow down phenomena for study.

2.2.2. Simulation Concepts

Although there are several different types of simulation methodologies, we will limit our concerns to a stochastic, discrete, process oriented approach. In such an approach, we model a particular system by studying the flow of *entities* that move through that system. Entities can be customers, job orders, particular parts, information packets, etc. An entity can be any object that enters the system, moves through a series of processes, and then leaves the system. These entities can have individual characteristics which we will call *attributes*. An attribute is associated with the specific, individual entity. Attributes might be such things as name, priority, due date, required CPU time, ailment, account number etc.

As the entity flows through the system, it will be processed by a series of *resources*. Resources are anything that the entity needs in order to be processed. For example, resources might be workers, material handling equipment, special tools, a hospital bed, access to the CPU, a machine, waiting or storage space, etc. Resources may be fixed in one location (e.g. a heavy machine, bank teller, hospital).

The essence or purpose of simulation modelling is to help the decision-maker solve a problem. Therefore, to learn to be a good simulation modeler, one must merge good problem solving techniques with good software engineering practice. Following steps are mentioned in Carson(2002) for a successful simulation study.

1. **Problem Definition.** Clearly defining the goals of the study so that we know the purpose, i.e. why are we studying this problem and what questions do we hope to answer?

2. **Project Planning.** Being sure that we have sufficient and appropriate personnel, management support, computer hardware and software resources to do the job.

3. **System Definition.** Determining the boundaries and restrictions to be used in defining the system (or process) and investigating how the system works.

4. **Conceptual Model Formulation.** Developing a preliminary model either graphically (e.g. block diagram or process flow chart) or in pseudo-code to define the components, descriptive variables, and interactions (logic) that constitute the system.

5. **Preliminary Experimental Design.** Selecting the measures of effectiveness to be used, the factors to be varied, and the levels of those factors to be investigated, i.e. what data need to be gathered from the model, in what form, and to what extent.

6. **Input Data preparation.** Identifying and collecting the input data needed by the model.

7. **Model Translation.** Formulating the model in an appropriate simulation language.

8. **Verification and Validation**. Confirming that the model operates the way the analyst intended (debugging) and that the output of the model is believable and representative of the output of the real system.

9. **Final Experimental Design**. Designing an experiment that will yield the desired information and determining how each of the test runs specified in the experimental design is to be executed.

10. **Experimentation.** Executing the simulation to generate the desired data and to perform sensitivity analysis.

11. **Analysis and Interpretation**. Drawing inferences from the data generated by the simulation runs.

12. **Implementation and Documentation**. Reporting the results, putting the results to use, recording the findings, and documenting the model and its use.

Further discussions of these topics in simulation can be found in Banks et al(1995), Carson(2002,2003), Kelton(1995,1996). These well established methodology was used by us also in our work.

2.3. SIMULATION FOR DESIGN AND OPERATION IMPROVEMENT

Several case studies, briefly described here, illustrate the power of and benefits from simulation in improvement of operations. Simulation can profitably be applied to manufacturing system design during any or all stages of the production system life cycle - the conceptual design phase, the detailed design phase, the launching phase, or the fully operational phase (Ülgen and Upendram,1997).

The flexibility of simulation permits its application to a wide variety of manufacturing problems, such as capacity planning, machine and personnel scheduling, inventory control, and job routing (Martinich 1997). However, the combination of other competing objectives (e.g., reduction of material handling costs, high resource utilization, and low variance of output production) and stochastic variation required the analytical power of simulation. Simulation has a long and strong track record in analysis of manufacturing systems whose complexity and interaction of components defy closed-form methods (Clark,1996).

Simulation had already become an accepted tool for improvement of manufacturing productivity in this context through documentation of previous successes and availability of training, as advocated by (Williams and Sadakane, 1997). Furthermore, simulation is most profitably used not as a "one-shot" technology for addressing questions during process design, but as a continuous improvement tool throughout the lifetime of the manufacturing process Nelson 1994). Application of simulation study in material requirements planning [MRP] is described in (Dittrich and Mertens, 1995). Swamidass and Winch(2002) present simulation and modelling as one of soft technologies included in a list of commonly accepted Advanced Manufacturing Technologies(AMT).

Material handling, the art and science of moving, storing, protecting, and controlling material between value adding operations, is one of the most complex and economically important function within a manufacturing system. Specifically, examples of simulation applications to material handling abound in the literature, such as optimization of operating policies for an automated material handling system (Dallari et al. 1996), evaluation of a distribution center tow-line material handling system (Bakst, Hoffner, and Jacoby, 1996), configuration of a material delivery system with dolly trains (Jeyabalan and Otto, 1992), development of dispatching rules for multiple-vehicle automatic guided vehicle [AGV] systems (Lee 1996), and improvement of a pull-strategy in the order-picking area of a distribution warehouse (Alicke and Arnold, 1997).

2.4. TECHNIQUES OF PERFORMANCE IMPROVEMENT USING SIMULATION

With the continuing advances in computer technology, simulation is increasingly used as a decision making tool. Most real-world systems are complex and computing values of performance measures and finding optimal decision variables analytically is very difficult and sometimes impossible. Computer simulation is frequently used in evaluating complex systems and optimizing responses.

A number of techniques and approaches have been proposed to solve the simulation optimization problem. There are several survey papers that discuss foundations, theoretical developments and applications of these techniques (Meketon, 1987; Jacobson and Schruben, 1989; Safizadeh, 1990; Azadivar, 1992; Fu, 1994a; Andrad'ottir, 1998; Swisher et al., 2000). The simulation optimization techniques discussed in these papers are listed in Figure 2.1(Tekin and Sabuncuoglu, 2004).

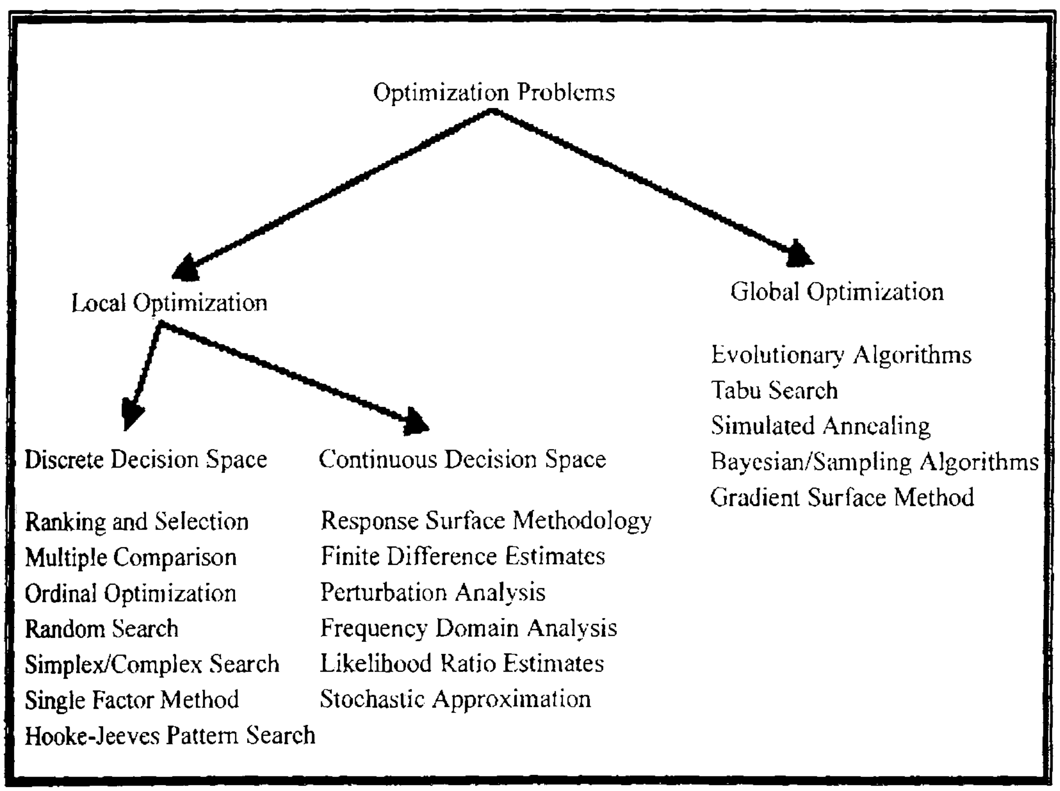

Figure 2.1: Simulation optimization techniques

Local optimization problems are discussed in terms of *discrete* and *continuous* decision spaces. In a discrete space, decision variables take a discrete set of values such as the number of machines in the system, alternative locations of depots, different scheduling rules or policies, etc, and in a continuous space, the feasible region consists of real-valued decision variables such as order quantity and reorder quantity in inventory problems, release time of factory orders, etc

Two most popular methodologies for the class of problems are: (i) ranking and selection; and (ii) multiple comparison procedures. For reviews of these two classes of techniques, one can refer to Bechhofer et al. (1995) and Goldsman and Nelson (1998). Other methods (e.g., random search, Nelder-Mead simplex/complex search, single factor method, Hooke-Jeeves pattern search) can operate in the infinite parameter space.

A great amount of work has been done with problems that have a continuous decision space. Below we discuss the most common methods from the literature.

Response surface methodology : Response Surface Methodology (RSM) is a class of procedures that: (i) fit a series of regression models to the responses of a simulation model evaluated at several points; and (ii) optimize the resulting regression function.

A survey of the RSM research from 1966 to 1988 is given in Myers et al. (1989). Box and Draper (1986) has an extensive discussion on response surfaces and experimental designs. Kleijnen (1998) discusses the use of statistical designs for what-if analysis in simulation and emphasizes how RSM combines regression analysis, statistical designs and the steepest descent (ascent) method to optimize a simulated system. Factorial and fractional factorial orthogonal designs are the best known first-order designs for RSM (Montgomery, 1991). Composite and rotatable designs are the most useful second-order designs (Montgomery and Evans, 1975). Ramberg et al. (1991) relate the orthogonal arrays advocated by Genichi Taguchi to classical experimental designs and use Taguchi's techniques in the construction of mathematical metamodels for RSM.

Some researchers use RSM with other methods such as gradient-based techniques, quasi-Newton methods, and simplex experimental designs (Safizadeh and Signorile, 1994; Joshi et al., 1998). There are many examples of its real-time implementations. Kleijnen (1990, 1995) presents optimization of a decision support system of a Dutch company via RSM. Shang and Tadikamalla (1993) investigate a computer-integrated manufacturing system of an automated printed circuit board manufacturing plant and implement RSM to maximize output.

RSM provides a general methodology for optimization via simulation. Compared to many gradient methods, RSM is a relatively efficient method of simulation optimization in the number of simulations experiments needed. Another advantage is that it uses well-known statistical tools. The main drawback of RSM is its computational requirements if applied blindly.

Gradient-based methods: Four methods in the simulation optimization literature that are used for estimating gradients of the response: (i) finite difference estimates; (ii) perturbation analysis; (iii) frequency domain analysis; and (iv) likelihood ratio estimates.

Perturbation Analysis (PA) was introduced by Ho et al.(1979) in the context of a buffer allocation problem in serial production lines. PA, when applied properly to models that satisfy certain conditions, estimates all gradients of an objective function from a *single* simulation run. There are two classifications of PA: Finite Perturbation Analysis (FPA); and Infinitesimal Perturbation Analysis (IPA). FPA is designed for discrete parameters and is an heuristic that approximates the difference in a performance measure when a discrete parameter is perturbed by one unit. IPA is used to obtain derivatives of continuous parameters and estimates all partial derivatives from a single run by keeping track of related statistics of certain events during a run.

Since PA performs well in simple discrete-event dynamic systems which can be modeled as queueing networks, there are a number of papers on the applications of PA to queueing systems; i.e., Ho et al. (1984), Ho (1985). Wardi et al.(1991), Chong and Ramadge (1993) and also Fu and Hu (1994). PA has been widely used for optimizing manufacturing systems of interest. Donohue and Spearman (1993) determine the most profitable capacity configuration for a production line by using PA. Yan et al. (1994) use PA to develop algorithms to approximate the optimal threshold values in a manufacturing system with two tandem machines. Heidergott (1999) uses smoothed PA to optimize threshold values of repair times in a maintenance model.

Various metaheuristics have been suggested for simulation optimization. Such methods include genetic algorithms, simulated annealing, tabu search, and neural networks. Although these methods are generally designed for combinatorial optimization in the deterministic context and may not have guaranteed convergence, they have been quite successful when applied to simulation optimization.

Evolutionary Algorithms (EAs) are heuristic search methods that implement ideas from the evolution process. As opposed to a single solution used in traditional methods, EAs work on a population of solutions in such a way that poor solutions become extinct, whereas the good solutions evolve to reach for the optimum. Recently, there has been an increasing interest in using EAs in simulation optimization because they require no restrictive assumptions or prior knowledge about the shape of the response surface (B¨ack and Schwefel, 1993). Biethahn and Nissen (1994) identify alternative combinations of EAs in simulation optimization and discuss how they differ from traditional optimization methods. In general, an EA or simulation optimization can be described as follows: (i) generate a population of solutions; (ii) evaluate these solutions through a simulation model; (iii) perform selection, apply genetic operators to produce a new offspring (or solution), and insert it into the population; and (iv) repeat until some stopping criterion is reached.

The most popular EAs are Genetic Algorithms (GAs) (Goldberg, 1989), Evolutionary Programming (EP) (Fogel, 1992), and Evolution Strategies (ES) (Schwefel, 1981). These algorithms differ in the representation of individuals, the design of variation operators, and the selection of their reproduction mechanisms. B¨ack et al. (1997) describe the purpose, structure, and working principles of these three well-known EAs. In general, each point in the solution space is represented by a string of values for the decision variables (i.e., each position in the string represents the decision alternatives regarding a parameter in the system). The use of appropriate crossover and mutation operators reduces the probability of trapping to a local optimum. The crossover operator breaks the strings representing two members of the population and exchanges certain portions of the strings to produce two new strings, where the mutation operator selects a random position in a string and changes the value of that variable with a prespecified probability.

2.5. SIMULATION OF LOGISTICS SYSTEMS AND SUPPLY CHAINS

One of the great strengths of simulation modelling is the ability to model and analyze the dynamical behavior of a system. This makes simulation an ideal tool for analyzing supply chains because supply chains can exhibit very complex dynamical behavior. For example, simulation has been used to demonstrate and study the bullwhip effect (i.e., the amplification of demand variation as demand signals move up the supply chain from the end customer –see Forrester 1958 and Lee et al. 1997) in the MIT Beer Distribution Game

2.5.1. Strategic analysis

This involves taking a look at the various components involved in the process and selecting the best logistics process among the alternatives. These components, which are to be reviewed, are revealed during the first step. This may include revamping the entire process to assessing how a single component can be used more effectively.

2.5.2. Planning

This involves the assembling of a plan that outlines the mission and goals for the logistics function and the programs and activities to achieve these goals.

Logistics planning is an iterative process. The plans have to be redefined every year to improve the quality of performance.

2.5.3. Managing change

this involves effective management to implement enhanced ways of conducting business. The management should keeping changing the plans in accordance with the change in the market and also coach the organization to effectively embrace this change.

A list of processes/activities modelled and represented in a logistics simulation model are given below:

- Order processing at the warehouse (manual, EDI)
- Push order
- Pull order
- Terminal operations at the plants, warehouse, and the customers
- Grouping and palletizing
- Ungrouping
- Transportation mode selection
  At plant
  Warehouse
- Handling shortages (or surplus inventories)
- Send an order message to another warehouse
- Movement of parts
- Movements of finished products
- Customer orders
- Customer locations
- Direct shipments

2.6. TRANSPORT TERMINALS

Transport terminals are key elements in the supply chains of industrial systems. Ideally, a terminal must be planned so as to ensure an acceptable level of service in terms of waiting time for trains and customers. However, the increase of transport demand in a network through time, and other unpredictable problems (such as delay in train or airplane arrival, variability in train sizes, breakdowns, etc.), can reduce the level of service. There are basically two ways to face up to this situation: to improve operational methods, and/or invest in new facilities. The second solution is usually much more expensive, so the analysis should begin by exploring operational methods. If the desired performance is not achieved, then the investment in new facilities should be considered. Literature related to three important types of terminal systems are presented here.

a) Studies related to Container terminal operations

b) Studies related to Rail terminal operations

c) Studies related to Airport terminal operations

2.6.1. Studies Related To Container Terminal Operations

Port Terminals are evolving very fast due to factors such as demands of ships, material handling technology, information systems and automation to provide shorter handling times for more and more cargo. The ports are service facilities that have 24-hour work time per day, 365 days working in a year, all-weather operations. Port facilities involve big investments and require special operative and management skills. Container terminals have become hubs of international trade; container terminals assume an important role in the distribution of goods around the globe. Seagoing vessels are unloaded, and containers stored in the stack area are loaded onto inland water vessels, railway trains and road trucks at container terminals. Literature in this field is related to the areas of container terminal systems, terminal logistics and optimization methods, ship planning processes and storage and stacking logistics. General information about technical equipment for container terminals can be found in engineering oriented journals as well as specialized outlets (see, e.g., http://www.porttechnology.org/).

2.6.1.1. Container terminal systems

Container terminal operations are becoming more and more important and critical in the field of logistics. Therefore, an ever increasing number of publications on container terminals have appeared in the literature. While we refer to many of them in the subsequent chapters, some deserve special mention due to some of their general perspectives. Decision problems at container terminals are comprehensively described by Vis and de Koster (2003) (with some 55 references up to 2001). An overview of relevant literature for problem classes like arrival of the ship, (un)loading of a ship, transport of containers from/to ship to/from stack, stacking of containers, interterminal transport and complete terminals is provided.

Meersmans and Dekker (2001) present an overview of the use of operations research models and methods in the field of design and operation of container terminals with its decision problems on strategic, tactical and operational level.

Murty et al. (2003) describe various interrelated complex decision problems occurring daily during operations at a container terminal. They work on decision support tools and discuss mathematical models and algorithms.

Murty et al (2005) describe a variety of inter-related decisions made during daily operations at a container terminal. The ultimate goal of these decisions is to minimize the berthing time of vessels, the resources needed for handling the workload, the waiting time of customer trucks, and the congestion on the roads and at the storage blocks and docks inside the terminal; and to make the best use of the storage space. Given the scale and complexity of these decisions, it is essential to use decision support tools to make them. This paper reports on work to develop such a decision support system (DSS). They also discuss the mathematical models and algorithms used in designing the DSS, the reasons for using these approaches, and some experimental results

Nam and Ha (2001) investigate aspects of adoption of advanced technologies such as intelligent planning systems, operation systems and automated handling systems for container terminals. They set criteria for evaluation of different handling systems and apply them to examples in Korea. Results show that automation does not always guarantee performance (e.g. higher productivity) – it depends on terminal characteristics such as labour costs.

Four different types of automated container terminals were designed, analyzed and evaluated in a simulation model with very detailed cost considerations by Liu et al(2002).The performance criteria that are used in this study to evaluate and compare different terminal systems are summarized as follows: Throughput: number of moves/hour/quay crane; throughput per acre; ship turnaround time: time it takes for a ship to get loaded/unloaded; truck turnaround time: average time it takes for a truck to enter the gate, get served, and exit the gate, minus the actual processing time at the gate; gate utilization: percent of time the gate is serving the incoming and outgoing container traffic; container dwell time: average time a container spends in the container terminal before taken away from the terminal; idle rate of equipment: percent of time the equipment is idle. The authors conclude that performance and costs of conventional terminals can be improved substantially by automation

2.6.1.2. Terminal logistics and optimization methods

The need for optimization using methods of operations research in container terminal operation has become increasingly important in recent years. This is because the logistics especially of large container terminals has already reached a degree of complexity that further improvements require scientific methods. The impact of concurrent methods of logistics and optimization can no longer be judged by operations experts alone. Objective methods are necessary to support decisions. Different logistic concepts, decision rules and optimization algorithms have to be compared by simulation before they are implemented into real systems.

Many of the problems in container terminal logistics can be closely related to some general classes of transportation and network routing problems (and therefore more or less standard combinatorial optimization problems) discussed comprehensively in the literature. Examples of these problems and some basic references may be given as follows: An early and very comprehensive survey on various types of routing problems is Bodin et al.(1983). For a recent survey on the vehicle routing problem (VRP) see Toth and Vigo (eds) (2002), arc routing problems are also considered in Dror (ed) (2000). The traveling salesman problem (TSP) asks for the shortest closed path or tour through a set of cities that visits every city exactly once. It is well explained in Lawler et al (eds) (1985);

more recent pointers can be found in Gutin and Punnen (eds) (2002). The rural postman problem (RPP), which is the problem of finding a least cost closed path in a graph that includes, at least once, each edge in a specified set of arcs, is considered in container terminal logistics by Steenken et al (1993). In the pickup and delivery problem a set of routes has to be constructed in order to satisfy a given number of transportation requests by a fleet of vehicles. Each vehicle has a certain capacity, an origin and a destination(depot).

The application of combinatorial optimization techniques has had little success in analyzing and increasing the performance of CTs (Hayuth and Fleming 1994). The complexity of the CT often requires complex models (combinatorial and non-linear), so the resulting models are extremely difficult or take too much time for solving problems (Hayuth and Fleming 1994). This motivated us to go for the use of simulation models.

2.6.1.3. The ship planning process

Ship planning consists of three partial processes: the berth planning, the stowage planning and the crane split.

Berth allocation: Before arrival of a ship, a berth has to be allocated to the ship. The schedules of large oversea vessels are known about one year in advance. They are transferred from the shipping lines to the terminal operator by means of EDI. Berth allocation ideally begins before the arrival of the first containers dedicated to this ship – on average two to three weeks before the ship's arrival.

Berth planning problems may be formulated as different combinatorial optimization problems depending on the specific objectives and restrictions that have to be observed. Lim (1998) reformulates the problem as a restricted form of the two-dimensional packing problem and explores a graph theoretical representation. For this reformulation it is shown that this specific berth planning problem is NP-complete. An effective heuristic algorithm for solving the problem – applied to historical test data – is proposed.

Kim and Moon (2003) formulate a MIP-model for determining berthing times and positions of vessels in container ports with straight-line shaped berths. They develop a simulated annealing (SA) algorithm and show near-optimal results.

Stowage planning: In practice, stowage planning usually is a manual or offline optimization process using respective decision support systems (see, e.g., Shields (1984)). Most of the papers below describe research work applicable to enhance existing systems by appropriate optimization functionality.

Sculli and Hui (1988) investigate distribution effects and the number of different types of containers with respect to an efficient stowage in an experimental study. Performance of stacking policies is measured by volumetric utilization, wasteful handling ratios, shortage ratio, and rejection ratio. Results indicate that the number of different types of containers has the largest impact on these measures. Effects of stacking policy and maximum store dimensions are also significant.

Wilson and Roach (1999, 2000) divide the container stowage process into the two subprocesses and related subproblems of strategic and tactical planning level due to complexity of a stowage plan across a number of ports. They use branch and bound algorithms for solving the first problem of assigning generalized containers to a block in a vessel. In the second step a detailed plan which assigns specific positions or locations in a block to specific containers can be found by a tabu search algorithm. Good results (not always optimal) can be found in reasonable time. The same principles are described by Wilson and Roach (2001). They present a computer system for generating solutions for the decomposed stowage (pre-)planning problem illustrated in a case study. The authors present a GA approach in order to generate strategic stowage plans automatically. Initial computational experiments show effective sub-optimal solutions.

Simulation and online optimization in stowage planning is considered in Winter (2000), Winter and Zimmermann (1999). Especially in online settings as they are encountered in practice, waiting times of the cranes as well as congestions of transport means below the cranes have to be minimized to avoid productivity reduction. Winter (2000) presents an integrated just-in-time scheduling model and algorithms for combined stowage and transport planning.

Crane split: Crane split allocates a respective number of cranes to a ship and its sections (bays) on hold and deck and decides on which schedule the bays have to be operated. Daganzo (1989) shows a MIP for a static crane allocation problem with no additional ships arriving during the planning horizon. It is exactly solved for small problem instances (i.e. small number of ships), and a heuristic procedure for larger problems is proposed. In addition, the dynamic problem is considered. In both models the berth length is assumed to be unlimited.

Gambardella et al. (2001) present a solution for the hierarchical problems of resource allocation – namely the allocation of quay cranes for (un)loading vessels and yard cranes for stack operations – and scheduling of equipment (i.e. (un)loading lists for each crane). Simulation results show reduction of equipment conflicts and of waiting times for truck queues.

Bish (2003) develops a heuristic method for minimizing the maximum turnaround time of a set of ships in the so called 'multiple-crane-constrained vehicle scheduling and location problem (MVSL)'. The problem is threefold: determination of a storage location in the yard for unloaded containers, dispatching vehicles to containers and scheduling of (un)loading operations to cranes.

Park and Kim (2003) discuss an integer programming model for scheduling berth and quay cranes and propose a two-phase solution procedure. A first near-optimal solution for finding a berth place and time for each vessel and assigning the number of cranes is refined by a detailed schedule for each quay crane.

2.6.1.4. Storage and stacking logistics

Stacking logistics has become a field of increasing importance because more and more containers have to be stored in ports as container traffic grows continuously and space is becoming a scarce resource.

Cao and Uebe(1995) propose a tabu search based algorithm for solving the transportation problem with nonlinear side constraints – a general form of the problem of assignment of storage positions for containers with minimized searching and/or loading costs and satisfaction of limited space and other constraints.

Kim(1997) investigates various stack configurations and their influence on expected number of rehandles in a scenario of loading import containers onto outside trucks with a single transfer crane. For easy estimation regression equations are proposed.

Kim et al.(2000) formulate a dynamic programming model for determination of the storage location of export containers in order to minimize the number of reshuffles expected for loading movements. The configuration of the container stack, the weight distribution of containers in the yard, and the weight of an arriving container are considered. For real-time decisions a fast decision tree is derived from the set of optimal solutions provided by dynamic programming.

A GA-based approach for minimizing the turnaround time of container vessels is described by Preston and Kozan (2001). The problem is formulated as an NP-hard MIP-model for determining the optimal storage strategy for various schedules of container handling (random, first-come-first-served, last-come-first-served). Computational experiments show that the type of schedule has no effect on transfer time if a good storage layout is used. Changes of storage area utilization in the range of 10–50% result in linear changes of transfer time.

Zhang et al.(2003) study the storage space allocation problem in a complex terminal yard (with inbound, outbound and transit containers mixed). In each planning period of a rolling-horizon approach the problem is decomposed into two levels and mathematical models. The workload among blocks is balanced at the first level. The total number of containers associated with each vessel and allocated to each block is a result of the second step which minimizes the total distance to transport containers between blocks and vessels. Numerical experiments show significant reduction of workload imbalances and, therefore, possible bottlenecks.

2.6.1.5. Transport optimization

Quayside transport: Li and Vairaktarakis (2001) address the problem of minimizing the (un)loading time for a vessel at a container terminal with fixed number of internal trucks (not shared among different vessels). An optimal algorithm and some heuristic algorithms are developed for the case of a single quay crane. Effectiveness of the heuristics is shown by analysis and computational experiments. The case with multiple identical quay cranes is not solved, but the complexity is analyzed.

Bish et al. (2001) focus on the NP-hard vehicle-scheduling-location problem of assigning a yard location to each import container and dispatching vehicles to the containers in order to minimize the total time for unloading a vessel. A heuristic algorithm based on an assignment problem formulation is presented. The algorithm's performance is tested in computational experiments.

Meersmans and Wagelmans(2001) consider the problem of integrated scheduling of AGVs, quay cranes and RMGs at automated terminals. They present a branch and bound algorithm and a heuristic beam search algorithm in order to minimize the makespan of the schedule. Near optimal solutions are obtained in a reasonable time. A beam search algorithm and several dispatching rules are compared in a computational study under different scenarios with similar results. The study also indicates 'that it is more important to base a planning on a long horizon with inaccurate data, than to update the planning often in order to take newly available information into account'.

Carrascosa et al. (2001) present multi-agent system architecture to solve the automatic allocation problem in container terminals in order to minimize the ships' docking time. The paper focuses on the management of gantry cranes by a 'transtainer agent'. This work is framed into a project to the integral management of the containers terminal of an actual port. The independence of subsystems obtained from a multi-agent approach is emphasized. (The approach is also described by the same group of authors in Rebollo et al.(2000).

The landside transport: The landside transport is split into the rail operation, the truck operation and the internal transports. A common means of operation is to allocate a given number of vehicles to each sphere of operation appropriate to the workload expected. A more advanced strategy is to pool the vehicles for all these working areas.

The problem of assigning jobs to straddle carriers is solved with linear assignment procedures combining movements for export and import containers. Steenken et al. (1993) deal with the optimization for the rail operation and internal moves. Different algorithmic approaches are used to solve the routing problems, as they can be found in machine scheduling, for solving the travelling salesman problem, the rural postman problem, etc. Both solutions were implemented in a real time environment and resulted in considerable gains of productivity. Results and architecture of implementation are presented in Steenken D (2003). Kim et al. (2003) discuss approaches and decision rules for sequencing pickup and delivery operations for yard cranes and outside trucks, respectively.

Crane transport optimization: Another field of application of optimization methods are the transports of gantry cranes operating in stacks. Kim and Kim (1997) present a routing algorithm for a single gantry crane loading export containers out of the stack onto waiting vehicles. The objective is to minimize the crane's total transfer time including set-up and travel times. The model's solution determines the sequence of bay visits for pick-up operations and the number of containers to be picked up at each bay simultaneously. The developed algorithm is named 'efficient' and shows solutions to problems of practical size 'within seconds'. In a more detailed paper (Kim and Kim,1999) the same algorithm is used for solving the MIP of a 'practical problem of a moderate size'. The load sequence of individual containers within a specific bay remains undetermined.

Zhang et al.(2002) describe the dynamic RTG deployment problem with forecasted workload per block per planning period (4 hours).

2.6.1.6. Simulation systems

In recent years, simulation has become an important tool to improve terminal operation and performance. Three types of simulation can be distinguished: strategical, operational and tactical simulation. Strategical simulation is applied to study and compare different types of terminal layout and handling equipment in respect to efficiency and costs expected. It is mainly used if new terminals are planned or the layout or the equipment of existing terminals has to be altered. Strategical simulation systems allow for easy design of different terminal layouts and employment of different types of handling equipment. The chief goal of strategical simulation is to decide on terminal layout and handling equipment which promises high performance and low costs. To match reality, simulation systems allow to design realistic scenarios or to import data of existing terminals.

Operational simulation is applied to test different kinds of terminal logistics and optimization methods. It has achieved growing acceptance at least at large terminals. Terminal operation and logistics at large terminals are already very complex and the effect of alternative logistics or optimization methods has to be tested with objective methods. Therefore, optimization methods are tested in a simulation environment before they are implemented in real terminal control and steering systems. Tactical simulation means integration of simulation systems into the terminal's operation system. Variants of operation shall be simulated parallel to the operation and advices for handling alternatives shall be given especially if disturbances occur in real operation. Real data of operation then have to be imported and analyzed synchronously to the operation. Because of this ambitious requirement, tactical simulation is seldom or only partially installed at container terminals.

The simulation of harbour processes is normally based on stochastic discrete-event models, however combined simulation for some specific application is a growing sector (Nevins et al. 1998). Veenstra and Lang(2004) describes a conceptual approach and presents a first study for analysing the economic performance of a container terminal design, using operational indicators. The study consists of the extension of an operational simulation model into a model allowing economic evaluation of the terminal in terms of cash flow generated. The concepts and preliminary results of the study are presented. The paper argues that the integration of the economic evaluation into the simulation model might give rise to problems with aggregation, but will also lead to the development of a potentially very interesting tool that can be used to assess advanced operational and financial strategies, such as dynamic pricing.

Gambardella(1996) present the first results in the development of a methodology to integrate simulation, forecasting and planning to support day by day and long term decisions for operators working in intermodal container terminals.

Gambardella et al(1998) discusses decision support system for the management of an intermodal container terminal. Among the problems to be solved, there are the spatial allocation of containers on the terminal yard, the allocation of resources and the scheduling of operations in order to maximise a performance function based on some economic indicators. These problems are solved using techniques from optimisation, like job-shop scheduling, genetic algorithms or mixed-integer linear programming. At the terminal, the same problems are usually solved by the terminal manager, only using his/her experience. The manager can trust computer generated solutions only by validating them by means of a simulation model of the terminal. Thus, the simulation tool also becomes a means to introduce new approaches into traditional settings.

Kulick and Sawyer (2000) mentions that simulation modelling that has been successfully used to analyze intermodal capacity issues for a wide variety of facilities. Simulation technology provides an analysis mechanism for large intermodal facilities that are difficult to duplicate with other methods due to the interaction of many variables.

Simulation of logistics processes at the Baltic Container Terminal (BCT) was performed using the Arena simulation tool (Merkuryev et al., 2000). The model considers the terminal layout (with its two berths, container yards, roads, railway centre and In/Out gate), elements of the outside transport flows (ships, trains and trucks), internal transport (trailers, forklifts, quay and yard cranes), and information about simulation results as well: berth productivity and number of containers on a ship. The model allows productivity evaluation for the terminal equipment as well.

In designing container terminals one have to consider the choice for a certain type of storage and retrieval equipment by performing a feasibility and economic analysis. Vis(2006) compare, by means of a simulation study, the performance of manned straddle carriers and automated stacking cranes. As main performance measure, the total travel time required to handle storage and retrieval requests from both the sea- and landside of the terminal is used . It is concluded that automated stacking cranes outperform straddle carriers in a stack with a span width smaller than nine containers. From that point on straddle carriers reach a comparable performance.

2.6.2. Studies Related To Rail Terminal Operations

Many aspects of Railway operations have been studied by a number of authors. These include terminal operations, rail network optimization, freight movement, scheduling passenger trains and freight trains etc. There are many studies which consider intermodal terminals. Models in general include simulation as well as analytical models.

2.6.2.1. Simulating Rail Terminals

Klima and Kavicka (1996), used simulation to model marshalling yards in railway networks. The costly technology and high complexity of the operations performed require a great degree of coordination and control. Because of the intricacy of the system, the only suitable tool for evaluating conditions in this system is believed to be a simulation model. One of the features of the Klima and Kavicka model is the ability of the user to plan some standard activities such as interruption, termination, snapshots of the system state, etc., prior to initiation of the simulation run. Dessouky and Leachman (1995) present a detailed computer simulation modelling methodology that can be used to analyze the increased traffic burden on rail track networks and delays to trains caused by congestion.

2.6.2.2. Intermodal Railroad Terminal Simulation

Intermodal terminals are critical components in the total intermodal freight transportation process, and their efficiency must be optimized if they are to remain competitive. In Ferreira and Sigut (1995), two different types of terminals are simulated: the conventional road/rail container transfer facility, and a proposed system named the RoadRailer terminal facility. Boese(1983) notes that the future demands that are to be placed on intermodal transportation systems will require substantial investments in existing and new terminal facilities. In order to optimize the operations of these terminals, computer modelling of these sites is imperative. The model developed by Boese has several program modules simulating different functions of the terminal in question. The simulation of the daily train operations reflects given cargo volume fluxes, types of load units, train schedules, selected rail operational strategies, and equipment capacities. The road counterpart utilizes a Monte Carlo simulation of the stochastic properties of truck arrivals at the terminal, according to different truck operating patterns. The core module simulates the single movements and actions of the transshipment equipment. A dispatch control module decides on the transshipment sequences prescribed by train operation and truck arrivals, while simultaneously trying to maximize equipment productivity and minimize truck waiting times. The presented simulation provides some information concerning terminal economies, operational strategies, and control systems. A trailer-on-flatcar (TOFC) terminal simulation model (TSM) is discussed in a paper by Golden and Wood (1983). This model provides information about productivity and throughput of trains and trailers at an intermodal facility using a detailed simulation.

Sarosky and Wilcox (1994) utilize a SLAMSYSTEM model to examine the feasibility of eliminating a terminal from Conrail's intermodal network and shifting the remaining traffic volume to an alternate facility. Described in the paper is the problem of optimal terminal size in the construction and operation of an intermodal terminal.

2.6.2.3. Simulating Truckload Trucking Networks

Research has been undertaken to examine the effects of hub and spoke (H&S) networks, similar to those utilized in less-than-truckload (LTL) and airline settings. See Taha et al. (1996), or Taha and Taylor (1994) for information about this problem, and for information about the HUBNET simulation tool developed for and employed in this analysis.

2.6.2.4. Terminal Operations and Capacity

Ferreira (1997) discuss the research and development of optimization and simulation tools in the operations planning of an Australian freight rail system. The author claims that the market share for rail freight is greatly determined by the level of service, especially in terms of transit times and the reliability of arrivals. These, in turn, are largely associated with track infrastructure design and maintenance schedules. Summarized in the paper are requirements for planning track maintenance and a description of a model to optimize the placement of sidings along a single-track corridor.

2.6.2.5. Non-Simulation Methods

Substantial literature discussing work-using techniques other than simulation to examine rail yards also exists. For example, Feo and Gonzalez-Velarde (1995) use a mathematical model to optimally assign highway trailers to rail car hitches in intermodal transportation terminals. An integer linear programming formulation that allows problems to be effectively solved by use of general-purpose branch-and-bound code is constructed.

2.6.2.6. Scheduling issues

On busy congested rail networks, random delays of trains are prevalent, and these delays have knock-on effects which result in a significant or substantial proportion of scheduled services being delayed or rescheduled. Carey and Carville(2000) develop and experiment with a simulation model to predict the probability distributions of these knock-on delays at stations, when faced with typical patterns of on-the-day exogenous delays. These methods can be used to test and compare the reliability of proposed schedules, or schedule changes, before adopting them. They can also be used to explore how schedule reliability may be affected by proposed changes in operating policies, for example, changes in minimum headways or dwell times, or changes in the infrastructure such as, layout of lines, platforms or signals. This model generates a reliability analysis for each train type, line and platform. They also use the model to explore some policy issues, and to show how punctuality and reliability are affected by changes in the distributions of exogenous delays.

In scheduled (timetabled) transport systems (for busses, trains, etc.) it is desirable at the planning stage to know what effect proposed or planned changes in the schedule may have on expected costs, expected lateness, and other measures of cost or reliability. Carey and Kwiecifiski (1995) consider such effects here, taking account of the random deviations of *actual* times (or arrivals, departures, etc.) from the corresponding scheduled times. They also take account of various forms of interdependence (knock-on effects) between the timings (arrivals, departures, connections, lateness, etc.) of different transport units and formulate a stochastic model of such a complex transport system. (For generality, the underlying deterministic version of the model is consistent with versions of various existing deterministic transport models).

2.6.3. Studies Related To Airport Terminal Operations

The modelling of airport terminal operations has advanced significantly over the last 15 years (Tosic, 1992). Available models have improved in detail and fidelity, as well as "user friendliness". As a result, their use as decision support aids or design tools in terminal development projects has been steadily increasing. Some existing models are "strategic" in nature sacrificing level of detail in exchange for speed and flexibility, while others are primarily "tactical" incorporating high levels of detail in data and system definition. Mumayiz (1990, 1997) and Tosic (1992) have presented exhaustive overviews on the development of terminal simulation technology and on their applications to airport terminals.

Jim and Chang(1998) mentions that recent airport capacity studies have indicated that there is an imbalance in passenger terminal, airfield and airspace planning at many major airports. Traditionally, the emphasis has been on airfield and airspace development and analysis. Not much emphasis has been made on passenger terminal design. Therefore, there are many cases around the world exhibiting congestion problems at the airport passenger terminal as the number of air passengers continue to increase.

Following the analysis presented in (Transportation Research Board, 1987), landside elements may be subdivided into three classes:

- *Processing facilities*: they process passengers and their luggage.
- *Holding facilities*: areas in which passengers wait for some events (as the check-in opening for a flight, the start of flight boarding, etc).
- *Flow facilities*: the passengers use them to move among the landside elements.

2.6.3.1. Ticket counter and baggage check-in

Capacity of check-in processing facilities is judged by considering the average service time and by comparing the number of passengers in a terminal holding area with the size of that area. Some of the analytical models proposed in the literature for check-in counters belong in the class of Queuing Theory Models. This is also the case for most of the other processing facilities in airport operations. Lee proposed a pioneering application of M/M/n queuing systems to check-in procedures (Lee, 1966).

Newell initially proposed a deterministic approach (Newell, 1971). This model had a strong influence on further developments in this area, and it has applications in modelling several types of facilities where service is provided to individuals by a "processor" of some kind. Basically, this is a graphical model that computes approximately the total waiting time of passengers, given the cumulative arrival function at the check-in counter and the service rate for each time period. This simple and effective model has also been extended (to representing more than one flight) in (Tosic et al., 1983). A simulation model based on the Monte Carlo method has been presented in (Tosic et al., 1983). Being a simulation model it needs detailed data, and provides quite realistic information on the behaviour of check-in counters.

2.6.3.2. Passenger security screening

Originating passengers must undergo a security screening operation. Sometimes transfer passengers also have to pass through security screening while moving to a connecting flight. For this reason, security-screening areas are often elements of queuing and delay for passengers. Both stochastic and deterministic queuing models have been proposed in the literature. Examples of application of the stochastic models are in (Rallis, 1958, 1963, 1967). In particular, the Copenhagen terminal building was analyzed by applying M/D/n queuing systems. Newell proposed a deterministic model by means of graphical analysis using cumulative diagrams of number of passengers versus aircraft departure time (Newell, 1971).

2.6.3.3. Gates

A lot of models for gate assignment have been proposed. Some of them take into account both the type of aircraft and the passenger walking distances. Basically, they are based on a gate assignment with *first in - first out* (FIFO) rule (Le et al., 1978) and (Hamzawi, 1986). Babic et al. proposed a method to minimize passenger walking distances by properly assigning aircraft to gates every day, taking into account passenger flows on that particular day (Babic et al., 1984). Mangoubi and Mathaisel incorporated transfer passengers in their formulation of the flight-to-gate assignment problem (Mangoubi and Mathaisel, 1985). Both approaches assume that a specific configuration is given so that walking distances are known and fixed, and, therefore, these models are appropriate at the tactical level. Wirasinghe and Vandebona proposed a long-term planning model (Wirasinghe and Vandebona, 1987). As for gate position requirements, Bandara and Wirasinghe proposed a way for determining the gate position requirements based on a deterministic model (Bandara and Wirasinghe, 1989). Edwards and Newell investigated stochastic models of gate utilization (Edwards and Newell, 1969). Steuart proposed a different stochastic model (Steuart, 1974).

Yan et al.(2002) proposes a simulation framework, that is not only able to analyze the effects of stochastic flight delays on static gate assignments, but can also evaluate flexible buffer times and real-time gate assignment rules. A simulation based on Chiang Kai-Shek airport operations is performed to evaluate the simulation framework.

2.6.3.4. Baggage claim facilities

Baggage claim is the most critical step of the inbound baggage system. The number of passengers waiting in the baggage claim depends on the rates at which passengers arrive from the gate and luggage is processed. In general, the maximum demand levels occur when larger aircraft arrive.The baggage claim area capacity can be measured considering the average time passengers must wait to retrieve their checked baggage and comparing the number of people in the claim area with the size of that area. The number of passengers claiming baggage must be calculated from schedule forecasts. In general, the linear dimension of the device is determined on the basis of the number of passengers, rather than of baggage, except in some cases in which baggage ratio is very high. The expected average time passengers have to wait for bags and the number of waiting passengers in the claim area can be computed by simple queuing models.

In the literature, mathematical queuing and simulation models have been developed to predict the arrival (of deplaning passengers and baggage) to baggage claim areas, and to forecast possible future conditions. In (Horonjeff, 1969) and (Barbo, 1967) a deterministic queuing model was developed to relate the arrival distributions of passengers (and the arrival distributions of baggage) to the number of passenger bags that are on the carousel at a given time. Browne et al. studied the baggage claim areas of the JFK airport in New York (Browne et al., 1970). Their objective was to compute the expected maximum inventories of passengers and bags using inventory type models. Newell analyzed a baggage claim device and proposed a two queues system, one for passengers waiting for bags, the other for bags waiting for their owner (Newell, 1971). The problem was to estimate the number of passengers waiting in front of the devices for their bags. Tosic et al. proposed a Monte Carlo type simulation model to evaluate the elements of the baggage claim area (Tosic et al., 1983). In this model each passenger and all his/her bags are treated individually.

2.6.3.5. Passenger holding areas

Passenger holding areas are spaces where passengers move around and wait for flight departures and arrivals. These facilities include lobbies, gate lounges, transit passenger lounges, baggage claim area, the arrival area, the area set aside for ancillary facilities, etc.

The number of waiting passengers is a function of the number of aircraft served by the holding area, and their functional characteristics, including capacity and loading factors. The number of passengers simultaneously waiting in the terminal is also influenced by other important factors, such as passenger The amount of time spent in a particular area, that is a fraction of passenger dwell time, is central to determine the number of simultaneous occupants of a given area (Odoni and de Neufville, 1992).

Dwell time is mainly caused by the amount of "slack" time that passengers spend in the various parts of the terminal building. This slack time is in turn allocated among the terminal holding areas. Clearly the loading, that is the number of simultaneous occupants, depends on the fraction of the slack time spent in that area. This discussion applies both to departing and transit; for arriving passengers the concept of slack time is less important because they try to leave the airport as soon as possible. Stochastic models for estimating dwell time are presented in (Odoni and de Neufville, 1992).

Ballis et al(2002) presents a simulation model that enables the investigation of charter passenger effects on air terminal facilities and enables the estimation of the level of service offered. Some of the model's features can be easily implemented by use of spreadsheets. The paper concludes with a critical assessment of the results arisen in the master plan of two Greek airports where the simulation model was implemented.

2.6.3.6. Flow facilities

The total time spent by a passenger to cross the terminal building from its entrance point to the gate is the sum of the waiting and service times in the processing facilities plus the sum of the times required to move from a service station to another.

Large airport terminals with multiple gate positions necessarily involve large internal transfer distances. Mechanized circulation aids are commonly used to improve circulation in large terminal buildings. In airports with multiple terminal designs (e.g., Paris Charles de Gaulle), and remote satellites (i.e., London Gatwick), the distances can be so large that mechanized movement becomes essential. The terminal circulation component may be seen as a flow pedestrian problem and analyzed by using procedures and standards such as those suggested in (Transportation Research Board, 1987). The time required to travel from the curb to the gate is the most important measure of service level.

The arriving passenger flow is typically defined as a queuing network system with a series of processors, including gates, concourse, immigration checks, baggage claim systems, customs declaration, secondary examination, and lobby (FAA, 1988). Hence, the method needs to be capable of modelling tandem queues with multiple servers, probabilistic arrivals and services, pooled and separate queues, as well as various aircraft mixes. With the capability of handling various aircraft mixes, this model can also be applied in determining the impacts on domestic terminal operations for any larger aircraft.

Lozano et al.(2004) have developed a package that can simulate in detail passengers' traffic within the departures terminal of Málaga airport. The package performs a passenger-by-passenger "accelerated-time simulation" that considers at each step details like the class, flight and destination of each passenger. Once the simulation has been performed, it can show, plot or give details about any queue in the terminal at any minute. Moreover, given a list of flights, it can also produce an enlarged list of flights with the same spectrum (models of planes, schedules, destinations). It has been implemented in the Computer Algebra System *Maple 8*.

Ray and Claramunt(2003) introduces a novel distributed computing environment designed as a simulation tool for the analysis of large and disaggregated data flows. The potential of the software is illustrated by a case study that simulates large people flows for different hall configurations of an airport terminal.

2.6.3.7. Capacity Estimation Models

A distinction between analytical and simulation models may be made based on the methodology used to compute capacity, delay or other such metrics(Bazargan et al., 2002). Analytical models are primarily mathematical representations of airport and airspace characteristics and operations and seek to provide estimates of capacity by manipulation of the representation formulated. These models tend to have a low level of detail and are mainly used for policy analysis, strategy development and cost-benefit evaluation (Odoni et al., 1997).

Monte-Carlo simulations have been used extensively to study the airport environment.This is a common simulation tool for sampling from cumulative distributions using random numbers until a steady state evolves. Given known or reasonable distributions, as the number of simulations increase, the results match the distributions and predict the likely outcome. This tool was used by Pitfield et al. (1998) to analyze potentially conflicting ground movements at a new airport proposed in Seoul, Korea. Pitfield and Jerrard (1999) uses Monte-Carlo simulations to estimate the unconstrained airport capacity – taking only safety requirements into consideration, and assuming all other factors such as air traffic management and control procedures and best pilot practices as "ideal" - at the Rome Fiumucino International Airport.

2.7. CONCLUSION

The above literature review helped us to understand the methodology for use of simulation for solving problems related to logistic terminals. It also helped us to understand the terminal systems, its structure, characteristics and problems. This was very useful when we undertook the study of real terminal systems for our work presented in next few chapters.

From the review of literature above it can be seen that mathematical models, heuristic models as well as simulation models are popularly used. Closer look shows that for small subsystems, which are, clearly defined mathematical models are more likely to be used. In case of larger systems or for ease of solving the problem, good heuristics are also popular. When complete systems have to be modeled simulation is found to be the best suited technique. We have therefore decided to use discrete-event simulation to build models of a few terminal systems and use them for problem solving. There is a need for development of common framework for simulation modeling of logistic terminals so as to be able to use minimum models to solve maximum variety of problems. The work on this is presented in the subsequent chapters.

CHAPTER THREE

STUDY, MODELLING AND ANALYSIS OF A CONTAINER TERMINAL

3.1. INTRODUCTION

Shipping is an expanding, global business that carries most of the world's traded goods. It is one of the most efficient, and least harmful to the environment when compared other transport modes. The future offers substantial opportunities for the shipping industry, bringing with them the potential for significant investment and wider economic benefits for India. Efficient shipping is vital to India's economic well-being, especially now in the era of globalization. In general, above 80% of external trade by weight moves by sea. The competitiveness of exporters and importers requires that international markets are open and not unnecessarily expensive. Container transport is a complex multi-modal chain, the importance of which is growing beyond the most optimistic of expectations in recent years. Some salient features of containerized traffic are:

- Longest distances are traveled by large container ships, along transoceanic routes linking the different continents

- Other modes of transport (mainly road, railway and inland navigation when possible) cover the legs remaining to effect a door-to-door service.

Most of the dry cargo transported in ocean-going ships around the world today can be classified into two types:

- bulk shipping of huge quantities of commodities like crude oil, coal, ore, grain, etc., which are shipped using specialized ships called bulk carriers; and
- containerized shipping in which a variety of goods are packed into standard-size steel containers that are shipped in vessels

Containers are steel boxes of dimensions (in feet) 20x8x8.5 or 20x8x9.5 (called 20-ft containers), or 40x8x8.5 or 40x8x9.5 (called 40-ft containers), or specialized slightly larger size boxes (for example, refrigerated containers). For measuring terminal throughput and vessel capacity, etc., a unified unit, TEU (twenty-foot equivalent unit), is commonly used, with each 40-ft or larger container being counted as 2 TEUs. The use of standardized containers helped in inter-modalism in international trade, and the movement of cargo from an origin in one country to a destination in another by more than one transport mode became commercially feasible.

The number of containers handled in ports worldwide was well over 200 million TEUs in the year 2000 and by 2006 this figure was above 300 million TEUs, and it is predicted to reach 500 million TEUs by 2015. To move material fast operators search to cut times, this puts ports near the shortest route at an advantage, even if this is countable only in terms of hours. Obviously this only applies to those ports that prove to be competitive in a market that is currently demand driven: small differences in the quality of service can influence ship owners' choices to an extent that was unimaginable in the past.

Ship-owners demand short berth times for their ships at the port and transportation companies require fast loading and unloading of their trucks to ensure that containers are delivered on time. To respond these demands, container terminals need to perform all the unloading, loading, transshipment and storage and retrieval operations quickly and efficiently. Regardless of how it is achieved, the users' point of view only takes into account the external (or gross) productivity, by measuring parameters such as the turnaround time of ships in ports. On the other hand, terminal operators have to deal with the internal efficiency of their systems; hence the need to measure a set of parameters considering the efficiency and utilization of the resources employed. As cargo volumes continue to grow, planners and engineers through out the world are working on solutions to move cargo more efficiently. This is prompted by: (a) The ever-decreasing inventory which manufacturers and retailers prefer to keep on hand to supply assembly lines and customers (b) High congestion around traditional maritime centers due to truck traffic and train service (c) Increasing use of waterfront property for non-industrial uses, such as tourist and shopping centers, business parks and condominiums.

Literature in the field provides many papers dealing with port related problems, both from the external and the internal point of view, in which various techniques have been used to analyze the productivity, sometimes of the terminal as a whole, or sometimes of a specific part of it. Simulation has also been used as tool for studying various aspects of port operation.

3.1.1. Cochin Port

This study is related to the operations at the Rajiv Gandhi Container Terminal (RGCT) at Cochin Port. The modern port of Cochin was developed during the period 1920 to 1940 due to the untiring efforts of Sir Robert Bristow. Cochin was given the status of a major port in 1936. The Port of Cochin is located on the Willingdon Island at latitude 9 degree 58' north and longitude 76 degree 14' east on the south west coast of India about 930 kilometers south of Bombay and 320 kilometers north of Kanyakumari. Facilities offered by the Port include berths for handling cargo and passenger ships, cargo handling equipments, storage accommodation, dry dock, bunkering facilities, fisheries harbour etc. Figure 3.1 shows the location of Port and facilities.

The port has the following facilities

- Well equipped Container Terminal with CFS.
- 16 berths including 3 Oil jetties
- Alongside draft of 9.14 metres to 12 metres
- Vast Estate covering 1940 acres including land at Puthuvypeen, Vallarpadam & South end reclamation area.
- 1 Dry Dock

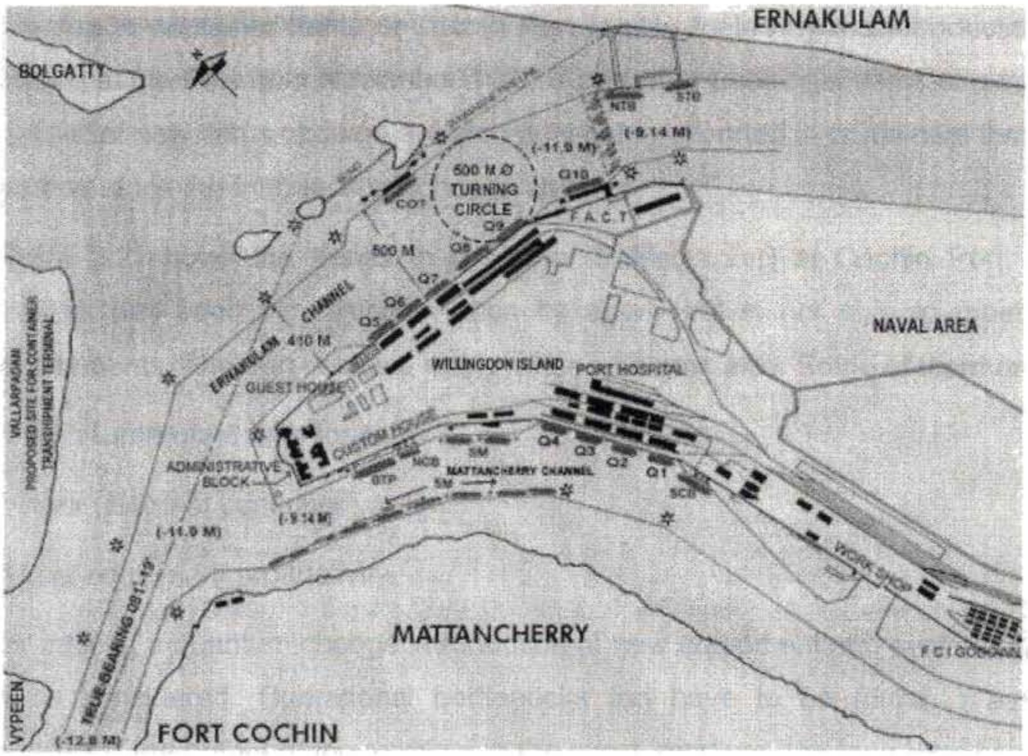

Figure 3.1: A map showing position of RGST(near Q8)

Cochin Port is an all weather Port, strategically located on the East-West trade route, only 10 nautical miles away from direct sea route to Australia and Far East and Europe. Cochin is one of the premier ports in India. The Port has introduced containerization in cargo handling as far back as in 1973. In March 1995, its fully computerized container terminal, Rajiv Gandhi Container Terminal became operational. It is equipped with sophisticated systems, and has capacity to handle traffic of 1,00,000 TEU's annually. Container traffic during the period 2006-'07 was 2,26,808 TEUs as against 2,03,112 TEUs handled during 2005-06 – a growth of 11.82 %.

3.2. PROBLEM AND OBJECTIVES

The past ten years, has witnessed a high growth in containerization. This is mainly due to two reasons

- Increase in cargo flow
- Container penetration

The rise in container traffic at Cochin Port is also fueled by the introduction of stuffing at the Port from November 1992. Apart from traditional items of cargo, a number of new items of cargo are also now being exported in containers through the Port since the introduction of house stuffing.

Figure 3.2 shows the trends in container traffic(export) at Cochin Port. The terminal has been increasing in capacity slowly but is not able to meet the requirements. The port is facing many other problems also. Some of them are

1) High turnaround time for ships

2) Poor usage of container yards

3) Low equipment productivity.

For making a quantum change introduction of new equipment and systems have to be considered. Operational bottlenecks too have to be found. Ways of increasing the output of the terminal in the short, medium and long term have to be found out.

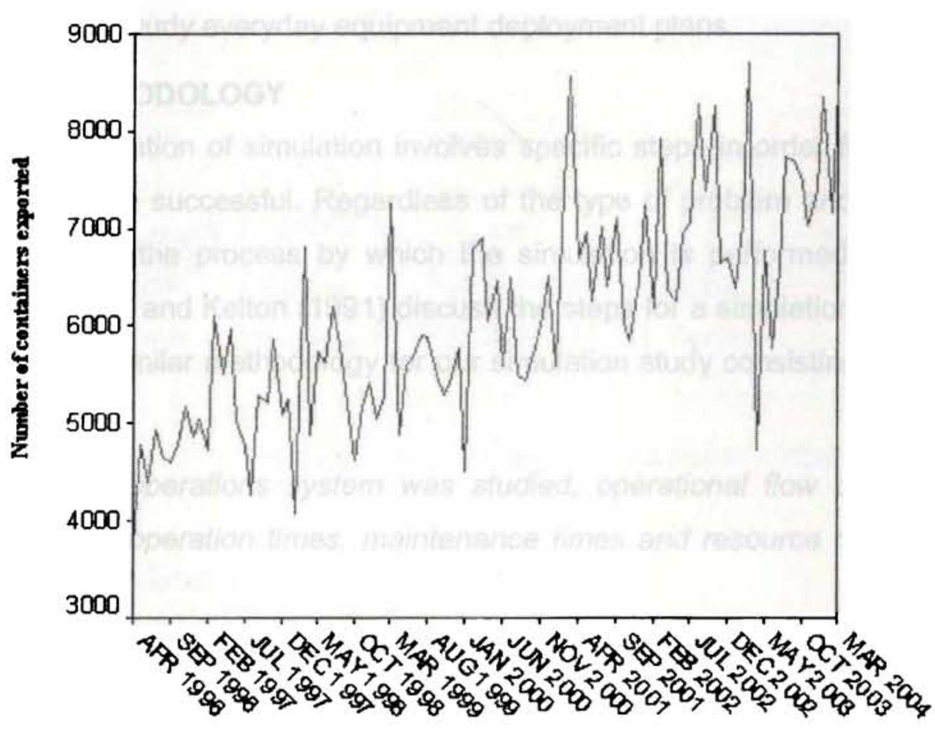

Figure 3.2: Trends in Container Traffic(Export) at Cochin Port from April 1996 to March 2004

It is proposed to develop simulation models of Rajiv Gandhi Container Terminal(RGCT) at Cochin Port with the following objectives.

- To develop simulation models of above terminal that computes throughput and determines resource utilization at a high level of detail.
- To allow planners to see operational constraints and bottlenecks, as opposed to inferring operational limitations through reviewing the statistical reports, graphs and charts.
- To study the impact of increased container traffic on facility and equipment utilization.
- To study the effect of introduction of a new facility e.g. a new berth or quay crane on throughput and turnaround times.
- To study the problem of how much space is to be given in total for the stacking of containers and for queues of trucks
- To be able to determine the number of vehicles, cranes etc to employ, given the layout of the terminal and its required throughput.
- To study everyday equipment deployment plans.

3.3. METHODOLOGY

The application of simulation involves specific steps in order for the simulation study to be successful. Regardless of the type of problem and the objective of the study, the process by which the simulation is performed remains almost same. Law and Kelton (1991) discuss the steps for a simulation study. We have followed similar methodology for our simulation study consisting of the following steps.

1. RGCT operations system was studied, operational flow charts, time data related to operation times, maintenance times and resource requirement were obtained.

2. Conceptual modeling was done and three classes of models to suit three classes of problems were made.

3. A modelling platform was selected and models were made to get sufficient representation of the actual operations and suitable for the problem studied. The models developed were verified and validated.

4. Experiments were done on the models by changing parameters like inter-arrival times of the ships, various activity durations, number of equipments and resources and corresponding effect on various performance measures were studied.

An overview of the operations of a container terminal is presented in next section.

3.4. OPERATION OF CONTAINER TERMINAL

A container terminal interfaces with the sea and land operations of container movement. A container terminal (or terminal in short) in a port is the place where container ships dock at berths and unload inbound (import) containers (empty or filled with cargo) and load outbound (export) containers(Murthy et al, 2005). The terminals have storage yards for the temporary storage of these containers. Figure 3.3 shows the operation of a container terminal in general.

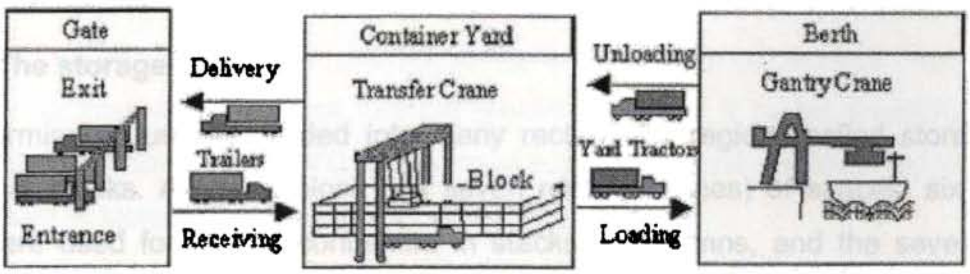

Figure 3.3: Shows the operation of a container terminal

3.4.1. Functions of a container terminal

Being an interface between ocean and land transportation, a container terminal

- receives outbound containers from operators loading onto ships and unloads inbound containers from ships for picking up by consignees; and

- provides temporary storage of containers between ocean passage and land transportation.

Various activities at the terminal include planning and performing orderly loading and unloading of ships, storage, handling and delivery of containers in the terminal, while collecting all necessary information regarding ship's schedules, booking position, land transportation situation, progress of jobs in the container yard, container freight station (CFS), demand and supply of container, delivery schedules, etc to organize smooth flow of containers through all segments.

3.4.2. Outbound and inbound containers

An outbound container is one that is being shipped by a customer of the terminal through this port to another destination port in the world. An inbound container is one that comes on a ship from some other port in the world, to be unloaded in this port and kept in temporary storage until the customer picks it up.

Customers bring outbound containers to the terminal, and take away inbound containers from the terminal, on their own trucks, which are called External Trucks (XTs). Within the terminal itself, containers are moved using trucks known as Internal Trucks (ITs or Stevedoring Tractors).

3.4.3. The storage yard

In a terminal is usually divided into many rectangular regions called storage blocks or blocks. A typical block has seven rows (or lanes) of spaces, six of which are used for storing containers in stacks or columns, and the seventh reserved for truck passing. Each row typically consists of over twenty 20-ft container stacks stored lengthwise end to end. For storing a 40-ft container stack, two 20-ft stack spaces are used.

3.4.4. Transfer Cranes(TC)

These cranes operate at import yard and export yard to load or unload the containers to and from trailers. A picture of TC is shown in Figure 3.4.

In each stack, containers are stored one on top of another. The placing of a container in a stack, or its retrieval from the stack, is carried out by big cranes called yard cranes. The most commonly used yard cranes are Rubber Tyred Gantry Cranes (RTGCs) that move on rubber tyres. The RTGC stands on two rows of tyres and spans the seven rows of spaces of the block between the tyres. The bridge (top arm) of the RTGC has a spreader (container picking unit) that can travel across the width of the block between rows one to seven. The RTGC can move on its tyres along the length of the block. With these two motions, the RTGC can position its spreader to pick up or place down a container in any stack of the block, or on top of a truck in the truck passing row.

The height of an RTGC determines the height of each stack (i.e., the number of containers that can be stored vertically in a stack). Older models of RTGCs are five-level-high RTGCs. This model can store only four containers in a stack, the 5th level is needed for container movement across the width of the block. Newer models are six-level-high RTGCs. They can store five containers in a stack and use the sixth level for container movement. Some blocks are served by fixed Rail Mounted Gantry Cranes (RMGCs) with 13 rows of spaces between their legs and a higher storage height (six levels of containers). The RMGCs are fixed to a block, but the RTGCs, which move on rubber-tyred wheels, can be transferred from block to block offering greater flexibility. It is this flexibility for movement that makes the RTGCs the most commonly used container handling equipment in storage yard operations.

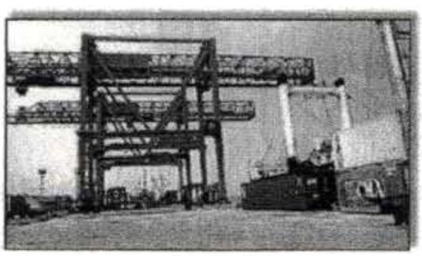

Figure 3.4: A picture of TC

3.4.4.1. RTGC operations

The RTGCs are expensive equipment whose proper utilization is very critical to the efficiency of container handling operations in the storage yard. The RTGCs move containers from ITs or XTs and put them in their storage locations, and they retrieve stored containers and put them on ITs or XTs. ITs and XTs that arrive at a block to deliver or pick up a container queue in the truck passing lane of the block until the RTGC working in that block can serve them.

Thus, if RTGCs are not efficient in their work, there may be truck congestion on the road near the block and inside the block itself. Also, if the RTGC holds up the ITs serving a QC(Quay Gantry Crane) working on a ship, the QC may have to wait, resulting in a delay in unloading or loading the ship.

There are two types of container retrieval operations of an RTGC:

- A productive move: When a container is moved directly from its storage location to a truck waiting to pick it up, this is a productive move. For example, retrieving the top container, A, from the stack of four stored containers shown in Figure 3.6 is a productive move.
- An unproductive or reshuffling move: If containers are moved, to retrieve another container stored underneath it in the same stack, such movements are unproductive moves. For example, to retrieve container C in Figure 3.5 containers A and B, stored above C, have to be moved away first in reshuffling moves.

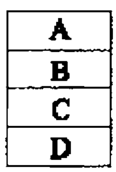

Figure 3.5: Stacking of containers

The number of reshuffling moves depends on how storage spaces are allocated to arriving containers. Repositioning an RTGC from one block to another is usually slow. RTGC can move between adjacent blocks by width(as B1 and B2 in Figure 3.6) without any turning motion. In the case of movement to an adjacent block by length (as B1 and B3 in Figure 3.6), the RTGC has to come to the road on one end of the block, make a 90° turn of its wheels, then move on the road parallel to the width line to the correct position for the adjacent block, make another 90° turn, and enter that block. Every 90° turns take extra time and also hinder traffic on the road for the time that the RTGC is on the road.

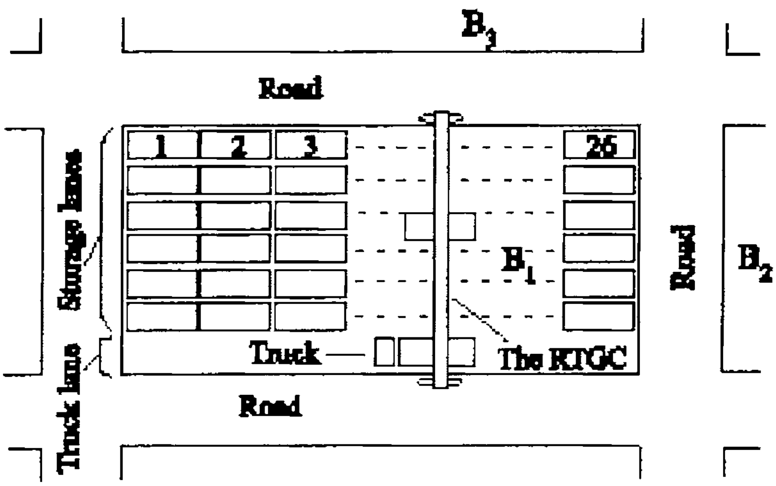

Figure 3.6: Shows the movement of RTGC

Straddle carriers are also used to stack containers in the storage yard. Straddle carriers carry containers between their legs to the appropriate place in a storage yard bay. Containers are stacked three high so that there will be clearance for one loaded straddle carrier.

3.4.5. Quay gantry cranes (QC)

The unloading of containers from a ship, or the loading of containers into a ship, is carried out by huge cranes called Quay Cranes (QCs). These cranes operate at the shipside for lifting containers from the ship and load them onto trailers. QC's are also used to load ship by lifting the containers from the trucks to the ship. Figure 3.7 shows a typical QC.

Figure 3.7: Picture of a QC

On a ship, containers are stacked lengthwise along the length of the ship. Along its length, the ship is divided into segments, known as hatches or holds or bays. Each of these can accommodate one 40-ft or two 20-ft containers along its length. In each hatch, up to 20 containers may be stacked in a row across the width of a large ship. The number of hatches in a ship may be over 20 depending on its total length. Some of the big ships may carry over 7000 TEUs. A ship may call on 5–10 ports in a voyage. For quick unloading and loading, they usually assign containers to hatches according to ports of call. When the ship is docked on the berth, several QCs work on it simultaneously, with each QC working on a separate hatch. A QC itself is wider than a hatch. Different QCs cannot work on adjacent hatches at the same time.

A QC has four legs arranged in two rows of two legs each. The space between the two rows is divided into truck lanes(Figure 3.8). While the QC is working on a ship, it has a set of ITs serving it (either taking away the containers unloaded by the QC, or bringing containers to be loaded into the ship by the QC).

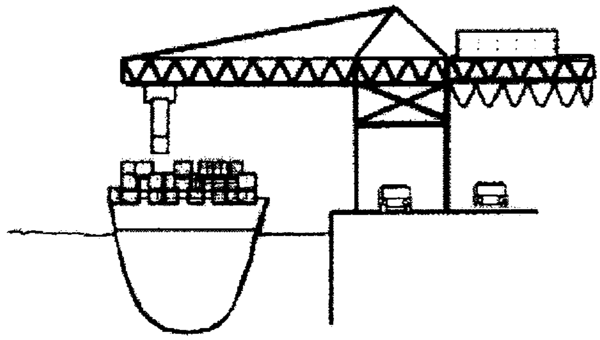

Figure 3.8: Quay crane serving ship and trucks waiting for containers

The ITs serving a QC always line up in one of the lanes between the two rows of legs of the QC. The number of QCs that can work on a ship is usually limited by the number of these lanes. Normally, three or four QCs work on a ship simultaneously for big ships.

The unloading and loading sequence of containers is usually determined by a special algorithm to make sure that the docked ship's balance is not affected while it is on the berth.

3.4.6. Trailers/trucks

IT's with trailers are used to carry the containers inside the yard. They usually operate inside the terminal. IT's carry imported containers to respective position in the storage yard. IT's also carry the containers from storage space to a position near ship for loading the containers to the ship. Containers are taken to/sent out of the terminal gate by External trucks(XT) operated by private parties.

Broadly there are two types of operations being carried out in the container yard i.e. import operations and export operations. When ship arrives at the port it waits in the outer sea for berthing permission. When the berth is free it is berthed. Usually ships coming to Cochin port will be unloaded first and then loaded (See Figure 3.9). If sufficient QC's are available both operations are done simultaneously. QC positions unloaded containers on the trailers. This will be moved to a pre-assigned space in the temporary storage area. From here TC's will load the imported containers to the trucks of concerned operators.(Figure 3.10 shows a schematic of import operations) These trucks leave out through the yard gate to their destinations. XT's with containers for export enter through the yard gate into the yard and TC's unload them to a pre-assigned space in the storage yard. Figure 3.11 shows the movement of trucks in the terminal. TC's load the trucks operating inside the yard with the demanded containers for the outgoing ship and these trucks are taken to a position near the ship. QC's pick these and load them to the ship for export.

The workload in the terminal in any specific time period can be measured by the number of containers processed during that period. This is the sum of four different quantities: containers unloaded from ships and stored in the storage yard; containers retrieved from the storage yard and loaded onto ships; Containers received from external customer trucks and stored in the storage yard; and, finally, containers picked up by external customers from the storage yard. Each of these quantities for any future time period is subject to many uncertainties in terminal operations (arrival and departure times of ships depend on uncertainties posed by weather; arrivals of customers' trucks at the terminal gates are subject to uncertain traffic conditions on roads, which face congestion at certain times).

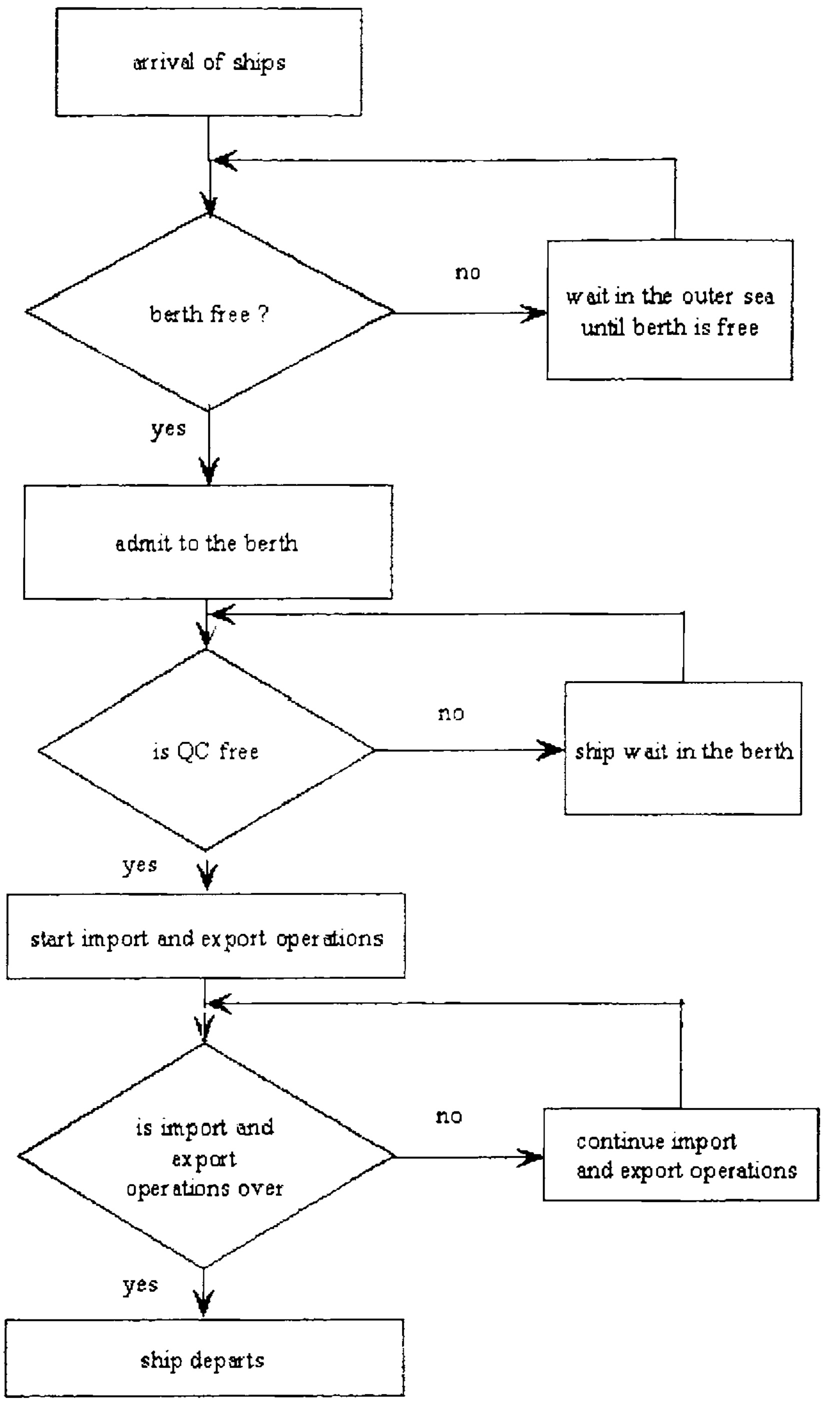

Figure 3.9: Flow chart of operations at quayside in RGCT

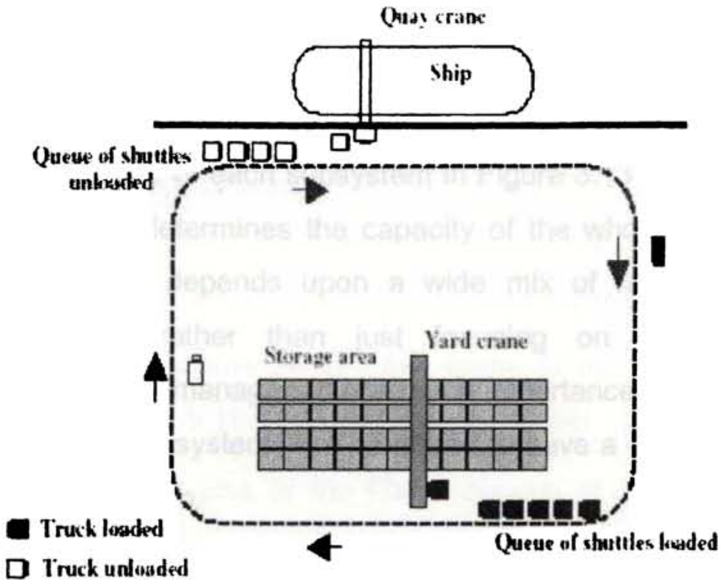

Figure 3.10: A schematic diagram of import operations

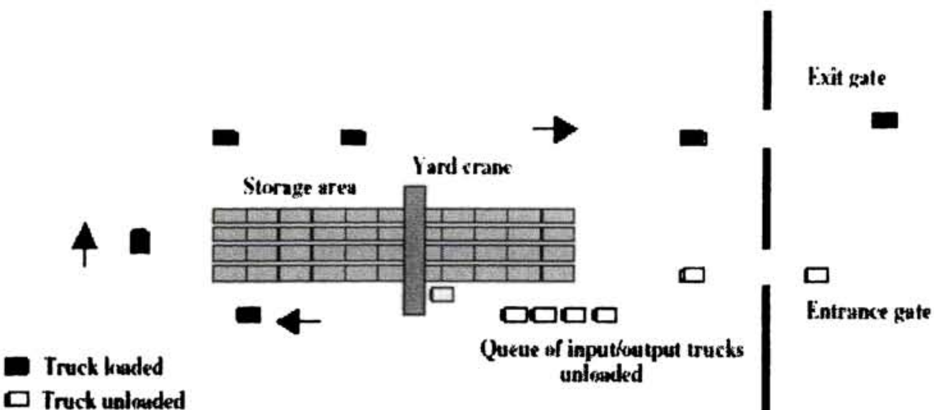

Figure 3.11: A schematic diagram of movement of inbound/outbound trucks

3.4.7. Key performance measures of a container terminal

The flows of containers that go through the Container Terminal(CT) system in Figure 3.12 are determined by the capacity of the bottlenecks (realized or unrealized). The diameter of each subsystem in Figure 3.13 suggests its typical capacity, which in turn determines the capacity of the whole CT system. The performance of the CT depends upon a wide mix of factors affecting the individual subsystems rather than just focusing on the gantry crane performance, which some managers place much importance on. The operations within each of the four subsystems are observed to have a direct relation to the other parts of the CT system.

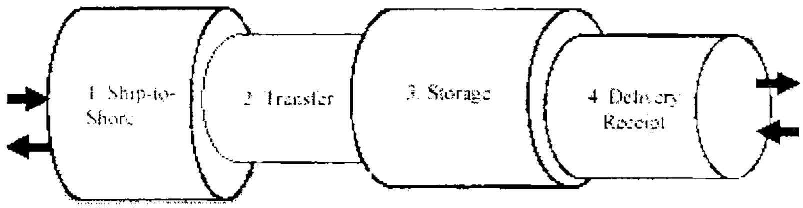

Figure 3.12: Flow of containers in a CT system

The interactions of the subsystems may affect overall performance, i.e. pre-stacking containers to be loaded onto a ship may optimize the crane, but may increase congestion and in the transfer system and traffic in the storage system

Container terminals work under multiple operational objectives. The most critical performance measure for rating the terminals is the ship turnaround time (also called the port time of the ship), which is the average time the terminal takes to unload and load a docked ship. This important performance measure must be minimized.

Closely related to the ship turnaround time, another important measure is the average QC rate, which is the quay cranes' throughput measure during a period, given by

$$\text{QC rate} = \frac{\text{Number of containers unloaded, loaded}}{\text{Total number of QC hours of all QCs that worked}} \quad 3.1$$

Some of the other measures of performance are given below.

- The average waiting time of XTs that come to the terminal to deliver outbound containers or pick up inbound containers
- The average waiting time of the ITs in queues at the QC and RTGC waiting to be serviced
- The waiting time of the QC waiting for an IT
- The number of unproductive moves in the storage yard
- The total number of ITs used in the various shifts each day

3.5. THE MODELS OF CONTAINER TERMINAL

The decision problems of container terminal management can be classified as Strategic, Tactical and Operational. In Chapter 1, we have discussed the need for different models to suit the type of decision problems. For example, many of the container terminal related events are pre-scheduled (e.g. ship arrivals), and a model developed for studying crane deployment plans containing details of coming week's time schedules may not be suitable for decision problems such as "what would be the impact of a new facility(say a new berth), for a given container traffic?".

To address different classes of problem of container terminals, our modeling effort began at conceptual level. We have found that models could be classified into tightly pre-scheduled, moderately pre-scheduled and unscheduled systems. This gave us a match between tightly prescheduled models and their use for solving operational type problems. Moderately prescheduled models found their match with Tactical type problems, and there was a match between unscheduled models and strategic problems. Three types of models(TYPE 1,TYPE 2 and TYPE 3) were developed considering above.

3.5.1. Model TYPE 1

For such models, the schedule related inputs include operational schedules for cranes and arrival and departure schedules of ships. For output analysis, data for one cycle was repeated for getting statistical confidence intervals. Typically these models were used to study the impact of changes in schedules and operational times. Due to priorities in schedules, these models offer only very little flexibility for studying tactical and strategic decision.

3.5.2. Model TYPE 2

For such models, the schedule related inputs include operational schedules for cranes and arrival and departure schedules of ships. These models also have some simulation blocks for giving statistical distributions of wait times, interarrival times instead of schedules for the use of some of the terminal's facilities(For example, the ship arrival may be pre-scheduled, and crane deployment not pre-scheduled). For output analysis, data from many cycles were taken for establishing statistical confidence intervals. Typically these type of models were used to study the impact of changes in schedules, operational times and changes in number of some facility . Tactical problems like effect of change in number of cranes or trucks on turnaround time for coming months were studied.

3.5.3. Model TYPE 3

Such models totally discard time schedules for arrival or departure of entities. Ships arrive according to specified statistical interarrival time distributions. Blocks for interarrival and wait time distributions were also attached to various equipments and facilities. Longer term behaviour was checked for output analysis using steady state non-terminating anlysis. Typical problems studied using these models include changes in operation times, changes in number of facility and changes in key technology resulting in operational time change.

3.5.4. Model Building Blocks

Simulation models were developed in the Simulation Package Extend. Only discrete event type models were developed. When developing the model the actual working of the terminal was kept in mind rather than the ideal situations.

The model logic of the basic model can be divided into following sections:

(a) Modelling ship arrival (b) Modelling Import side operations (c) Modelling export side operations (d) Modelling the departure of ships

The model contained the following types of Extend blocks.

- Executive - Needed in every discrete event model to handle events
- Activities - Processing items

Besides the above blocks the model contains numerous blocks for

- Routing - Moving items to the correct place
- Batching - Joining and dividing items
- Information - Getting information about items
- Arrays - Storing, accessing global data
- Decisions - Routing or deciding which value to use
- Holding -Accumulating or storing values
- Input/Output - Reading and writing files, or generating values
- Math - calculating values
- Statistics - Calculating Mean, Variance

For more on Extend, please refer Appendix II.

3.5.5. Model Verification and Validation

Verification is the process of ensuring that the model design (conceptual model) has been transformed into a computer model with sufficient accuracy(Robinson,2004).

Various aspects of the model checked during model coding were:

- Timings
- Control of flows
- Control logic
- Distribution sampling e.g. the samples obtained from an empirical distribution

Although verification and white-box validation are conceptually different, they are usually treated together because they are both performed continuously throughout model coding(Robinson,2004). Also, they are both micro checks of the model's content. Verification ensures that the model is true to the conceptual model, while whitebox validation ensures that the content of the model is true to the real world (in this way it is an indirect form of conceptual model validation). In our case expert opinion was used to understand how the models should behave. We then used facilities in Extend such as information modules to check whether the model behaved as expected. Entities such as ships and containers were checked at different blocks in the model. Number of containers coming to QC related blocks, number of containers coming in and going out after service from various activity blocks, number of ships *exited* by *exit* block were also checked. Each of model blocks were opened up and information gathered were checked thoroughly at various points of time. This white box method of verification was used by us.

Further visual checks were done by

- Stepping through the model event by event
- Stopping the model, predicting what will happen next, running the model on and checking what happens
- Interactively setting up conditions to force certain events to take place(such as break downs of cranes)
- Tracing the progress of an item through the model(by use of animation, the movement of containers through various points were understood)

Validation is concerned with determining to which extent a simulation model can be considered an accurate representation of the real system (Law and Kelton, 1991). Therefore the first step in this process was to check whether the representation of all system operating rules were accurate enough to reproduce future system trajectories with a high degree of confidence. Real system input was fed into simulation models in historical order(called trace driven simulation). Then validation is done by statistically comparing real response measures with simulation output as discussed in Kleijnen(1998) and Legato and Masso(2001). In practice when modeling complex systems like container terminals, for this type of analysis, large amount of recorded historical data is required. In our case such data was not available. However aggregated data over one month period was available regarding container output, which was used by us for validation.

Arrival instants of ships were generated within their fixed time window, according to a uniform distribution. As for the number of containers discharged, data on minimum, maximum and mode was available. Therefore we have used a triangular distribution for generating samples of containers for import and export. A long run or a number of simulation runs were required for TYPE 2 and TYPE 3 models. For validation purpose average estimates of simulated arrivals were used in the case of TYPE 2 and 3 models. TYPE 1 models are easier to validate due to the exact correspondence of arrivals and departures in many blocks.

For validation purposes, averaged estimates for simulated arrivals, moves and utilisation of QC and their standard deviations were obtained through 30 independent replications. A number(r) of average simulation responses were compared with real measures for the reference month, by applying the classical Student t-test(two sided) combined with Bonferroni's inequality(Banks, 1995). Under a probability of rejecting a valid model fixed to the level of α = 0.10, a sample size fixed to m = 30, and r = 2 responses, the resulting critical value of the test is $t_{m-1,\alpha/(2r)} = t_{29,0.025} =$ 2.045. Table 3.1 shows that the model outputs compare acceptably with real system measures, as all $|t_s|$ values are below critical values.

	Q.C. utilisation %	Number of Container Moves
Model output	Avg. 47.742 σ=1.39	Avg. 12900.0 σ=1.40
Real Measures	48	12904

Table 3.1: Comparison of model output with real system measures.

3.5.6. Some important model blocks used in various experiments

SHIP ARRIVAL: Ship arrival is an exogenous activity and hence it is not a controllable variable. A ship leaves when all containers scheduled for import are unloaded and export are handled. Only when berth becomes free, next ship is allowed to the berth. The number of containers for import and export vary depending on the arriving ship. For modelling ship arrival rate, the model used a *generator* block named **ship arrival**. The minimum value, maximum values for the interarrival rate of ships had to be given. A *variable unbatch* block provides the container load for import and export. *Set value block* assigns random values of container load. Triangular distributions are used for setting the values for container load.

LORRY ARRIVAL: External Trucks coming for export purposes were generated by this block using an Extend *generator* block. The trucks come upto the gate of the yard and wait for permission so that a few of them can go inside at a time.

LORRY EXIT: This *generator block* generates arrival of External Trucks carrying imported containers (stacked in the import yard). These trucks take the containers to various destinations.

QCEXPOPERATION: This *activity block* represents the time taken by the QC crane for the export operations related to a container movement from a ship. The operation was modeled using the machine block in Extend. The times were fed by an *input random number block* setting using a triangular distribution.

Figure 3.13 shows a block representing QC export operation activity time in the simulation model.

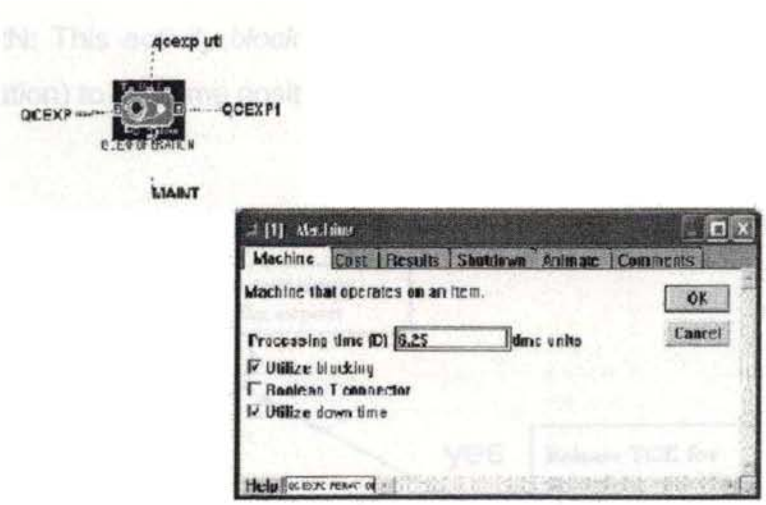

Figure 3.13: Block representing QC export operation activity time in the simulation model

QCIMPOPERATION: This *activity block* represents the time taken by the QC crane for the movement of a container during the import operations from a ship. The operation was modeled using the machine block in Extend. The times were fed by an *input random number block* setting using a triangular distribution.

Transfer Crane's operations: Several transfer cranes were required for the container terminal activities. Figure 3.14 shows a flow chart of TCE (Transfer cranes at export) yard operations. Figure 3.15 shows a flow chart of TCI(Transfer cranes at import yard) operations. These cranes load or unload the containers to the trucks. The containers for export and import were stacked in marked places (The TC yard plan identifies this position). These areas form in fact a large cubical space. Containers were stacked in these areas in up to 3 or 4 level high. The TC's have to travel to the position of the container and reach for the correct position. All the times were fed by *input random number block* setting using a triangular distribution.

TCE LOAD TRUCK: This *activity block* sets the time TC's(export operation) take for lifting the containers from the export stack and place it on the IT's moving to the ship side.

TCE RETURN: This *activity block* sets the return time per movement, of TC's (export operation) to its home position just after loading the container.

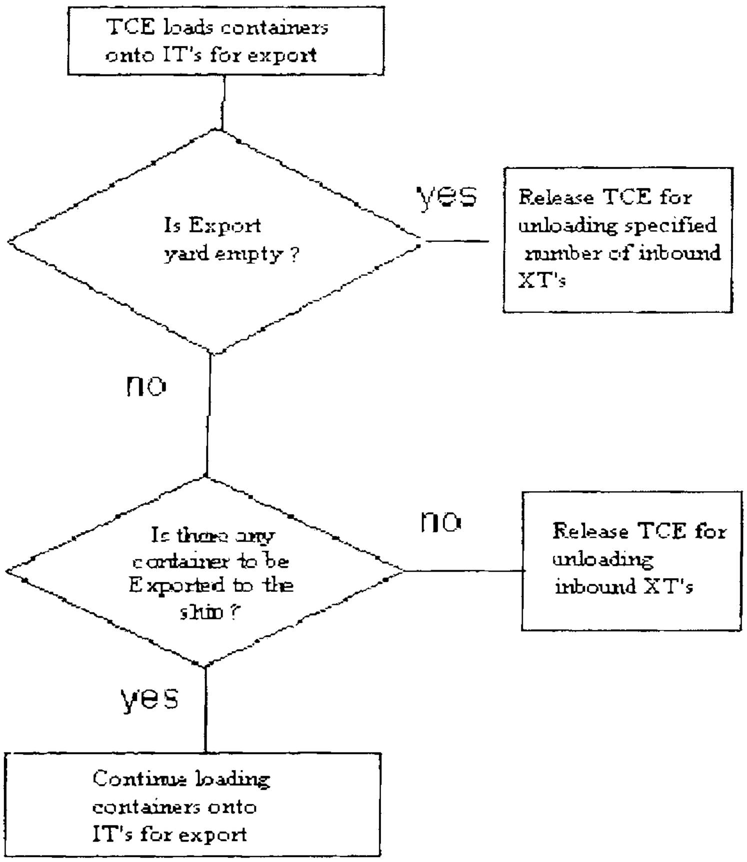

Figure 3.14: Flow chart of TCE operations

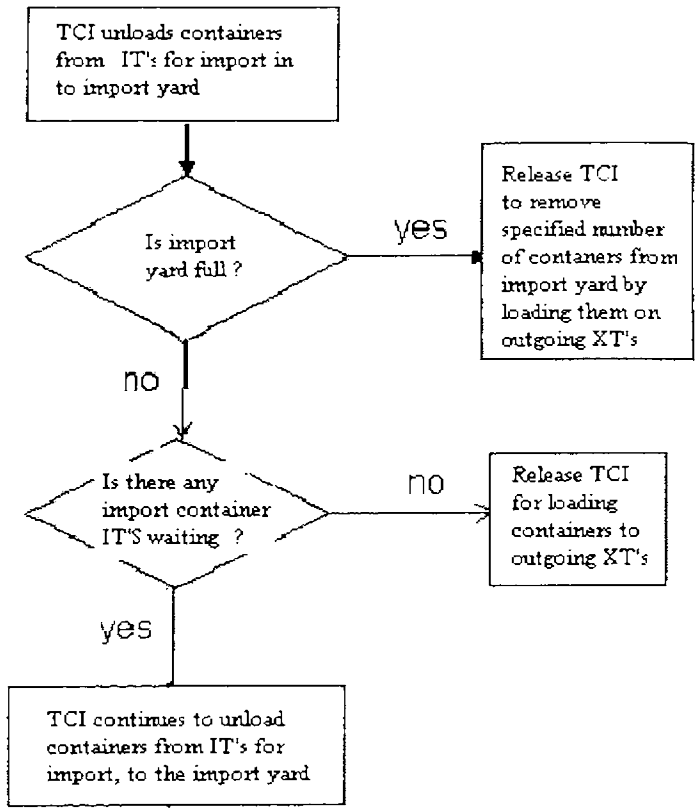

Figure 3.15: Flow chart of TCI operations

TCE UNLD LORRY: This *activity block* sets the time of TC's(for Export Operations) for unloading XT's carrying containers from outside for export purpose. TC's stack the containers in appropriate places. If the export stack is full they operate only on loading the IT's(for export) thus freeing up space. If export stack is empty their first preference will be to unload XT's from gate till the container storage reaches a predetermined level.

TCI LOAD LORRY: This *activity block* sets the time for TC's(for when engaged to load ET's with imported containers kept at the import storage space. If the import stacks are full, TC's will be first used to remove some of containers(in order to make room for storing imported containers brought by IT's) by loading XT's before proceeding to unload trucks for import.

TCI RETURN : This *activity block* sets the return time per movement, of TC's marked for export operation to its home position just after loading the container.

Truck movements: Several trucks were put into service for import and export container movements. These times are variable depending upon the distances traveled, speed of movement, obstacles in road, driver skill, condition of vehicles etc. Triangular distributions were used in our model for these times. Following are the various blocks used.

TRK GO TO SHIP: This *activity block* sets the time taken by a loaded IT when it moves from the export stack area to the position of QC. Trucks travel a few hundred metres carrying the load of the container on the trailer body.

TRK EXPRT RET: This *activity block* sets time taken by an unloaded IT as it returns from the position of QC to the export stack area.

TRUCK IMP CARRIES: This *activity block* sets time taken by a loaded IT (by QC) as it returns from the position of QC to the export stack area.

TRUCK IMP RET: This *activity block* sets the time taken by an unloaded IT (by TC) as it returns from the position of import stack to the QC position.

For easily changing parameter values in experimental settings, various activities and resources blocks were grouped together, by using the feature of *named connections* available in Extend. Figure 3.16 and 3.17 shows screen shots of part of simulation model with this feature implemented.

Information Blocks: Plotters attached various blocks to study behavior of entities at various time points.

Maintenance Consideration: For most of machines/equipments the model gives the flexibility to add maintenance and repair times, which was used by us.

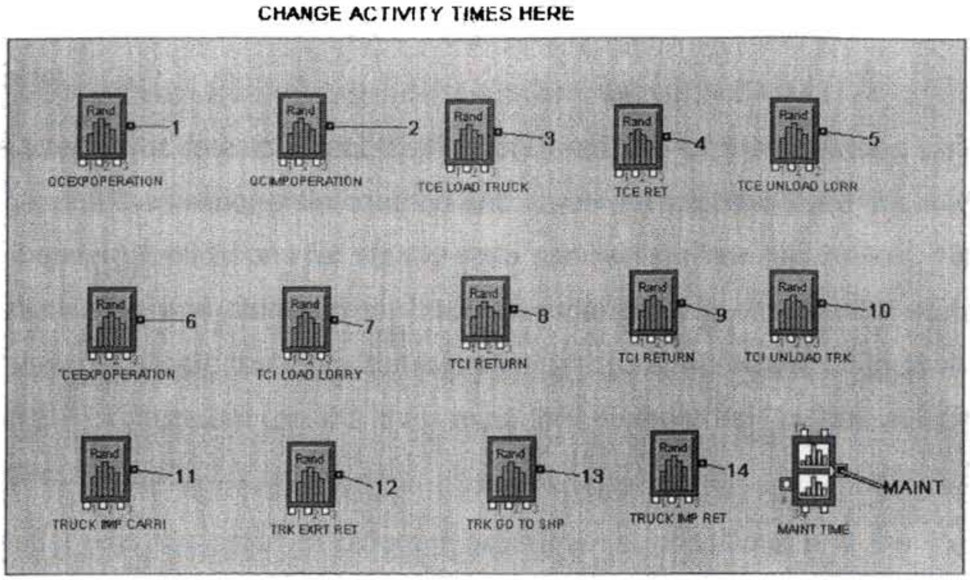

Figure 3.16: Part of the simulation model where activity times can be modified for experiments

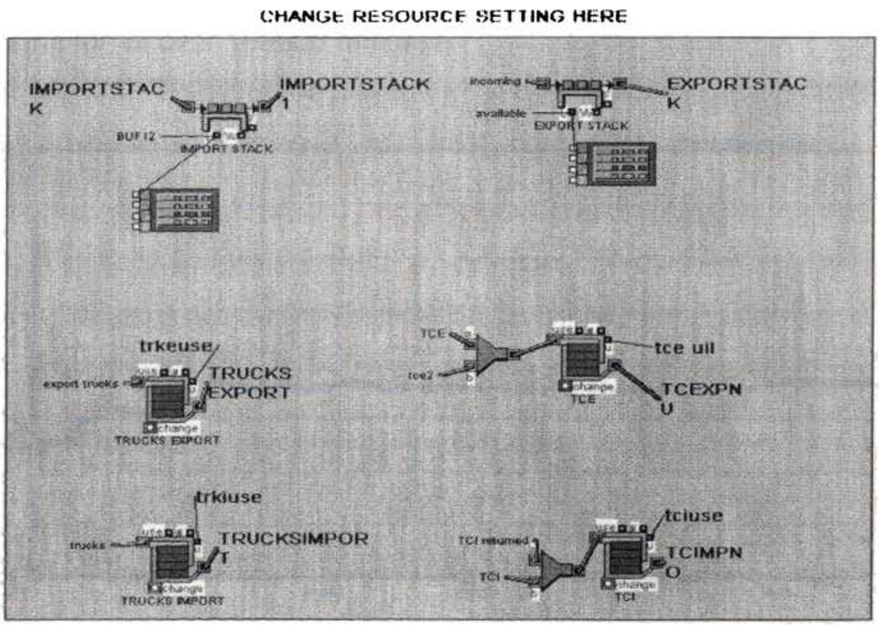

Figure 3.17: Part of the simulation model where resource settings can be modified for experiments

3.5.7. Finding ship turnaround time and other performance measures

The model collects information about ship turnaround time, which is the average time; a ship spends in the system from its arrival to departure from berth. The value of this performance measure depends on factors like the inter arrival time of ships, the number of containers carried by the ship and efficiency of terminal equipment.

As we need to be free to select distribution functions for time between arrivals more general than exponential method and, therefore we have used the method of independent replications for steady-state simulation (Law and Kelton, 1991). Each replication was started from the (non-regenerative) empty initial state of the system (terminal); therefore some preliminary runs were needed to evaluate the length of transient period that must be disregarded to get stationery estimates.

The model was subjected to different experimental conditions and the steady state behavior was noted. Figure 3.18 shows a part of the plot of the average turnaround time of the ship when simulated for 1000000 minutes at an inter-arrival time of 1440 minutes (ie one ship a day). It shows a steady behavior after a simulation time of over 100000 minutes.

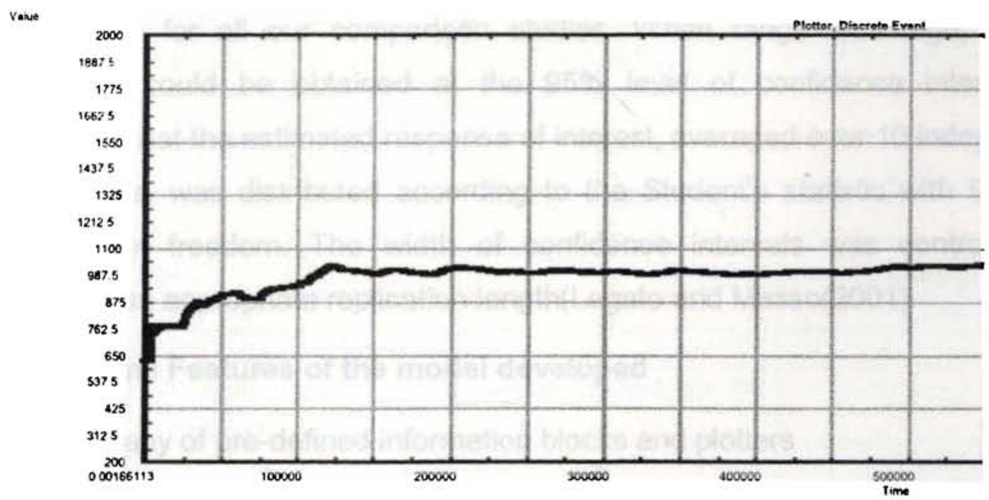

Figure 3.18: Plot of ship turnaround time when simulated for 1000000 minutes at an arrival rate of 1440 minutes

Statistics blocks gets collective information regarding the utilization of each activity blocks, average length, maximum length, average wait and maximum wait in each queues, utilization of each resource required etc at a specified confidence interval(See Figure 3.19).

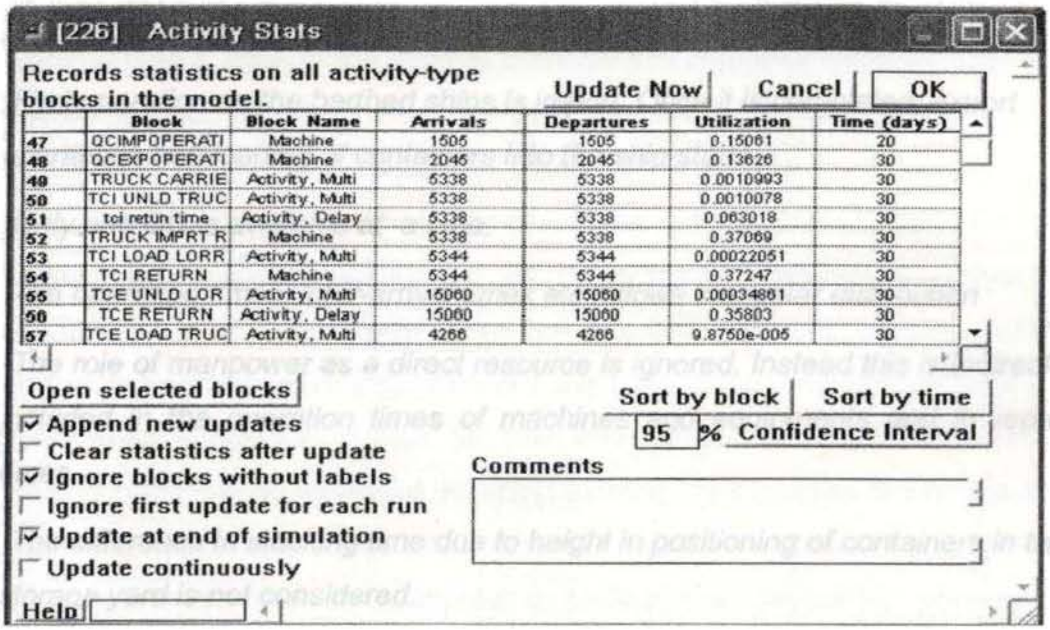

Figure 3.19: Use of Activity Stats Blocks

It may be noted that whenever range was small, estimates of average values were used for all our comparison studies. When range was high, interval estimates could be obtained at the 95% level of confidence interval, by assuming that the estimated response of interest, averaged over 10 independent replications, was distributed according to the Student's statistic with 9(=10-1) degrees of freedom. The width of confidence intervals was controlled by selecting an appropriate replication length(Legato and Masso(2001).

3.5.8. Some Features of the model developed

- Many of pre-defined information blocks and plotters
- Easily changeable parameters for a simulation study
- Can be modified easily to incorporate additional resources of same type
- Statistical distributions or empirical data can be used.
- Can easily adapted to multiple ship processing

3.5.9. Assumptions

considering operational realities, following assumption were made in the model

1. Berthing permission is given to only one ship at a time.

2 .First operation on the berthed ships is import. Once it is completed, export operations and loading of containers into the ship starts.

3. Only one QC is available at a time.

4. The operation times, inter-arrival times etc follows triangular distribution

5. The role of manpower as a direct resource is ignored. Instead this is indirectly included in the operation times of machines and equipments and in repair times.

6. The difference in stacking time due to height in positioning of containers in the storage yard is not considered.

3.6. PROBLEMS AND ANALYSIS

As discusses earlier the decision problems of container terminal management can be classified as Strategic, Tactical and Operational. In this section we discuss use of simulation models to help solve a number of problems related to operational design/improvement of the container terminal. The problems and corresponding model types used for solution are given in Table 3.2.

Problem Type	**Model Type**
Strategic level	TYPE 3
Case 1: Planning for a new Berth	
Case 2: How much space is to be given in total for the stacking of containers	
Tactical level	TYPE 2
Case 1: Determination of the necessary number of transport vehicles to transport all containers in time.	
Case 2: Queue space for import trucks(XT)	
Operational level	TYPE 1
Case 1: Everyday crane deployment plans.	

Table 3.2: Problems and model types

3.6.1. Strategic level

3.6.1.1. Case 1: Planning for a new Berth

Problems such as "Whether a new berth needs to be built to accommodate increasing load?" arise in the mind of managers of container terminal. This is a strategic question involving many different considerations related to technical, financial and even social feasibility. Planning for a new berth requires an assessment of the maximum capacity of existing system. The forecast of future demand (here arrival of containers) will be available. Knowing the projected demand, the simulation model may be run first with the existing facility configuration. Performance indicators like ship turnaround time can be found out under varied conditions. Based on this information the requirement of an additional berth can be assessed. Keeping existing fixed facilities like berths and augmenting with more equipment's may be helpful in meeting some of the coming year's demand or in improving performance measures. Sometimes procurement of *advanced technology* like an upgraded quay crane may be effective. This aspect is illustrated here. The simulation model for single berth case was run under different interarrival times of ships shown in table 3.3. The minimum, average and maximum values of turnaround times are also shown in above table.

The effect of inter-arrival time on average ship turnaround time is given in table 3.3 and figure 3.20. It clearly indicates the possibility of exponential increase in ship turnaround time with decrease in inter-arrival time from 1980 minutes to 720 minutes. The plot shows that it will become almost unmanageable if frequency of arrival is just doubled(say if the number of ship arrivals per day is changed from 0.9 per day to 1.8 per day then turnaround time increase from 0.9 days per ship to about 12 days per ship). It is imperative that if the terminal has to accommodate more ships per day, the high turnaround times due to increased load must be brought within reasonable limits.

INTER ARRIVAL TIME OF SHIPS	NO OF SHIPS PER DAY	TURNAROUND TIME IN DAYS		
		Minimum	Average	Maximum
720	2.0	13.94	14.15	14.22
1080	1.3	9.66	9.73	9.91
1260	1.1	5.65	5.83	5.96
1440	1.0	2.61	2.72	2.77
1620	0.9	0.88	0.94	1.02
1800	0.8	0.65	0.73	0.79
1980	0.7	0.66	0.73	0.77

Table 3.3: Effect of interarrival times on turnaround times

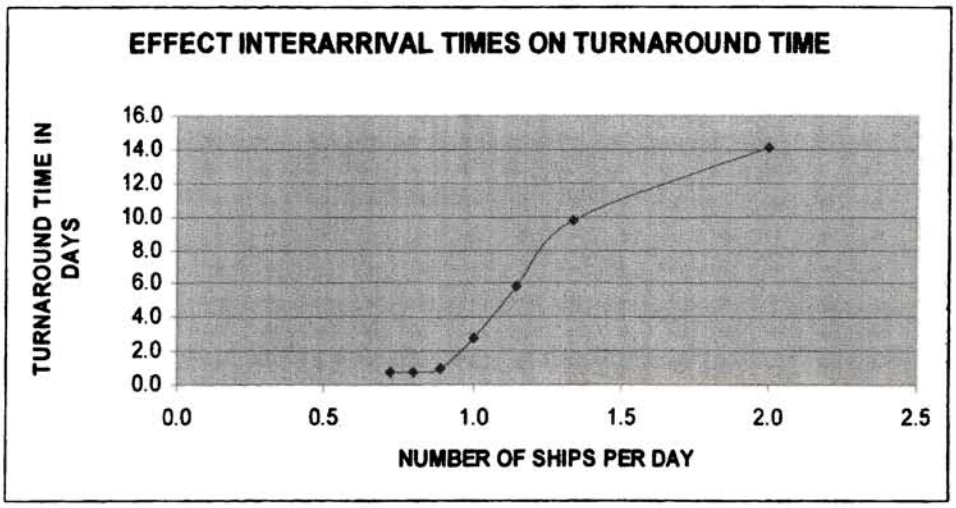

Figure 3.20: Plot showing the effect of number of ships per day on turnaround times

Turnaround time depends on the how much time per movement of a container is required at each equipment, number of these equipment available, downtimes etc. The contribution of various factors in deciding the value of performance measure would be different. So in order to improve productivity one would like to concentrate on most significant factors. Finding most significant factors that affect a performance measure can be found using a statistical screening experiment.

We have identified 15 factors related to performance of equipments that can affect turnaround times. These factors are discussed in section 3.5. A Plackett-Burman Design with 16 runs was selected(See Table 3.4). Plackett-Burman Designs are particularly useful for screening experiments when the number of factors are high(Montgomery, 1991).

Data Matrix (randomized)

Run	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P
1	-	+	-	+	+	+	+	-	-	-	+	-	-	+	+
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	+	+	+	+	-	-	-	+	-	-	+	+	-	+
4	-	-	+	+	-	+	-	+	+	+	+	-	-	-	+
5	+	-	-	+	+	-	+	-	+	+	+	+	-	-	-
6	+	-	+	-	+	+	+	+	-	-	-	+	-	-	+
7	+	+	-	+	-	+	+	+	+	-	-	-	+	-	-
8	+	+	-	-	-	+	-	-	+	+	-	+	-	+	+
9	+	+	+	-	-	-	+	-	-	+	+	-	+	-	+
10	+	-	-	-	+	-	-	+	+	-	+	-	+	+	+
11	-	-	-	+	-	-	+	+	-	+	-	+	+	+	+
12	-	+	-	-	+	+	-	+	-	+	+	+	+	-	-
13	-	-	+	-	-	+	+	-	+	-	+	+	+	+	-
14	+	-	+	+	+	+	-	-	-	+	-	-	+	+	-
15	+	+	+	+	-	-	-	+	-	-	+	+	-	+	-
16	-	+	+	-	+	-	+	+	+	+	-	-	-	+	-

Table 3.4: Plackett-Burman Design

The Pareto Chart of the Effects (Figure 3.21) shows that under a given load, four factors significantly affect value of turnaround times. These factors are

1) TCE UNLD LORRY 2)TCE LOAD TRUCK 3)QCIMPOPERATION and 4)TRUCK IMP RET. It is recommended that these times may be strictly controlled and kept to a minimum.

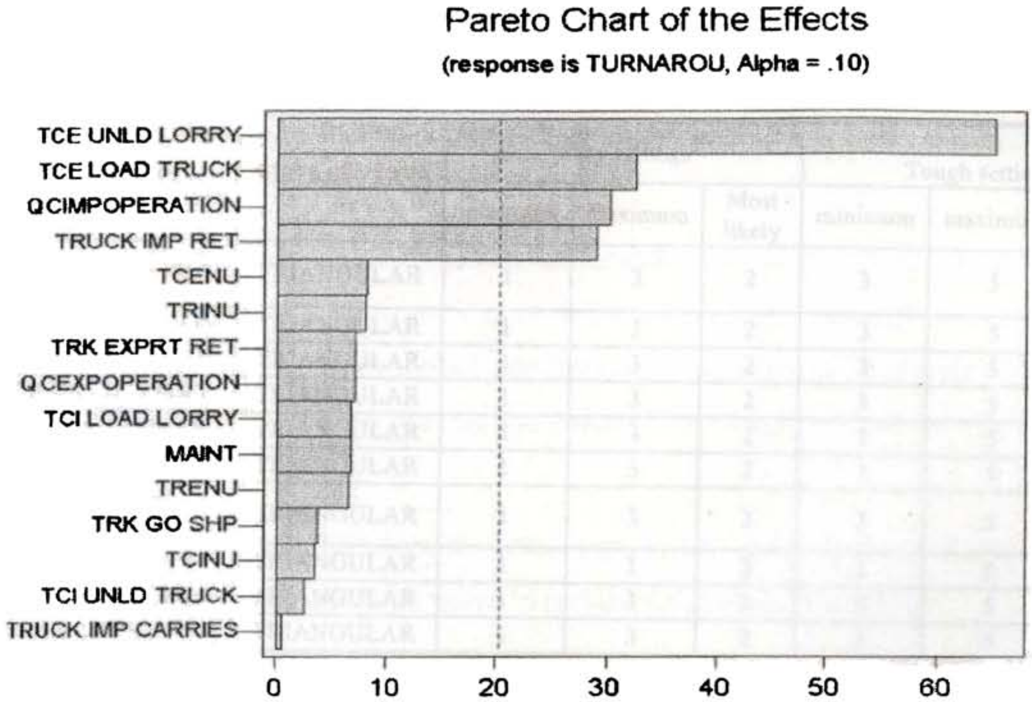

Figure 3.21: Pareto chart of effects

To reduce activity times, an alternative is to use *more sophisticated cranes* and other equipment. Here we discuss use of simulation model to study the effect of quay cranes on turnaround times under two conditions.

a) Easy setting: In easy settings the terminal processes may operate efficiently so that processes are not delayed and there will be enough resources and with little maintenance. Some typical values used for these run are given below. All operational times are given in minutes.

b) Tough setting: In tough settings the terminal processes may be operating with less resources and more operational delays and maintenance. Table 3.5 shows the values of parameters under easy and tough settings.

In both settings we assumed that only one berth was available, only one QC was available. The simulation model *for single berth* was run by ***sensitizing*** the parameter values(most likely value) of QC operational times for import and export and the interarrival times of ships, keeping other parameter values same.

The value of turnaround time and throughput per day obtained from the simulation runs under *tough settings* are given in tables 3.6 and 3.7.

OPERATION	DISTRIBUTION	Easy settings			Tough settings		
		minimum	maximum	Most likely	minimum	maximum	Most likely
QCEXPOPERATION	TRIANGULAR	1	3	2	3	5	4
QCIMPOPERATION	TRIANGULAR	1	3	2	3	5	4
TCE LOAD TRUCK	TRIANGULAR	1	3	2	3	5	4
TCE UNLD LORRY	TRIANGULAR	1	3	2	3	5	4
TCI LOAD LORRY	TRIANGULAR	1	3	2	3	5	4
TCI UNLD TRUCK	TRIANGULAR	1	3	2	3	5	4
TRUCK IMP CARRIES	TRIANGULAR	1	3	2	3	5	4
TRK EXPRT RET	TRIANGULAR	1	3	2	3	5	4
TRK GO TO SHP	TRIANGULAR	1	3	2	3	5	4
TRUCK IMPRT RET	TRIANGULAR	1	3	2	3	5	4

Table 3.5: showing the values of parameter used in the experiments under easy and tough settings conditions

It is evident from figures 3.22 and 3.23 that QC operational time per container movement has a very significant effect on both turnaround times and throughput. Plots show that by reduction of import cranes operational times, higher throughputs and better turnaround times can be achieved. The times for QC must be kept under 4 minutes per container movement for reasonable throughput and turnaround times and arrival rate of ships below 0.9 ships per day.

A better way to show throughput per day is by calculating the **percent handled per day.** When ship arrival rate is low, throughput per day shows a lesser value indicating less efficiency. But this is not due to system inefficiency.

$$\textbf{Percent handled per day} = \frac{\textbf{Throughput per day} * 100}{\textbf{Number of containers arriving per day}} \qquad 3.2$$

For example if the ship arrival rate is 0.8 ships per day(interarrival time of ships 1800 minutes) and the corresponding expected total number of containers is 280 containers per day and if the throughput per day was 259, then percent handled is 259/280 = 92.5 percent.

Mean value of percent handled per day(under different arrival rates) can used to quantify the impact of QC times. Figure 3.24 shows improvement possible by reducing QC times under assumed conditions of experiment. It shows that by reducing the QC time by one minute, the *percent handled* improves by about **2.3** percent.

So by reducing QC operational time, significant gains was obtained in productivity. Following are some ways to reduce QC operational times.

- by advanced technology

- by reducing downtimes

- by more efficient work methods

In the above analysis our stress was to highlight the point that the terminal could handle additional load by reducing operational times of equipment even without adding more facility. We have illustrated this with respect to QC cranes. Reduction of other operational times also could similarly be useful in improving productivity.

NUMER OF SHIPS PER DAY	TURNAROUND TIME IN DAYS				
	QC TIME 1 MINUTE	QC TIME 2.5 MINUTES	QC TIME 4 MINUTES	QC TIME 5.5 MINUTES	QC TIME 7 MINUTES
1.1	8.1	9.0	9.5	10.7	11.3
1.0	5.2	6.7	7.4	8.7	9.3
0.9	2.8	4.2	5.6	6.5	7.3
0.8	0.7	0.9	3.0	4.3	5.3
0.7	0.7	0.9	1.0	2.2	3.3

Table 3.6: Showing turnaround times under various QC time settings

NUMER OF SHIPS PER DAY	EXPECTED TOTAL NUMBER OF CONTAINERS PER DAY	THROUGHPUT PER DAY				
		QC TIME 1 MINUTE	QC TIME 2.5 MINUTES	QC TIME 4 MINUTES	QC TIME 5.5 MINUTES	QC TIME 7 MINUTES
1.1	400.0	285.7	271.8	259.0	245.0	233.1
1.0	350.0	290.1	271.7	259.0	245.0	232.2
0.9	311.1	293.8	272.4	258.2	245.0	232.8
0.8	280.0	280.0	280.0	259.0	245.0	233.0
0.7	254.5	254.2	252.4	252.0	245.0	232.5
		PERCENT HANDLED PER DAY				
1.1	400.0	71.4	67.9	64.8	61.3	58.3
1.0	350.0	82.9	77.6	74.0	70.0	66.4
0.9	311.1	94.4	87.6	83.0	78.8	74.8
0.8	280.0	100.0	100.0	92.5	87.5	83.2
0.7	254.5	99.9	99.2	99.0	96.3	91.3

Table 3.7: Showing throughput and percent handled per day under various QC time settings

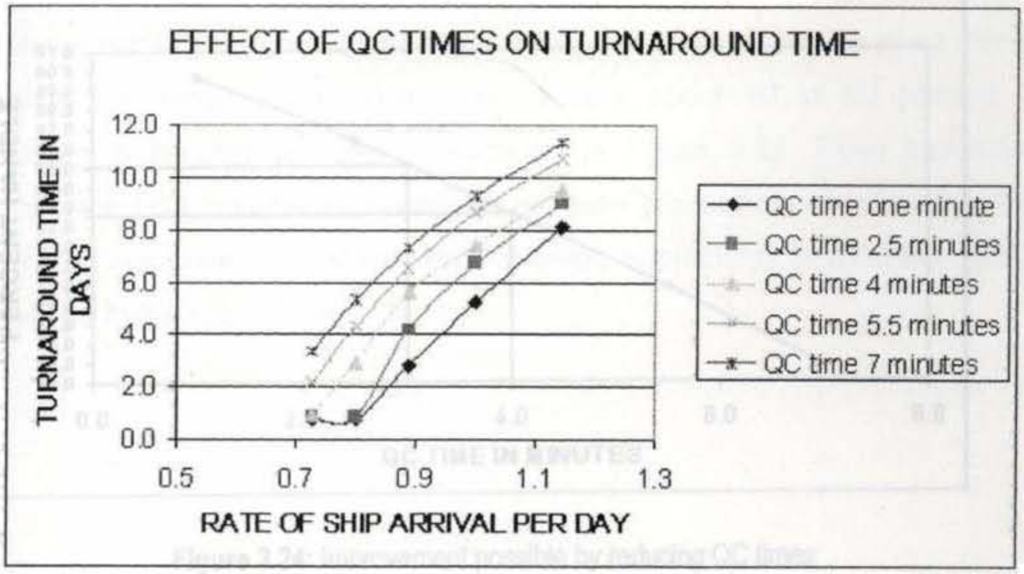

Figure 3.22: Plot showing rate of ship arrival per day Vs turnaround time under various QC time settings (Tough settings)

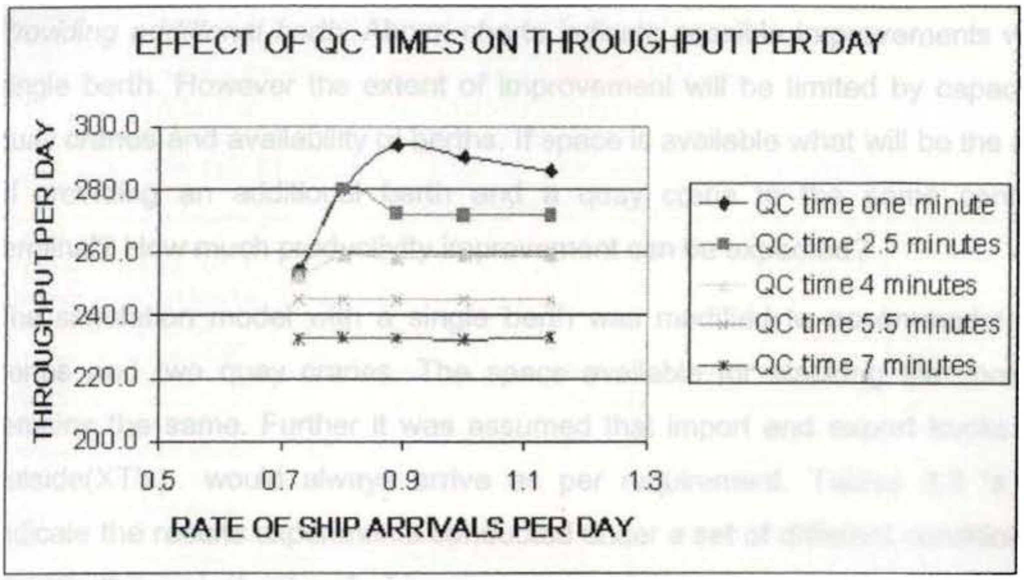

Figure 3.23: Plot showing rate of ship arrival per day vs. throughput per day under various QC time settings (Tough settings)

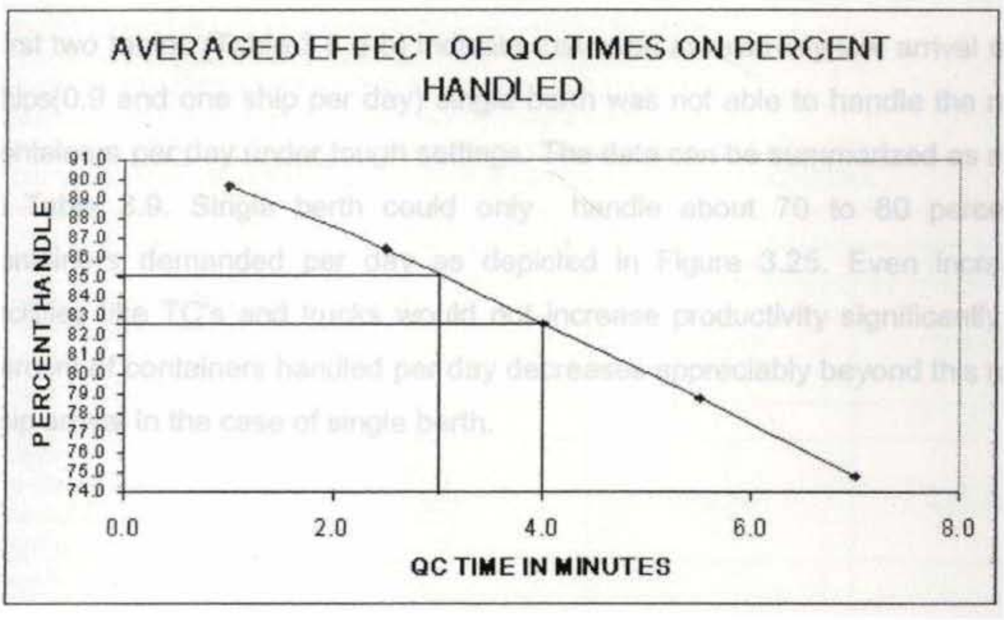

Figure 3.24: Improvement possible by reducing QC times

Providing additional berth: Above charts indicate possible improvements with a single berth. However the extent of improvement will be limited by capacity of quay cranes and availability of berths. If space is available what will be the effect of providing an additional berth and a quay crane in the same container terminal? How much productivity improvement can be expected?

The simulation model with a single berth was modified to accommodate two berths and two quay cranes. The space available for stacking the container remains the same. Further it was assumed that import and export trucks from outside(XT's) would always arrive as per requirement. Tables 3.8 'a to f' indicate the results experiments conducted under a set of different conditions by varying the arrival rate of ships (consequently the number of containers for import and export) and changing the number provided with respect to transfer cranes and trucks. The conditions set for the study were the tough settings discussed earlier.

First two tables (Table 3.8 a-b) indicate that even at relatively low arrival rate of ships(0.9 and one ship per day) single berth was not able to handle the rate of containers per day under tough settings. The data can be summarized as shown in Table 3.9. Single berth could only handle about 70 to 80 percent of containers demanded per day as depicted in Figure 3.25. Even increasing facilities like TC's and trucks would not increase productivity significantly. The percent of containers handled per day decreases appreciably beyond this rate of ship arrival in the case of single berth.

INTERARRIVAL RATE 1600 MINUTES I.E 0.9 SHIP PER DAY AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 180 AVERAGE NUMBER OF EXPORT CONTAINERS PER DAY 146.25 AVERAGE TOTAL CONTAINERS PROCESSED PER DAY 326.25 LIMITATION ON THE STACKING OF IMPORT CONTAINERS: 400 NUMBERS. LIMITATION ON THE STACKING OF EXPORT CONTAINERS: 350 NUMBERS.		
Throughput per day(Containers)		
Case 1	Single berth	Two berth
Number of import TC 3 Number of import trucks 9 Number of export TC 2 Number of export truck 6	253.764	326.232
Case 2		
Number of import TC 4 Number of import trucks 12 Number of export TC 3 Number of export truck 9	261.5	325.644
Case 3		
Number of import TC 5 Number of import trucks 15 Number of export TC 4 Number of export truck 12	263.564	327.456

Table 3.8a

INTERARRIVAL RATE 1440 MINUTES I.E ONE SHIP PER DAY AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 200 AVERAGE NUMBER OF EXPORT CONTAINERS PER DAY 162.5 AVERAGE TOTAL CONTAINERS PROCESSED PER DAY 362.5 LIMITATION ON THE STACKING OF IMPORT CONTAINERS: 400 NUMBERS. LIMITATION ON THE STACKING OF EXPORT CONTAINERS: 350 NUMBERS.		
Throughput per day (Containers)		
Case 1	Single berth	Two berth
Number of import TC 3 Number of import trucks 9 Number of export TC 2 Number of export truck 6	255.916	355.636
Case 2		
Number of import TC 4 Number of import trucks 12 Number of export TC 3 Number of export truck 9	260.108	362.408
Case 3		
Number of import TC 5 Number of import trucks 15 Number of export TC 4 Number of export truck 12	265.988	358.732

Table 3.8b

INTERARRIVAL RATE 1310 MINUTES I.E 1.1 SHIP PER DAY
AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 220
AVERAGE NUMBER OF EXPORT CONTAINERS PER DAY 178.75
AVERAGE TOTAL CONTAINERS PROCESSED PER DAY 398.75
LIMITATION ON THE STACKING OF IMPORT CONTAINERS: 400 NUMBERS.
LIMITATION ON THE STACKING OF EXPORT CONTAINERS: 350 NUMBERS.

Throughput per day (Containers)		
Case 1	Single berth	Two berth
Number of import TC 3 Number of import trucks 9 Number of export TC 2 Number of export truck 6	255.64	354.672
Case 2		
Number of import TC 4 Number of import trucks 12 Number of export TC 3 Number of export truck 9	260.688	371.072
Case 3		
Number of import TC 5 Number of import trucks 15 Number of export TC 4 Number of export truck 12	267.828	377.412

Table 3.8c

INTERARRIVAL RATE 1107 MINUTES I.E 1.3 SHIP PER DAY
AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 260
AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 211.25
AVERAGE TOTAL CONTAINERS PROCESSED PER DAY 471.25
LIMITATION ON THE STACKING OF IMPORT CONTAINERS: 400 NUMBERS.
LIMITATION ON THE STACKING OF EXPORT CONTAINERS: 350 NUMBERS.

Throughput per day (Containers)		
case 1	Single berth	Two berth
Number of import TC 3 Number of import trucks 9 Number of export TC 2 Number of export truck 6	254.692	368.102
Case 2		
Number of import TC 4 Number of import trucks 12 Number of export TC 3 Number of export truck 9	259.768	368.112
Case 3		
Number of import TC 5 Number of import trucks 15 Number of export TC 4 Number of export truck 12	266.86	370.408

Table 3.8d

INTERARRIVAL RATE 1028 MINUTES I.E 1.4 SHIP PER DAY AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 280 AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 227.5 AVERAGE TOTAL CONTAINERS PROCESSED PER DAY 507.5 LIMITATION ON THE STACKING OF IMPORT CONTAINERS: 400 NUMBERS. LIMITATION ON THE STACKING OF EXPORT CONTAINERS: 350 NUMBERS.		
Throughput per day (Containers)		
Case 1	Single berth	Two berth
Number of import TC 3 Number of import trucks 9 Number of export TC 2 Number of export truck 6	255.08	368.014
Case 2		
Number of import TC 4 Number of import trucks 12 Number of export TC 3 Number of export truck 9	260.872	368.14
Case 3		
Number of import TC 5 Number of import trucks 15 Number of export TC 4 Number of export truck 12	268.84	370.04

Table 3.8e

INTERARRIVAL RATE 1200 MINUTES I.E 1.2 SHIP PER DAY AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 240 AVERAGE NUMBER OF IMPORT CONTAINERS PER DAY 195 AVERAGE TOTAL CONTAINERS PROCESSED PER DAY 435 LIMITATION ON THE STACKING OF IMPORT CONTAINERS: 400 NUMBERS. LIMITATION ON THE STACKING OF EXPORT CONTAINERS: 350 NUMBERS.		
Throughput per day (Containers)		
Case 1	Single berth	Two berth
Number of import TC 3 Number of import trucks 9 Number of export TC 2 Number of export truck 6	254.116	368.122
Case 2		
Number of import TC 4 Number of import trucks 12 Number of export TC 3 Number of export truck 9	258.928	368.572
Case 3		
Number of import TC 5 Number of import trucks 15 Number of export TC 4 Number of export truck 12	267.864	368.98

Table 3.8 a-f: Shows throughput per day under single berth and two berths in various cases

Providing an additional berth with an additional quay crane could take all the load (nearly hundred percent) and handle all daily rate when ship arrival rate were 0.9 and one ship per day. The turnaround times found from experiments in above case are to be 0.75 days and 1.66 days per ship respectively which are reasonable.

When arrival rate was 1.1 ship per day two berth case could handle about 90 percent of the load per day. But the turnaround time rise to a high value of 12.97 per day. See Figure 3.26. This high turnaround time could be significantly reduced if it is feasible to equip the terminal with more TC and trucks. When the number of TC were increased by one each for import and export and the number of trucks put in service were increased by 3 each, the turnaround time was reduced to about 7.4 days. Further increase of TC and trucks by the same quantity could decrease the turnaround time to a reasonable level of less than 4 days.

When arrival rate was above 1.1 ships per day, providing additional berth and equipment for the same terminal would not be effective unless the rate at which each equipment handled the containers was improved significantly.

Interarrival time of ships	Expected number of ships per day	Expected total number of containers per day	Average total number handled by single berth	% handled single berth	Average total number handled by two berths	% handled two berth
1600	0.9	326.3	259.6	79.6	326.3	100.0
1440	1.0	362.5	260.7	71.9	358.9	99.0
1310	1.1	398.5	261.4	65.6	367.7	92.2
1200	1.2	435.0	260.3	59.8	368.6	84.7
1107	1.3	471.5	260.4	55.3	368.9	78.3
1028	1.4	507.8	261.6	51.5	368.7	72.7

Table 3.9: Showing the containers handled by single berth and two berths

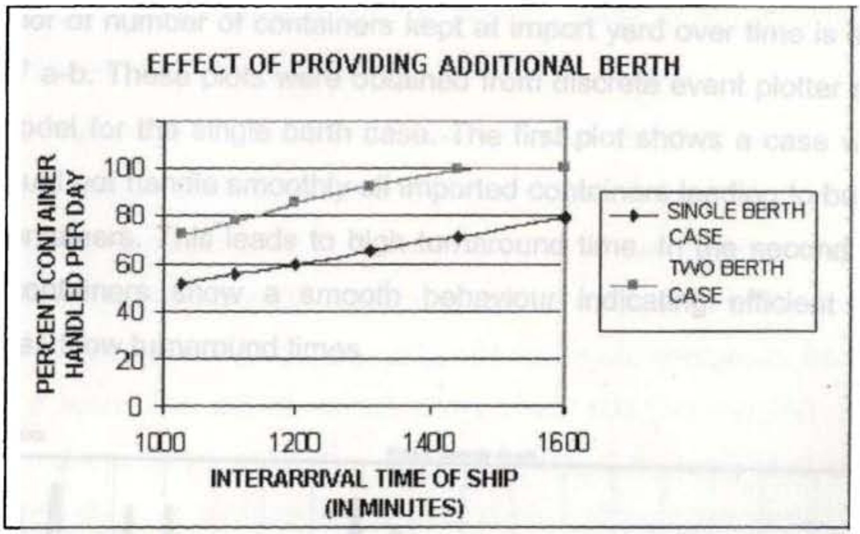

Figure 3.25: Plot showing the effect of providing additional berth

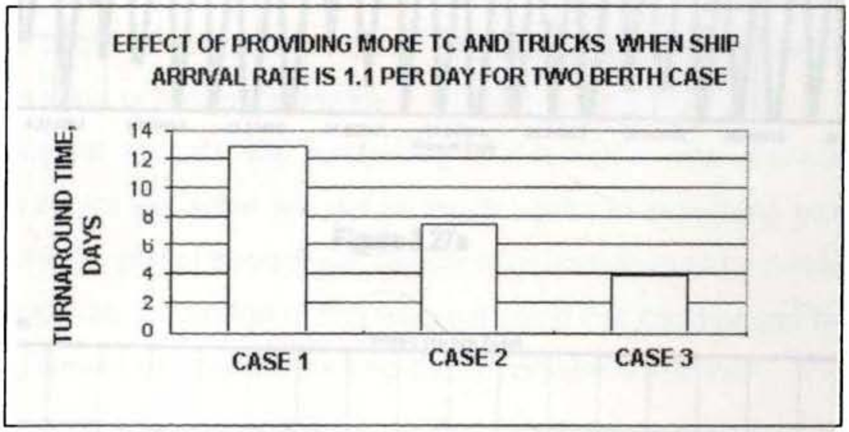

Figure 3.26: Plot showing the impact of providing more TCs and trucks in the two berth case.

3.6.1.2. Case 2: How much space is to be given for the stacking of container at import yard

Containers are stacked separately for import and export. The space required for stacking is a critical area of concern for terminal managers. If sufficient area is not available it will affect the entire operation of the yard. Costly quay cranes will become idle and ships will have to wait further for loading and unloading. The management must be aware of possible scenarios and the alternatives. In this study we illustrate how simulation model can be used to decide the space required for stacking containers at the import yard.

The behavior of number of containers kept at import yard over time is shown in Figure 3.27 a-b. These plots were obtained from discrete event plotter attached with the model for the single berth case. The first plot shows a case when the terminal could not handle smoothly all imported containers leading to build up of stock of containers. This leads to high turnaround time. In the second plot the stock of containers show a smooth behaviour indicating efficient terminal processes and low turnaround times.

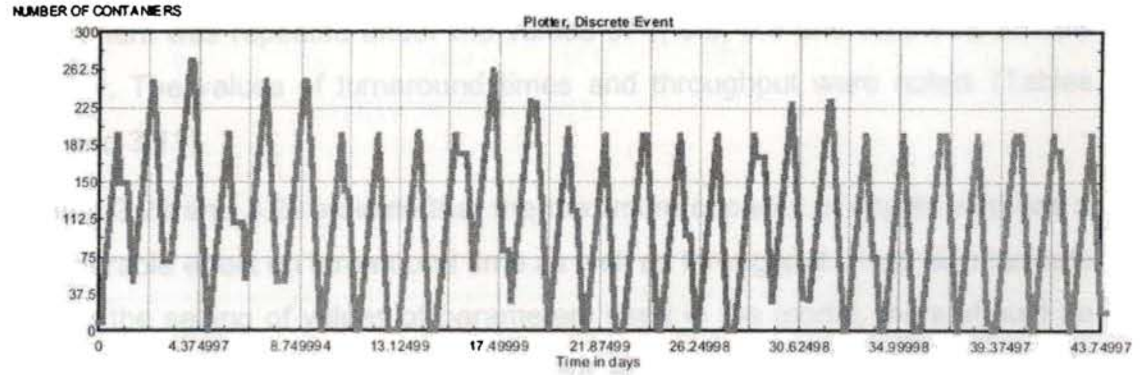

Figure 3.27a

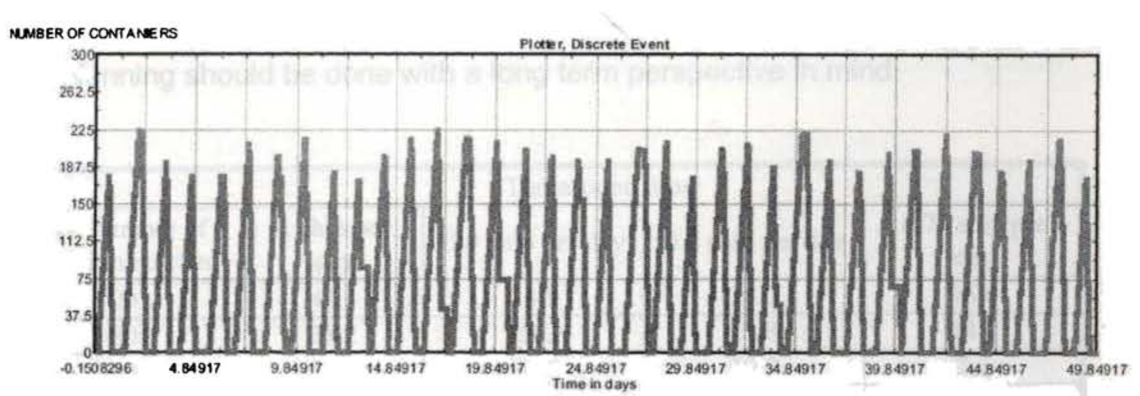

Figure 3.28b

Figure 3.27 a-b: Plot of variation in level of import containers over time

Above plots indicate that there will be peaking levels of containers in the yard at times. If there is not enough space to stock the containers, it will lead to unnecessary delays. Only after clearing some space, further unloading of containers at the ship side can begin. For clearing some space, transfer cranes are put on service.

An important strategic aspect in the design of a terminal is the decision regarding the space required to stock the containers at the import and export side. This space requirement is in direct proportion to the *maximum number of containers* that may possibly turn up. Experiments were done on the model for single berth cased by changing the number of maximum containers that can be stacked at a time. The set of values used were 100,150,200,250 and 300. Experiment was repeated under the values of 1, 0.9, 0.8 and 0.75 ship arrivals per day. The values of turnaround times and throughput were noted. (Tables 3.10 and 3.11).

Figures 3.28 and 3.29 indicate that the maximum capacity of import yard has a considerable effect on turnaround time as well as throughput. Plots also indicate that for the setting of values of parameters used in the model, there should be enough space for at least **250** containers at the import side. Increasing this space much above this value will not be much useful in increasing productivity as indicated by the plot of throughput. Similar experiments may be conducted for two berth model as the design of the terminal could not be changed frequently and planning should be done with a long term perspective in mind.

	Turnaround time			
Max. number of containers stocked	1 ship per day	0.9 ship per day	0.8 ship per day	0.75 ship per day
100	42.4	34.9	26.3	16.0
150	38.2	29.2	21.8	14.2
200	32.5	20.5	10.9	2.6
250	28.8	19.0	9.4	0.8
300	29.2	17.4	7.2	0.8

Table 3.10: Effect import yard capacity on turnaround time

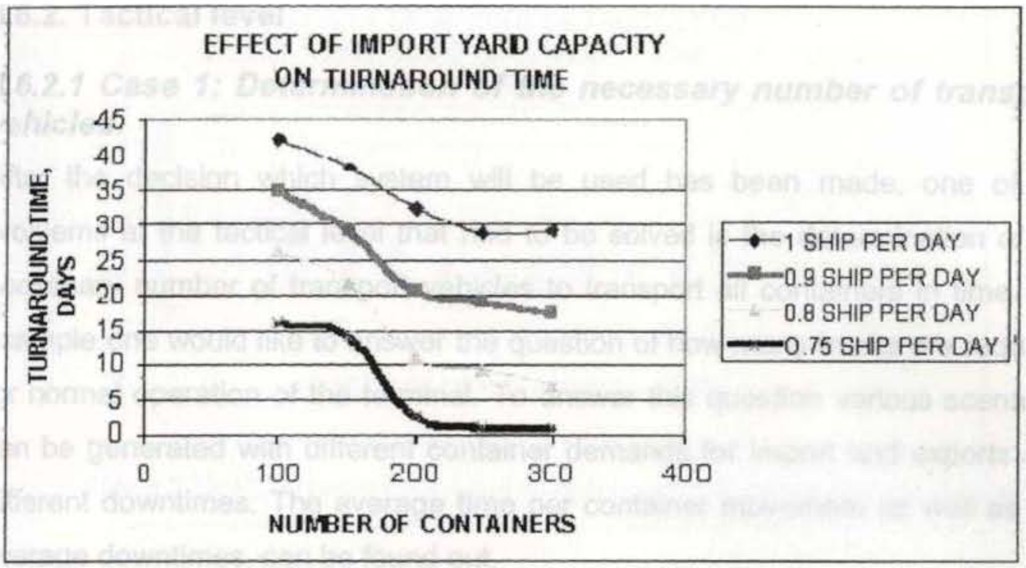

Figure 3.28: Plot of effect of import yard capacity on turnaround time

Max. number of containers stocked	Throughput Per Day			
	1 ship per day	0.9 ship per day	0.8 ship per day	0.75 ship per day
100	240.1	238.5	240.4	240.4
150	251.3	253.6	249.9	248.7
200	271.3	273.8	275.4	274.5
250	282.3	281.8	280.6	275.6
300	281.9	281.8	282.7	274.1

Table 3.11: Effect of import yard capacity on throughput per day

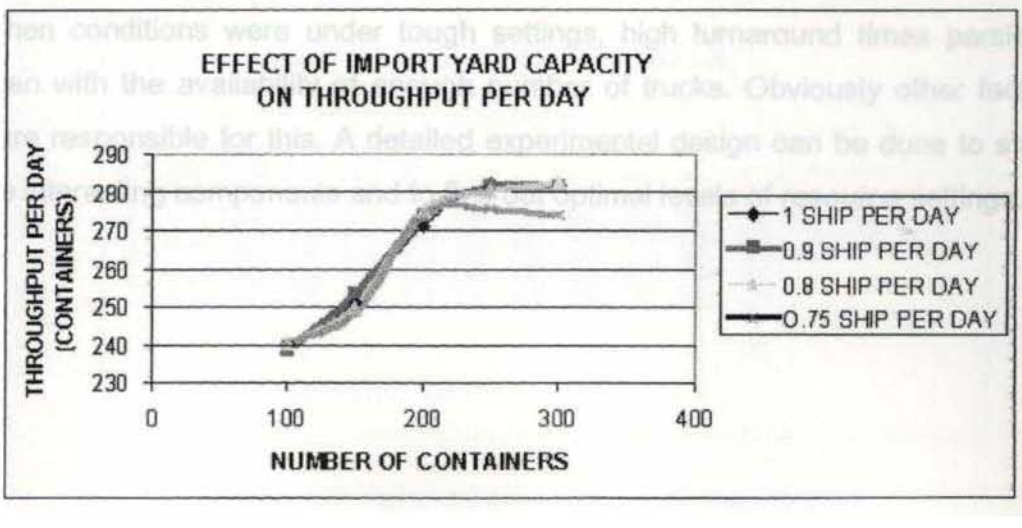

Figure 3.29: Plot of effect of import stack size on throughput per day

3.6.2. Tactical level

3.6.2.1 Case 1: Determination of the necessary number of transport vehicles.

After the decision which system will be used has been made, one of the problems at the tactical level that had to be solved is the determination of the necessary number of transport vehicles to transport all containers in time. For example one would like to answer the question of how many trucks are required for normal operation of the terminal. To answer this question various scenarios can be generated with different container demands for import and exports and different downtimes. The average time per container movement as well as the average downtimes, can be found out.

Experiments were done on the single berth model under the settings of easy and tough settings discussed earlier. Figure 3.30. and 3.31 show the effect of number of trucks for import and export on turnaround times under these conditions. It can be seen that under most favorable conditions of operational times and equipment availability, we require about 3 trucks each for import and export so that the turnaround time was kept low. However one would have to watch for the equipment utilization when only minimum number of trucks were provided. This would almost reach 100 percent when only three trucks were used (see Figure 3.32).

When conditions were under tough settings, high turnaround times persisted even with the availability of enough number of trucks. Obviously other factors were responsible for this. A detailed experimental design can be done to study the interacting components and to find out optimal levels of resource settings.

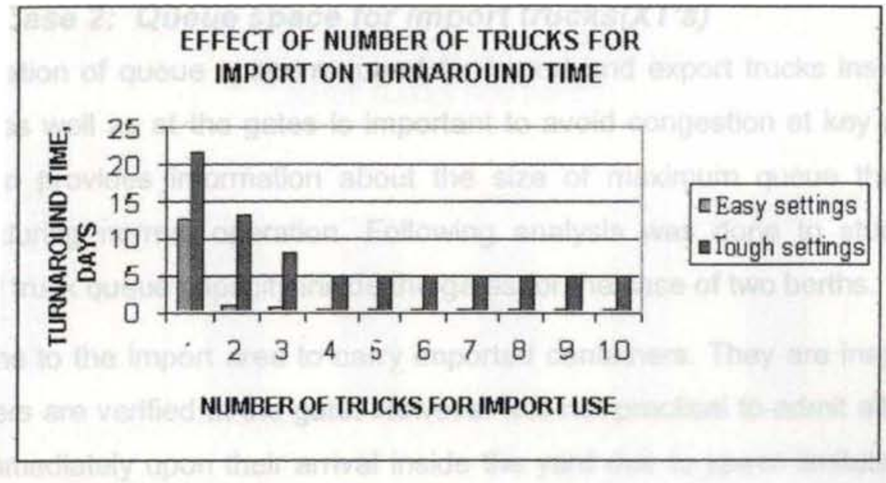

Figure 3.30: Plot showing the effect of number of import trucks on turnaround times

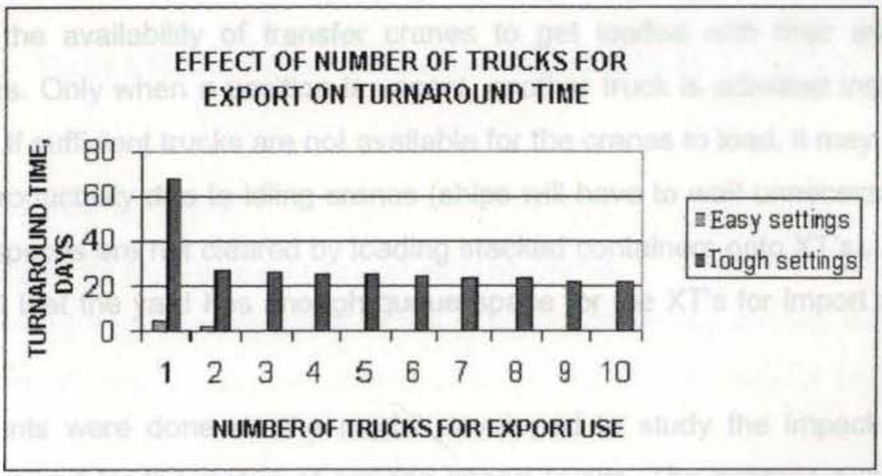

Figure 3.31: Showing the effect of number of export trucks on turnaround times

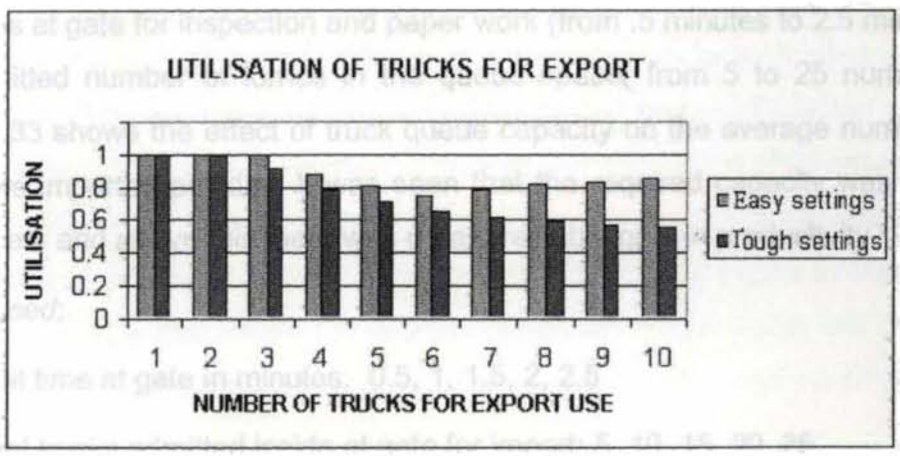

Figure 3.32: Plot showing the utilization of trucks for export

3.6.2.2. Case 2: Queue space for import trucks(XT's)

Determination of queue space required for import and export trucks inside the terminal as well as at the gates is important to avoid congestion at key points. Simulation provides information about the size of maximum queue that can happen during normal operation. Following analysis was done to study the impact of truck queue capacity inside the gates for the case of two berths.

XT's come to the import area to carry imported containers. They are inspected and papers are verified at the gate. However it is not practical to admit all these trucks immediately upon their arrival inside the yard due to space limitations. A limited number are admitted at a time inside the terminal. The admitted trucks wait for the availability of transfer cranes to get loaded with their assigned containers. Only when a position is vacant, another truck is admitted inside the terminal. If sufficient trucks are not available for the cranes to load, it may lead to loss of productivity due to idling cranes (ships will have to wait unnecessarily, if storage spaces are not cleared by loading stacked containers onto XT's). So it is important that the yard has enough queue space for the XT's for import as well as export.

Experiments were done on the model developed to study the impact of the space required for the queue of arriving import trucks. The average number of containers imported per day was found out under different conditions of truck wait times at gate for inspection and paper work (from .5 minutes to 2.5 minutes) and admitted number of lorries in the queue space(from 5 to 25 numbers). Figure 3.33 shows the effect of truck queue capacity on the average number of containers imported per day. It was seen that the required capacity was about **15** numbers and above this there was no appreciable gain in productivity.

Setting used:

Truck wait time at gate in minutes: 0.5, 1, 1.5, 2, 2.5

Number of trucks admitted inside at gate for import: 5, 10, 15, 20, 25

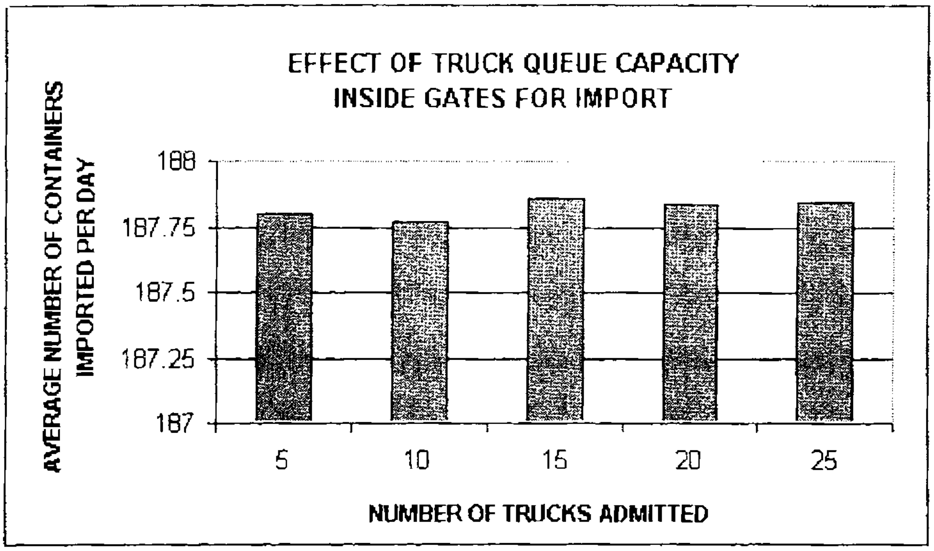

Figure 3.33: Plot of effect of truck queue capacity inside gates for import

3.6.3. Operational level:

3.6.3.1. Case 1: Everyday TC deployment plans.

The number of Transfer Cranes to be put in service to meet everyday load is to be decided on day to day or weekly basis. Simulation is helpful to predict performance under any particular load in a day.

Suppose the scenario for a particular day is as given below.

A ship is to arrive at the berth soon. It has with it 200 number of import containers to be unloaded and 150 export containers are to be loaded onto it. The planning engineer has to decide immediately the number of transfer cranes to be put in service. Crane is working at an average distribution of its operational times per container moved given by the parameters of the triangular distribution (min: 3, max: 5 and most likely: 4 minutes). The number of trucks available on that day is 16. It is also desired to estimate when work on the ship will be over (give this result) and studying the effect of changing these control parameter on days plan.

The engineer could use a slightly modified simulation model for the single berth case to get quick answers to these questions. For example our model file named

'TERMINAL MODEL SINGLE BERTH OPERATIONAL DECISIONS. mox' may be used in the following way.

1. Open the model file in the Extend 4 software.

2. Schedule one arrival of a ship using a PROGRAM generator.

3. Assign the values for import and export containers.

4. Give values for all parameter values for activity times and resources.

5. Run the model several times (at least 3 times) with the following set of values for TC. For this go to the 'Run' menu in Extend and select 'simulation setup'(see a screen shot of this in Figure 3.34). The number of simulation runs can be assigned here.

6. Find the averaged values of turnaround times.

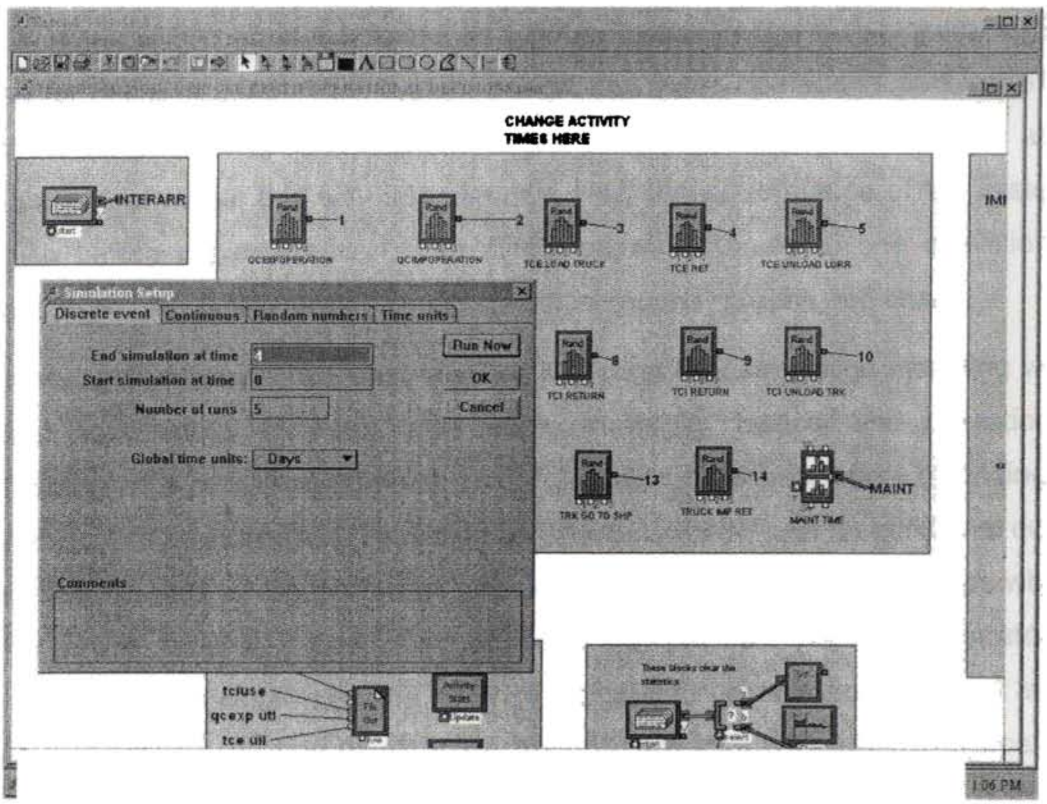

Figure 3.34: A Screenshot simulation setup menu in Extend

Number of import TC	Number of export TC	Turnaround times in days
1	1	1.727
2	1	1.297
2	2	1.080
3	2	1.065
3	3	0.795

Table 3.12: Turnaround time under given conditions

Table 3.12 shows the turnaround times. A single run of simulation is finished under a second. Depending on the availability of cranes and the urgency of work the engineer can allot the cranes. In the present case by providing 2 transfer cranes each for import and export, a low turnaround time of **1.08 days** can be achieved. He can plan further equipment similarly.

3.7. CONCLUSION

In this chapter we have presented the development of simulation models of the operations of a container terminal in a South Indian Port and demonstrated its use for decision support for system design and fixing operational policies. The model computes ship turnaround time and determines resource utilization at a high level of detail; this will help planners view the performance of the system much before implementation. The model allows planners to see operational constraints and bottlenecks through statistical reports, graphs and charts.

From the discussions in earlier sections it is clear that simulation modeling was used successfully to help solve some strategic, tactical and operational problems of a container terminal. Under strategic problems, effect of adding a berth and QC was studied. Providing an additional berth with an additional quay crane could take all the load (nearly hundred percent) and handle all ships when ship arrival rate is less than or equal to one ship per day. The second strategic problem was to determine the area of storage for containers at import side required for smooth operations. It was found there should be enough space for at least 250 containers at the import side.

Determination of the necessary number of transport vehicles to transport containers in time was the first tactical problem studied. It was found that under most favorable conditions of operational times and equipment availability we require about 3 trucks each for import and export so that the turnaround time were kept low. The next tactical problem considered was to determine the queue space for inbound trucks. It was seen that when queue size capacity was about 15 numbers, performance was near peak and above this there was no appreciable gain in productivity, with addition of trucks.

For the operational problem of finding everyday crane deployment plans, the simulation model showed the ship turnaround time under various crane deployment options allowing the manager to select the most appropriate for the day. For the case studied, deploying two TC's and getting a ship turnaround time time of 1.08 days was recommended.

CHAPTER FOUR

STUDY, MODELLING AND ANALYSIS OF A RAILYARD

4.1. INTRODUCTION

Indian Railways is one of the largest railway systems in the world. Railways play a vital role in economic, industrial and social development of the country. Compared to road transport, railway transport has a number of advantages. Railways are more energy efficient, more efficient in land use and significantly superior from the standpoints or environment impact and safety. Railways being the more energy efficient mode of transport are ideally suited for movement of bulk commodities and for long distance travel.

Railways cover the length and breadth of India with 63,140 route kms as on 31.3.2002, comprising broad gauge (45,099 kms), meter gauge (14,776 kms) and narrow gauge (3,265 kms). Indian Railways have a fleet of 2,16,717 wagons (units), 39,236 coaches and 7,739 number of locomotives and run 14,444 trains daily, including about 8,702 passenger trains. They take more than a million tonne of freight traffic and about 14 million passengers covering 6,856 stations daily [1].

Indian Railways now faces many problems especially in the era of globalization .Some of these issues that was presented in Railway Status Paper (2002) are a) High operational losses b) High Costs of Inputs c) Maintenance and Replacement of Assets d) Maintenance of rolling stock e) Surplus Capacity in Production Units

Different aspects of Railway operations have been studied by a number of researchers. These include terminal operations, rail network optimization, freight movement, scheduling passenger trains and freight trains etc. There are many

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[1] Salient Features of Indian Railways, Website of Indian Railways, http://www.indianrail.gov.in.

studies, which consider intermodal terminals. Models in general include simulation as well as analytical models.

Most of the models related to rail yards described in papers above are oriented towards problem solving for long term facility planning. From the review of literature it can be seen that there have been reports of use of simulation in operational, tactical and strategic decision making for railway systems in separate cases with each case concentrating on one type of problem. In this chapter we examine the possibilities of using simulation models of a railway marshalling yard in three types of decisions i.e. operational, tactical and strategic points of view for the same case and would like to bring out the differences in models when type of decision changes.

4.2. PROBLEM AND OBJECTIVES OF THE STUDY

For the Railways, providing a high level of service to passengers is of utmost importance. This requires a high punctuality of trains and an adequate rolling stock capacity. There should be more running time of its rolling stock than idling at yards. Yard performance measures must be found out under varying conditions of its utilization. This study was done at the *passenger rake yard* in *Ernakulam marshalling yard* of Southern Railway Zone of Indian Railway. The study was carried out with the following objectives

1) To create a simulation model of the above yard.
2) To identify and develop yard performance measures.
3) To find out the level of utilisation of major facilities.
4) To study the effect of varying operation times on train schedules.
5) To study different operating strategies for train scheduling at the pit of the yard.
6) To study the problem of finding an optimum inventory level of spare coaches.

4.3. METHODOLOGY

The development and use of simulation models involves specific steps in order for the study to be successful. Regardless of the type of problem and the objective of the study, the process by which the simulation is performed remains almost same. Law and Kelton(1991) have discussed these steps for a simulation study. We have followed similar methodology for our simulation study consisting of following steps.

1. Operational flow charts, data regarding operation times and resource requirement were found out from a system study.
2. Conceptual modeling was done and three classes of models to suit three classes of problems were made.
3. A modelling platform was selected and models were made to get sufficient representation of actual operations. Models developed were verified and validated.
4. Experiments were done on the model by changing various parameters and its effect on utilization of equipments and resources were studied.

4.4. THE ERNAKULAM MARSHALLING YARD AND ITS OPERATION

This work involves simulation modelling of the passenger rake yard of Ernakulam marshalling yard located in South India.

4.4.1. Main Facilities

Figure 4.1 shows a block diagram showing facilities available at the passenger yard. The main facilities here are two pits where the workmen gang does various types of inspection, cleaning, maintenance and overhaul on arriving rakes. Each of the pits has a length of 650 meters and hold 26 coaches. The yard is equipped with required tools, watering and cleaning equipment, a large compressor for adjusting brake power of coaches, various electrical equipment for electrical maintenance are also provided. When a pit schedule starts, the designated engineers and his gang of workmen start their work, simultaneously on various coaches. At the end of the yard there is a coach care center. Here sick coaches

(A sick coach is one that is in need of repairs or maintenance and withdrawn from service for that purpose) are attended. Figure 4.2 shows the operations performed at the yard.

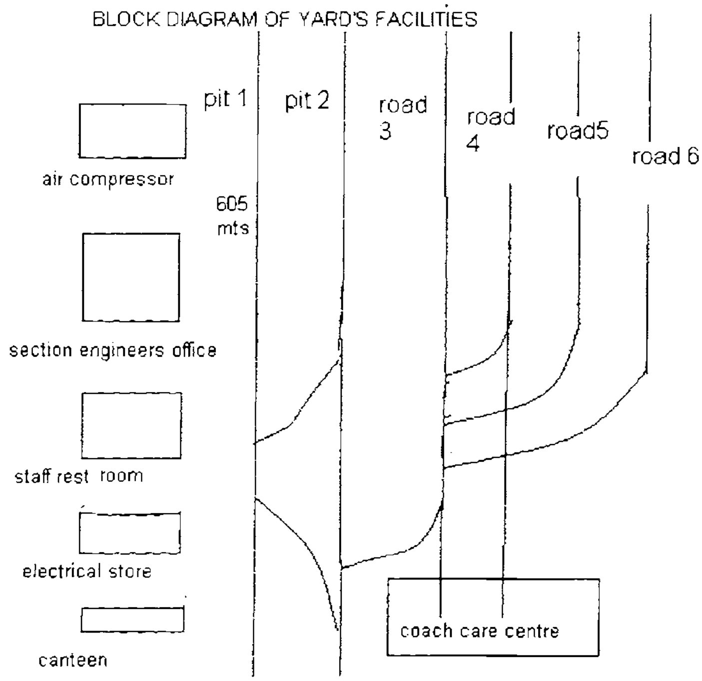


Figure 4.1: Facilities at the Ernakulam passenger rake yard

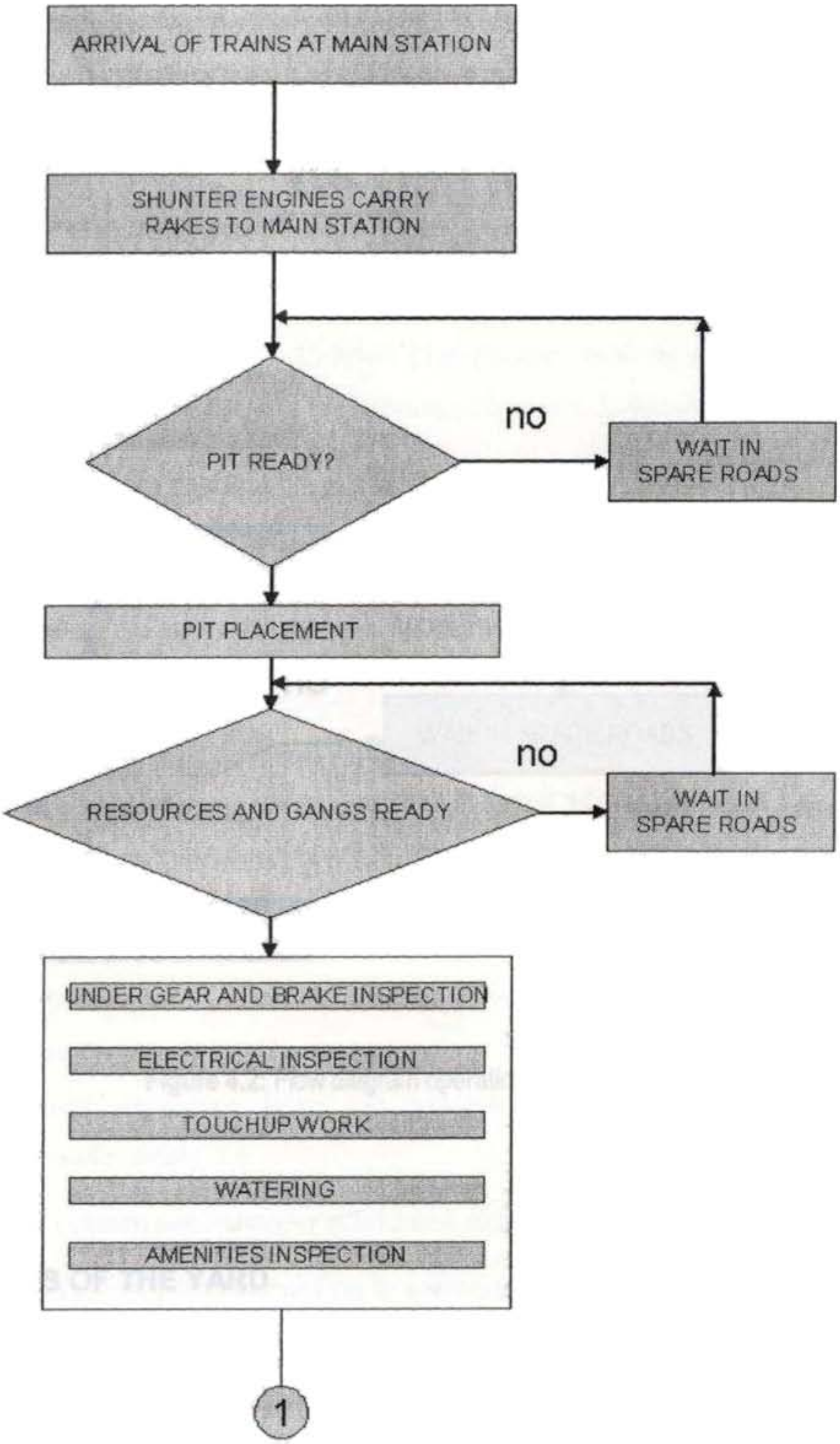
4.4.2. Activities at Marshalling Yard

A Marshalling yard is a yard where rakes (consists) for various trains are assembled and disassembled as required; typically contains a huge maze of highly interconnected sidings and tracks, lots of coaches, wagons, tankers, etc. being shuffled around to put together in formations as required, and equipped with lots of shunter locos. The passenger trains scheduled to Ernakulam yard first arrives at the Ernakulam South railway staion. From there shunters(Shunter is a person who move shunting locos and others in and out of tight spots on shunting sidings, e.g., to allow the turner to move the main loco to some desired location. Shunter is also used to mean 'shunting locomotive'.) take the rakes to the passenger rake yard.

The overall high-level plan for rake movements is described in a rake link issued by a zonal railway, which has details of the planned rake compositions and rake movements for all trains handled by the zone.This has the details of which trains share rakes with which other trains, how and when rakes need to be formed or split up, and many other details: composition, marshalling order, vacuum or air braked, permissible loads, train watering, postal accommodation, sanctioned runs, locomotive allotment, maintenance stations, lie-over periods, distance (km) earned by a rake in a round trip, instructions for sending sick/defective coaches or coaches due for Periodic Overhauling(POH) to shops. The rake link book contains informion regarding the types coaches to be attached to various rakes. The railways have a large variety of coaches. These coaches are understood by looking at their codes.

Inspection: Pre-departure inspections for a train include testing the brake system continuity for the entire rake, locomotive inspection by the crew (checking fuel and oil levels, inspecting the traction equipment, the bogies, etc). The guard ensures the availability of safety equipment, last-vehicle indications and warning lamps, etc. En route at important stations where the train stops, the wheels/axles and bogies of the rake are checked: visual inspection to check for defects, trailing or hanging equipment, etc., using a mallet to test the bogie fittings, using contact or non-contact thermometers to detect hot bearings or axles. At many stations, track-side fluorescent or halogen lamps are provided to help in this inspection.

Maintenance and Overhauls: Normal maintenance work at trip termini or intermediate stops (if needed) is done at trip sheds which have facilities for minor repair and maintenance but which normally do not home locos. Primary maintenance is carried out on all coaching stock every 2500km or so, and is a basic maintenance regimen taking around 6 hours. Mail and express coaches are sent to workshops for periodic overhaul once in about 13-14 months. Ordinary passenger train coaches receive periodic overhaul once in about 18-19 months. Passenger coaches are usually sent back to the owning zoning railway for overhaul. Figure 4.2 shows a simplified flow chart of operations at the yard.


ARRIVAL OF TRAINS AT MAIN STATION
SHUNTER ENGINES CARRY RAKES TO MAIN STATION
PIT READY?
no
WAIT IN SPARE ROADS
PIT PLACEMENT
RESOURCES AND GANGS READY
no
WAIT IN SPARE ROADS
UNDER GEAR AND BRAKE INSPECTION
ELECTRICAL INSPECTION
TOUCHUP WORK
WATERING
AMENITIES INSPECTION
1

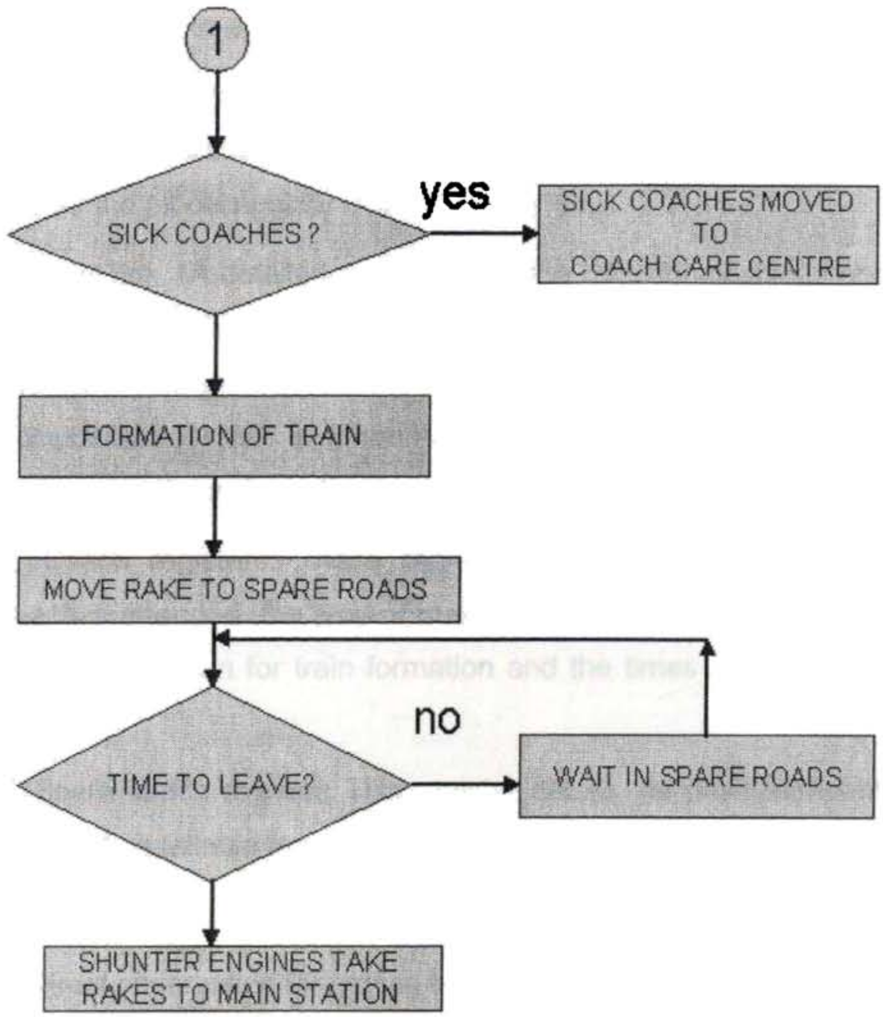


Figure 4.2: Flow diagram operations at rake yard

4.5. MODELS OF THE YARD

Fairly complex simulation models of the yard operations were developed in the simulation package Extend. All models were of the type discrete-event simulation. Data was collected from following documents and time study.

1. Site visits - to understand yard operations, constraints and local traffic.

2. Pit occupancy chart: The Occupancy chart for a station details which platforms and sidings are occupied, and by which trains, at different times. Figure 4.3 shows the pit occupancy chart at the centre.

3. Rake link (A detailed description of the rake compositions and movements for various trains handled by a particular division or zone. It usually covers the movement of stock for about 2500km (the primary maintenance period)). The composition of rakes is different for various schedules. Different types of coaches are used in these formations.

4. Coach registers: These registers give details of incoming rakes, of the coaches attended ,the type of maintenance given, the number of coaches made sick,and the plan for train formation and the times at which the specified rakes left.

5. Spare coach register: This register details the position(inventory) of coaches received , available from coach care center ,number of sick coaches etc.

6. The railway timetable.

7. Direct observation for getting times of operations.

Our observation on the behaviour of system revealed that performance of such system on short term is highly dependent on time schedules of entities arrival, operations and departure from the system. This aspect lead us to the categorisation of models, i.e.

1) Model the system according to schedules existing (TYPE 1 models)

2) Model the system partly according to schedules (TYPE 2 models)

3) Model the system discarding existing schedules (TYPE 3 models)

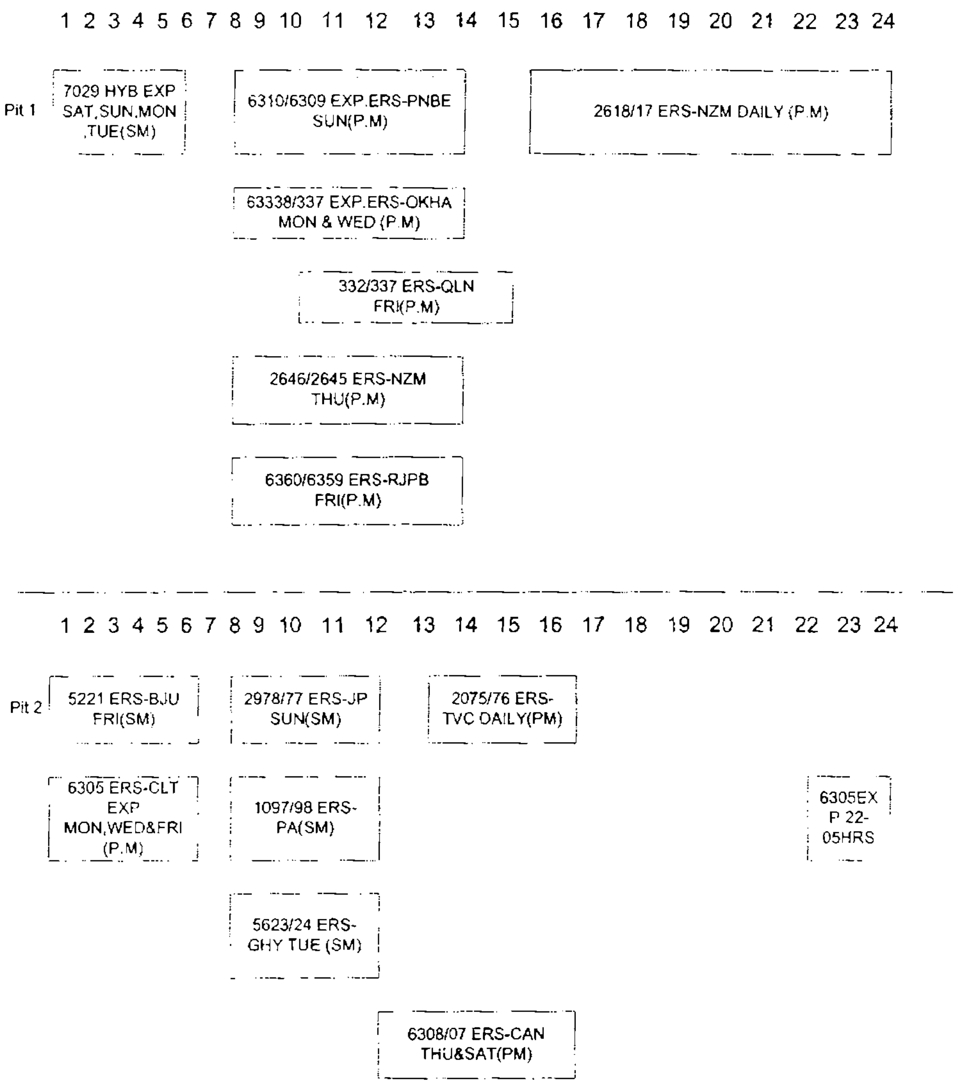


Figure 4.3: Pit occupancy chart

4.5.1. TYPE 1 models

When a model is prepared by considering yard elements as isolated from the main station, we call such models TYPE 1(see Figure 4.4). The yard has to act by given arrival schedule and departure schedules of rakes. The decision maker can use the model for decisions related to changing pit placement schedules. This is usually the task for the yard senior engineer who is in charge of daily operation of the railway yard.

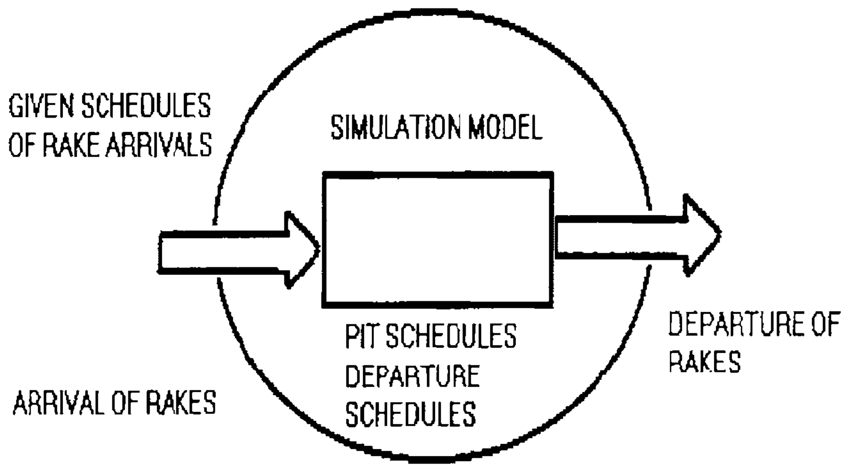


Figure 4.4: TYPE 1 Model

This type of models behaves strictly according to the time schedule. In the rail yard there are schedules for

1) rake arrival
2) pit placement
3) rake departure

The model generates arrival of rakes in the yard based on the given schedules. The model then receives rakes, holds it if necessary, places it for pit service, completes service and delivers the rake out from the system at the scheduled time. Model has enough flexibility to change operational times, and for viewing various statistics. This type of models is of great help in operational decision making as it could be used to analyse the impact of actual schedule of a day or week. A major limitation with above model is in case of facility planning for additional capacity. Analyst will be at great difficulty in augmenting the times for rake arrival, pit placement and departure schedules.

4.5.2. TYPE 2 models

If output schedules can be changed, ways to achieve better performance can be investigated. These decisions go to a tactical level, which is carried by zonal managers. He has to prepare the train time tables for trains starting from this station.

This type of models of system behaves partly according to schedules (see Figure 4.5). For rail yard models, this type models have provision for schedules for some of the following: receiving rakes, placement for pit service and exit of rakes at the scheduled time. Model has provision to set a probability distribution for wait time and operation times. Model has enough flexibility to change operational times, and viewing various statistics. Model blocks allow repeated schedules over time. These types of models are of great help in tactical and strategic decision making as it could model actual schedule of that day or week, and these schedules can be changed easily.

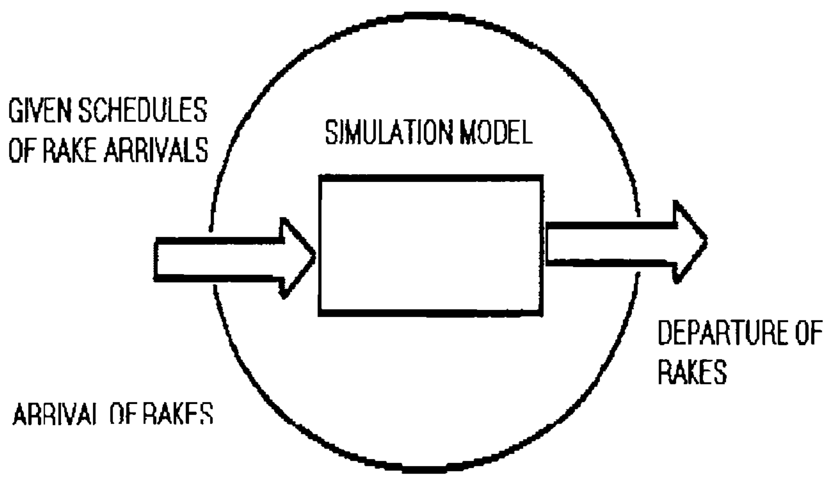


Figure 4.5: TYPE 2 Model

4.5.3. TYPE 3 models

If both arrival and departure schedules and pit placement schedules are flexible (see Figure 4.6), it is possible to investigate the maximum work that can be got out from the railway yard. Also

a) Facility bottlenecks could be detected and alternatives for de-bottlenecking can be investigated.

b) Cases regarding stock of spare coaches, shifting of coach care centre, addition of roads/pits etc are problems that come under this category.

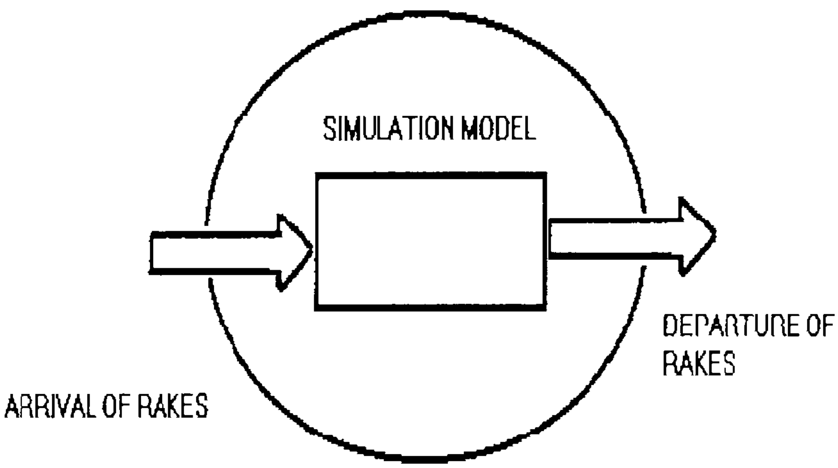


Figure 4.6: TYPE 3 Model

4.5.4. Simulation related characteristics

Various simulation related characteristics of the above three types of models are given in Table 4.1. The model details, validation procedures, run length and types of analysis were different in each case.

MODEL TYPE	MODEL DETAILS	VALIDATION	RUN LENGTH	ANALYSIS	REMARKS
MODEL: TYPE 1	Operational schedules, arrival and departure schedules	Scheduled times in and out from blocks	One cycle, repeat for confidence interval	Changes in schedules, Operational times	Due to priorities in schedules, little flexibility for studying tactical and strategic decisions
MODEL: TYPE 2	arrival schedules and wait time distributions	Scheduled times in and out from blocks. Longer term behavior checked on output.	Many cycles, repeat for confidence interval	Changes in schedules, Operational times, Changes in number of some facility	Due to priorities in schedules, little flexibility in some blocks. More flexibility in blocks without specific schedules and priorities.
MODEL: TYPE 3	interarrival and wait time distributions	Longer term behaviour checked on output	Steady state non terminating	Changes in operation times, Changes in number of facility, Changes in key technology	No specific priorities given to study long term behaviour, wait times and inter arrival time distributions based averaged values of present schedules

Table 4.1: Simulation related characteristics of TYPE 1,TYPE 2 and TYPE 3 models

4.5.5. Basic model features

A basic model which represented only the operations at the pit of the yard was developed first. For subsequent analysis, features depending on the type of problem were added. Figure 4.7 shows a block diagram representing the elements in the basic model. The DE (Discrete Event) library of Extend was used for modelling.

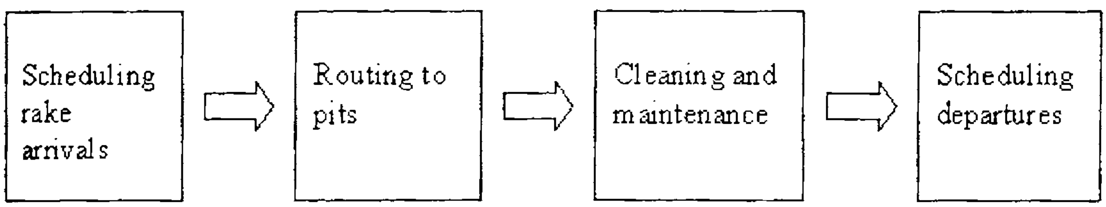


Figure 4.7: Block diagram representing the elements in the basic model

4.5.5.1. Modelling periodic nature

When modelling situations like the operations of the yard one faces a peculiar situation when dealing with timing of events. The railway time table indicates the arrival and departure times of trains. These events are repeated periodically ie some schedules are daily schedules and some schedules are weekly etc. Simulation usually move forward in time upon each events as depicted in Figure 4.8. The arrival(i-1),pit placement (i),departure(i+1) events of a any train schedule is shown in cyclic as well as linear sequencing

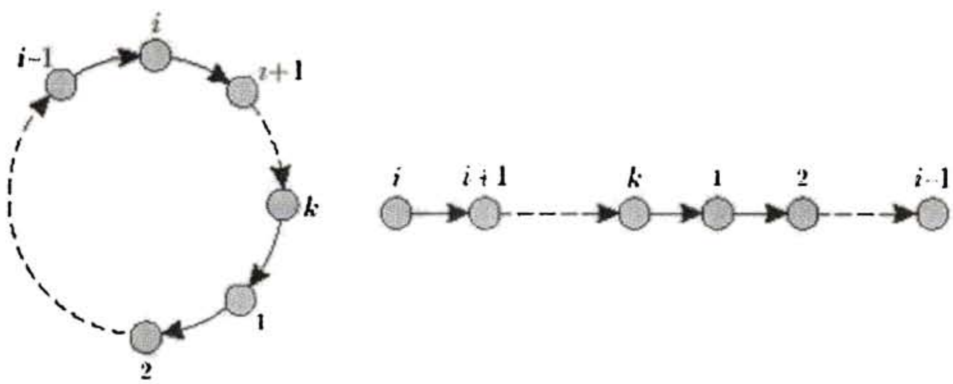


Figure 4.8: Cyclic Vs. linear sequencing

This means we can not directly put the times on the railway time table for modelling. For example consider the timing of train number 6310 given below.

TRAIN NO	DAY	ARRIVAL TIME		TRAIN NO	DAY	DEPARTURE TIME
6310	Sat	18.45		6309	Mon	17.20

This train reaches the railway station at Ernakulam South on Saturday at 18.45hrs. This train turns around as 6309 and departs from above station on Monday at 17.20hrs.

The total time it spends in Ernakulam = ((24-19)*60 +15) + 24*60+(17 *60 +20) minutes

The first term in above represents the balance time on Saturday in minutes. Second term reperesents time on Sunday ie 24 hours. And the third term represents time available on Monday . Figure 4.9. Clearly illustrates this concept. Thick dotted line shows the balance time on each day. In short if A_i represent the arrival time and D_i represent the departure time the difference (A_i - D_i) will not represent the time total time the train spends in the yard. This difficulty can be overcome by considering a 10 day schedule starting with first Sunday's beginning as 0.00 hrs and and adding total minutes of a day (1440 minutes) when a day is over. Maximum is 10*1440 =14400 minutes. All train arrival times, pit placement and departure times changed to times obtained by above conversion method.

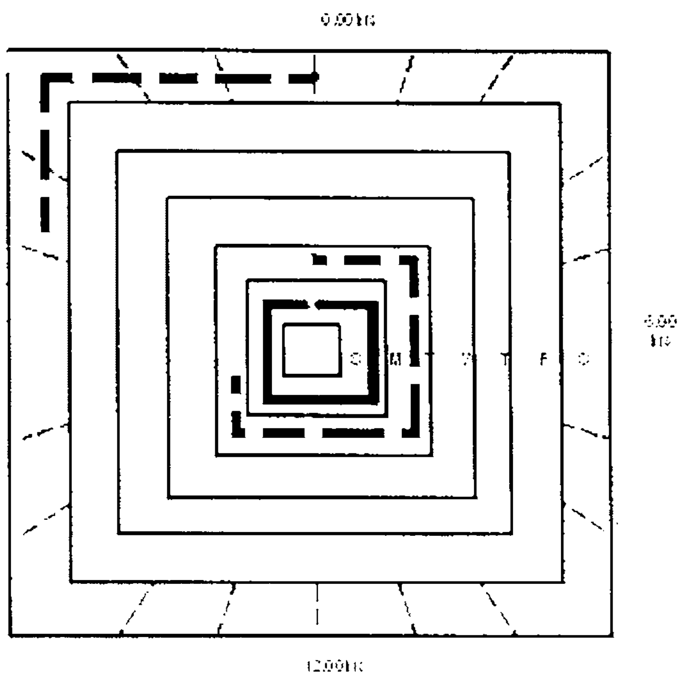


Figure 4.9: Illustration of the calculation of time differences

4.5.5.2. Generating rake arrival:

The coaching yard services 33 train schedules. The pit chart shows the train arrival times in the station and pit placement times. For studying problems like pit and other facility utilisation in general, the rake arrivals are scheduled as per their pit schedules. Upon arrivals, the rakes are set with its attributes like train number, its designated pit, and the type of maintenance i.e. primary or secondary.

4.5.5.3. Routing train units to appropriate pits

Once the rakes start arriving they all go either to the pit for the scheduled maintenance or to the spare lines in case the pit is busy at that time. Modelling was done by filtering rakes as per their attribute of pit. If the pit is busy they wait in the resource pool queue for pits. They will be immediately released when the pit is free.

4.5.5.4. Scheduling the type of maintenance

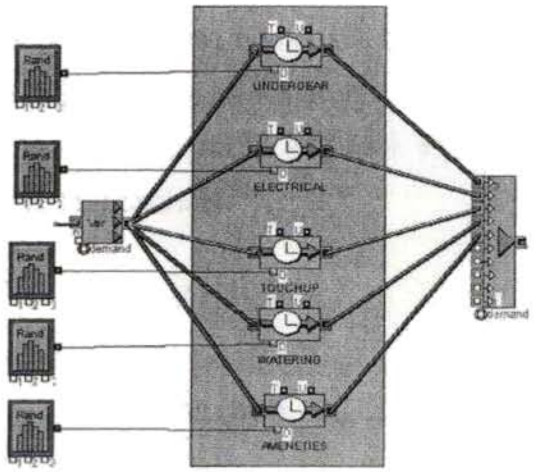
The rakes coming to the pit were filtered according to type of maintenance ie primary or secondary. The operation times vary accordingly. For primary maintenance it takes about 6 hours and for secondary maintenance it takes about 4 hours. Some of the coaches may be found to be sick here. A uniform random variate (here an integer between 0 and 4) was used for generating the number of sick coaches.

4.5.5.5. Shunting and pit operations

The sick coaches are to be taken to the coach care center. For this, the unit is to be detached and then pulled out. Further some fit coaches from the coach care center are to be taken and shunted to the designated position of the coach (In actual practice, at times when sufficient number of fit coaches are not available, some coaches of set rakes for other schedules are detached and used. This is not a recommended practice). However the present model has the facility to set a time for shunting operation in proportion to the sick units. The shunter is released immedeately after its operation. Once the shunting operations are over each of the rakes are released to destination.

The actual time of operation at the pit is modelled as random variable. Many different gangs starts working on coaches related to inspection,cleaning,checking brake power, electrical maintenance etc. Pit maintenance time to be taken is the largest of each these times.

Pit Maintenance time = Max { T_k } where T_k represent the operational times of different gangs(k). Delays occur due to a number of reasons like lack of availability of spare parts, major damages on coaches which require more time for repair, failure of equipment etc. Figure 4.10 shoes a screen shot of the hierarchical block for setting these time delays.



View of contents of the hierarchical block for pit operations Note that provision is given to enter the times for each operations as a random value according to a distribution

Figure 4.10: Contents of heirarchical block of pit operations

The basic model was modified to study the effect of the pit maintenance delays. A number of parallel operations of random times (a uniform time approximately 10% less and above scheduled times was used) were added and condition is set that the rake is subjected to further operations only after completion of each of gang activities.To study how many rakes left in time, a number of additional simulation blocks were to be added. The purpose of these blocks are to schedule the exit of each rakes from pit according to time table. If time is not up for the rakes to leave they are put on the spare rakes waiting for departure. A Discrete-Event plotter catches the times when the rakes leave.

To study problems like requirement of spare coaches, a modified form of basic model was also developed. For this, more simulation blocks including a '*Coaches resource pool*' were added. Coaches were added to the *coaches* *resource pool* when a rake arrives(not everytime - discussed below) and released at the time of rake formation.

When coaches of a rake with all its set composition, is released to the resource pool is a tricky question. This cannot be done in each arrival. For example train number 2617/18 Mangala Express has a departure arrival schedule everyday. This does not mean that this train requires 7*18 coaches for its operation. Instead 6 rakes are required and this number is dependant on the up and down journey time of each of the trains as illustrated in Figure 4.11. The first rake returns on seventh day and released to the pool. Figure 4.12 shows a screen shot of the resource pool for coaches.

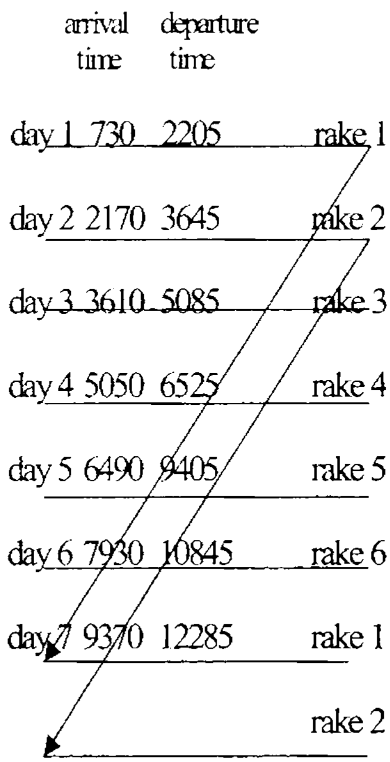


Figure 4.11: Rake arrival and departure pattern

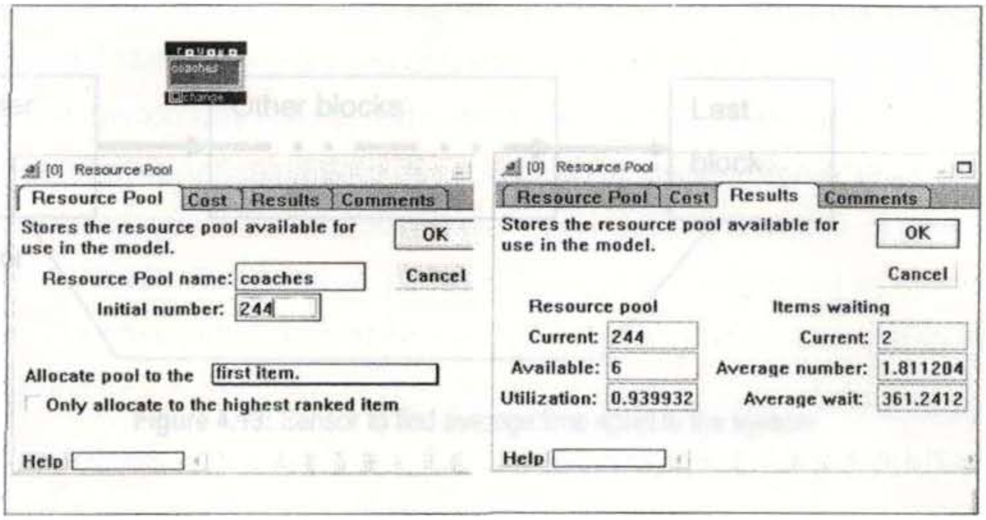


Figure 4.12: Details of the resource pool of coaches

4.5.6. Some Performance Measures

A measure of operational efficiency of the yard can be the ratio of rakes on time

$$\frac{\textbf{number of rakes exited in right time}}{\textbf{total number of rakes exited}} \qquad (4.1)$$

For example in a particular run, 28 rakes left in time out of 32 rakes. Therefore the percentage rakes sent on time is 28/32 ie. 87.5 %.

Another measure of the operational efficiency is the average time trains are late over scheduled times. This can be found out from the formula of average lateness

$$\sum \textbf{(actual times left - scheduled times) / number of late rakes} \qquad (4.2)$$

The average time rakes spent in the system(turnaround time) can also be found out. A sensor (Figure. 4.13) added to the leaving point of rakes is connected to rake arrival point.These blocks gives the average time of rakes in the system.

Performance measures such as utilisation of pits and spare roads, average waiting time and average and maximum queue length were also used.

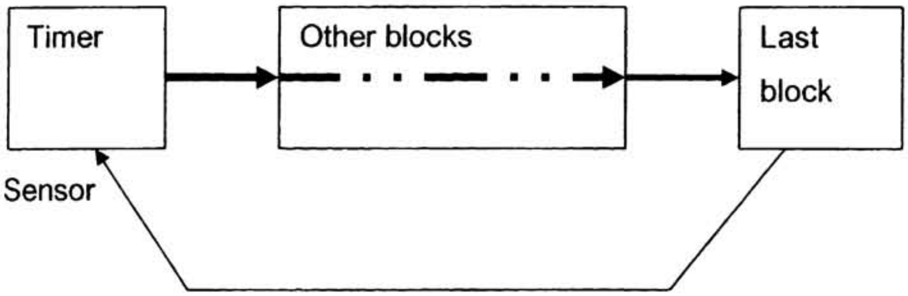


Figure 4.13: Sensor to find average time spent in the system

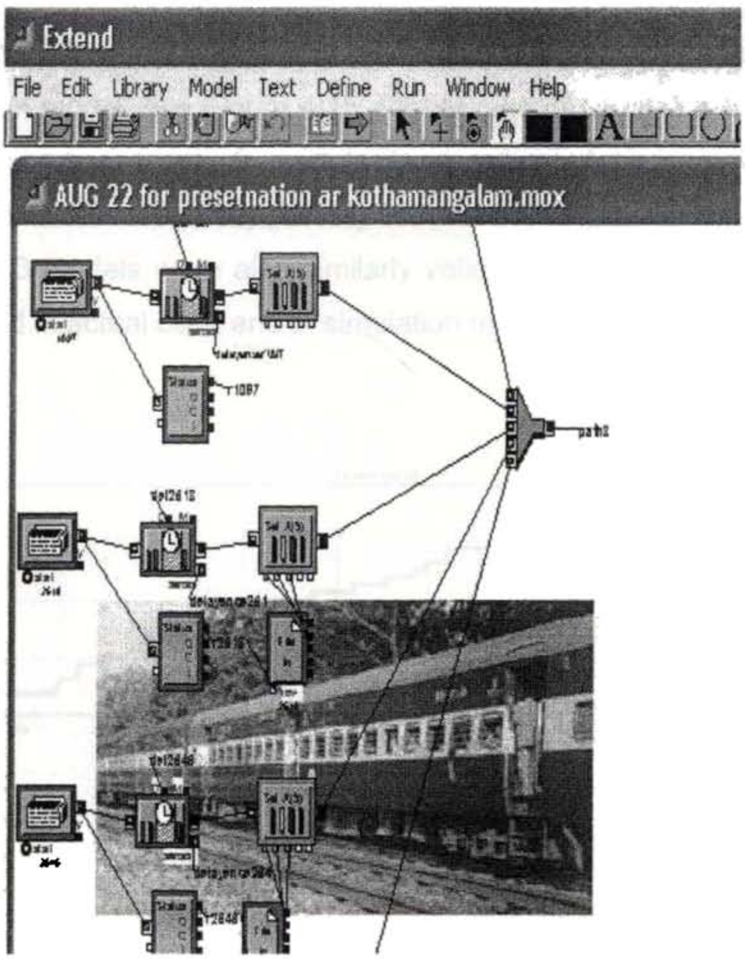


Figure 4.14: A screenshot of simulation model

4.5.7. Model Verification and Validation

Verification is the process of ensuring that the model does what the developer wants it to do. This is the first stage of quality check of a simulation model. In this case expert opinion was used to understand how the models should behave. We then used facilities in Extend such as information modules to check whether the model behaved as expected. Entities (here rakes) were checked at different blocks in the model like pit arrival, pit selection, type of maintenance as it passes from one block to another. This white box method of verification was used by us.

Sargent(1996) has demonstrated the use of graphical methods for validation of simulation models. We have also validated the simulation models developed using graphical methods which are discused below.

Models of TYPE 1 were validated by comparing the simulation output(number of rakes exited in model- see Figure 4.15, Plot of rake departure) and rail time table values(Figure 4.16). TYPE 2 models were validated by comparing average number of rakes exited actually per day with the same ouput of simulation(Figure 4.17). TYPE 3 models were also similarly validated by comparing with average number exited in actual case and in simulation model(Figure 4.18).

Figure 4.15: Plot of rake departure

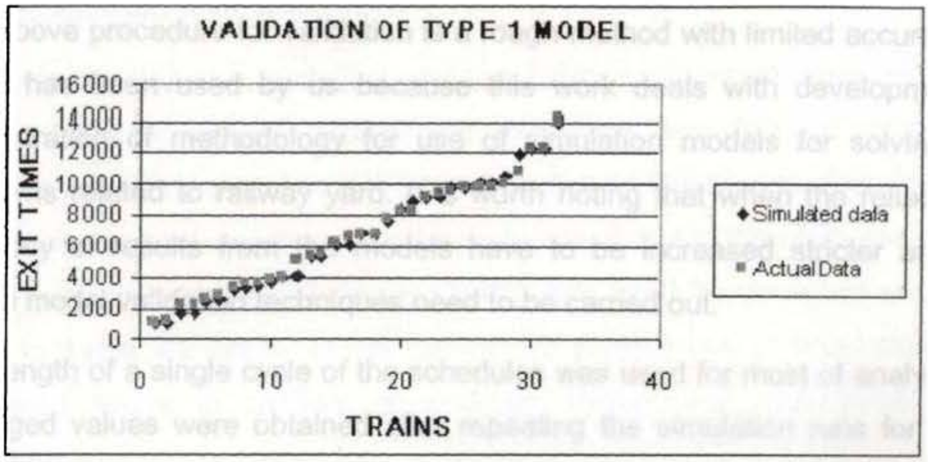


Figure 4.16: Validating TYPE 1 model

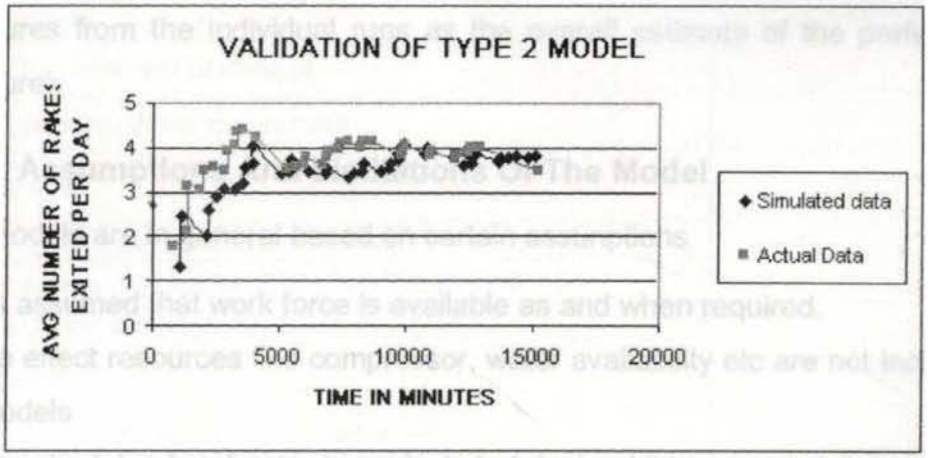


Figure 4.17: Validating TYPE 2 model

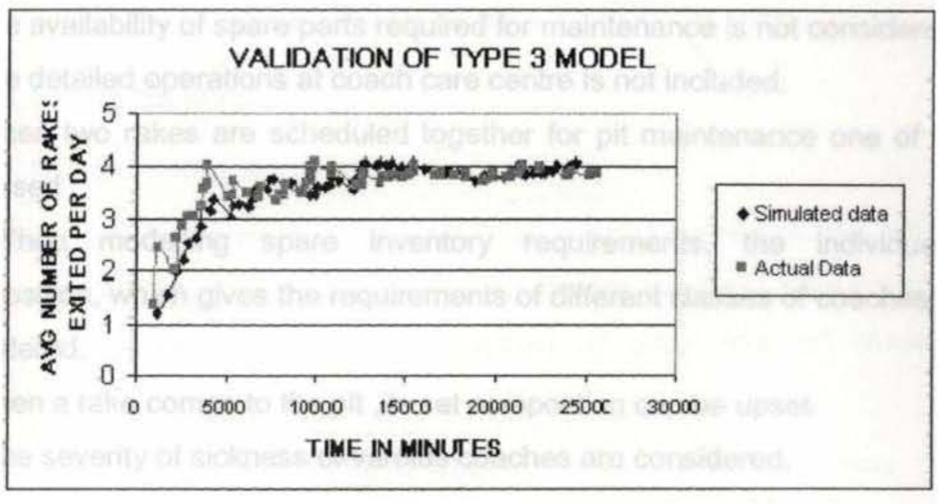


Figure 4.18: Validating TYPE 3 model

The above procedure for validation is a rough method with limited accuracy. The same has been used by us because this work deals with development and demostration of methodology for use of simulation models for solving some problems related to railway yard. It is worth noting that when the reliablity and accuracy of results from the models have to be increased stricter and more formal model validation techniques need to be carried out.

Run length of a single cycle of the schedules was used for most of analysis. The averaged values were obtained after repeating the simulation runs for 5 times (Law and McComas(1997) recommend making at least three to five independent runs for each system design, and use the average of the estimated performance measures from the individual runs as the overall estimate of the performance measure).

4.5.8. Assumptions And Limitations Of The Model

The models are in general based on certain assunptions

1) It is assumed that work force is available as and when required.

2) The effect resources like compressor, water availability etc are not included in the models

3) The schedules for shunter is not included. Instead it is assumed that shunter is sufficiently available.

4) The availability of spare parts required for maintenance is not considered.

5) The detailed operations at coach care centre is not included.

6) When two rakes are scheduled together for pit maintenance one of them is bypassed .

7) When modelling spare inventory requirements, the individual rake composition, which gives the requirements of different classes of coaches are not considered.

8) When a rake comes to the pit ,its set compostion can be upset.

10) The severity of sickness of varoius coaches are considered.

11) Details of train signalling,track maintenance are not considered.

4.6. PROBLEMS AND ANALYSIS

We have developed a modelling and simulation approach for simulation based decision aids for strategic, tactical and operational type decision problems that are typical in terminal systems. We have developed three types of models helpful in such situations depending upon the problems. Some of the problems related to above yard for which simulation modelling was used for decisions support are given in Table 4.2 below. In this section we present use of simulation models described above in analysis of strategic, tactical and operational decision scenarios.

DECISION PROBLEM	MODEL TYPE
Strategic level	TYPE 3
Case 1: Requirement of additional pit	
Case 2: Deciding number of spare roads	
Tactical level	TYPE 2
Case 1: Deciding number of spare coaches	
Case 2: Allocation of separate shunter engine to the yard	
Case 3: Comparison of train time tables	
Operational level	TYPE 1
Case 1: Routing arriving rakes to appropriate pit	
Case 2: Deciding shift timings, preparing pit schedules	

Table 4.2: Decision problems and model type used

4.6.1 Strategic level

4.6.1.1 Case 1: Requirement of additional pit

At present, the yard receives about 4.9 rakes on average per day. What will be the scenario if more rakes are coming for service per day? How construction of an additional pit will be helpful provided all other required resources are provided?

By simulation using the TYPE 3 models, one could answer these questions. Such models with two pits and three pits were constructed. Figure 4.19 and 4.20

indicate cases of two pits and three pit respectively. It was seen that the present facility with two pits could handle about 5.5 rakes per day without appreciably increasing the delay for pit's availability. If three pits were provided this number could be improved to about 7 rakes per day without undue delays at pits.

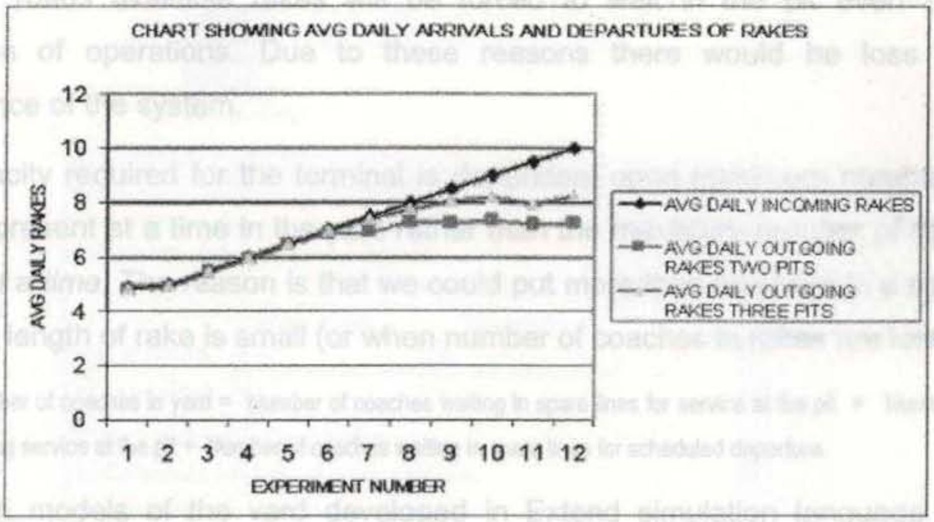


Figure 4.19: Plot of average daily rakes with two and three pits

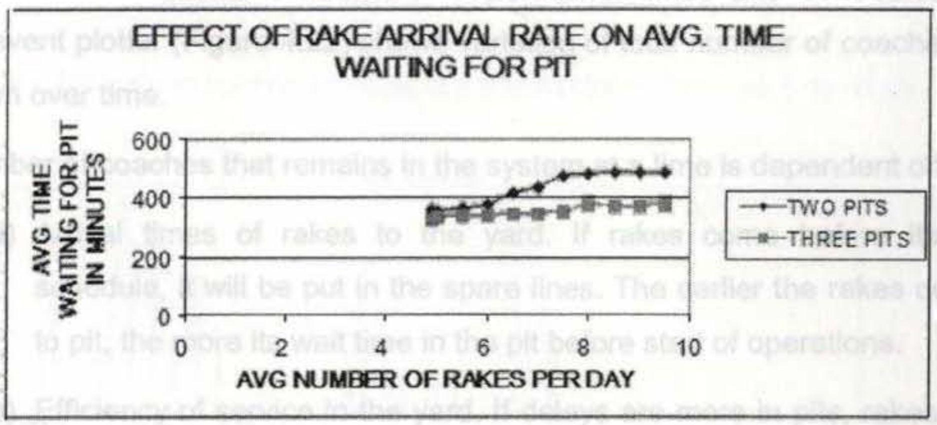


Figure 4.20: Plot of average delay at pit for two pit and three pit case

4.6.1.2. Case 2: Deciding the capacity of spare roads

The incoming rakes to the yard wait in spare roads till it is called for placement in the pit. After operations at the pit, the rake is held in spare roads till its scheduled departure time is reached. If sufficient capacity is not available in these lines, incoming rakes will have to wait outside the yard, blocking the system and with no spare roads available rakes will be forced to wait in the pit even after completion of operations. Due to these reasons there would be loss in performance of the system.

Line capacity required for the terminal is dependent upon maximum number of coaches present at a time in the yard rather than the *maximum number of rakes present at a time*. The reason is that we could put more than one rake in a spare line when length of rake is small (or when number of coaches in rakes are less).

The total number of coaches in yard = Number of coaches waiting in spare lines for service at the pit + Number of coaches getting service at the pit + Number of coaches waiting in spare lines for scheduled departure.

Simulation models of the yard developed in Extend simulation language are capable of giving values of maximum number of coaches in yard at a time (see Figure 4.21) under varied conditions of operational times and schedules. A discrete event plotter (Figure 4.22) shows variation of total number of coaches in the system over time.

Total number of coaches that remains in the system at a time is dependent on

a) Arrival times of rakes to the yard. If rakes come before its pit schedule, it will be put in the spare lines. The earlier the rakes come to pit, the more its wait time in the pit before start of operations.

b) Efficiency of service in the yard. If delays are more in pits, rakes will have to wait more in spare lines.

c) Departure schedule of rake. If rake departure is scheduled at a later time, rakes wait in spare lines after completing operations at pit.

d) Availability of key resources like shunter engine for shunting.

e) Number of services. If more rakes (or coaches) are allotted to the yard for service, more capacity is required.

f) Inventory of spare coaches. Any additional coaches allotted to the yard are kept in spare lines.

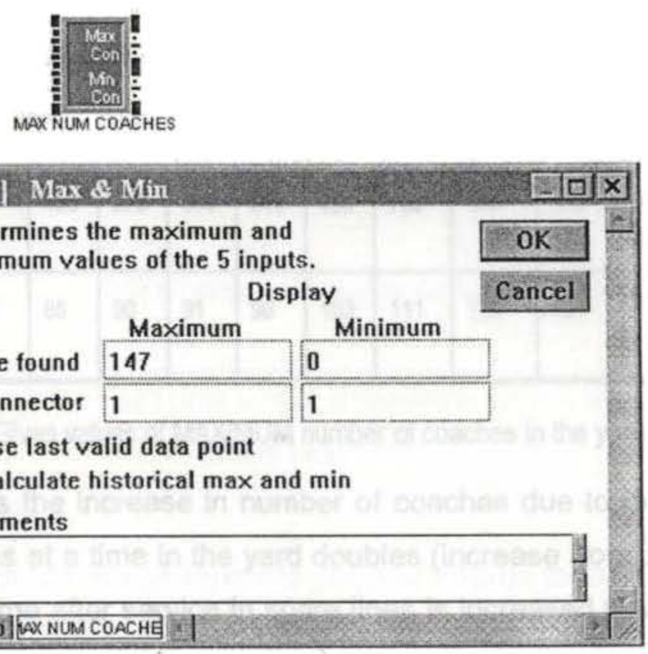


Figure 4.21 Maximum number of coaches at a time is obtained from max & min block

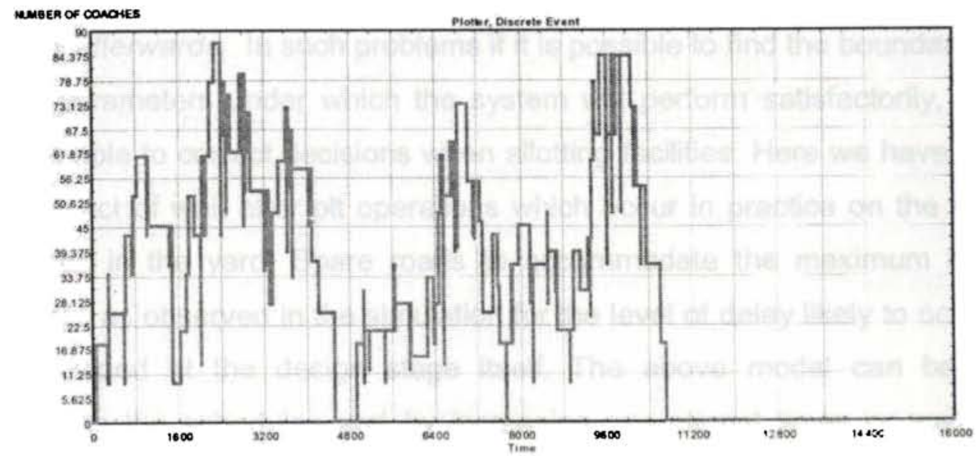


Figure 4.22: Showing the number of coaches present in the yard over time

Simulation models developed considers all of these aspects. We have used a simple experiment to assess the levels of coaches present in the yard at a time. We assumed that resources like shunter engines were available on call, and the pits operate with its normal efficiency and no spare coaches. The rakes were scheduled to arrive according to time schedule. The wait times for departure were varied to different levels. Table 4.3 gives values of MAXIMUM number of coaches in the yard at a time averaged over repeated simulation runs each for about two week cycle.

WAIT TIMES IN MINUTES	30	150	270	390	510	630	750	870	990	1110	1230	1350
MAX NUMBER OF COACHES	72	85	90	91	98	103	111	123	131	142	142	144

Table 4.3: Gives values of MAXIMUM number of coaches in the yard at a time

Figure 4.23 shows the increase in number of coaches due to delays. Maximum number of coaches at a time in the yard doubles (increase from 72 to 144) when each rakes wait time after service in spare lines is increased from 30 minutes to 1350 minutes.

When deciding capacity of spare roads a long term perspective is required because once a layout is made with a design capacity, it is difficult to change or modify afterwards. In such problems if it is possible to find the boundary levels of input parameters under which the system will perform satisfactorily, designers will be able to correct decisions when allotting facilities. Here we have examined the impact of wait after pit operations which occur in practice on the number of coaches in the yard. Spare roads to accommodate the maximum number of coaches as observed in the simulation for the level of delay likely to occur should be provided at the design stage itself. The above model can be used by modifying the schedules and by increasing operational times or wait times to study the impact of these on facilities. These studies help in determining level of facilities to be provided at layout design stage.

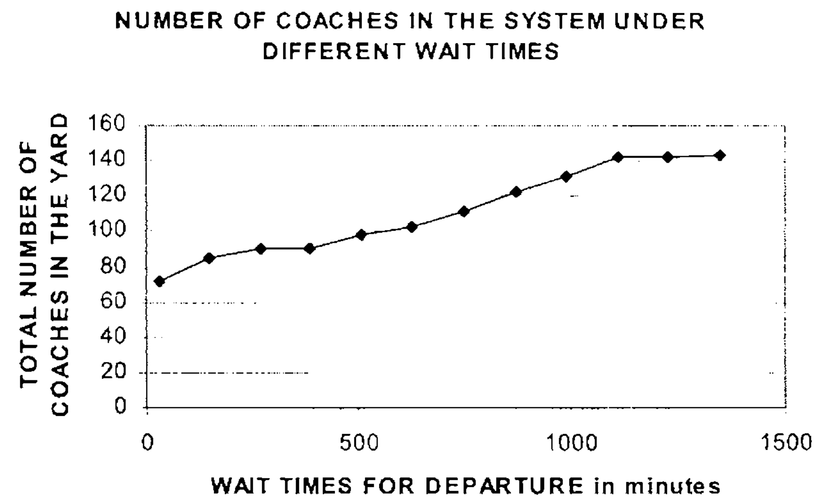


Figure 4.23: Plot showing max number of coaches in the yard at a time under different wait times

4.6.2. Tactical level

4.6.2.1. Case 1: allocation of separate shunter engine to the yard

Usually Marshalling yards will be attached to corresponding stations itself. In this case the yard is about two kilometers away from the railway station; the loco shed is near the station. There is the second busiest signal point in Southern Railways between the yard and the station, creating hindrance for free movement of rakes and loco between the station and the yard. At present a shunter engine is not allotted exclusively for Marshalling yard operations. Instead this facility is given according to schedules i.e., shunter engine could be utilized by the Marshalling yard only according to time schedules decided by authorities at main station. As a result, re-planning of schedules due to unexpected delays is constrained by availability of shunter engine.

Shunter is utilized for the following tasks

1) Bringing rakes from the Ernakulam South Station to spare roads of the yard.
2) Taking rakes to Pits from spare road, for pit placement
3) Removing sick coaches

4) Attaching new coaches and train formation
5) Transferring rakes from pits (after service) to spare roads
6) Taking prepared rakes to the Ernakulam South Station

A shunter engine is a key resource required at the yard. When a shunter is not available at the requested time it could

a) delay operations and scnedules at the pit
b) cause spare roads choked with rakes
c) cause main station lines becoming choked with rakes
d) cause knock-on delays in main station and subsequent stations
e) cause idling of resources in the pit
f) increase turnaround times of rakes from the yard

An investigation was made on the effect of availability of the shunter engine using simulation models.

CASE 1) out of every 45 minutes the shunter was not available for 30 minutes
CASE 2) out of every 60 minutes the shunter was not available for 30 minutes
CASE 3) out of every 75 minutes the shunter was not available for 30 minutes
CASE 4) out of every 90 minutes the shunter was not available for 30 minutes
CASE 5) out of every 105 minutes the shunter was not available for 30 minutes
CASE 6) out of every 120 minutes the shunter was not available for 30 minutes
CASE 7) out of every 135 minutes the shunter was not available for 30 minutes
CASE 8) out of every 150 minutes the shunter was not available for 30 minutes
CASE 9) out of every 165 minutes the shunter was not available for 30 minutes
CASE 10) there was no restriction on the availability of shunter engine

Values of Performance variables maximum *number of coaches in the yard and turnaround times (average time a rake spends in the yard)* were noted. Simulation answers the question of how much improvement in performance could be obtained by using a separate shunter allotted to the marshalling yard. Table 4.4 shows the average of maximum wait times at various points where this resource was required. We see a reduction in this when the shunter was made more and more available to the yard. The best performance was obtained when the shunter was fully made available to the service in the yard (CASE 10).

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8	CASE 9	CASE 10
Avg. of max wait times(in minutes) for shunter at various blocks	65.0	44.3	44.9	41.9	39.7	41.2	36.9	38.8	32.0	31.71

Table 4.4: Showing the effect of shunter availability on performance

The rail simulation model could be used by the yard management to convince higher authorities the situations when shunter availability becomes a bottleneck. A shunter engine is a costly resource. Procuring additional shunter is a tactical decision by which the efficiency of service at the base station as well as at the yard gets improved.

4.6.2.2: Case 2: deciding number of spare coaches

The Marshalling yard controls (for full formation of the train as well as primary maintenance) the trains as given in Table 4.5.

TRAIN	TRAIN NUMBER	NUMBER OF COACHES	NUMBER OF RAKES	TOTAL COACHES
Mangala Express	2617/18	18	6	108
Patna Express	6309/10	18	1	18
Janasadabdi Express	2075/76	9	1	9
Cannoore Express	6307/08	12	1	12
Millenium Express	2645/46	12	1	12
Passenger	332/37	12	1	12
Okha Express	6338/39	21	2	42
Intercity Express	6305/06	13	1	13
Varanasi Express	6359/60	18	1	18
		Total : 244		

Table 4.5: List of trains and rake requirements for schedules under the control of the Ernakulam Yard

At present the yard is allotted about 250 coaches of different categories. A small number of coaches are provided extra to take care of sick coaches and special requirements. Yards like these are always demanding for more coaches. How many coaches will be required to operate the schedules smoothly? The answer to this question depends upon lot of factors. It depends upon the rake composition, arrival and departure schedules of rakes, management policies regarding rake allotments and priorities, number of coaches getting sick, pit operational times, efficiency of coach care centers, spare line capacity , shunter availability etc.

The TYPE 2 model developed was run for a period of 12 weeks. The balance of coaches at various instances are given in Figure 4.24. The initial part of this plot is the situation when the coaches of all trains operated by the yard were made available as initial inventory of coaches. Once these rakes leave from the yard, that many coaches get depleted from initial stock and the stock gets refilled upon each arrivals. Steady state on the coaches balance position is only achieved after the first two weeks where we see the effect of initial inventory. This plot provides some interesting insight for planners.

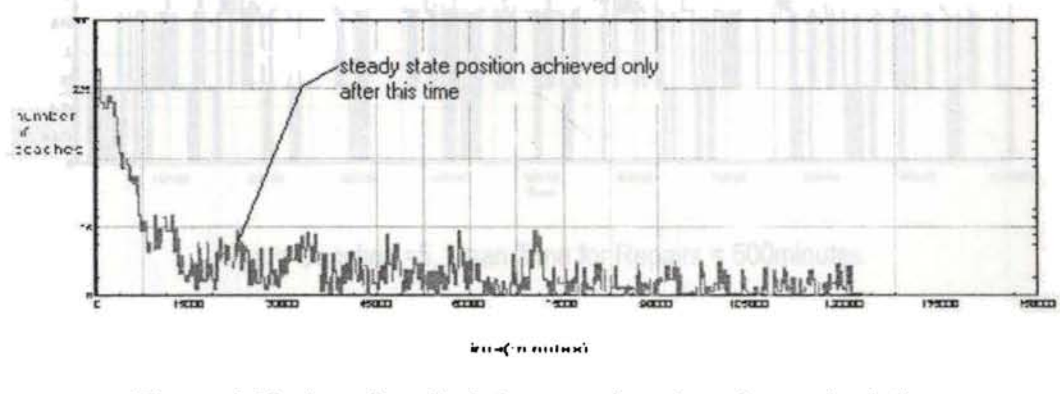
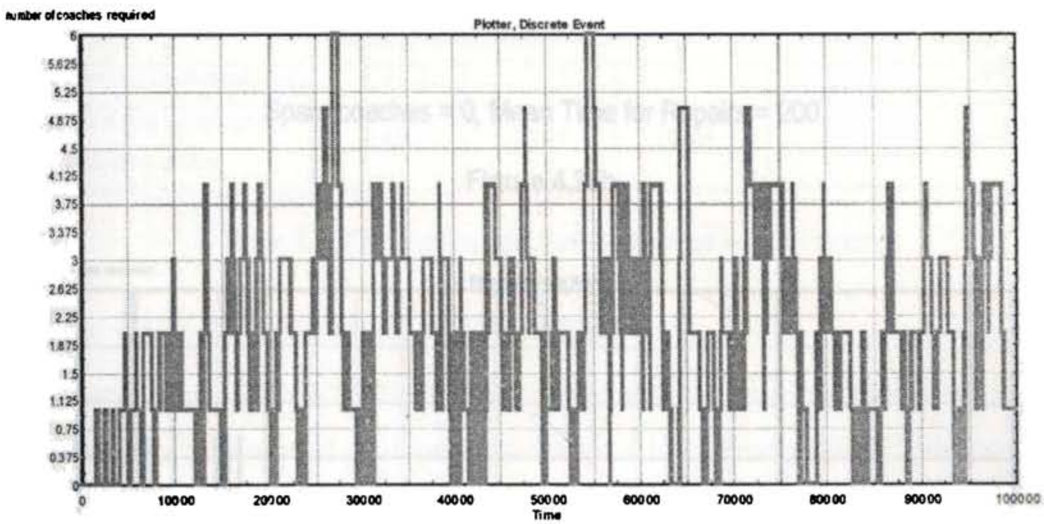


Figure 4.24: shows how the balance number of coaches varies in time

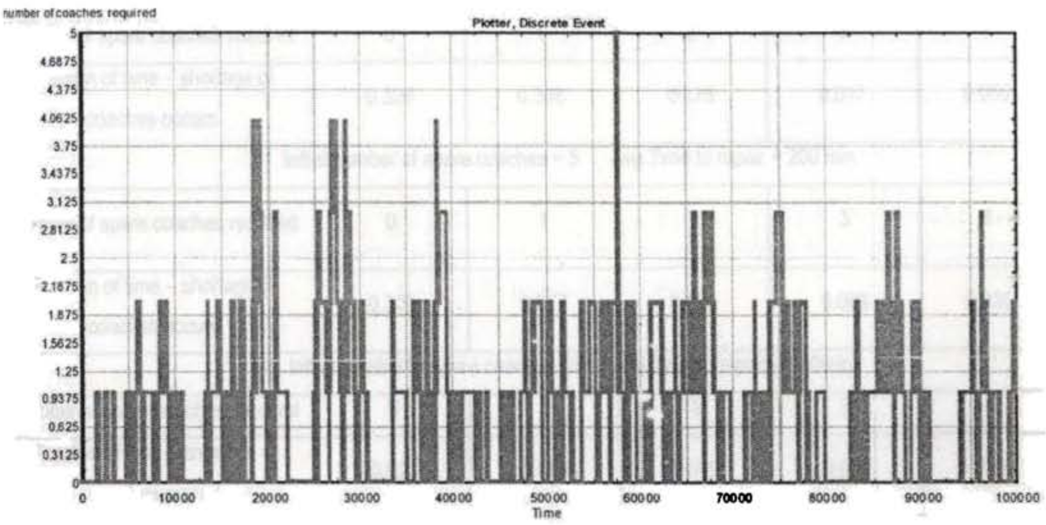
Maximum level: Information regarding the maximum level is useful in designing spare road capacity. Above chart shows that, there are peaking levels of coaches at many points. If the roads in the pits cannot hold this many, operational delays are expected. This information is also useful when the management plans for additional schedules.

It is difficult to manage the yard without sufficient number of coaches. If required numbers of coaches are not available, it will naturally affect train schedules (even a 10 minutes late train at some station can bring cascaded effects in the entire network). Models clearly indicate the effect of spare coach availability on train schedules. See Figure 4.25a-c and Table 4.6 . We know that average number of rake waiting for availability of coaches is related to number of coaches getting sick and number of coaches getting repaired and the number of spare coaches available. The coach care centre should be supplying repaired coaches efficiently. The desired number of spare coaches could decided by a level whereby operations at care centre is set at normal pace and at the same time the average number of rakes waiting is not excessive.



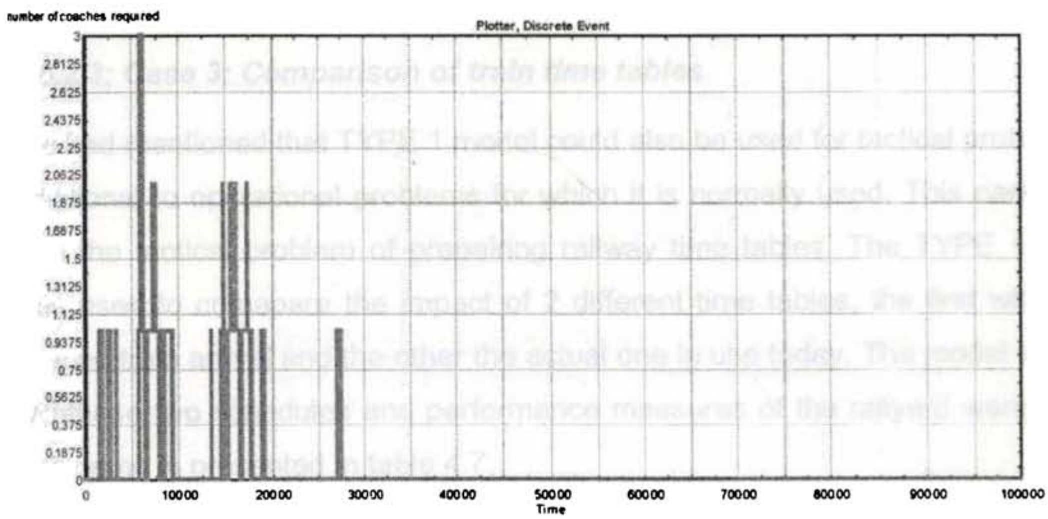
Spare Coaches =5, Mean Time for Repairs = 500minutes

Figure 4.25a



Spare coaches = 0, Mean Time for Repairs = 200

Figure 4.25b



Spare coaches = 0, Mean Time for Repairs =100

Figure 4.25c

Figure 4.25a-c: Plot of effect of spare coaches on average number waiting

INITIAL NUMBER OF SPARE COACHES = 0 AVG.TIME TO REPAIR = 200 MIN						
Number of spare coaches required	0	1	2	3	4	5
Fraction of time – shortage of coaches occurs	0.326	0.338	0.178	0.097	0.059	0.001
Initial number of spare coaches = 5 Avg.Time to repair = 200 min						
Number of spare coaches required	0	1	2	3	4	5
Fraction of time – shortage of coaches occurs	0.300	0.327	0.235	0.088	0.035	0.015
Initial number of spare coaches = 0 Avg.Time to repair = 100min						
Number of spare coaches required	0	1	2	3	4	5
Fraction of time – shortage of coaches occurs	0.923	0.048	0.018	0.011	0.000	0.000
Initial number of spare coaches = 5 Avg.Time to repair = 100min						
Number of spare coaches required	0	1	2	3	4	5
Fraction of time – shortage of coaches occurs	0.944	0.041	0.013	0.003	0.000	0.000

Table 4.6: Effect spare coaches on average number waiting

4.6.2.3: Case 3: Comparison of train time tables

We had mentioned that TYPE 1 model could also be used for tactical problems in additional to operational problems for which it is normally used. This case deals with the tactical problem of prepairing railway time tables. The TYPE 1 model was used to comapare the impact of 2 different time tables, the first with equi-spaced train arrival and the other the actual one in use today. The model was run withthese two schedules and performance measures of the railyard were noted. The same is presented in table 4.7.

From the table it can be seen that the performance in bothcase is more or less the same. However the current schedule is a slightly better one.

		PIT 1		PIT 2	
Schedules	Turnaround(excluding wait time at spare roads)	Average wait of rake	Maximum wait of rake	Average wait of rake	Maximum wait of rake
Equi-spaced	444.59	53.37	284.44	79.2	281.3
Actual	421.96	66.9	391.48	64.68	296.63

(All times in minutes)

Table 4.7: Comparison of Train time tables

4.6.3. Operational level:

4.6.3.1. Case 1: Routing arriving rakes to appropriate pit

Suppose an unscheduled rake is to be accommodated for some day in coming week. Questions like which pit is to be utilized and when the schedule for maintenance is to begin etc are to be answered. The simulation models are helpful in visualizing the effect of such additional schedules. The analyst can test the simulation model for his proposed time schedule and pit. This is done by assigning a schedule generator (See Figure 4.26) for proposed schedule and inputting its attributes of pit (PIT 1 or PIT 2).

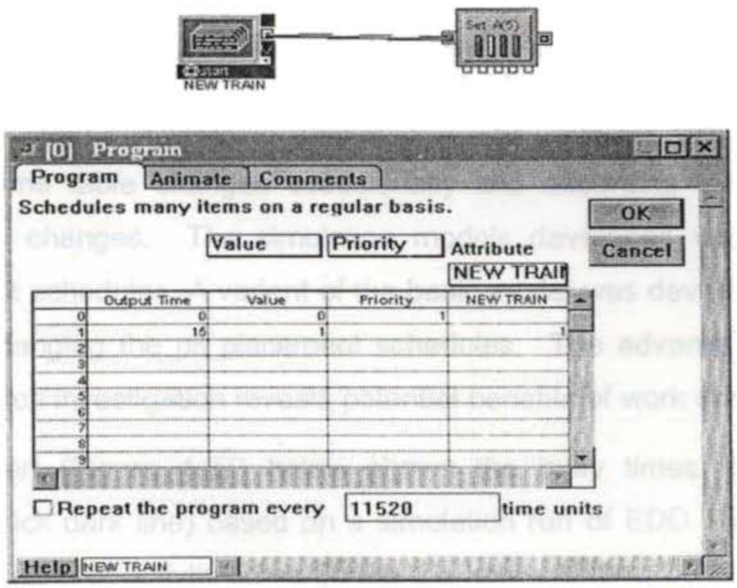


Figure 4.26: Showing a program block for scheduling a new train

Simulation could be used to generate and compare alternate rake schedules. Use of simulation in such situation reduces chances of unnecessary delays. Alternative schedule times can be compared using a suitable performance measure.

An obvious rule commonly used in scheduling problems is the Earliest Due Date (EDD) rule. This rule schedules work according to the preference of due dates i.e., the one which has earlier due date is scheduled first. Trains arriving from various places go to the pit with the condition that priority will be given to those trains which are scheduled to depart from the station first. This model discards pit placement schedules already existing. Table 4.8 shows the performance of EDD rule with FIFO rule (In this case the rakes are placed on pits on a FIFO basis disregarding existing priorities). It is found that the average lateness is less under EDD rule, as is expected from theory.

PERFORMANCE MEASURE	EDD RULE	FIFO RULE
Number of late trains	3	3
Average lateness in minutes	15.6	24.9

Table 4.8: Comparison of EDD and FIFO rules

4.6.3.2. Case 2: Deciding shift timings, preparing pit schedules

The Railway time table changes occasionally and according to this, the pit schedules also changes. The simulation models developed were helpful in preparing the pit schedules. A variant of the basic model was developed to study the effect of changing the pit placement schedules. The advantage of such a model is that such investigation reveals potential benefits of work rescheduling.

Example: Chart (Figure 4.27) below shows the busy times of pit activity (indicated by thick dark line) based on a simulation run of EDD rule. We see a heavy concentration of activity times during the hours 8.00 to 20.00. So if EDD rule is implemented for pit schedules, the employee shift timings are to be adjusted accordingly.

Preparing pit schedules:

The information blocks (see Figure 4.28) attached just before and after the entry of rakes into and from each of the pits would reveal the times of arrivals to the pit and departure from the pit. Typical timings for each of the pits obtained from using the EDD model is shown in Table 4.9. Based on this information detailed pit schedules could be prepared.

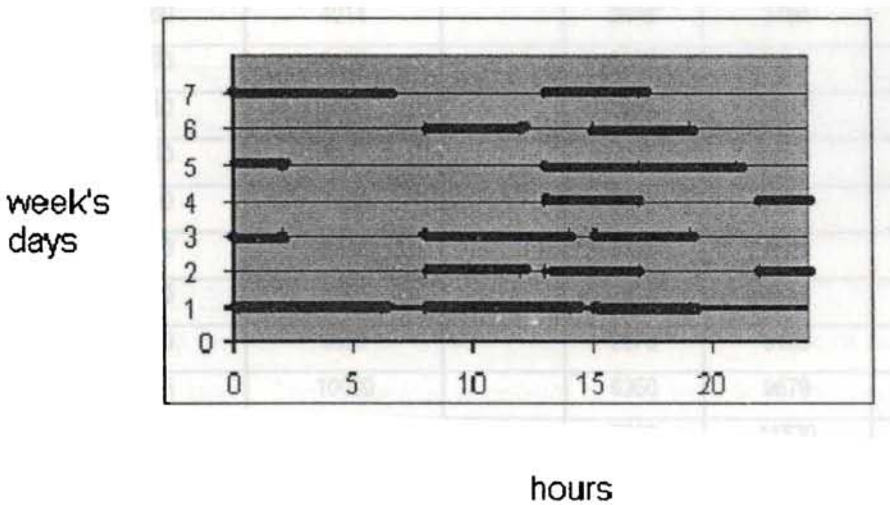


Figure 4.27: Chart showing pit busy time based on EDD rule

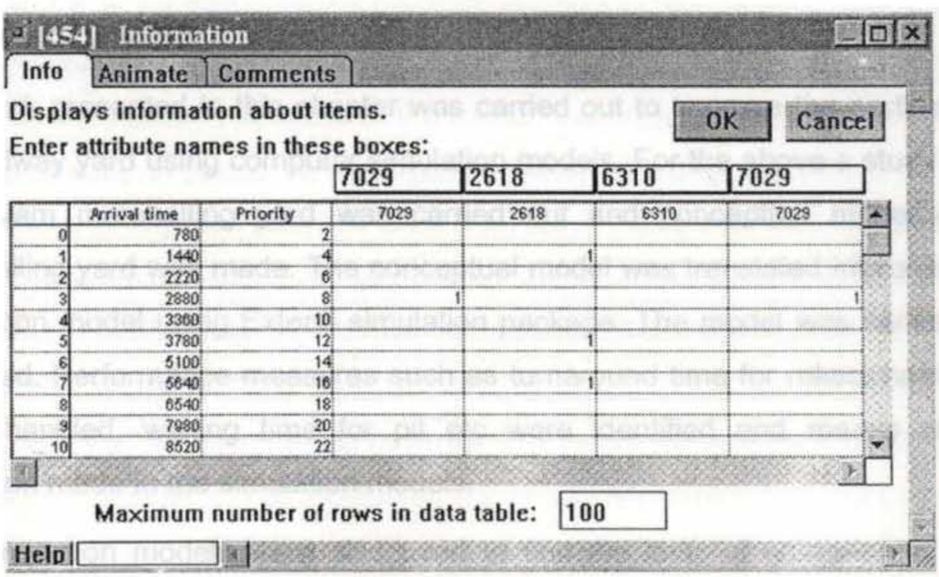


Figure 4.28: Contents of information blocks related to pits in the rail yard simulation model

		PIT1			PIT2	
TRAIN NUMBER	ARRIVAL TIME	DEPARTURE TIME		TRAIN MUMBER	ARRIVAL TIME	DEPARTURE TIME
2075	780	1031		2978	780	1171
7029	1440	1681		2618	1440	1821
2075	2220	2469		1097	2220	2618
6305	2760	3105		7029	2880	3129
2618	3105	3470		5623	3360	3739
2075	3660	4014		2618	3780	4140
2075	5100	5450		6338	5100	5331
6305	5640	5888		2618	5640	5888
6308	6540	6927		2075	6540	6880
5221	7200	7438		2075	7980	8211
6338	7980	8346		6305	8520	8882
7029	8640	8998		2618	8882	9236
6308	9420	9655		2075	9420	9679
2646	9655	10020		6360	9679	10047
2618	10020	10263		7029	11530	11868
2618	11530	11794		6310	12000	12254

Table 4.9: Time of rakes enty and exit from each of the pits

4.7. CONCLUSION

The work presented in this chapter was carried out to improve the performance of a railway yard using computer simulation models. For the above a study of the Ernakulam marshalling yard was carried out and conceptual model of the Marshalling yard was made. The conceptual model was translated into a working simulation model using Extend simulation package. The model was verified and validated. Performance measures such as turnaround time for rakes, number of rakes handled, waiting time for pit etc were identified and means of their collection made in the simulation models.

The simulation models were also used to find the level of utilization of major facilities. It was found that pit and waiting lines were facilities with high utilization and tended to be bottleneck facilities. A comparison of two train time tables to ascertain its impact on yard performance using the simulation model showed that the current time table was slightly better than an equi-spaced time table tried out. In order to study the effect of different operating strategies, scheduling at pit according to EDD and FIFO rules were tried out and it was found that EDD rule gives 3 number of trains late and average lateness of 15.6 minutes while the FIFO rule gives 3 number of late trains and 24.9 minutes of average lateness which is higher. Hence it is recommended that EDD rule be used for pit scheduling. Similarly other rules can be checked using the model.

Rakes with different coaches are put into service. Normally these coaches require only water servicing and minor electrical, mechanical and AC maintenance. These can be done without detaching the coach from the rake. However, at times when major work is required, the coach has to be detached from the rake and sent to the coach care center. In such cases, the coaches so detached have to be replaced, by spare coaches from the stock of extra coaches with marshalling yard. The simulation model was used to find how many such extra coaches are required in the yard. It was found from our experiments that at least four sleeper coaches should be provided to ensure no shortage.

Some other highlights of the the work presented in this chapter are that in Section **4.5** a modelling approach was developed for dealing with the cyclic nature of events in railyard models. The essence of designing the models was in deciding the inputs to be given to the model, the decision variables involved and the constraints imposed on the system. *When deciding capacity a long term perspective is required because once a layout is made with a design capacity, it is difficult to change or modify afterwards.* Overall it could be seen that the level of constraints became tighter as we moved from models for strategic to operational problems. The level of flexibility of the model (in terms of decision rules, facilities, and schedules) however decreased for models from strategic to operational problems. The validation, run length and type of analysis of each of these models were different.

CHAPTER FIVE

STUDY, MODELLING AND ANALYSIS OF AN AIRPORT TERMINAL

5.1. INTRODUCTION

The aviation sector in India is growing rapidly. About 95% of international tourist arrivals are by air. Airports facilitate growth of high-value and perishable commodity trade; 40% of exports and imports in India by value are carried by air. The sector might one day also serve to routinely provide connectivity to remote areas otherwise inaccessible by other modes of transport.

The Indian domestic and international air traffic is predicted to increase by about 20% annually, due to investments from the government and private sector. The investments have been estimated at USD20bn over the next five years and the increase of aircraft numbers is expected to double the number of civilian passenger aircraft in India to 400.

Table 5.1 reveals that the aircraft movements, passengers and freight traffic increased by 30.3 per cent, 38.8 per cent and 13.1 per cent respectively during year ending March 2006 over traffic handled during year ending March 2005(According to Airport Authority of India website[1]).

With more airlines operating in Indian skies and air travel becoming more affordable, the infrastructure facilities at airports have remained grossly inadequate. In metro airport terminals even basic facilities are not of acceptable standards, travelers have to line up for entry and exit and wait for screening of their check-in baggage. At international terminals, the wait for immigration clearance is very long.

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[1] Airport Authority of India website, http://aai.aero/AAI/main.jsp

CATEGORY	MARCH 2006	MARCH 2005	%CHANGE
Aircraft Movements(in '000)			
International	17.54	15.27	14.9
Domestic	65.32	48.30	35.2
Total	82.86	63.57	30.3
Passengers(in Million)			
International	2.02	1.77	14.4
Domestic	5.16	3.40	51.4
Total	7.18	5.17	38.8
Freight('000 Tonnes)			
International	92.98	80.41	15.6
Domestic	44.91	41.46	8.3
Total	137.89	121.87	13.1

(Source: Airport Authority of India website, http://aai.aero/AAI/main.jsp).

Table 5.1: Total traffic handled in March 2006 and March 2005

5.2. PROBLEM AND OBJECTIVES

The Cochin International Airport was founded as a green field project about ten years back. Initially there were only a few domestic flights operating from this airport and therefore the available facilities were abundant . However soon the airport became the busiest in Kerala with the operations of many international flights and cargo movements. This has led to a scenario where there is urgent need to synchronize the system and get maximum performance out of it in the short run. In the long run facilities need to be augmented. Decision support systems that could help in solving the above problems are very much required. Simulation has been used for the above as is evident from literature. It is proposed to develop a simulation model of the passenger terminals of the Cochin International Airport with the following objectives.

1) To develop an integrated simulation model that models passenger flow and aircraft schedules.
2) To develop models with capability to determine resource utilization at a high level of detail.
3) To allow planners to see operational constraints and bottlenecks, as opposed to inferring operational limitations through reviewing the statistical reports, graphs and charts.

4) To study the effect of additional flights on Runway capacity(utilization)
5) To find out the requirement of flight parking bays
6) To determine the number of X-ray machines
7) To study capacity required for Heating/Ventilation systems
8) To study the impact of rearranging schedules/passenger arrival patterns and to investigate possibility of additional schedules.
9) To study the problem of deployment of equipment

5.3. METHODOLOGY

The application of simulation involves specific steps in order for the simulation study to be successful. Regardless of the type of problem and the objective of the study, the process by which the simulation is performed remains almost same. Law and Kelton (1991) discuss steps for a simulation study. We have followed similar methodology for our simulation study consisting of following steps.

1. After a system study related to operations at the terminal to obtain operational flow charts, data regarding operation times and resource requirement were found out.

2. Conceptual modeling was done and three classes of models to suit three classes of problems were made.

3. A modelling platform was selected and models were made to get sufficient representation of actual operations. Models developed were verified and validated.

4. Experiments were done on the model by changing various parameters and its effect on utilization of equipments and resources were studied. Inferences were made and results presented.

5.4. COCHIN INTERNATIONAL AIRPORT

Cochin International Airport is a novel venture in the history of civil aviation in India where Government of Kerala, NRIs, Travelling Public, Financial Institutions, Airport Service Providers and others joined hands to float the company to make this project a reality. This airport has been constructed with state of the art facility to enable any type of wide-bodied aircraft to land.

There are two separate centrally air-conditioned terminals for domestic and international operations measuring a total area of around 0.45 lakhs sq. meters. The integrated cargo complex at the airport is capable of handling perishable/non perishable and dangerous cargo.

Kochi airport is, perhaps, the first airport in the country to have the infrastructure to handle the A-380, the biggest passenger aircraft expected in the near future. An apron capable of handling A-380 was built at a cost of Rs.2.8 crore. Another highlight of this airport is its runway length being 3.4 km, it is one of the longest in the country capable of handling wide-bodied jetliner

5.4.1. Terminal Complex

The Cochin airport consists of two terminals, one for domestic and the other for international passengers. The International Terminal caters to a peak capacity of 800 passengers per hour. Passenger's embarkation and disembarkation is through the aero bridges. Two aero bridges are provided. There are two conveyor belts in the arrival hall for baggage handling. Escalators have been provided to go to the aero bridges on the first floor.

A spacious 6000 Sq. Ft of Duty Free shopping area is available in the arrival hall. Similarly, 1250 Sq. Ft of Duty Free shopping area is also available for departing passengers after customs counter. Shopping complex with moderate number of shops is available.

Arrival hall is located on the ground floor, it has a peak hour capacity of 400 passengers. The passage to the arrival hall is through the escalators. There are 8 immigration counters in the arrival hall. Specific counters are earmarked for foreigners and Indians to expedite the clearing process. The health check is carried out along with immigration check.

Pre-immigration area is provided with facilities such as drinking water and public convenience. The arrival hall has two conveyor belts; these belts have individual flight indication boards to indicate flight number.

Two Customs channels are available for arrival passengers namely Red and Green Channels. The Green channel is also called as Walk through channel, through which arriving passengers without dutiable items can walk through. The Red channel is earmarked for clearance of passengers with dutiable items. There are 10 Customs counters, which include counters for currency declaration, transfer of residence and crew. A block diagram of the international terminal facilities showing its facilities is given in Figure 5.1.

The Domestic Terminal Complex consists of well separated arrival and departure areas with all modern passenger amenities. All domestic flights are handled through this complex. A large shopping complex consisting of 21 shops is situated at this terminal. There are two conveyor belts in the arrival hall.

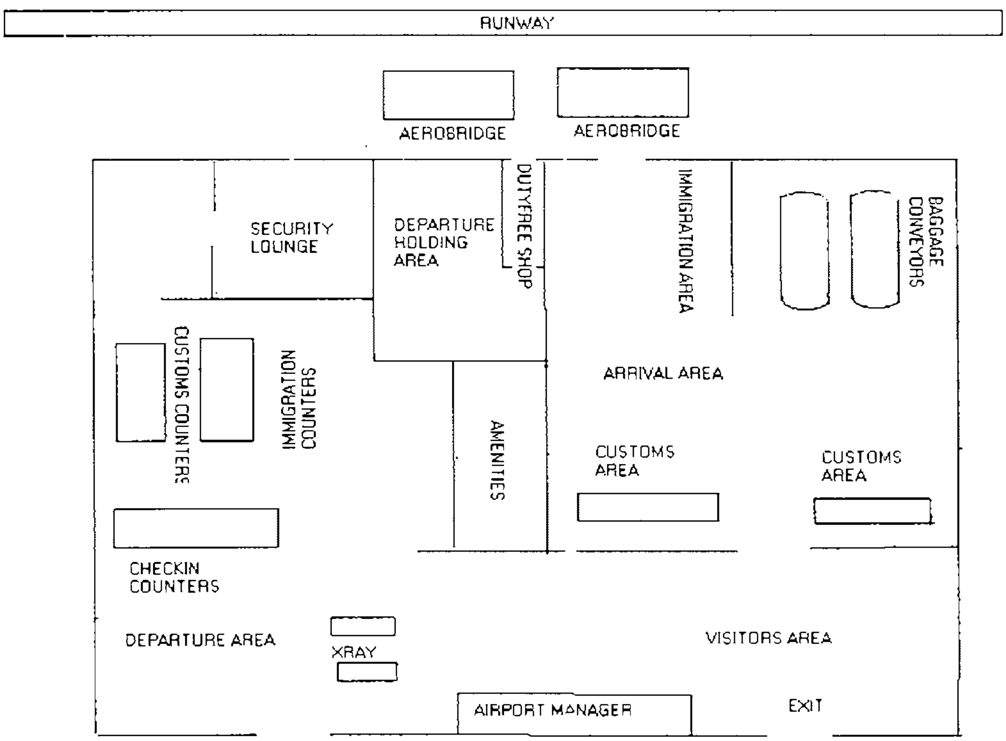

Figure 5.1: A block diagram of international terminal

5.5. TERMINAL COMPONENTS AND CHARACTERISTICS

Airport landside includes the passenger terminal with all of its components. We consider only *functional* components, i.e., elements providing services or amenities directly related to a passenger boarding or disembarking an aircraft. *Non functional* components such as concession areas, rest rooms and telephones are not used as a basis for defining airport landside capacity. The passenger's perception of the quality and conditions of service of one, or a set of, functional components constitutes the service level. A high level of service may be provided if the airport landside has ample capability to accommodate passengers, baggage and airport visitors. This airport landside capability is, of course, influenced by the *capacity* (in terms of persons processed per unit of time) of the facilities in the terminal. Capacity can be evaluated for each individual functional component of the airport landside. One or more of these components are likely to become the bottlenecks of landside capacity, i.e., the major constraints on serving additional passengers at the terminal.

5.5.1. Some basic definitions

We define the *dwell time* as the average time a person spends in a place or in a process.

Peak hour, i.e., a representative hour of busy conditions within a functional component. A peak hour is typically defined from historical records by frequency of occurrence. In fact, it may be the average daily peak hour of the peak month, or the peak hour of the 95-percentile busy day.

Demand patterns, i.e., the number of passengers and characteristics of their behaviour that materially influence the ability of a functional component (or group of components) to accommodate them. For the description of each facility, we will deal with the demand pattern.

We consider the terminal as a set of different facilities or facility components. By facility component we mean a subsystem of a facility. For instance, the check-in counters dedicated to a specific airline are a component of the "check-in" facility.

Facilities are classified as *processing* (e.g., check-in counters), *holding* (e.g., gate lounges) and *flow* (e.g., corridors, escalators).

Processing facilities: They process passengers and their luggage.

Holding facilities: Areas in which passengers wait for some events (as the check-in opening for a flight, the start of flight boarding, etc).

Flow facilities: The passengers use them to move among the landside elements.

Passenger holding areas are spaces where passengers move around and wait for flight departures and arrivals. These facilities include lobbies, gate lounges, transit passenger lounges, baggage claim area, the arrival area, the area set aside for ancillary facilities, etc. The number of waiting passengers is a function of the number of aircraft served by the holding area, and their functional characteristics, including capacity and loading factors.

The *total time* spent by a passenger *to cross the terminal building* from its entrance point to the gate is the sum of the waiting and service times in the processing facilities plus the sum of the times required to move from a service station to another. The time required to travel from the curb to the gate is one of the most important measure of service level.

5.5.2. Check-in

The *check-in* operation begins when a passenger enters the queue to obtain the boarding pass and checks his baggage(hand) at the check-in counter, and ends when the passenger leaves the counter area. It has to be noted that the (average) processing time at any particular airport depends on many factors (staff experience, flight market and passenger characteristics) as well as on airline operating policies (i.e., number of active counters). Processing time variance can also be large. Capacity of check-in processing facilities is judged by considering the average service time and by comparing the number of passengers in a terminal holding area with the size of that area.

5.5.3. Immigration

The immigration set up at the airport, works under Ministry of home affairs. The immigration processing of passengers both in International Arrival and Departure are regulated by Foreign Regional Registration Officer, who is of the rank of Deputy Commissioner of Police. He is assisted by Assistant Commissioner of Police. The Process of Immigration is controlled by set of rules and regulations issued from time to time. At International Terminal, Cochin Airport arriving passengers are checked cleared on entry into the Terminal. The number of counters available at International Terminal is: Departure - 6 and Arrival - 8.

Immigration checks comprises of 4 steps:

1. Checking of passport/travel documents to identify the holder and to look for possible forgery etc.

2. To ascertain the eligibility of holder either to leave or enter in the Country as per existing rules and regulations.

3. Computer confirmation in clearing passenger.

4. Health check on behalf of Airport Health Office.

For passengers with all documents correct, this is a straight forward process. When some problems are detected in the documents, it takes longer time for immigration process. Walking speeds and distances from check-in to inspection areas and from arrival gates to the inspection areas determine the distribution of actual passenger arrivals.

Originating passengers must undergo a *security-screening* operation. For this reason, security-screening areas are often elements of queuing and delay for passengers. The average time required for clearance of a passenger, the variability of that time and the rate of passenger arrival at the security screening area are key variables for its capacity assessment.

5.5.4. Customs

Central Board of Excise and customs, a department of the Ministry of Finance is the agency which regulates the clearance of arriving and departing International passengers through International Terminal under Customs Act, 1962. Rules & Regulations under this Act are revised by the Government of India from time to time.

The commissioner of Customs, Customs House, Cochin - 9 having jurisdiction over the Cochin International Airport is functioning from the office of the joint Commissioner of Customs, Air Customs, Cochin International Airport , Nedumbassery for regulating activities under the Customs Act, 1962 in the entire airport area.

The functions of Customs in passenger terminal include air customs wing for clearance of passengers and baggage, Air Intelligence Unit for Anti-smuggling work, prosecution and COFEPOSA cells.

The number of passengers waiting in the *baggage claim* depends on the rates at which passengers arrive from the gate and the luggage they pocess. In general, the maximum demand levels occur when larger aircraft arrive. The baggage claim area capacity can be measured considering the average time passengers wait to retrieve their checked baggage and comparing the number of people in the claim area with the size of that area.

5.5.5. The level of service

The *level of service* (LOS) represents the quality and conditions of service of one or more facilities as experienced by passengers. Interrelationships exist among the typical measures of service level such as waiting time, processing time, walking time, and crowding, and availability of passenger amenities for comfort and convenience.

Each component of an airport landside has its own unique operating characteristics and demands; hence it is hard to define service level in a unique way. Research conducted by the IATA on Traffic Peaks led to the need of standard definitions for evaluating LOS and airport capacity (IATA, 1995). To specify the LOS, a set of letters from LOS =A (best) to LOS =F (unacceptable) are used. In Table 5.2, (from Andreatta et al, 2006) the LOS are described in terms of flow, delays and level of comfort. Note that although the description of each individual service level remains the same, subsystems have different spatial requirements.

Service level targets are important because of their serious implications for airport costs and economics as well as for the "image" of the airport. In fact, maintaining a particular LOS at an airport may contribute to attracting new business and is also a reflection of the local or community's goals.

IATA LOS standards	
LOS Level	Description
A	Excellent Free flow, no delays, excellent comfort level
B	High Stable flow, very few delays, high comfort level
C	Good Stable flow, acceptable delays, good comfort level
D	Adequate Unstable flow, passable delays, adequate comfort level
E	Inadequate Unstable flow, unacceptable delays, inadequate comfort level
F	Unacceptable Cross-flow, system breakdown, unacceptable comfort level

Table 5.2: IATA LOS standards

For estimating the appropriate LOS of a facility, let us introduce the index of service (IOS) that represents the value of some measurable quantity, space or time, associated with that facility. The entire IOS range of values is divided into a set of intervals that correspond to internationally accepted, or airport specific, standards. The facility LOS is determined according to the interval where its IOS falls. For example, the space IOS of a waiting lounge is the number of m^2 per person. If it is above $2.7m^2$ per person, the corresponding LOS is A, if it is between 2.3 and $2.7m^2$ per person, then LOS =B, etc.

Typically, the IOS of a specific facility, during a specific time interval, can be computed from other data through a simple formula, like the following:

$$IOS = area/(AP \times ADT) \quad (5.1)$$

This equation means that the IOS is given by the area of that facility divided by the product of the average number per hour of arriving passengers (AP) at that facility, during the time interval under consideration, times the average dwell time (ADT) spent by a passenger in the facility. The IOS can then be used to obtain the LOS of that facility. For example, if the area in front of the check-in counters is $1500m^2$, the number of passengers arriving at the check-in during a particular hour is 3600, and the ADT is 0.15 h, then the IOS for that facility is $2.78m^2$ per person, which means that the corresponding LOS is A.

5.5.6. Computing dwell times in a processing facility

In this section we present a method to compute the ADT at a processing facility. The input required for this can be extracted from the statistical data that are typically available to an airport manager. The entire day is divided into periods of time having the same length (typically one hour). The output provides, among other things, the LOS of each facility during each period of time. To estimate the ADT spent by a passenger in a processing facility during a given period of time, we discarded the classic queuing theory approach (M/M/s or similar) because it is based on the often unrealistic assumptions that both the average number of AP at the processing facility and the average potential service volume (AS) of that same facility are approximately constant over a significant period of time and that AP is strictly lower than AS. This approach will not be able to take into account the dynamic effects of variations over time of AP or AS. These dynamic effects are too important to ignore.

The approach adopted here uses a deterministic equivalent approximation that exactly follows the evolution over time of AP and AS. Basically, this is a graphical model that computes approximately the total waiting time of passengers, given the cumulative arrival function at the processing facility and the service rate for each time period. This approach was initially proposed by Newell (1971). In this approach the dwell time for each processing facility is estimated by considering the passenger arrival profile and the profile of the number of passengers served, as functions of time.

For each flight, the passenger arrival profile (which must be given as input) is a function of time that provides the number of passengers that have already arrived in the system (i.e., the check-in facility). The profile of the passengers who have been served by the system (and therefore have left it) is again a function of time, but it also depends on the number of servers; this profile is not given as input, but can be inferred from the number of servers which are open and from the mean service time. The number of servers opened by a given air carrier is sometimes conditioned upon the carrier's target LOS standards.

Let $A(t)$ be the number of passengers that have arrived at the facility up to time t, and $D(t)$ the overall number of passengers that have already left the facility by time t. $A(t)$ and $D(t)$ are non-decreasing functions.

Passenger profiles can be properly approximated by piece-wise linear functions with time on the horizontal axis and the number of passengers on the vertical axis. Furthermore, the combined arrival profiles of the passengers of all flights assigned to the same check-in counter (or block of counters) can be summed up by using the arithmetic of piece-wise linear functions, thus producing an "overall piece-wise linear profile".

Let $C(t)=A(t)-D(t)$ be the difference of $A(t)$ and $D(t)$, i.e., $C(t)$ represent the number of passengers that are waiting in queue at the facility at time t. In Figure 5.2 we observe that a hypothetical $A(t)$ and $D(t)$ in the case where a single flight is assigned to a given counter. If a passenger is the nth passenger to enter the system, then his/her dwell time DT(n) can be computed as follows, under the natural assumption of a first-in first-out (FIFO) discipline:

$$\mathrm{DT}(n) = D-1(n) - A-1(n), \qquad (5.2)$$

where $A-1(n)$ and $D-1(n)$ are the inverse functions of $A(t)$ and $D(t)$. Since $A(t)$ and $D(t)$ are piece-wise linear functions, their inverses are also piece-wise linear functions and so is their difference.

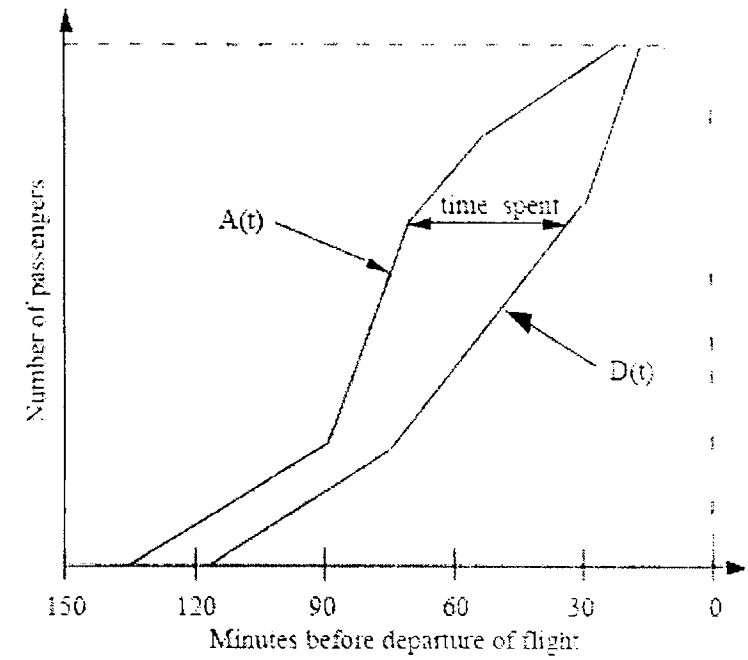

Figure 5.2: Processing facility dynamics (Andreatta et al, 2006)

The above deterministic equivalent approach allows Extend model to compute the averages of many random quantities. In order to compute the variance or other statistical indices for some variables other "tricks" can be implemented (Brunetta et al, 1999). For example, to estimate the upper tail of throughput through a processing facility, the following reasoning may apply. Assuming that throughput follows a Poisson distribution, which, when large numbers are involved can be approximated by a normal distribution, we first establish its mean μ. In the Poisson distribution, the mean and the variance are equal so that the standard deviation is the square root of the variance, $\sqrt{\mu}$. A property of the normal distribution is that (approximately) 95% of all "observations" will be within the limits of the mean plus or minus 2 times the standard deviation. This means that there is only 2.5% chance that the throughput during any peak period will exceed $\mu + 2\sqrt{\mu}$.

5.6. MODELLING APPROACH

Simulation models of terminal were built in Extend simulation language considering the processes above. Slightly different models are developed for the analysis of the type of problem considered. To address different classes of problem of airport terminals, our modeling effort began at conceptual level. The approach was similar to the cases already we have discussed in Chapters 3 and 4. Three types of models(TYPE 1,TYPE 2 and TYPE 3) were developed.

5.6.1. Model TYPE 1

For such models, the schedule related inputs include and arrival and departure schedules of flights. For output analysis, data for one cycle was repeated for getting statistical confidence intervals. Typically these models were used to study the impact of changes in schedules and operational times. Due to priorities in schedules, these models offer only very little flexibility for studying tactical and strategic decision.

5.6.2. Model TYPE 2

For such models, the schedule related inputs include arrival and departure schedules of flights. These models also have some simulation blocks for giving statistical distributions of wait times, interarrival times instead of schedules for the use of some of the terminal's facilities. For output analysis, data from many cycles were taken for establishing statistical confidence intervals. Typically these type of models were used to study the impact of changes in schedules, operational times and changes in number of some facility . Due to priorities in schedules, these models offer only very little flexibility in some of its blocks for studying strategic problems. More flexibility is avilable in blocks without specific schedules and priorities. Problems like effect of change in number of x-ray machines on turnaround time for coming months were studied using above model.

5.6.3. Model TYPE 3

Such models totally discard time schedules for arrival and departure of entities. Flght arrivals are generated according to specified statistical interarrival time distributions. Blocks for interarrival and wait time distributions were also attached to various equipments and facilities. Longer term behaviour was checked for output analysis using steady state non-terminating anlysis. Typical problems studied using these models include changes in operation times, changes in number of facility and changes in key technology resulting in operational time change.

5.6.4. Basic Model features

Some of the features of a basic model developed are given below. Additional features are added to this model depending upon the type of problem.

5.6.4.1. Input data

The input data for our model are: number of departing flights in the time interval, time of arrival of each flight, aircraft types, flight types, number of passengers on board, passenger arrival profiles (for each flight type), number of counters and service time.

5.6.4.2. Model logic

The model logic is described here briefly. The models follow the flow of passengers in the terminal as well the movement and parking of planes. Flights are generated (separately for domestic and international) according to time schedules when problems related to mainly operational decisions are considered. For this program blocks available in Extend are used. For strategic and tactical problems, the models developed include blocks for empirical distributions or probability distributions and interarrival times were be assigned in these blocks. Flights were given attributes related to its type, parking bay, whether international or domestic, ground time required (later this attribute is converted into activity time required for ground operations) and passenger attributes. Flights wait at airspace for landing (only a restricted number of airplanes are admitted to the system). After landing, airplanes are taxied to parking bays. Plane arrival and departure processes are shown in Figure 5.3.

Arriving passengers undergo a set of processes depicted in Figure 5.4. (Processes of international and domestic terminals are slightly different). The departing passengers were assigned various attributes of flights, check-in counters, terminal type, gate etc. They undergo the set of processes depicted in Figure 5.5. Both streams(passengers and airplanes) are batched together using a **batch block** and when all departing passengers have arrived for their corresponding flight, and all ground activities are over, the airplane is taxied to runway and take-off permission is given if runway is free. Only one plane(take-off or landing) is permitted on the runway at a time.

Airport authorities provided the originating passenger percentage. Once total originating passengers per flight were calculated, an arrival time distribution was applied to represent the fact that passengers arrive at various times before their flight. In our models we have generated all flights of a day using *Program blocks* in which specific schedule times can be given. Domestic and International departing passengers were generated by assigning corresponding *Generator blocks*, input from a *Random Input Block*. In *Random Input Block,* the passenger arrival distributions of domestic and international passengers were given (see Figures 5.6, 5.7 and 5.8 for screen shots of blocks for generation of flight and passengers).

The number of persons arriving at the check-in area could be easily estimated considering the index of the last passenger minus the index of the first passenger arrived at the check-in during the interval under consideration (usually the check-in peak hour). Check-in opening depends on the flight destination. The counter opening policies are discretionary to the airlines. Since this kind of information was not available we made the policy of making available any counter to passengers for strategic problems. Provisions were given in models for operational problems to separate passenger's streams to designated check-in counters (See Figure 5.9). More screen shots of various parts of the model are given in Figures 5.10 to 5.12.

To estimate the time needed by passengers to move within the building, the terminal is divided into different areas. All passengers held up in last processes or in movement, are not permitted to undergo certain avoidable processes (for example passengers reaching at duty-free at the last moment. In the duty-free shop, passengers spent extra time available for getting duty-free items).

Extend can capture the dynamic nature of many important quantities by displaying them as functions of time in colour graphs. Included among these quantities are: the cumulative number of served passengers, the number of passengers in queue, the number of passengers in queue per counter. The modes also estimated, for each period of interest, the ADT, the average waiting time, and the space and time LOS.

For each passenger facility, the graphs of the following quantities - as functions of time - are provided: facility throughput, i.e., cumulative number of served passengers, number of passengers in queue, number of passengers in queue per counter, number of counters with number of passengers in queue per counter, number of counters with expected queue time. To simplify modelling, we have not separated passengers into passenger classes like business class, economy class etc.

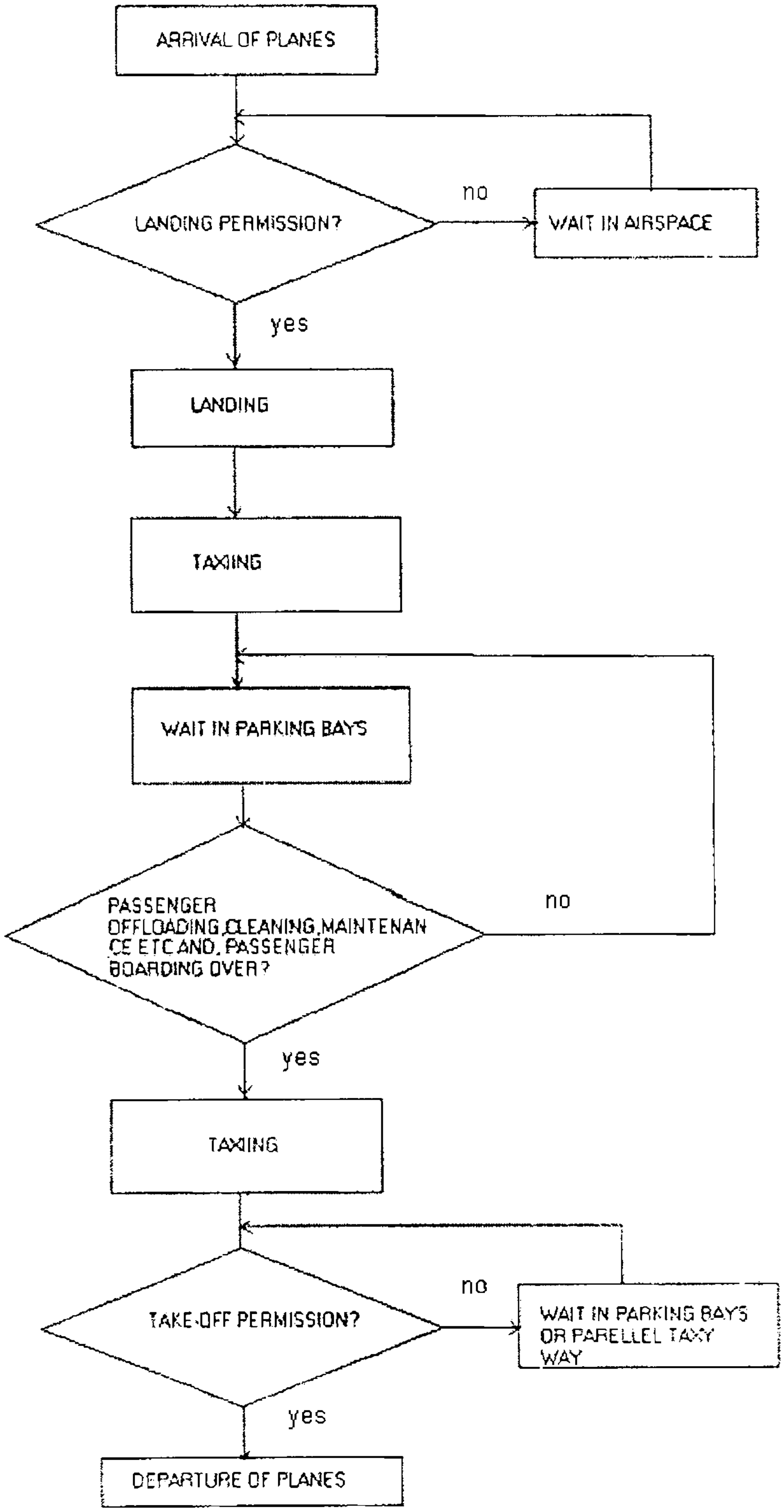

Figure 5.3: Diagram showing plane arrival and departure process

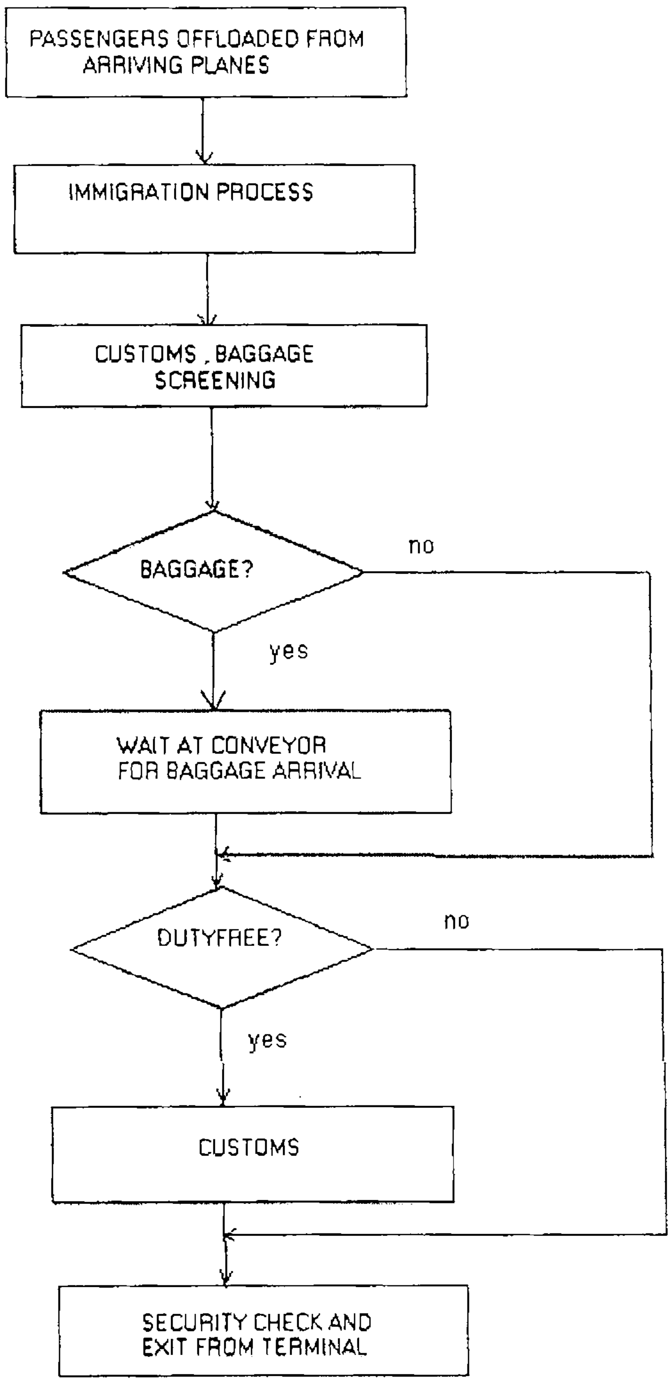

Figure 5.4: Diagram Showing Arrival Process Of International Passengers

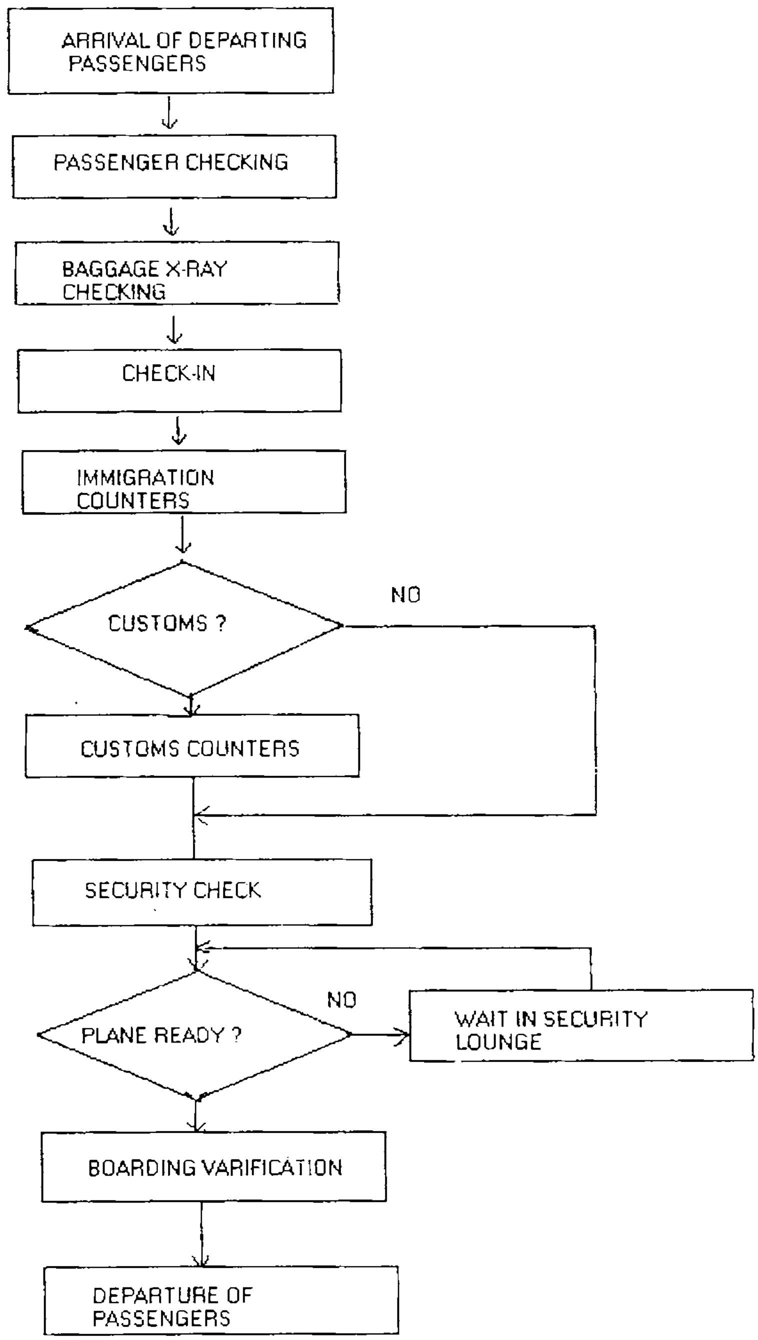

Figure 5.5: Diagram Showing Departure Process Of International Passengers

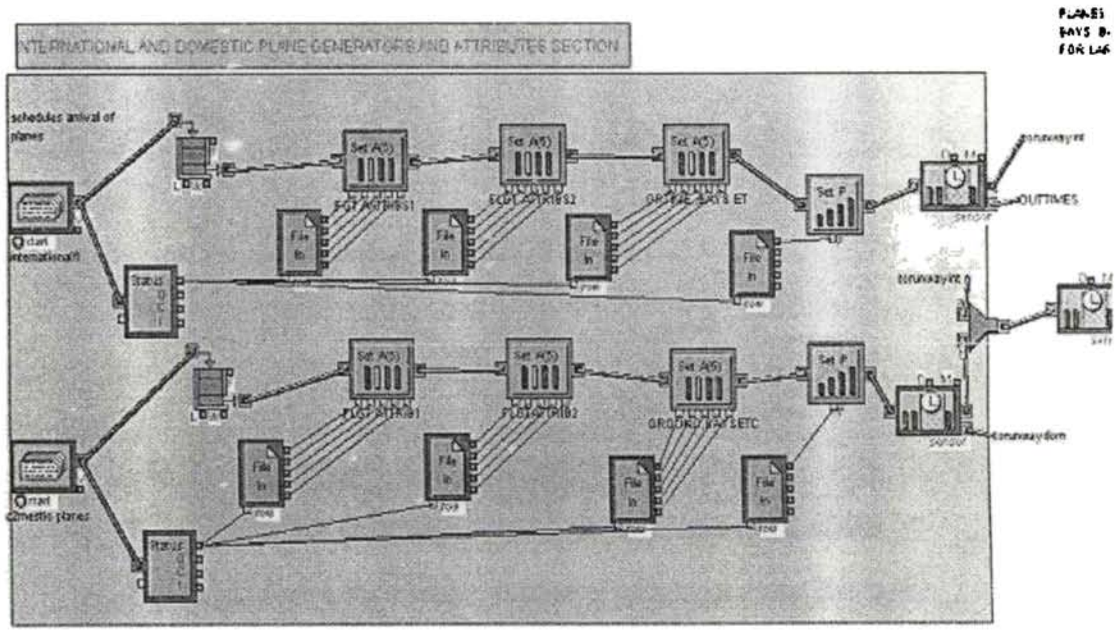

Figure 5.6: International And Domestic flight generators and attributes section in the simulation model

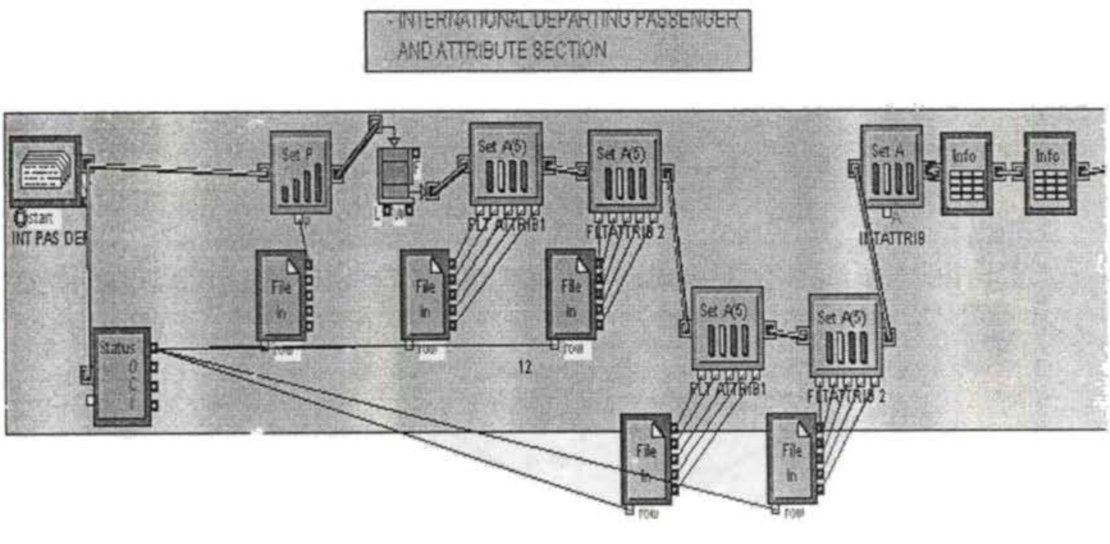

Figure 5.7: International departing passenger generators and attributes section in the simulation model

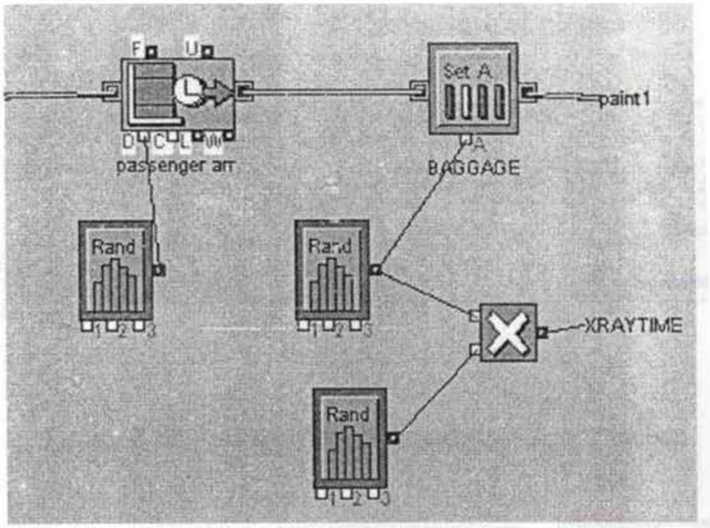

Figure 5.8: Above show implementation of passenger arrival distribution.

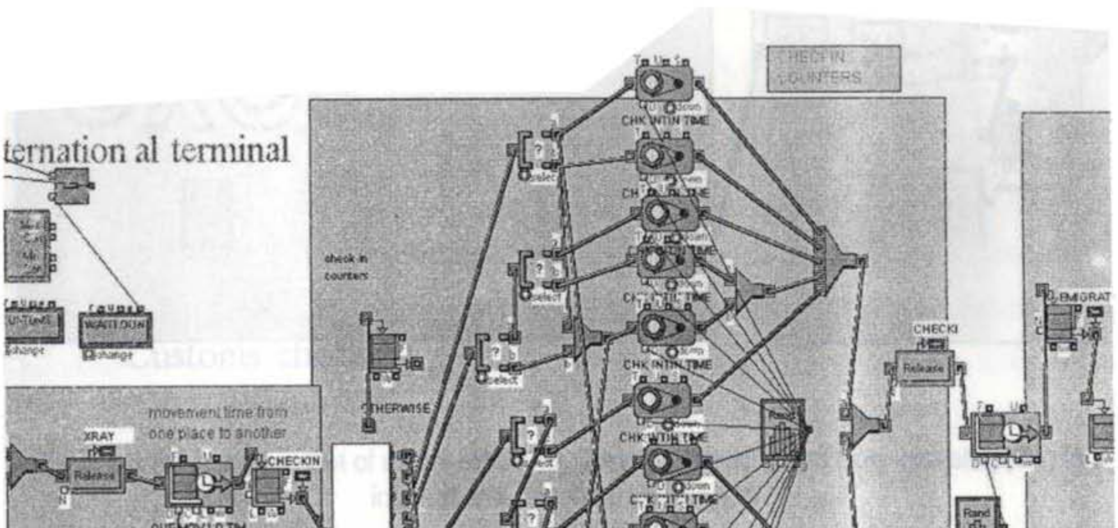

Figure 5.9: Check-in counters: passengers filtered using attributes of flight service (airlines) go through the process of check-in.

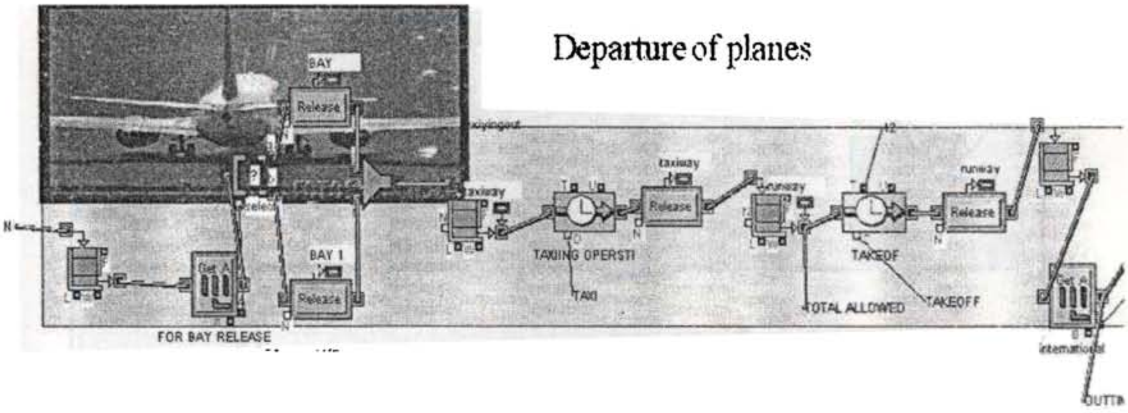

Figure 5.10: A screen-shot of departure of flight's section

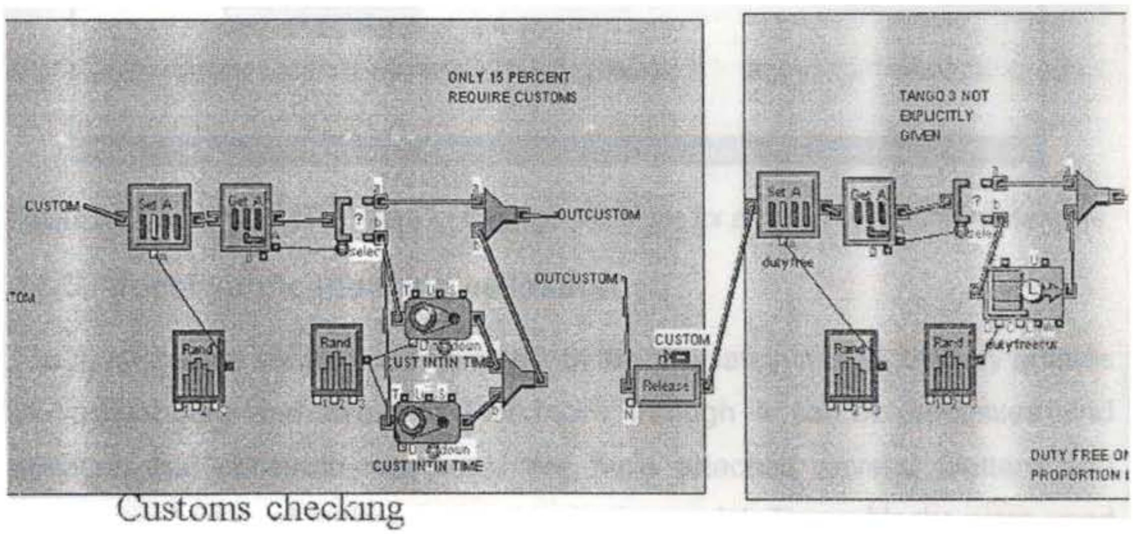

Figure 5.11: A screen shot of model blocks for Customs checking and Duty-free shopping for international departing passengers

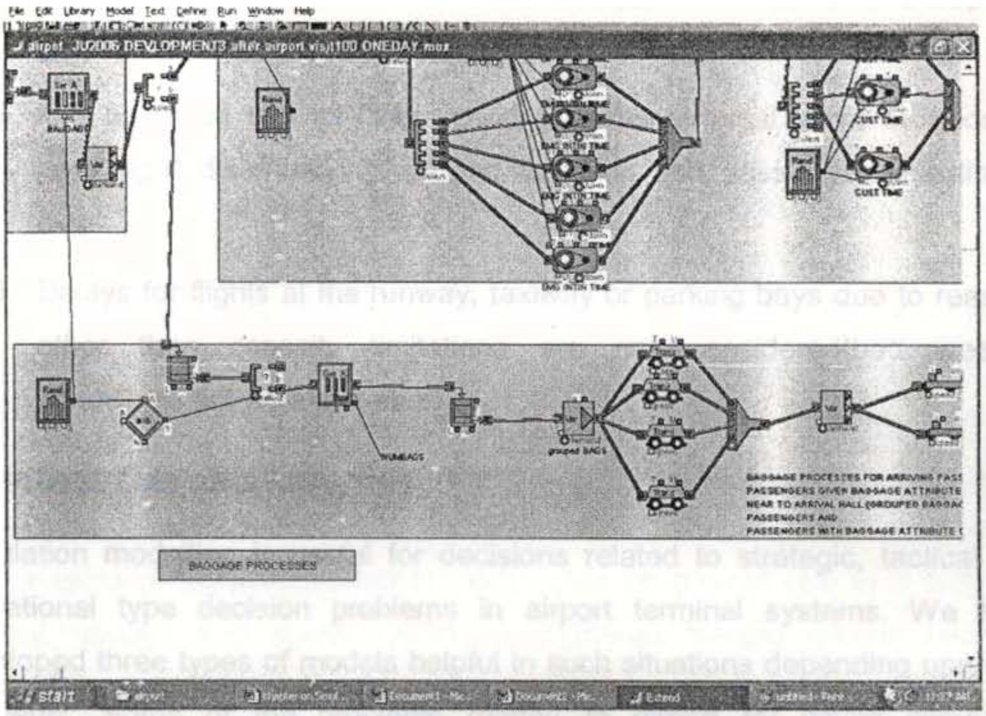

Figure 5.12: A screen shot of blocks for Baggage processes for arriving international passengers.

5.6.5. Model varification and validation

The models were verified and validated. In the simulation model, the key entities are passengers and airplanes that move through a set of processes and activities that consume resources. We have attached several plotters and information blocks at various flow points in the model. These blocks were used to verify the model. For validation, the graphical procedure similar to the case of Rail Yard was done. Plots of the model results and actual system showed similar behavior for flights and passenger profiles.

5.6.6. Assumptions

1. Cargo movements and cargo flights were not considered
2. Resources like labour(pilots, crew etc) were assumed to be available as required.
3. Ground handling operations and equipment availability was not separately considered.

4. Operations at the Air Traffic Control were not considered except for getting clearance for take-off and landing of flights.
5. It is assumed that all flights coming to the terminal leave as soon as passenger disembarking, ground handling and passenger boarding is over.
6. Delays for flights at the runway, taxiway or parking bays due to reasons other than capacity limitations are not considered(bad weather conditions, fire breakout etc).

5.7. PROBLEMS AND ANALYSIS

Simulation modelling is useful for decisions related to strategic, tactical and operational type decision problems in airport terminal systems. We have developed three types of models helpful in such situations depending upon the problems. Some of the problems related to airport for which simulation modelling were used for analysis and the corresponding model types are given below(Table 5.3).

DECISION PROBLEM	MODEL TYPE
Strategic level	TYPE 3
Case 1: Effect of additional flights on Runway capacity(utilization)	
Case 2: Number of parking bays	
Tactical level	TYPE 2
Case 1: Number of X-ray machines	
Case 2: Estimation of Maximum Occupancy of an Area to Determine Heating/Ventilation System Requirements	
Operational level	TYPE 1
Case 1. Rearranging schedules/Passenger reporting times to level peak load	
Case 2:. Investigating possibility of additional schedules	
Case 3: Deployment of facilities	

Table 5.3: Decisions problems and model types

5.7.1 Strategic

5.7.1.1. Case 1: Effect of additional flights on Runway capacity

Over the last few decades, air traffic has been increasing continuously. As a result a steady increase of transportation capacity is required. The increasing number of aircraft movements and the size of modern aircraft have reduced the capacity reserves of the whole air traffic system up to its limits. But not only the airspace is of limited size and capacity, major airports are becoming more and more a bottleneck for air traffic flow. Since they are nodes (starting point and destination) in the air traffic route network, traffic density in the vicinity of an airport is high and concentrates during the approach and departure process. The problem of capacity limitations also exists on ground due to a confined runway, taxiway and apron system. It continues for the ground handling capabilities as well as for the terminal and passenger management. Often only limited infra structural changes to airports are possible due to societal, economical and ecological reasons. Capacity in terms of the number of aircraft movements or amount of passenger transportation is not only limited by the airport infrastructure but also by the human operators who have to keep the airport system running. In such an environment, where safety has to be maintained by human beings, operators have to work under high workload.

Total aircraft movement traffic trends for year ending March 2006 at Cochin International Airport (CIAL)is given below (in '000).

MARCH 2005	MARCH 2006	% CHANGE
1.61	1.97	21.8

Total passenger traffic for year ending March 2006 at Cochin International Airport (CIAL) is given below (in million).

MARCH 2005	MARCH 2006	% CHANGE
0.13	0.17	27.0

Airports are very complex systems with many influences and several stakeholders like the airport operator itself, ATC providers, airlines, ground handling services and others(Sven Kaltenhauser,2003).

Bazargan et al(2002) mentions that airport's capacity is its ability to handle a given volume of traffic (demand). Congestion occurs when demand approaches or exceeds capacity. The Airports Council International (ACI) and International Air Transport Association (IATA) guidelines for airport capacity/demand management (1996) defines the most significant aspect of an airport's capacity, Runway System Capacity, as the hourly rate of aircraft operations which may be reasonably expected to be accommodated by a single or a combination of runways under given local conditions. The Runway System Capacity is primarily dependent on the runway occupancy times of, and separation standards applied to successive aircraft in the traffic mix. Other key items affecting runway capacity include: availability of exit taxiways, especially that of high speed exits that help minimize runway occupancy times of arriving aircraft; aircraft type/performance; traffic mix; Air Traffic Control (ATC) and wake vortex constraints on approach separation; weather conditions [Visual Meteorological Conditions (VMC)/Instrument Meteorological Conditions (IMC)]; spacing between parallel runways; intersecting point of intersecting runways; mode of operation, i.e., segregated or mixed.

Practical Capacity: is defined as the number of operations that can be accommodated in a given time period, considering all constraints incumbent to the airport, and with no more than a given amount of delay. On a typical delay curve, this may be depicted as in Figure 5.14 (Raguraman, 1999).

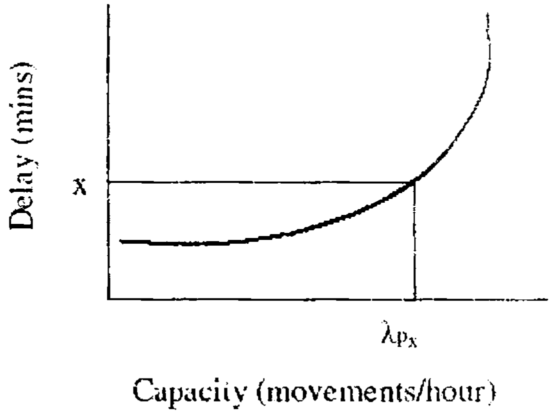

Figure 5.13: Practical Capacity

Capacity Estimation Models: A distinction between analytical and simulation models may be made based on the methodology used to compute capacity, delay or other such metrics. Analytical models are primarily mathematical representations of airport and airspace characteristics and operations and seek to provide estimates of capacity by manipulation of the representation formulated. These models tend to have a low level of detail and are mainly used for policy analysis, strategy development and cost-benefit evaluation (Odoni et al., 1997). Earlier analytical models generated to estimate runway capacity such as that proposed by Harris (1972).

Our models of airport are helpful in providing sufficient information related to occupancy of runways, with a given flight arrival pattern. The runway utilization is related the number of flights, arrival and departure schedules, number of parking bays available, efficiency of ground handling, time required for arrival of all passengers for each flight, time required for departure of all passengers from a flight, delays due to airspace limitations etc. The model has the limitation that it does not consider airspace or ground handling limitations explicitly. However since the model has integrated terminal side operations, the changes in capacity(for additional flights) can be checked simultaneously with bottlenecks in terminal side. For the following analysis we assume that there are no delays due to capacity problems at the terminal side.

A discrete-event plotter attached to the plane arrival section in the model of airport would give us how plane arrivals are distributed over time (see Figure 5.14). Peak rate of plane arrivals can be computed from this plot. For example, circled area shows steepest changes in arrival rate. The peak rate = ((15-9)/(615-515))*60 =3.6 arrivals per hour. Average rate of plane arrivals = 38/24 =1.5 arrivals per hour.

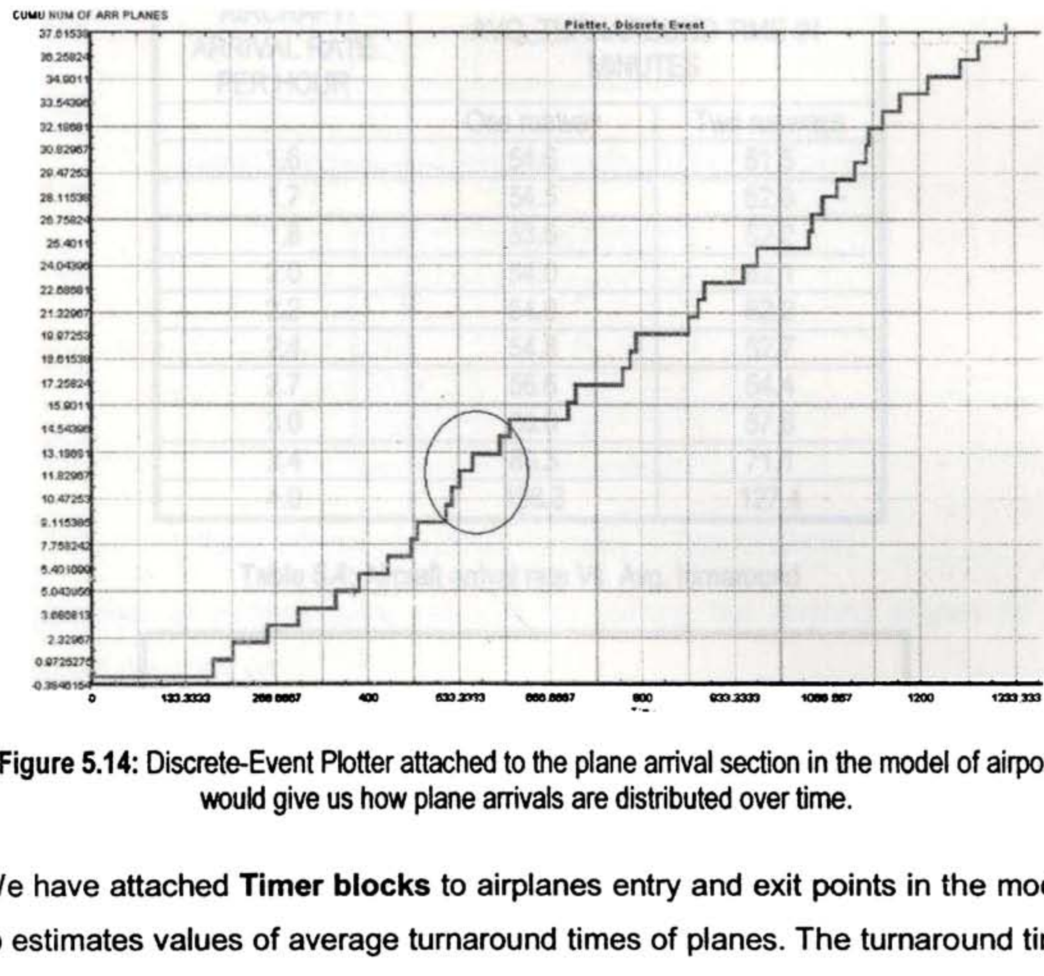

Figure 5.14: Discrete-Event Plotter attached to the plane arrival section in the model of airport would give us how plane arrivals are distributed over time.

We have attached **Timer blocks** to airplanes entry and exit points in the model to estimates values of average turnaround times of planes. The turnaround time is the time taken for a flight from its arrival to take-off. The turnaround time includes time for landing, ground handling, passenger disembarkation, boarding and any delay due to facility constraints. When time and resources for landing, ground handling, passenger boarding etc are kept same for each experiment, the changes in value of turnaround time is indicative of delays due to capacity limitations. Table 5.4 shows the results obtained from experimenting with the model with a single runway facility, by sensitizing the values of aircraft arrival rate per hour. The experiment is repeated on the model with an augmented runway, other conditions remaining the same. Figure 5.15 indicate that the airport with a single runway could not handle an aircraft arrival rate above 3 per hour on average-if turnaround time at runway is to be kept below 60 minutes. When this facility configuration is changed to two runways(without changing other facilities like parking bays), the improvement is marginal.

AIRCRAFT ARRIVAL RATE PER HOUR	AVG. TURNAROUND TIME IN MINUTES	
	One runway	Two runways
1.6	54.6	51.5
1.7	54.5	52.3
1.8	53.5	52.2
2.0	54.0	52.1
2.2	54.0	52.2
2.4	54.8	52.7
2.7	56.6	54.4
3.0	60.0	57.6
3.4	86.3	71.1
4.0	198.3	127.4

Table 5.4: Aircraft arrival rate Vs. Avg. turnaround

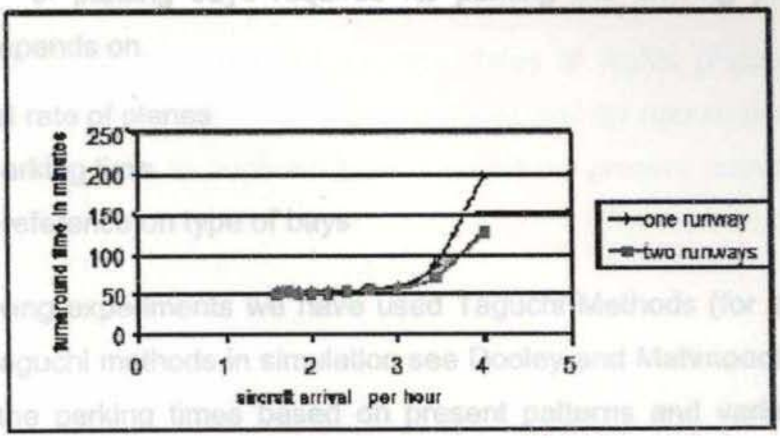

Figure 5.15: Plot of Aircraft arrival rate Vs. Avg. Turnaround time

5.7.1.2. Case 2: Number of parking bays

At present the airport uses 10 parking bays. Out of these 10 parking bays 2 are reserved for big planes like A-330, B-777. Major types airplanes and present weekly schedules are given in Tables 5.5 and 5.6. When these slots are free, more international planes are also accommodated in these bays due to the availability of aero bridges (we call it Type 2 bays and other bays Type 1 bays).

TYPE	SCHEDULES
A-300	32
A-319	11
B-737	28
B-777	10

Table 5.5: International Sorted According To Type Of Aircraft

TYPE	SCHEDULES
A-320	47
ATR	42
B-737	35
D-228	6

Table 5.6: Domestic Sorted According To Type Of Aircraft

The number of parking bays required for parking the arriving planes till its departure depends on

a) arrival rate of planes

b) the parking time

c) the preference on type of bays

In the following experiments we have used Taguchi Methods (for a discussion on use of Taguchi methods in simulation see Dooley and Mahmoodi, 1992). We have kept the parking times based on present patterns and varied the other factors for different levels of bays. We have used Taguchi L12 orthogonal arrays for the following experiments (See Table 5.7 for factors and responses).

FACTORS AND LEVELS				
Number of type 1 bays	Number of other bays	Arrival rate	Proportion of type 1	
			int	dom
2, 3	8, 10	3, 4.5	.75, 0.90	0.25, 0.40
RESPONSES				
1) Avg wait for bays 2) Avg delay time of flights				

Taguchi Orthogonal Array Design: L12(2**5) Factors: 5, Runs: 12

Table 5.7: Factors and responses in Taguchi L12 experiment.

Plots for mean and s/n ratio for max wait time at bay 1(Figures 5.16a-b) indicate that maximum wait time for type 1 bays is influenced largely by the number of type 1 bays available and the arrival rates of flights and that the little variation in the proportion of requirements of these bays will not produce a large effect on wait times.

Plots for mean and s/n ratio's of average delay of flights (Figures 5.17a-b) indicate that in order to meet the increasing demand for accommodating more flights, there is a need to augment type 1 bays from present number of two to three.

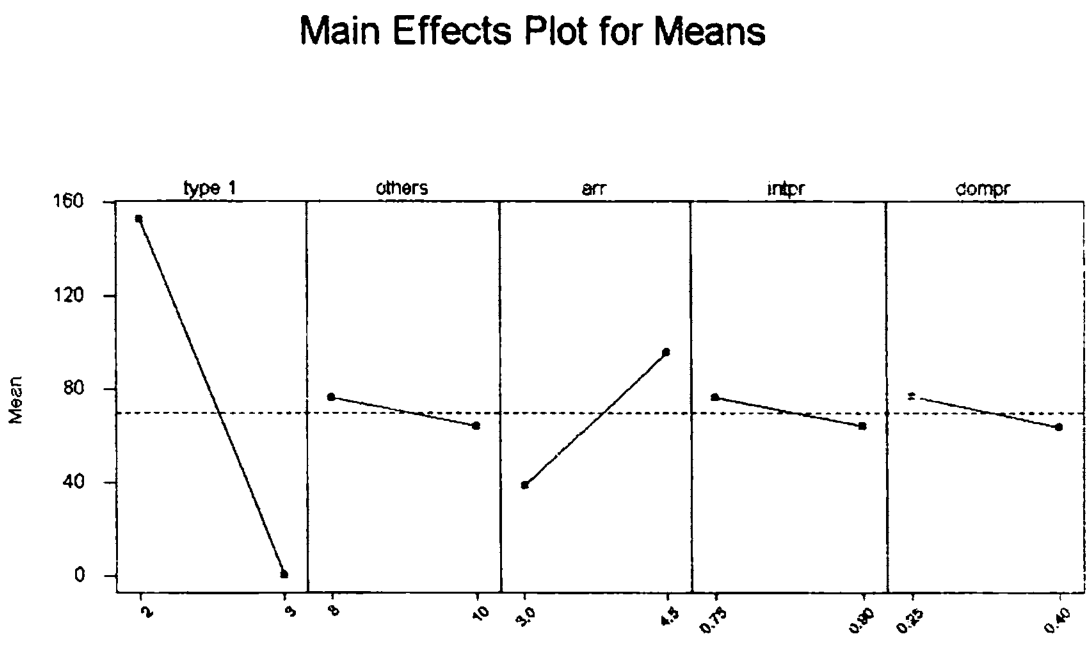

Figure 5.16 a

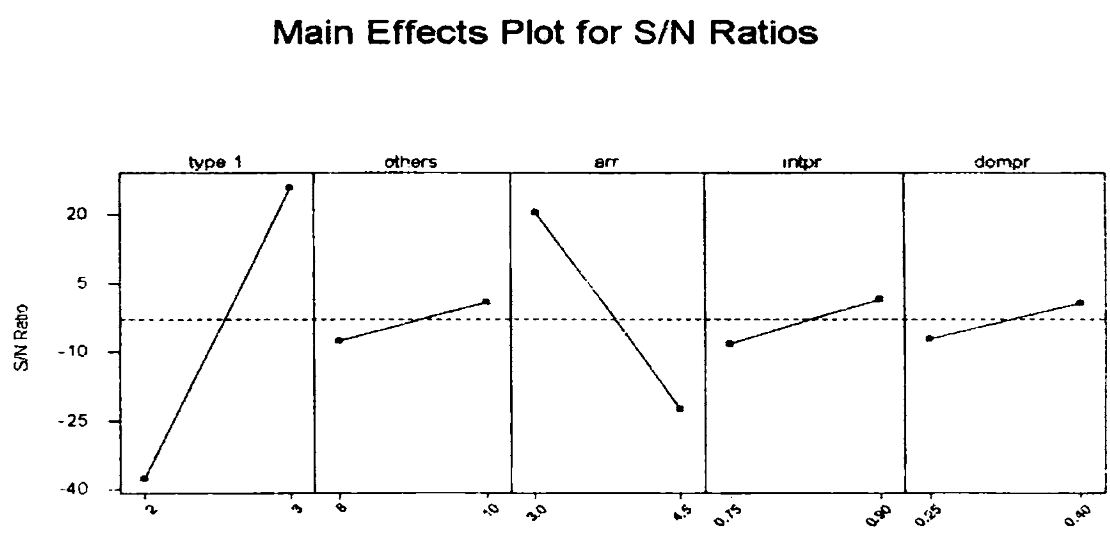

Figure 5.16 b

Figure 5.16 a-b: Effect Plot for Mean and S/N Ratio's Of Average Wait time For Bays

Main Effects Plot for Means

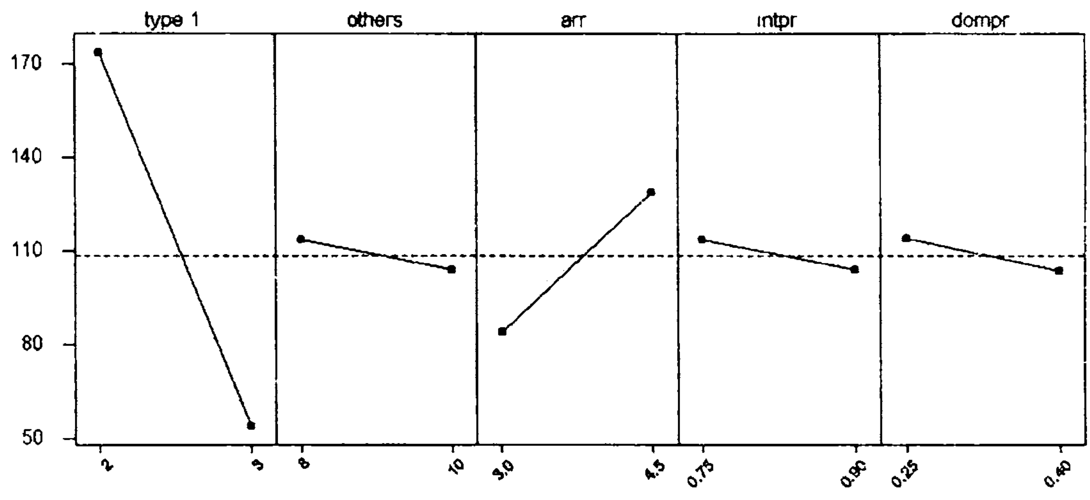

Figure 5.17 a

Main Effects Plot for S/N Ratios

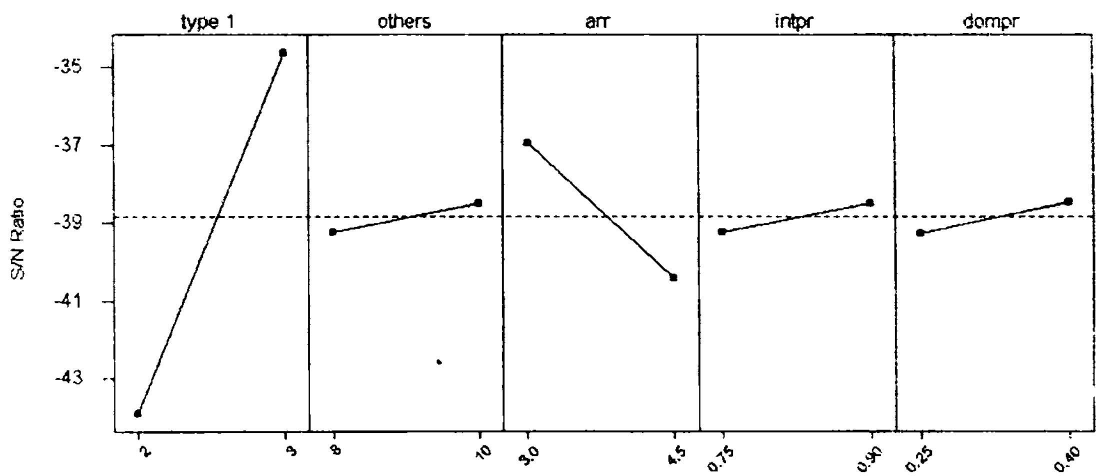

Figure 5.17b

Figure 5.17a-b: Effect Plot for Mean and S/N Ratio's Of Average Delay of Flights

5.7.2. Tactical level

5.7.2.1. Case 1: Number of X-ray machines

X-ray machines are located inside the terminal near the entry point of passengers. This is a critical resource, and if sufficient number of x-ray machines is not available, it could lead to

1) Undesired large queues in the area.

2) Passengers delayed for subsequent processes

3) Delayed flights

4) Reduced level of service

The number of x-ray machines required depends on

1) The time required for processing each baggage

2) Peak hour arrival rate

3) Number of baggage each passenger brings

4) Space available for waiting for this service

5) Level of service

The X-ray machines at CIAL, could handle about 250 bags per hour. However this time is dependant on the type of baggage. Some baggage are easily inspected. If objectionable material is found in a bag, the inspection could take a longer time. We have used triangular distribution based on data collected from actual operations, in our models with given minimum, maximum and most likely times for x-ray machines per baggage.

The number of bags a passenger brings varies from person to person. A proportion of passengers do not bring any bag at all except their hand bags which are not usually inspected at the main X-ray machines. The proportion of passengers with no bags, one bag, two bags, three bags etc were obtained from past data. A typical proportion is shown in Table 5.8.

NUMBER OF BAGGAGE	% OF CHANCE
0	10
1	20
2	40
3	30
4	5

Table 5.8: Number of Baggage per Person

The number of passenger handled within a stipulated time is important in deciding the X-ray machines because passengers usually report 3 hours before their flight, and there should be sufficient number of machines to handle this load so that all passengers finish x-ray baggage checks within one hour.

A Deterministic method to find the number of X-ray machines:

Here we present a deterministic method to estimate the number of X-ray machines and show our modelling can supplement useful information in this. The method is similar to Leone and Liu (2005), but for the determination of ADPM discussed below we show that simulation model we have developed is useful.

The x-ray capacity should be based on peak hour load. The planning day should be the average day of the peak month (ADPM), which represents the most common method of converting planning statistics to a daily and ultimately to an hourly demand baseline (US Department of Transportation, 1988). The determination of ADPM requires the identification of the peak month for the facility under consideration. Most common peak months are July and August. The next step is to identify an average day demand profile for the peak month. This is typically calculated by dividing the peak month demand by the number of days in the peak month. Additionally, the peak hour in a planning day can be calculated based on the actual flight schedule for the ADPM. Typically, large airports have peak hour volume of 10-20% of the daily volume.

The following groups of variables apply in the formula:

Demand parameters: **P** is the planning hour passenger volume (people per hour), **T** is the percentage of passengers that do not have checked baggage, **K** is the percentage of passengers to represent selectees, whose bags require more intense screening. **r** is the demand scale factor (DSF) between 1 and 1.4 to account for variability of arrival rate through the planning hour, **B** is the number of checked bags per passenger, and **L** is the effective demand on the CBS(checked baggage screening)system.

CBS parameters: **S** is the service rate of the machines (bags per hour) and **F** is the CBS utilization factor-typically lying between 0.80 and 0.95. This multiplier represents the utilization factor for both the equipment and the screening staff. It is essential in the design that the equipment and staff is not designed to operate on full capacity. This factor accounts for equipment breakdowns, staffing fluctuations, and other disruptions in the screening process.

The effective hourly load on the CBS system is a function of the peak hour volume, the percentage of passengers with no checked baggage, the percentage of selectee passengers, the number of checked baggage per passenger, as well as, the DSF.

$$N_{EDS} = \frac{P(1-T)(1+K)r \times B}{S \times f}, \quad (5.3)$$

A method to find peak hour load in a particular day

The graphical capabilities available in the model can be utilized to determine peak load in any given day. Following example illustrates this.

The passenger presentation profiles depend both on the flight type and on how and when the passenger has reached the Terminal. These average profiles have to be collected directly by airport that has observed passenger behaviour for over a year. The model generates the curve of passenger arrivals (see Figure 5.18). This curve is obtained from the discrete-event plotter attached to a

count block at the entry side for passengers' *generator*. Peak rakes can be obtained by magnifying the steep ascending areas in the plot. See Figures 5.19 and 5.20 for details. The peak arrival rate at x-ray machines = (1035-890)/(360-335)= 5.8 passengers per minute, or 348 passengers per hour for the above plots.

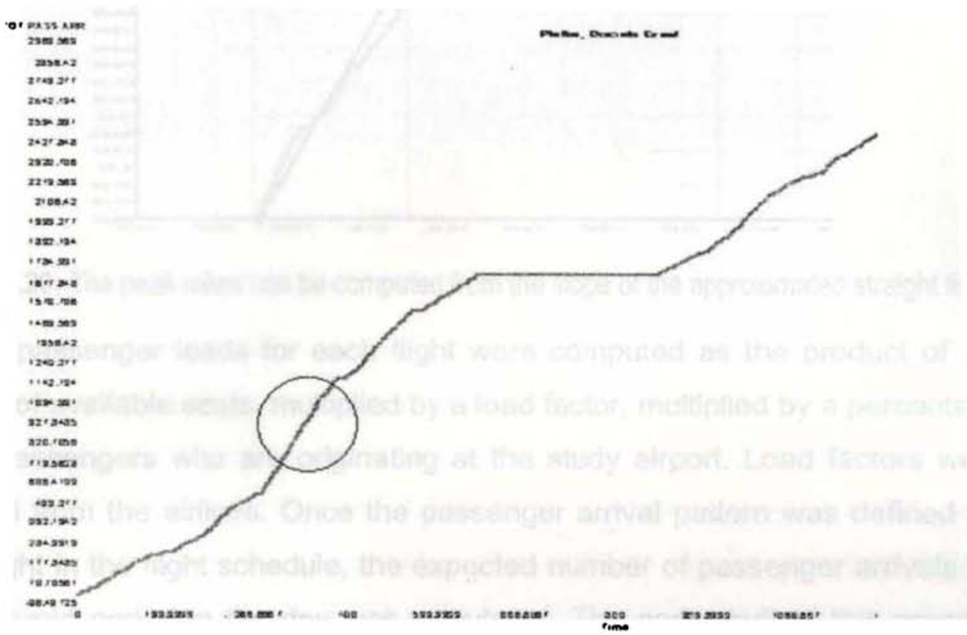

Figure 5.18: The model generates the curve of passenger arrivals. Circles portion shows region of peak arrival rate

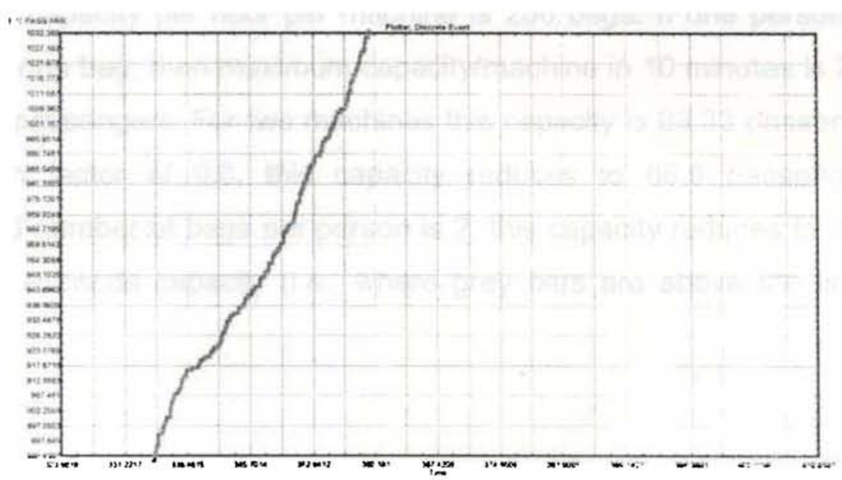

Figure 5.19: The circled portion in above plot can be magnified by a magnifier tool available in the DE Plotter

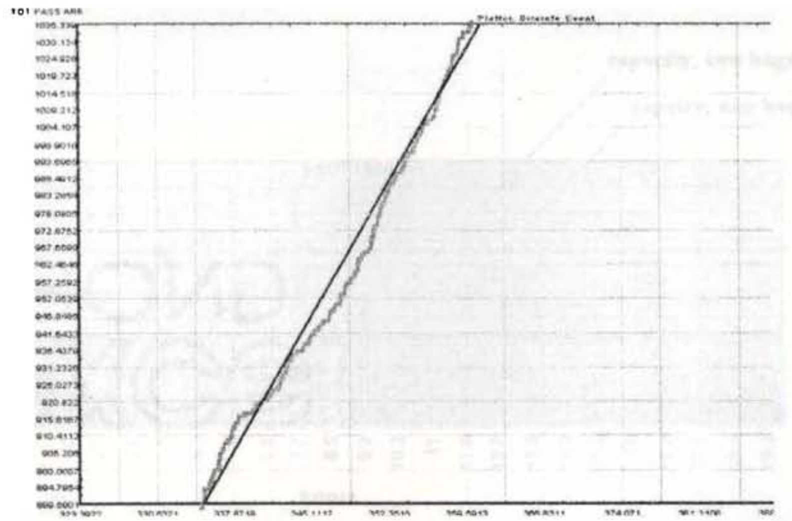

Figure 5.20: The peak rakes can be computed from the slope of the approximated straight line

Initially, passenger loads for each flight were computed as the product of the number of available seats, multiplied by a load factor, multiplied by a percentage of the passengers who are originating at the study airport. Load factors were obtained from the airlines. Once the passenger arrival pattern was defined for each flight in the flight schedule, the expected number of passenger arrivals for each 10-min period in the day was calculated. The end result of this process was an expected number of passenger arrivals for each 10-min interval, as shown in Figure 5.21. In the chart, the horizontal line represents capacity (For example capacity per hour per machine is 250 bags. If one person carries on average one bag, then maximum capacity/machine in 10 minutes is 250 x 10/60 = 41.66 passengers. For two machines this capacity is 83.33 passengers. For a utilization factor of 0.8, this capacity reduces to 66.6 passengers. When expected number of bags per person is 2, this capacity reduces to 33.3). When demand exceeds capacity (i.e., where grey bars are above the line). queues develop.

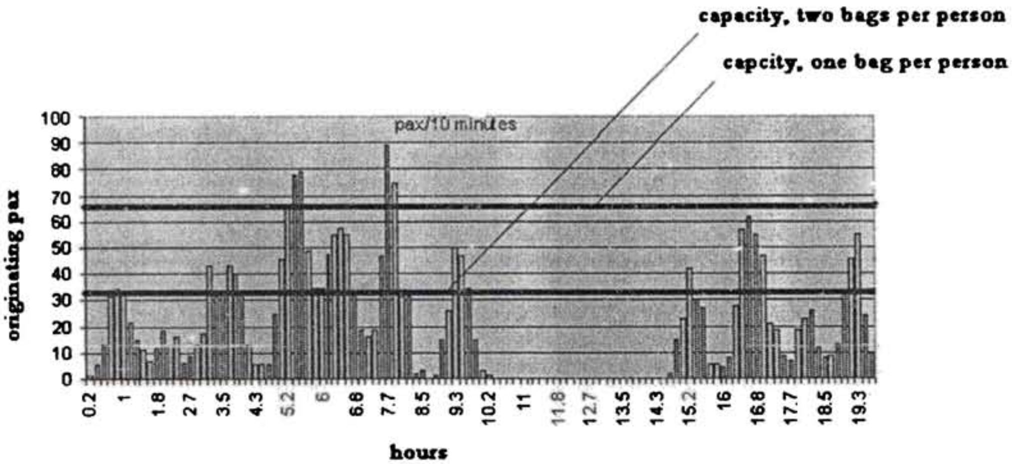

Figure 5.21: Chart showing capacity at various levels of baggage

The queue length depends on a number of factors such as the number of bags per person, uptime's of x-ray equipment, number of equipment, arrival profile of passengers etc. Using the models we have developed, one could catch the variability of these characteristics. The number of bags a passenger carries is given as an attribute of the passenger. This attribute can be assigned with a probability (as shown in figure 5.22). The time required for inspection per bag is given as a probability distribution. The load at the x-ray machine varies depending whether it is busy or slack time. A discrete-event plotter attached to the *resource pool queue* for x-ray machine could reveal the nature of load on the x-ray machine. Figure 5.23 for shows a plot for Average queue length (Average number in the queue. This is a time-weighted average) and Figure 5.24 shows a plot of average waiting times at X-Ray machines (Ave. wait: Average time a passenger waits for the facility).

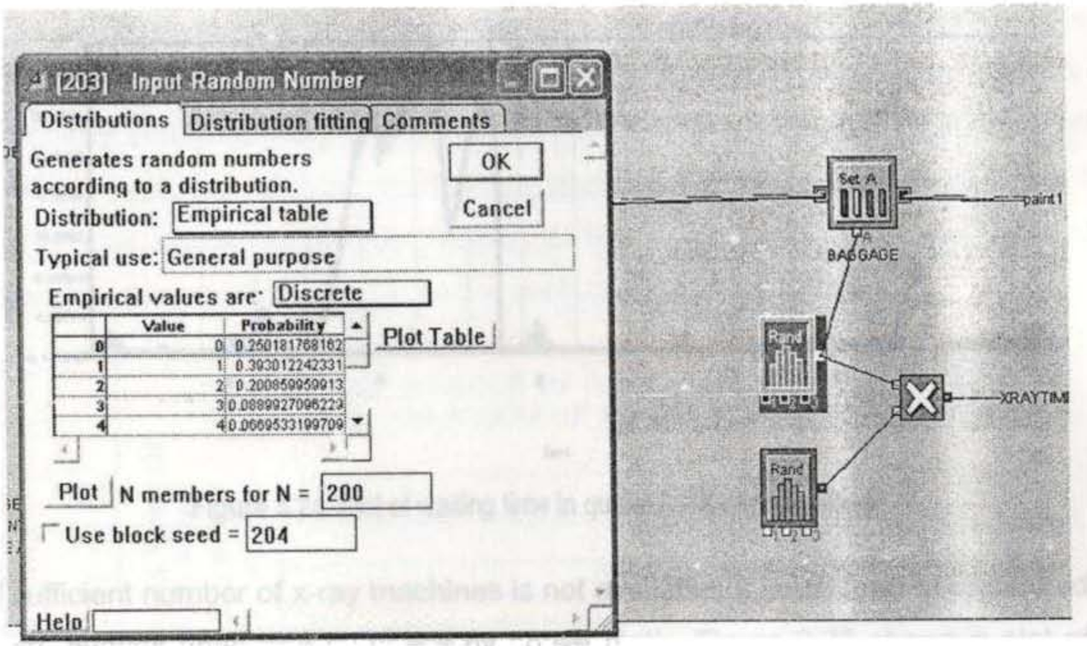

Figure 5.22: Assigning a baggage attributes and distribution

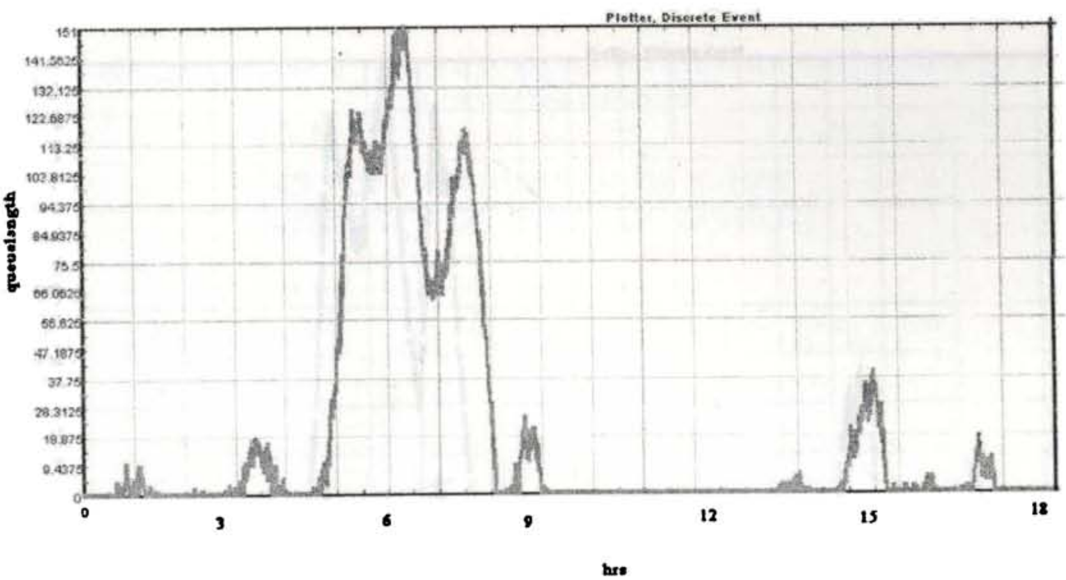

Figure 5.23: Plot of queue length for X-ray machines

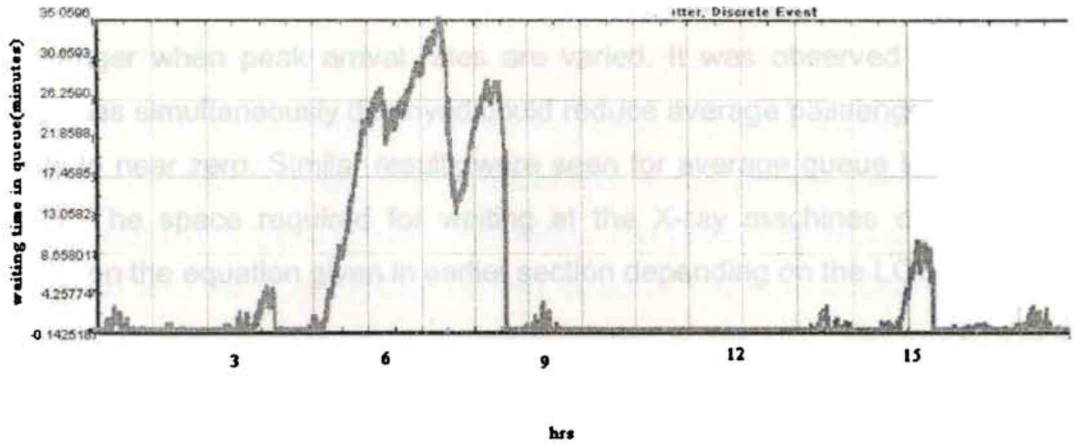

Figure 5.24: Plot of waiting time in queue for X-ray machines

If sufficient number of x-ray machines is not available, it could lead to undesired large queues (indicated by peaks by above plot). Figure 2.25 shows a plot of queue length for the cases of two and three X-ray machines. We observe a considerable reduction in queue length.

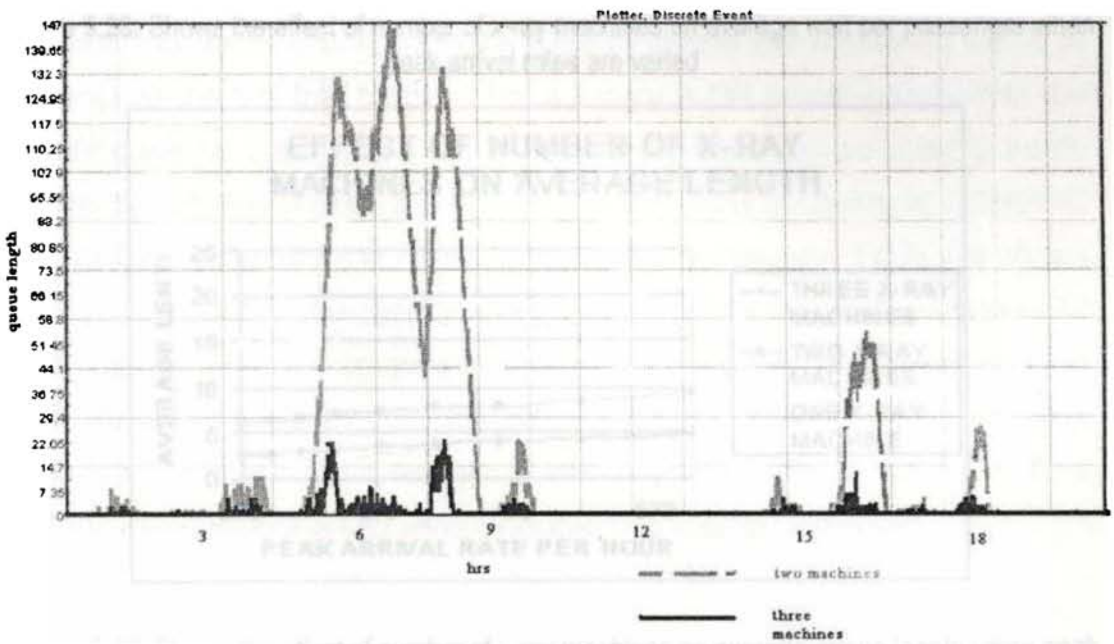

Figure 5.25: Shows a plot of queue length for the cases of two and three X-ray machines.

Figure 5.26 shows the effect of number of x-ray machines on average wait per passenger when peak arrival rates are varied. It was observed that three x-machines simultaneously deployed could reduce average passenger times at all loads to near zero. Similar results were seen for average queue length (Figure 5.27). The space required for waiting at the X-ray machines could decided based on the equation given in earlier section depending on the LOS.

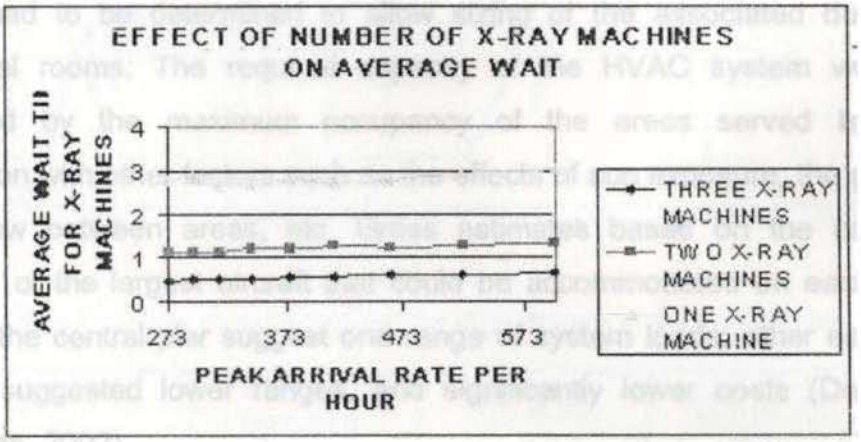

Figure 5.26: Shows the effect of number of x-ray machines on average wait per passenger when peak arrival rates are varied

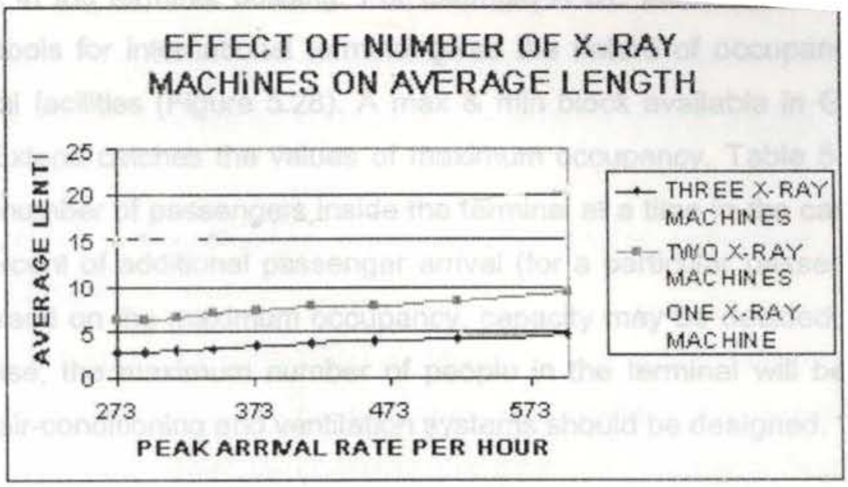

Figure 2.27: Shows the effect of number of x-ray machines on average queue length when peak arrival rates are varied

5.7.2.2. Case 2: Estimation of Maximum Occupancy of an Area to Determine Heating/Ventilation System Requirements

For design of the new terminals, or for augmenting present terminal with more facilities, practical issues like requirement Heating, Ventilation and Air Conditioning (HVAC) is of great significance. The specifications for the Heating, Ventilation and Air Conditioning system to serve the central pier of the new building had to be determined to allow sizing of the associated ducts and mechanical rooms. The required capacity of the HVAC system would be determined by the maximum occupancy of the areas served by it, in combination with other factors such as the effects of sun exposure, the potential for air flow between areas, etc. Gross estimates based on the combined capacities of the largest aircraft that could be accommodated on each of the gates on the central pier suggest one range of system loads; other estimation methods suggested lower ranges, and significantly lower costs (Doshi and Moriyamma, 2002)

Simulation models of airport could be used to assess the maximum levels of occupancy in the terminal building. For example A DE plotter attached to the resource pools for international terminal gives the nature of occupancy inside the terminal facilities (Figure 5.28). A max & min block available in GENERIC library of Extend catches the values of maximum occupancy. Table 5.9 shows maximum number of passengers inside the terminal at a time in the cases of 10 and 20 percent of additional passenger arrival (for a particular passenger load profile). Based on the maximum occupancy, capacity may be decided. For the present case, the maximum number of people in the terminal will be 748 fro which the air-conditioning and ventilation systems should be designed.

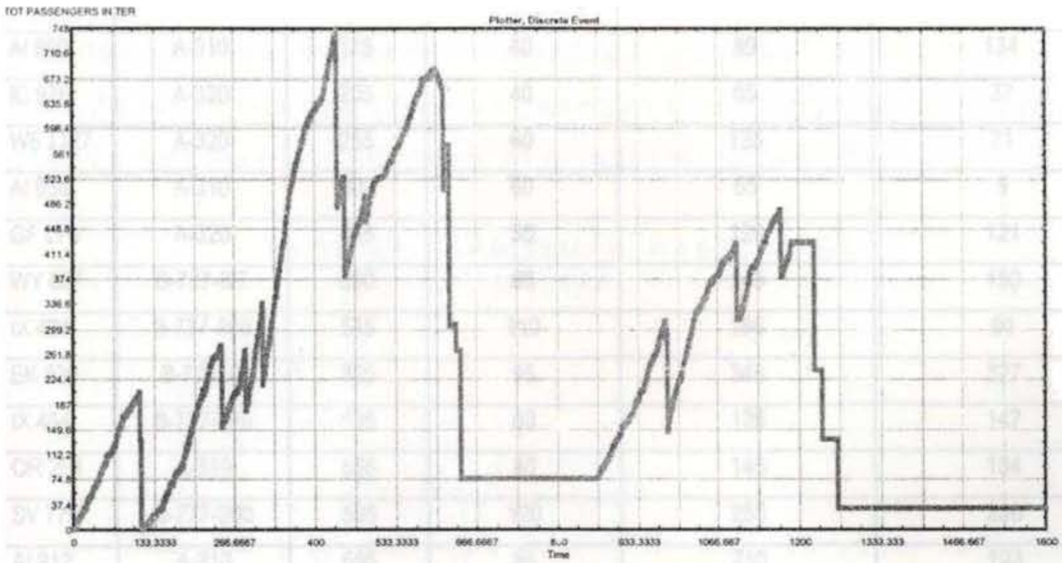

Figure 5.28: A DE plotter gives the total number of passengers at a time inside the terminal.

	PRESENT NUMBER	10% MORE	20% MORE
Total daily Passengers	2468	2714	2961
Max number in the terminal at a time	748	865	958

Table 5.9: Maximum number of passengers inside the terminal at a time

5.7.3. Operational

5.7.3.1. Case 1. Rearranging schedules/Passenger reporting times to adjust peak load

The simulation model for operational problems can be used to effectively utilize available resources on a day to day basis. For example the queue at x-ray machine could be levelled by changing the timing of passenger load. This is illustrated below. Assume the international departing passenger load of a day is known and as given in Table 5.10. Passengers usually report 3 hrs before international flights.

FGT	PLANE TYPE	ARR TIME	GROUND TIME	ARR PASS NUMBER	DEP PASS NUMBER
AI 690	A-310	175	40	89	134
IC 976	A-320	205	40	65	37
W5 1127	A-320	255	60	135	71
AI 956	A-310	300	60	65	9
GF 270	A-320	355	55	126	121
WY 827	B-737-8/7	390	60	143	150
IX 434	B-737-800	515	110	166	91
EK 530	B-772LD	525	95	346	327
IX 454	B-737-800	535	80	128	147
QR 264	A-319	555	80	145	134
SV 775	B-777-200	595	120	255	268
AI 912	A-310	695	85	210	193
IX378	B738	1045	50	126	150
G9 425	A-320	1125	45	173	162
UL 167	A-320	1130	105	77	28
IC 595	A-300	1150	55	51	114
IC 973	A-320	1215	50	74	103
IX 447	B-737-800	1285	80	61	192

Table 5.10: International departing passenger load of a day

Figure 5.29 shows the plot of International passenger arrivals, all arriving 3 hrs before departure of corresponding planes. Figure 5.30 shows the corresponding cumulative plot. Figure 5.31 shows the DE plot of the same obtained from the model. Note the extreme rush of passenger arrival during the time period 175 minutes to 415 minutes. During this time a total of 1117 passengers arrive. Due to this early morning rush should handle about 280 passengers per hour.

By running the model the queue length at x-ray machine is shown in Figure 5.32. We could see a heavy queue formation (above 300 passengers maximum queue length for both x-ray machines together and avg. wait time 20.59 minutes, avg. number 31.76). Obviously such long queues are not desired. If passenger load could be re-arranged, this queue could be drastically reduced (low utilization period of x-ray machines may be used for this). Figure 5.33

shows the queue length after rearranging passenger arrival for at 175,210 and 335 minutes. These passenger may be told to arrive half an hour or so earlier then the result is a much reduced maximum queue length and average wait time(i.e. less than 100 passengers as depicted in Figure 5.33)

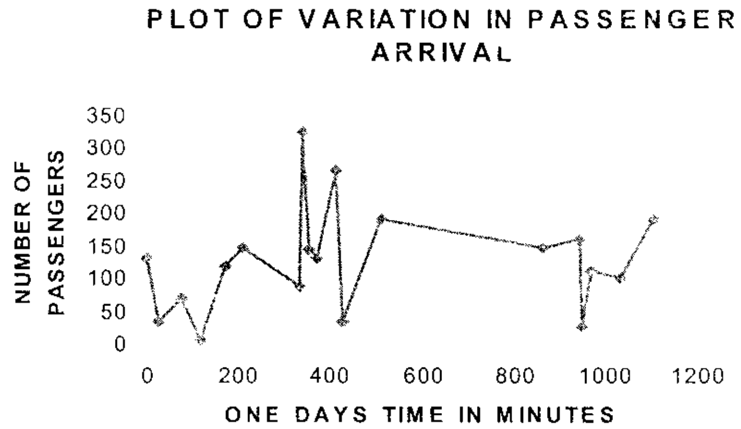

Figure 5.29: Plot of international passenger arrivals, all arriving 3 hrs before departure of corresponding planes

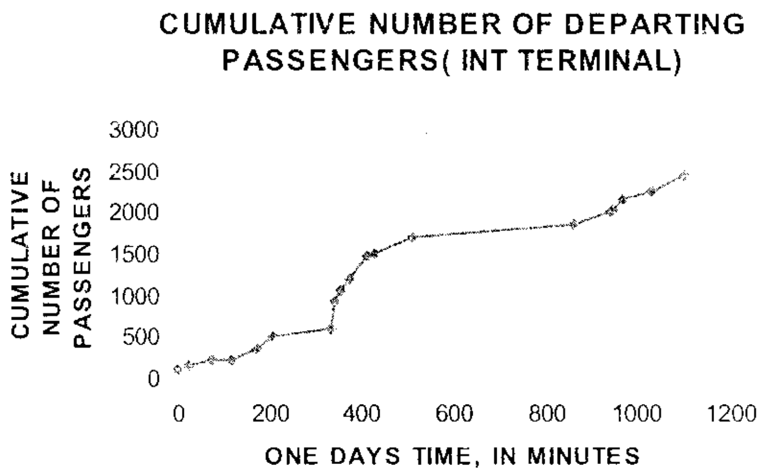

Figure 5.30: Plot of cumulative international passenger arrivals, all arriving 3 hrs before departure of corresponding planes

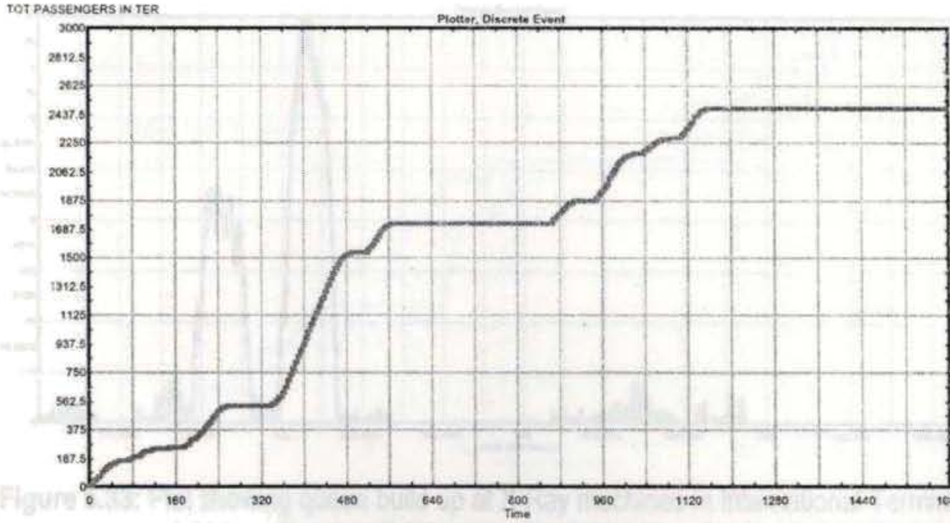

Figure 5.31: Plot obtained from the model by allowing international passengers arrive one by one before 3 hrs (up to one hour before departure of plane)

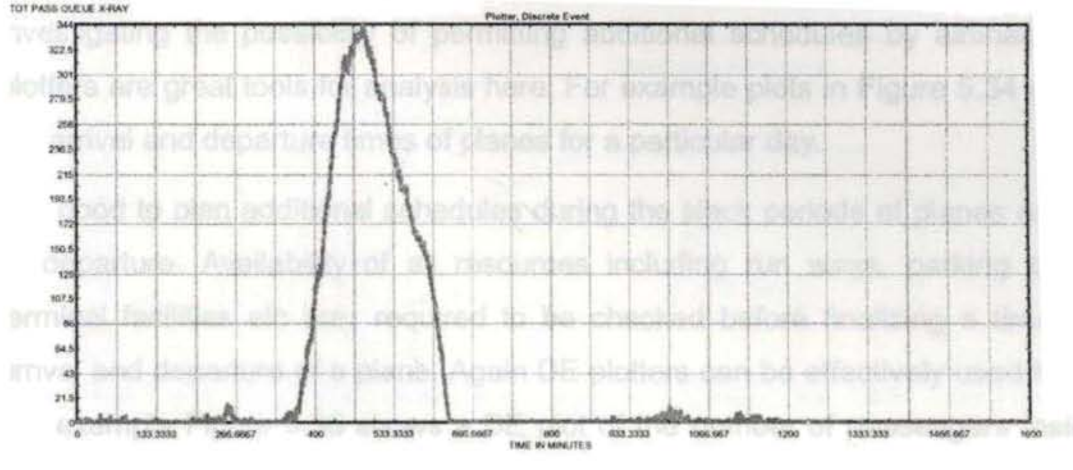

Figure 5.32: Pot showing queue build at Xray machines in international terminal when passengers arrive one by one before 3 hours of flight departure

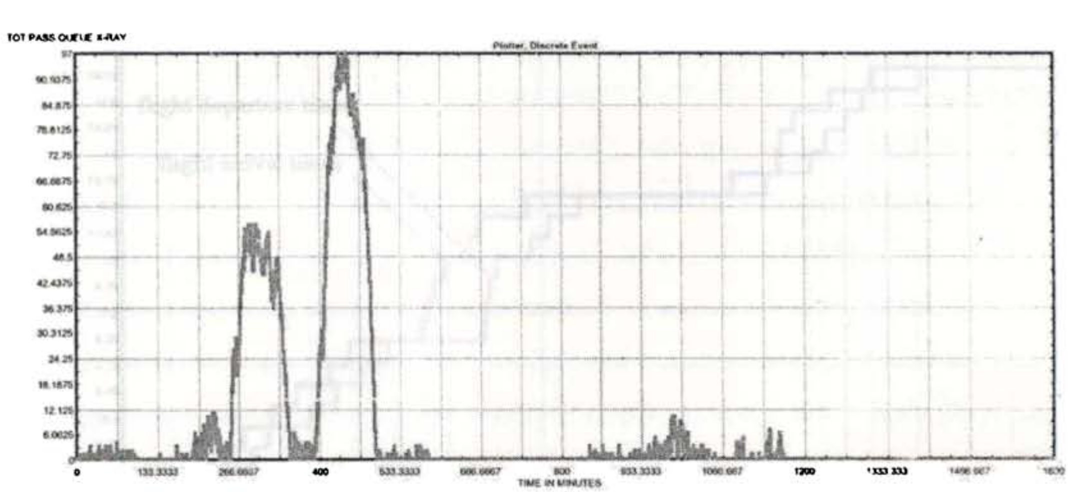

Figure 5.33: Plot showing queue build up at X-Ray machines in International Terminal when passengers are told to arrive at a slightly rearranged times keeping the flight schedules same.

5.7.3.2.Case 2. Investigating possibility of additional schedules

The simulation model for operational problems offers good graphical tools for investigating the possibility of permitting additional schedules by airlines. DE plotters are great tools for analysis here. For example plots in Figure 5.34 show the arrival and departure times of planes for a particular day.

It is good to plan additional schedules during the slack periods of planes arrival or departure. Availability of all resources including run ways, parking bays, terminal facilities etc are required to be checked before finalizing a time for arrival and departure of a plane. Again DE plotters can be effectively used here. For example Figure 3.35 shows a DE plot of the number of passengers inside the terminal (excluding that of security lounge) waiting for some service or engaged in some service. The service may be x-ray checking, emigration checking, customs, duty paid shopping etc. Whenever possible, additional schedules may be planned during the slack times of such activities.

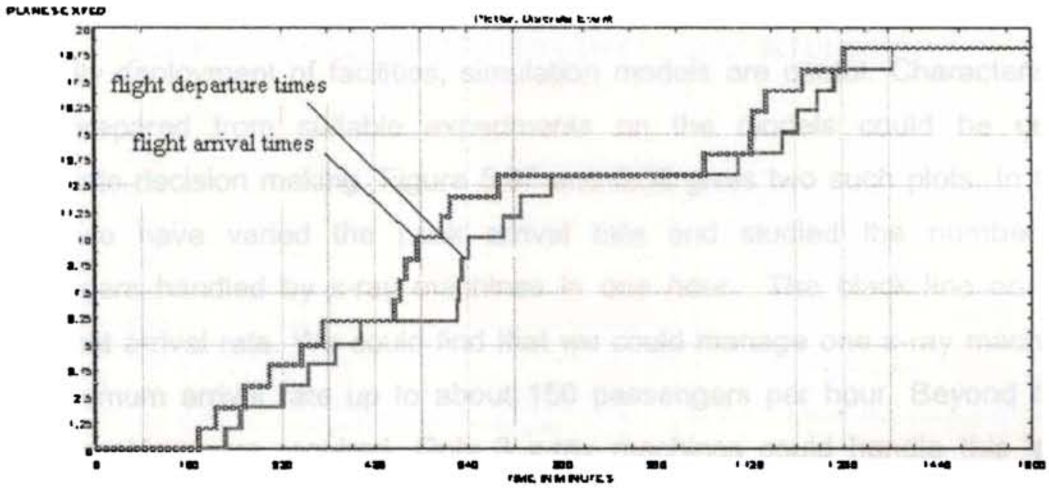

Figure 5.34: Plot of arrival and departure of international planes for a particular day.

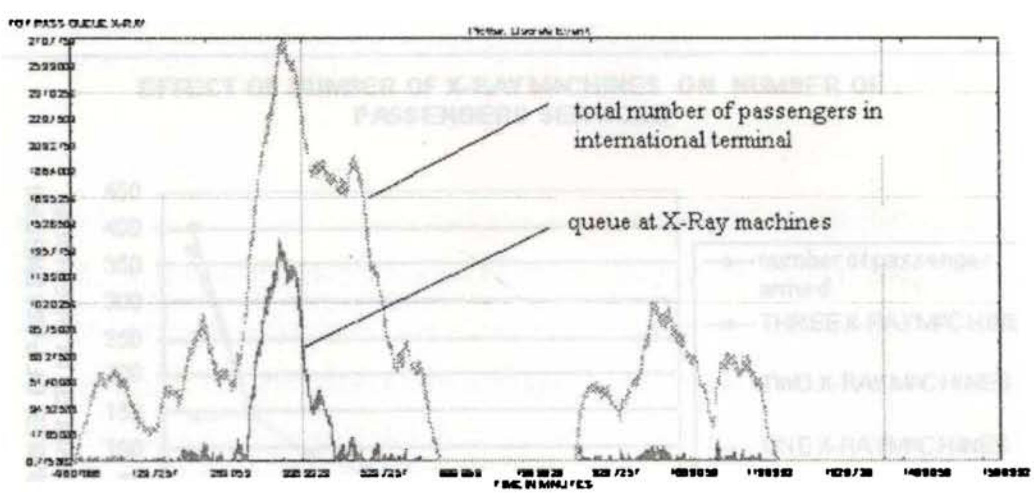

Figure 5.35: Plot showing the total number of passengers in international terminal excluding the security lounge, and queue at X-Ray machines

5.7.3.3. Case 3. Deployment of facilities

For daily deployment of facilities, simulation models are useful. Characteristic plots prepared from suitable experiments on the models could be used immediate decision making. Figure 5.37 and 5.38 gives two such plots. In first case, we have varied the peak arrival rate and studied the number of passengers handled by x-ray machines in *one hour.* The black line on top represent arrival rate. We could find that we could manage one x-ray machine for maximum arrival rate up to about 150 passengers per hour. Beyond that more machines are required. Only 3 x-ray machines could handle this load without much waiting. In second case passengers handled is plotted, keeping arrival rate of passengers the same and varying number of bags per passenger. It shows that more number of x-ray machines is to be deployed depending on the flights in which passengers are expected to carry more bags with them.

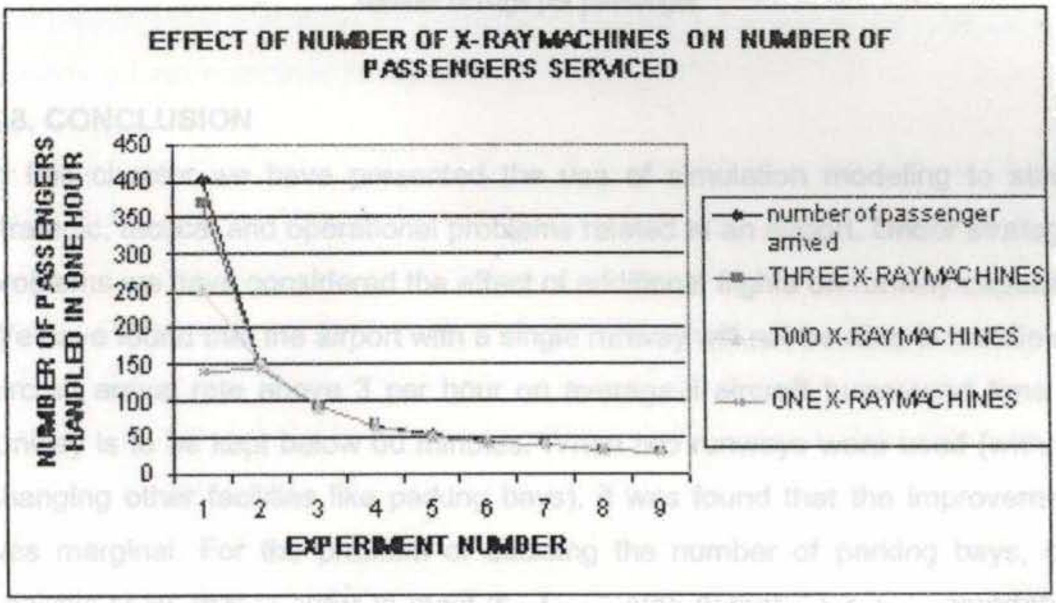

Figure 5.36: Effect of number of X-ray machines on number of passengers serviced in one hour

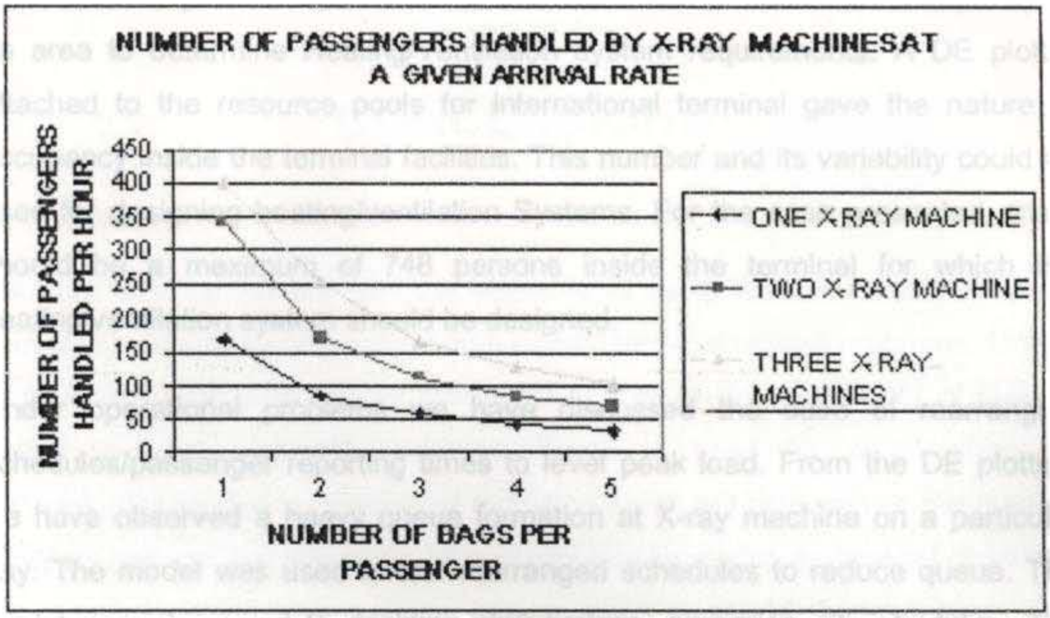

Figure 5.37: Number of passengers handled by x-ray machines in one hour depends on the number of bags per passenger.

5.8. CONCLUSION

In this chapter we have presented the use of simulation modeling to study strategic, tactical and operational problems related to an airport. Under strategic problems we have considered the effect of additional flights on runway capacity. We have found that the airport with a single runway will not be able to handle an aircraft arrival rate above 3 per hour on average-if aircraft turnaround time at runway is to be kept below 60 minutes. When two runways were used (without changing other facilities like parking bays), it was found that the improvement was marginal. For the problem of deciding the number of parking bays, our analysis show that in order to meet the forecasted demand for accommodating more flights, there is a need to augment type 1 bays from present number of two to three.

Determination of number of X-ray machines required is one of the tactical problem discussed. The analysis shows that three x-machines simultaneously deployed could reduce average passenger wait times at given loads to near zero. Another problem considered is the estimation of maximum occupancy of an area to determine Heating/Ventilation system requirements. A DE plotter attached to the resource pools for international terminal gave the nature of occupancy inside the terminal facilities. This number and its variability could be used for designing heating/ventilation Systems. For the case presented, there should be a maximum of 748 persons inside the terminal for which the heating/ventilation system should be designed.

Under operational problems we have discussed the case of rearranging schedules/passenger reporting times to level peak load. From the DE plotters we have observed a heavy queue formation at X-ray machine on a particular day. The model was used to test rearranged schedules to reduce queue. The model was also used to deciding shift timings, preparing pit schedules. The simulation model for operational problems offers good graphical tools for investigating the possibility of permitting additional schedules by airlines and assigning x-ray machines to flight.

In some case (Problems in **5.7.1.1 & 5.7.2.1)** simulation is used for supporting analytical methods. Use of Taguchi's design of experiment is illustrated in **5.7.1.2.** For long term and medium term decision problems **(5.7.1.1 & 5.7.1.2)** models developed are less tight on schedules. From the problems (**5.7.1.1, 5.7.1.2**) it is evident that bottlenecks in some of the facilities (for example less number of Type 1 bays) lead to under-utilization of major facilities like runway. In order to fully utilize strategic *fixed* facilities like the bottlenecks in other facilities like *machines and equipments* must also be removed. Further this work illustrates the use of DE plots in a number of situations ((**5.7.1.1, 5.7.2.1, 5.7.3.1, 5.7.3.2).**

CHAPTER SIX

CONCLUSIONS

6.1. SUMMARY

This work was carried cut with the objective of using discrete event computer simulation modeling to help solve some logistic terminal related problems. One of the problems related to use of simulation is that of the multiplicity of models needed to study different problems. There is need for development of methodologies related to conceptual modeling which will help reduce the number of models needed. For this some form of problem clustering and model clustering were members from problem cluster use models from model cluster is a possible approach. We have followed this approach in this thesis.

Conceptual modeling for simulation is in its early stages of development. Literature on classification of problems related to logistics revealed that the classification of problems into strategic, tactical and operational problems was often used. We decided to use this classification for our problems. Three different logistic terminal systems Viz. a railway yard, container terminal of apart and airport terminal were selected as cases for this study. The standard methodology for simulation development consisting of system study and data collection, conceptual model design. detailed model design and development, model verification and validation, experimentation, and analysis of results, reporting of finding were carried out.

Simulation models were successfully used to help solve strategic, tactical and operational problems related to three important logistic terminals as set in our objectives. Conceptual modeling and simplification were used to reduce the number of models needed to solve the problems studied.

Before developing simulation models, the ways of clustering problems and systems modelled was considered. In this case after considering different ways of catagorising problems we found that clubbing problems on the basis of whether they are operational, tactical or strategic would be a good method. This was done because in the case of transport terminals we found that models could be classified into tightly pre-scheduled, moderately pre-scheduled and unscheduled systems. This gave us a match between tightly prescheduled models and their use for solving operational type problems. Moderately prescheduled models found their match with Tactical type problems, and there was a match between unscheduled models and strategic problems. This pairing of model type and problem type made it easier to develop models that were used to solve similar type problems. This approach has been used by us to solve problems related to transport terminals such as Railway yard, Airport and Container terminal of a port. Three types simulation models(called TYPE 1, TYPE 2 and TYPE 3) of various terminal operations were created in the simulation package Extend. All models were of the type discrete-event simulation.

In the third chapter we have presented the development of simulation models of the operations of a container terminal in a South Indian Port and demonstrated its use for decision support for system design and fixing operational policies. The model computes ship turnaround time and determines resource utilization at a high level of detail; this will help planners view the performance of the system much before implementation. The model allows planners to see operational constraints and bottlenecks through statistical reports, graphs and charts.

Under strategic problems, effect of adding a berth and QC was studied. Providing an additional berth with an additional quay crane could take all the load (nearly hundred percent) and handle all ships when ship arrival rate is less than or equal to one ship per day. The second strategic problem studied was to determine the area of storage for containers at import side required for smooth operations. It was found there should be enough space for at least 250 containers at the import side.

Determination of the necessary number of transport vehicles to transport containers in time was the first tactical problem studied. It was found that under most favorable conditions of operational times and equipment availability we require about 3 trucks each for import and export so that the turnaround times were kept low. The next tactical problem considered was to determine the queue space for inbound trucks. It was seen that when queue size capacity was about 15 numbers, performance was near peak and above this there was no appreciable gain in productivity, with addition of trucks.

For the operational problem of finding everyday crane deployment plans, the simulation model showed the ship turnaround time under various crane deployment options allowing the manager to select the most appropriate for the day. For the case studied, deploying two TC's and getting a ship turnaround time time of 1.08 days was recommended.

The work related to a railway yard is presented in the fourth chapter. For this study the Ernakulam marshalling yard was selected. The simulation model was used to find the level of utilization of major facilities. It was found that pit and waiting lines were facilities with high utilization and tended to be bottleneck facilities. A comparison of two train time tables to ascertain its impact on yard performance using the simulation model show that the current time table was slightly better than an equi-spaced time table tried out. In order to study the effect of different operating strategies scheduling at pit according to EDD and FIFO rules were tried out and it was found that EDD rule gives 3 number of trains late and average lateness of 15.6 minutes while the FIFO rule gives 3 number of late trains and 24.9 minutes of average lateness which is higher. Hence it recommended that EDD rule be used for pit scheduling. Similarly other rules can be checked using the model.

Rakes with different coaches are put into service. Normally these coaches require only water servicing and minor electrical, mechanical and AC maintenance. These can be done without detaching the coach from the rake. However at times when major work is required the coach has to be detached from the rake and send to the coach care center. In such cases the coaches so detached have to be replaced by spare coaches from the stock of extra coaches with marshalling yard. The simulation model was used to find how many such extra coaches are required in the yard. It was found from our experiments that at least four sleeper coaches should be provided to ensure no shortage.

In fifth chapter we have presented the use of simulation modeling to study strategic, tactical and operational problems related to an airport. Under strategic problems we have considered the effect of additional flights on runway capacity. We have found that the airport with a single runway will not be able to handle an aircraft arrival rate above 3 per hour on average-if turnaround time at runway is to be kept below 60 minutes. When two runways were used (without changing other facilities like parking bays), it was found that the improvement was marginal. For the problem of deciding the number of parking bays, our analysis show that in order to meet the forecasted demand for accommodating more flights, there is a need to augment type 1 bays from present number of two to three.

Determination of number of X-ray machines required is one of the tactical problems discussed. The analysis shows that three x-machines simultaneously deployed could reduce average passenger wait times at given loads near to zero. Another problem considered is the estimation of maximum occupancy of an area to determine Heating/Ventilation system requirements. A DE plotter attached to the resource pools for international terminal gave the nature of occupancy inside the terminal facilities. This number and its variability could be used for designing heating/ Ventilation Systems.

Under operational problems we have discussed the case of rearranging schedules/passenger reporting times to level peak load. From the DE plotters we have observed a heavy queue formation at X-ray machine on a particular day. The model was used to test rearranged schedules to reduce queue. The model was also used to deciding shift timings, preparing pit schedules. The simulation model for operational problems offers good graphical tools for investigating the possibility of permitting additional schedules by airlines and assigning x-ray machines to flight.

As described above we have successfully developed and used computer simulation models to solve problem related to three types of logistic terminal namely railway yard, container terminal of a port and airport terminal. From the point of contribution to conceptual modeling we have demonstrated that clubbing problems into operational, tactical and strategic and matching them with tightly pre-scheduled, moderately pre-scheduled and unscheduled systems is a good workable approach which reduces the number of models needed to study different terminal related problems.

6.2. SIMILARITIES AND DIFFERENCES IN THE THREE CASES

Of the three terminal systems examined the simplest was the case of rail yard. In this there is the service providing facility which is the rail yard into which rakes arrive according to fixed schedules, these have to be serviced and released to meet fixed departure schedules. The fixed entities in this system are the facilities such as pits, waiting lines, coach care centre etc. The variable facilities are number of spare coaches allotted, number shunter engines etc. The transient entity in this case is the rakes that arrives and departs after service. The holding times of the rakes in this system is long, reducing the pressure on the service system. There are spare coaches in the system to take care of large repair times for sick coaches.

The case of the container terminal is more complicated. Here the fixed entities are the QCs, Berth, Storage space etc. The variable entities are TCs and internals trucks. The transient entities that pass through the system are the ships, containers and external trucks. On sea side ships come in with import containers which are unloaded by QCs, carried to the storage yard by internal trucks and stored there by TCs. These are later taken away by external trucks. The external trucks also bring in export containers which are unloaded and kept in the export yard from where they are taken and loaded onto ships for export. There exits a buffer called container storage yard that delinks the export and import truck arrival and departure from the ship loading and unloading operations. This helps in decreasing the ship turnaround time which is key performance measure for the container terminal. Ships that come in also serviced with bunkers, water, provisions and minor repairs. This could be viewed as similar to the service provided to a rail rake in a railway yard. But here the number of ships received at a time are fewer and their arrival is not tightly scheduled. The additional elements here is the containers that have to be loaded and unloaded from the ship when compared to the railway yard.

The airport is the most complicated of the three cases. In an airport the fixed entities are runways, parking bays, terminal waiting spaces for passengers etc. The variable facility entities include X-Ray machines, Check-in, Customs, Emigration and Security Check counters. The main transient entities here are the aircrafts, the passengers and cargo. The aircrafts is the most important entity in the system and the system is designed to provide the shortest turnaround time for aircrafts. But since passengers are also an important entity in the system and they cannot be made to wait too long passenger and their baggage handling has to be synchronized with aircraft arrival and departure. Therefore on one hand, on the airside aircrafts have to be received, passengers disembarked, baggage and cargo unloaded, the airplane serviced and made ready for next flight. The passenger handling side has to ensure quick flow of disembarked passengers from the flight, make their baggage available in time for them collect the same and leave the airport in the shortest possible time. Passengers coming to catch flight have to be checked in, their luggage handled and they have to be put on to their flights with minimum inconvenience and delay. In this system also the airplane that comes in has to be fuelled, cleaned, inspected and minor repairs done to prepare it for the next flight. So in this case we see that the aircraft has to be serviced, the cargo loaded and unloaded and passengers disembarked ans embarked. This increases the complexity of the system when compared to the earlier cases of rail yard and container terminal.

Though these three terminals were very different, the analysis of the service providing system to identify fixed entities, variable entities, and the transient entities that pass through the service system and get service was an approach used by us in conceptual modeling. This approach helped us in designing and developing the simulation blocks in models. This approach also helped us to bifurcate the Models into TYPE 1, TYPE 2 and TYPE 3 models and use them to help solve problems of strategic nature related to fixed facility, tactical problems related to variable facilities, and operational problems related to transient entities and their schedules.

Verification and Validation of the three types models developed for each of the terminal systems were slightly different. For TYPE 1 models, scheduled times of entities in and out from blocks were thoroughly checked due tight nature of schedules in TYPE 1 models. For TYPE 2 models, scheduled times in and out from blocks as well as longer term behavior was also checked on output, since some times entities were also serviced as per time schedules. For TYPE 3 models longer term behaviour were checked on output. This way validation help in solving problems in a categorized way, at the same time help in use for a few problems that lie on the boundaries of Strategic, Tactical and Operational problems.

A performance measure that was used by us in all three cases was related to turnaround times and waiting times of the transient entities. Utilization of key fixed and variable facilities was monitored and bottlenecks detected, de-bottlenecking was carried out by examining the effect providing additional fixed or variable facility. The capacity of the system was determined by changing the quantum and/or schedules of transient entities processed by the system. Thus we could demonstrate the usefulness of a common approach to conceptual modeling, model building, verification and validation, experimentation and use in the case of three diverse logistic terminal system that were studied. This approach can be used for study of logistic and manufacturing systems.

6.3. LIMITATIONS OF THE STUDY

The standard limitation of any modelling study is related to the assumption made during modeling. This study also has these limitations. Hence generalizing the findings from the model will not be correct. More specifically TYPE 1 models are least flexible, more case specific and therefore most difficult to generalize. Flexibility increases as we go through from TYPE 1 through TYPE 2 through TYPE 3 models, making TYPE 3 models the easiest to generalize. The time distributions and process logic used in the models are specific to the cases studied. In case of time distributions for many activities enough time data to fit and use the most accurate distributions were not available. Hence approximate distributions were used. Though this is an important limitation, it was not found to significantly affect the parameters that we have studied. For conducting experiments on the models we have used simple techniques most of the time since the same met our needs. It is possible to use more sophisticated experimentation techniques to understand system behavior using the model. Since the study was primarily simulation based, and intended only as a decision support system, cost and economic viability aspects were not considered. The will have to be done separately using inputs for costs and benefits from output provided by the model. Problems of each category was identified and selected based on expert advice and convenience. Formal methods for problem identification and selection were not used.

We have presented a scheme of clustering problems and models during conceptual modeling to reduce the number of models needed to solve the problems studied. This clustering method has not been compared to other possible methods to evaluate its performance.

6.4. SCOPE FOR FUTURE WORK

The first area of extension of this work relates to demonstration that the framework for concoptual modelling that we have suggested works in many more case in logistics and manufacturing. Another area of work could be to seacrh and find other ways of clustering problem types and making model types that match with these clusters. The performance of such clustering methods could also be compared to add to the body of knoledge in the area of conceptual modeling.

The next area of work is related to the developemnt of models and use of different simulation packages for the same. Comparison of simulation packages for solving logistics problems could be one type of work. The models that we have built could themseives be used to study new problems.

Research could carried out to develop an integrated system which has the ability to support strategic level decisions with the finer elements of local schedules. This DSS framework insulates the decision maker from the type of models and by using a user-friendly interfaces. The basis for classification of models in a model base (collection of models) and developing a logic for selection of the model for the decision problem involved will be the result of extensions of this work. This will be necessary to make an integrated DSS from which, depending upon the problem at hand, an appropriate model will be selected from the model base by the DSS.

APPENDIX I

SIMULATION LANGUAGES

A number of simulation languages are now available for development of simulation models. Various simulation related features are available in these languages. A list of generally desired features of simulation languages[1] is given below.

1. Graphical model construction (icon or drag-and-drop)
2. Model building using programming/ access to programmed modules
3. Run time debug
4. Code reuse (e.g., objects, templates)
5. Model Packaging (e.g., can completed model be shared with others who might lack the software to develop their own model?)
6. Does this feature cost extra?
7. Cost Allocation/Costing
8. Mixed Discrete/Continuous Modeling (Levels, Flows, etc.)
9. Animation
10. Real-time viewing
11. Export animation (e.g., MPEG version that can run independent of simulation for presentation)
12. Compatible animation software
13. 3D Animation
14. Import CAD drawings
15. User Support/Hotline
16. User group or discussion area
17. Training Courses
18. On site Training
19. Consulting Available

[1] Based on "Simulation Software Survey" in OR/MS Today. (http://www.lionhrtpub.com)

Further we have identified that we require following desirable characteristics for our type of modeling study.

1. Capability for discrete-event simulation study: The items of interest in the terminal systems are discrete in nature (for example rakes, planes, passengers and containers)
2. Capability to represent flow of items. The several items in the system is passed from facility to another facility.
3. Ability to represent various facilities, equipments and machines
4. Generation of schedules
5. Availability of a number of statistical distributions for representing activity durations, item arrival, and maintenance times.

Based on information from many simulation software websites and the article "Simulation Software Survey" in OR/MS Today, (http://www.lionhrtpub.com) we have narrowed down our search for a suitable language for our study to the simulation platforms in Manufacturing/Logistics with discrete-event capability. A list of 16 such languages is given in Table AI.1. A comparison of various features is given in Table AI.2. Since most of these languages have the capabilities we have mentioned earlier, our final selection depended much on local availability.

Simulation Languages						
No:	Software	Vendor	Typical Applications of the software	Primary Markets for which the software is applied	RAM	Operating Systems
1	AnyLogic 6.0	XJ Technologies	Marketplace and competition modeling, supply chains, logistics, business processes, project and asset management, pedestrian dynamics, health economics	Global modeling for any kind of business: telecom, transportation, distribution, insurance, service, agriculture, etc.	512M, 1G recom.	Any Java-enabled platform
2	Arena	Rockwell Automation	Facility design/configuration, scheduling, effective passenger and baggage-handling processes, patient management, routing/dispatching strategy	Airports, health care, logistics, supply chain, manufacturing, military, business process	64M	Windows 98, 98 SE, Me, 2000 (SP 3-later), Server 2003, XP (SP 1-later)
3	AutoMod	BrooksSoftware	Decision support tool for the statistical and graphical analysis of material handling, manufacturing, and logistical applications using true to scale 3D graphics. Templates for Conveyor, Path based movers, Bridge Cranes, AS/RS, Power & Free and Kinematics	Warehousing and distribution , automotive, semiconductor, manufacturing, transportation, logistics, airports/baggage/cargo/security, mail and parcel handling, steel and aluminum, controls testing and emulation	.512 mb recommend 1 gig	Win2K/XP Professional
4	eM-Plant	UGS	Object-oriented, hierarchical discrete event simulation tool for modeling visualisation, planning and optimisation	Automotive OEM, tier1 supplier, services/consulting, aerospace, industry, truck/bus and more	128MB	Microsoft Windows 2000, XP
5	Enterprise Dynamics Simulation Software	Production Modeling Corporation	Material handling, manufacturing, call center and service industry applications; process improvement; capacity planning	Steel, electronics, aerospace, automotive, food and beverage, consumer goods industries; airports; railways	64MB	Windows 98/2000/XP

6	Extend Industry	Imagine That, Inc.	Adds rate-based simulation to Extend OR	Large scale and rate-based systems: distribution logistics, high volume call centers, packaging lines, etc.	128MB; additional memory may be required for large models	Windows XP and 2000
7	Flexsim	Flexsim Software Products, Inc.	Manufacturing, logistics, material handling, container shipping, warehousing, distribution, mining, supply chain	Manufacturing, logistics, material handling, container shipping, warehousing, distribution, mining, supply chain	512 recom.	Windows XP and 2000
8	Micro Saint Sharp Version 2.1	Micro Analysis & Design	General purpose, discrete event simulation modeling environment. Improves facilities design, maximizes worker performance and more.	Military, human factors, health care, manufacturing, service industry, Fortune 500 companies, small businesses	64MB, 128MB recom.	Windows 2003, XP, ME, 2000, 98 (must support .NET Framework 1.1)
9	Process Simulator	ProModel Corporation	Lean, SixSigma, value stream mapping, process mapping, flow chart simulation, continuous process improvement	All	128MB min., 512MB recom.	Windows 98 or later
10	PSM++ Simulation System (new version of PASION)	Stanislaw Raczynski	General purpose simulation software. Supports discrete event, queuing models with animation, continuous ODE and more.	Education, queuing and manufacturing simulation, mass-service systems, design, research	256	Windows 98 or later, NT, XP, requires Borland's Delphi
11	ShowFlow 2	Webb Systems Limited	Process improvement; investment feasibility; what-if; cycle time, work in process and waiting time reductions; layout improvement	Manufacturing, logistics, retail, distribution, financial services, teaching	128Mb min., 256Mb recom.	Win9x, Me, 2000, XP

12	SIGMA	Custom Simulations	General discrete event systems, supporting all world views with an event relationship graphical interface	General manufacturing and service systems, including bioproduction, semiconductor, health care and business enterprises	640K	All MS Windows systems
13	SIMUL8 Professional	SIMUL8 Corporation	Work flow management, throughput analysis, de-bottlenecking, new product/process development, capacity analysis, continuous improvement	Business process, call centers, manufacturing, supply chain, logistics, healthcare, financial, pharmaceutical and others	64MB	Windows 95, 98, ME, NT 4, 2000, XP or later
14	Supply Chain Builder	Simulation Dynamics, Inc.	Address inventory problems and transportation or resource issues. Library describes inventories, items, resources, operations, BOMs, and actions.	Manufacturing, service organizations, transport management and other corporations seeking ongoing, online process management tools	512MB	Windows 98, ME, 2000, XP running .NET runtime
15	Visual Simulation Environment (VSE)	Orca Computer, Inc.	Integrated development and execution environment for discrete-event, general-purpose, object-oriented, picture-based, simulation applications and more	VSE is applicable for solving problems using discrete-event simulation	512MB	Windows NT, 2000 and XP
16	WITNESS 2006	Lanner Group	Modeling of factories, hospitals, logistics, business processes	Manufacturing, finance, health, defense, oil and gas, police	256MB	Windows 98, 2000, NT, ME and XP

Table AI.1: A list of common simulation languages suitable for Logistics/Manufacturing simulation

Features	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total of features
Arena	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
Flexsim	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
Enterprise Dynamics Simulation Software	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	18
AutoMod		1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	17
eM-Plant	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	17
Extend Industry	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1	1	1	17
ShowFlow 2	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	17
SIMUL8 Professional	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	17
WITNESS 2006	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	17
AnyLogic 6.0	1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1	16
Process Simulator	1	1	1	1	1	1	1		1	1				1	1	1	1	1	1	15
SIGMA	1	1	1	1	1	1		1	1	1	1	1					1	1	1	14
Micro Saint Sharp Version 2.1	1	1	1	1					1	1			1		1	1	1	1	1	12
PSM++ Simulation System (new version of PASION)	1	1		1	1			1	1						1		1		1	9
Supply Chain Builder	1		1	1	1					1					1			1	1	8
Visual Simulation Environment (VSE)	1	1	1	1					1								1	1	1	8

Table AI.2: Availability of desirable features in common simulation languages suitable for Logistics/Manufacturing simulation

Note: Features 1-19 listed in the first page of this Appendix are indicated as available in a package by '1' in the corresponding cell

APPENDIX II

SOME COMMON EXTEND BLOCKS USED IN MODELLING

Here we discuss some important simulation blocks used in our models. Extend comes with an extensive set of iconic building blocks for modeling discrete event systems(DE Library). Extend[i] DE blocks are used for generating items arrival, different activity times, queues and resources. In addition to these blocks we have also used various blocks for data collections, decision-making etc from the generic and manufacturing library of Extend.

GENERATIONS OF ITEM'S ARRIVAL

Generators are used to create items arrivals. In our models items represent containers coming in ships, rakes, airplanes etc.

Extend blocks used for generators

Generator in Extend DE Library: Provides items for a discrete event simulation at specified interarrival times. Choose either a distribution on the left, or choose the empirical distribution and enter probabilities in the table. Items can be created with a random distribution or at a constant rate of arrival. The block *input random number* from the generic library of Extend is used to generate many distributions.

Extend blocks used for queues

First-in-first-out (FIFO) queue. The maximum length, which determines how many items the queue can hold, can be set in the dialog. We can specify that the simulation should stop when the queue is full (reaches the maximum length). We can also see the average queue length, average wait time, and utilization of the queue in the dialog.

Buffer :Simulates a first-in-first-out (FIFO) queue for buffering items needed by machines, conveyors, or batching operations. The maximum length, which determines how many items the buffer can hold, can be set in the dialog.

Queue for resource pool units. Items wait until the specified number of resource pool units become available. The order of items in the queue is determined by the ranking rule in the dialog of the Resource Pool block. The maximum length, which determines how many items the queue can hold, can be set in the dialog. We can also see the average queue length, average wait time, and utilization of the queue in the dialog.

ACTIVITY TIMES

Several activities are involved in the terminal operations

Extend blocks used for activities

Machine : Simulates a machine operating on a single item for a specified processing or delay time. When the machine is ready, it pulls an item from a resource or operation (buffer, conveyor, transporter, batch, and so on) and processes it for the time specified. Once an item is processed, it is held until it is picked up by another block. The machine is only ready to process the next incoming item when the processed item is taken by another block.

Activity ,Delay :

Holds an item for a specified amount of delay time, then releases it. The delay time is the value in the dialog or, if connected, the value at the D connector when the item is received (the connector overrides the dialog).

Activity multiple :

Holds many items and passes them out based on the delay and arrival time for each item. The item with the smallest delay and earliest arrival time is passed out first. The delay time for each item is set through the D connector or, if nothing is connected there, can be specified in the dialog.

RESOURCES

Various resources are required for the operation of terminals . Resources include cranes, trucks, berth, stocked containers etc.

Extend blocks used for resources

Resources: This block holds and provides items (coaches, workers, bays, etc) to be used in a simulation. It can be used as part of an open or closed system. Unlike the Generator and Program blocks, this block does not push items. If we use it in place of a Generator or Program block to provide items for the simulation, there should be sufficient items in initial number to satisfy item requirements for the duration of the simulation. This block is similar to a queue. Items can be pulled from the resource through the item output connector as long as they are available. If the block's contents become negative, the block will not output any values until the contents become a positive number.

Resource Pool: This block holds resource pool units to be used in a simulation. These units limit the capacity of a section of a model. For example, this could be used to represent a limited number of tables at a restaurant.

Stock: Provides and stores stockroom items such as raw materials, work in process, and so on. This block may be used in an open system such as when items are shipped, or in a closed system such as when we exchange parts in spares inventory. Items can be pulled from the output as long as there are items available. We can add attributes and priorities to items passing through the block.

Maintenance blocks: Generates downtime for machines in the Manufacturing Library. Connect the output to the down connector on another block. An item is generated at random intervals according to the Time Between Failure (TBF) distribution. This is a distribution of the durations between the start time of consecutive failures. Each time a failure occurs and an item is generated, a random duration of downtime is selected according to the Time To Repair (TTR) distribution. The duration is assigned as the "value" of the item sent.

Information blocks and plotters: In our model we have used a large number of blocks related to collection of information in various aspects. They include statistical counters, timers and plotters.

For more information on use of Extend, refer to Krahl (2001)[ii].

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[i] Extend and ModL are trademarks of Imagine That, Inc.

[ii] Krahl D. (2001). The EXTEND simulation environment. Proceedings of the 2001 Winter Simulation Conference, *B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds*

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PUBLICATIONS

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2. **James K.C and Dr M Bhasi**, 'Discrete-Event Simulation Model of a Container Terminal', Vilakshan, March, 2006, p127-136.

3. **James K.C and Dr M Bhasi**, 'Modeling Container Terminal Using A Discrete -Event Simulation Package', proceedings of Port Handling Systems, 2004, **The international Conference and Exhibition of Dry Bulk, Break-bulk and Containers**, Oct 5-8,2004, Mumbai, p41-45.

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Accepted in Conferences

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Under Review

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2. **James K.C and Dr M Bhasi,** 'Simulation Models for Strategic, Tactical and Operational Decisions in Transport Terminals: The Case of a Passenger Rail Yard', TRANSPORTATION RESEARCH PART E: LOGISTICS AND TRANSPORTATION REVIEW.