2002

SIMULATION STUDY OF MULTILANE SELECTIVITY BANK IN AUTOMOTIVE INDUSTRY

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ABSTRACT OF THESIS

SIMULATION STUDY OF MULTILANE SELECTIVITY BANK IN AUTOMOTIVE INDUSTRY

This study deals with a very common problem encountered in many automotive industries. Automotive companies try to level the production of different models over time based on the demands for these models in the market. In order to achieve this, they introduce a leveled stream of cars in the beginning of the production line. But because of many reasons this leveled stream gets disturbed in its course. In order to re-level the stream, buffers are used between the shops. One such buffer is called as selectivity bank and it sits between paint shop and assembly shop. This buffer receives a disturbed sequence from the paint shop. The thesis tries to develop different algorithms that can be used to discharge cars from this buffer in order to achieve better leveling in the presence of rework and assembly constraints. These algorithms continuously try to steer the system from an undesirable state to a more desirable state by keeping track of current conditions in the plant. A simulation model is developed, which gives a platform for comparing relative performance of these logics under different conditions. The simulation tool is also helpful in designing optimum size of this buffer that will result in desired leveling performance.

KEYWORDS: Simulation, Selectivity Bank, Leveling, Lean Manufacturing, dynamic goal chasing.

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June 21, 2002

Simulation Study of Selectivity Bank in Automotive Industry

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SIMULATION STUDY OF SELECTIVITY BANK IN AUTOMOTIVE INDUSTRY

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Engineering at the University of Kentucky

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2002

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Overview

This document is divided in 6 main sections.

Chapter 1 describes the general flow of vehicles in an automotive assembly plant and then it describes the problem statement under investigation

Chapter 2 describes the problem at Toyota on which the author worked. The chapter concludes with describing the solution to the problem and insights gained through the study.

Chapter 3 discusses about the similar problems at other automotive plants and the need of creating a framework for studying this problem.

Chapter 4 explains the methodology followed in the creation of general purpose simulation model for studying the system. The mathematical formulation of the problem and the flow chart of the simulation model are also described.

Chapter 5 presents the experimental framework for carrying out the case study with the model. It also describes the variance reduction done using the principle of common random numbers.

Chapter 6 summarizes the findings of the experiments done with this model and the general insight gained by plotting the output results in different ways. The results are not the unique observations but they are more of general results and they set up guidelines for a person who is going to conduct a simulation study for a particular plant using this model.

Overview of automotive manufacturing system

Automotive manufacturing can be described as a discrete mass production. Customer requirements vary in large extent. This results in a large variety of models, each with a different set of options. If each combination of features is considered as a different model then virtually thousands of models are produced on a single assembly line.

As the demand for each model is very small they should not be produced by batch production. In order to launch a batch of a single model, there is a need of enough orders already placed by the customers. If there are not enough orders then the scheduler waits, which increases the lead time for the customers who have already placed orders. If the scheduler starts producing cars in big batches without getting the orders in hand, then there is the possibility of increasing the finished goods inventory, which is expensive and undesirable.

The TOYOTA Production System (TPS) tries to solve this problem by designing plants, which can assemble a large variety of models with almost single piece flow of individual models. This enables them to track the customer demand very closely. In order to achieve this, TOYOTA uses many different techniques such as goal chasing, load leveling, KANBAN, intermediate buffers, re-sequencing [17] etc. The meanings of these terms will be explained during the course of the thesis.

In general any automobile manufacturing plant consists of four main sections.

1) Press Shop

2) Body Shop

3) Paint Shop

4) Assembly Shop

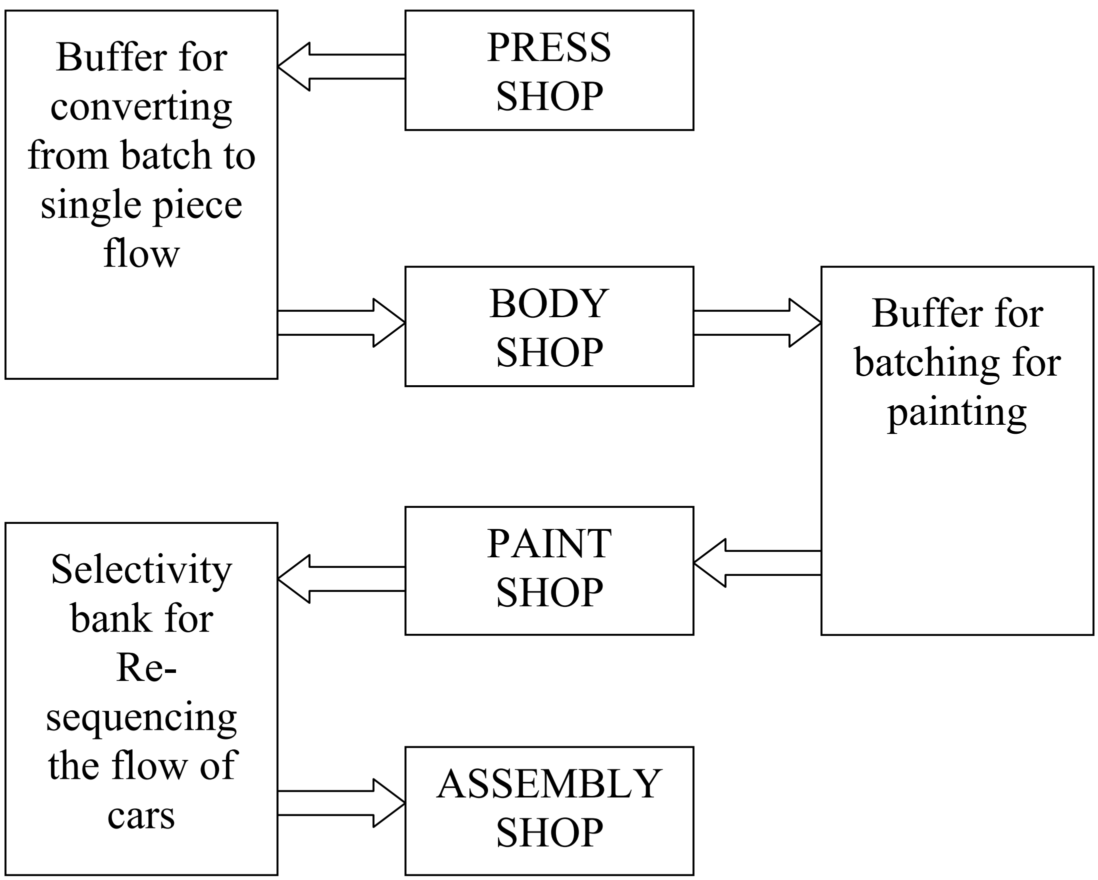


Figure 1.1: General Production Flow in an Automotive Plant

Figure 1.1 shows the general flow of cars in an automotive plant. The production scheduling across the sequential flow through the workstations is synchronized based on concept of TAKT time. TAKT time stands for time available to complete task on the workstation for a single vehicle. Production equipments in these shops differ. This necessitates the use of different production control systems internal to these shops as well as intermediate buffers. The buffers can have different configurations. The most common of them are lane layout or AS/RS (Automatic Storage and Retrieval System). The layout of the buffer puts restrictions on the selection of individual cars. for example only the first car in the row can be selected in case of a lane structure but any car can be selected when the design of the system is of AS/RS type. Speed of retrieval is also important in a fast paced environment such as automotive production where one car is built every minute.

The press shop is the section where the sheet metal panels of the body are formed. The nature of production here is typically batch production. It is necessary because of the inherent nature of the process. A press requires long setup times because of the time delays associated with die mounting and adjusting. High capacity presses are used to achieve economics of scale for these expensive heavy machines. Each Press is used for stamping several different parts. TOYOTA tries to reduce this setup time by using SMED (Single Minute Exchange of Dies) technique [12]. But still because of setup and use of press to make multiple parts, it is not feasible to produce in really one piece flow manner. Typically the batch production in press shop is difficult to synchronize with other shops, which work on one-piece flow.

In the body shop the metal panels are spot welded either manually or by robots. The production can be scheduled in single piece flow fashion here because of the quick changeover capability of the process, across the model variants. (e.g. simple program need to be changed for the holding fixtures as well as the spot welding guns.)

In the paint shop the flow is in the form of small batches based on color of vehicle. When the color needs to be changed the painting guns are purged. This results in loss of time and paint. It also adds the expense of treating the environmentally hazardous components of paint such as thinner before they are released in the atmosphere. This process of batching of vehicles based on color is actually against the principles of lean manufacturing and TPS (TOYOTA Production System).

After the paint shop the bodies go to the assembly line where they are trimmed and all the components such as transmission, engines etc. are assembled to it. Here the production is leveled and is scheduled in accordance with the demand for various models. This scheduling actually drives the scheduling of the whole plant in the case of JIT manufacturing.

The definition of model types differs in every shop. In the body shop the models may be defined on the basis of the number of panels to be welded or the welding fixtures that it has to pass through. For example a two door, a four door and a wagon may have to pass through different welding fixtures. In the paint shop the models might be defined on the basis of color or the special treatment required such as double coating or special finish etc. On the assembly line the models are defined on the basis of trim work or options or accessories to be fitted on the model. It can also depend upon the kind of drive system is to be fitted on the car such as 2WD versus 4WD or automatic versus manual transmission.

Automotive plants attempt to operate on the principle of heijunka [17]. The objective of heijunka is to level the production of different models over a short time period. But as described above model definition is shop dependent, the sequence which is ideal for one shop may not be ideal for another shop. So it is not good to allow the flow of cars from one shop directly to another shop without modification.

Issues associated with the sequencing and scheduling of entities

Depending upon the demand for the different models by the customer, those models are introduced to the body shop for production, the point where single piece flow begins. A stream of different models simultaneously leveled across all important features is introduced into this system. In the ideal case it is expected that this leveled stream will continue to flow through the system and will result in leveled output at the other end. Importantly this would result in leveled pull of major feeder lines (e.g. instrument panel assembly) major components (e.g. engine type, transmission type). This leveled pull reduces demand variability for these parts enables use of small buffers between feeder and assembly line. But in reality this leveled stream is disturbed during its flow at various points in the process because of quality problems as well as conflicting objectives at the different processes. Following are some issues which introduces disturbance and randomness in the process.

Quality problems

The quality of painting of a car is one of the most valued quality attributes from the customer point of view. Good automobile companies are extremely careful about maintaining consistent paint quality. Any minor defects in the paint are also very strictly treated. Unfortunately, the painting process is not as stable as some other manufacturing processes like machining. This is because of the large variety of influencing parameters including environmental conditions such as weather. This results in a large percentage of cars undergoing rework and coming back into the main line. On a bad day, when the paint shop is not operating properly, it can disrupt the operation of the whole plant. For all these reasons paint shop is usually considered as a “trouble spot” in an automobile plant.

Conflicting Objectives

At the entrance to the paint shop the vehicles are batched based upon their color attribute. This is done in order to reduce the number of purges required to be done. This disturbs the original sequence. Also this is against the main objective of JIT or lean manufacturing to reduce the batch size of production to size of 1.

The color attribute related to interior has meaning when the cars are introduced in the assembly shop. If the color batches related to exterior color are not broken it creates uneven demands for color dependent parts and often lack of leveling of major model types. This gives rise to conflicting objectives between the two shops.

Sequencing Issues

Different models have different work content depending upon the complexity of assembly. Assembly lines, which are designed for production of multiple models, under JIT, are quick and flexible enough to adjust themselves to the changing workload pattern. But this is possible only when both the high work content and low work contents models are arriving regularly. However if the many models with high work content are put successively then it may result in line stoppages or incomplete work.

To avoid these kinds of problems generally high work content and low work content models are identified and care is taken that the high work content models are not scheduled successively. The rules formulated for this are in the form of at least and at most . E.g. at least 3 models between successive appearances of the high work content models and not more than 2 successive appearances of very high work content models.

Buffers are provided between two shops with the intention of absorbing the fluctuation in the production output and demand for input from the adjoining shops. As the buffers accommodate different models at the same time, they are also used as an opportunity to sequence or re-sequence the stream of models and make the stream more suitable to the nature of the downstream process. But the question arises what policy should one use when selecting the models from the buffer? Also what should be the size of buffer that will be able to provide a good sequence of cars to the downstream process, without excess inventory being held between the shops.

Different sequencing rules can be used to discharge cars from these buffers. It has been an issue of research to design the best heuristics that can achieve the best desired performance. The desired performance might be different in different systems. In this research a simulation model is created to depict the system under consideration. It identifies the major parameters such as the sequencing rules, which might affect the system performance. After this initial modeling the parameters in the system are assigned values from a hypothetical but realistic system in order to conduct the simulation study. The simulation study concludes with general comparisons regarding the relative effectiveness of these rules with respect to performance evaluation criteria. Also it tries to answer some questions like how much buffer size is optimum in order to achieve desired leveling.

Chapter 2: Description of the work done at TOYOTA and the insights gained

Introduction to problem at Toyota

Toyota Motor Manufacturing Kentucky (TMMK) approached University of Kentucky requesting an investigation of work on the scheduling and sequencing problems they were encountering which initiated this research effort. At this particular plant the company was manufacturing six different model variants based on work content difference.

1) Camry
2) Camry with Moon Roof
3) Avalon
4) Avalon with Moon Roof
5) Avalon Right Hand Drive
6) Avalon Right Hand Drive with Moon Roof

The discharge of these models on the assembly line was constrained by the following rules.

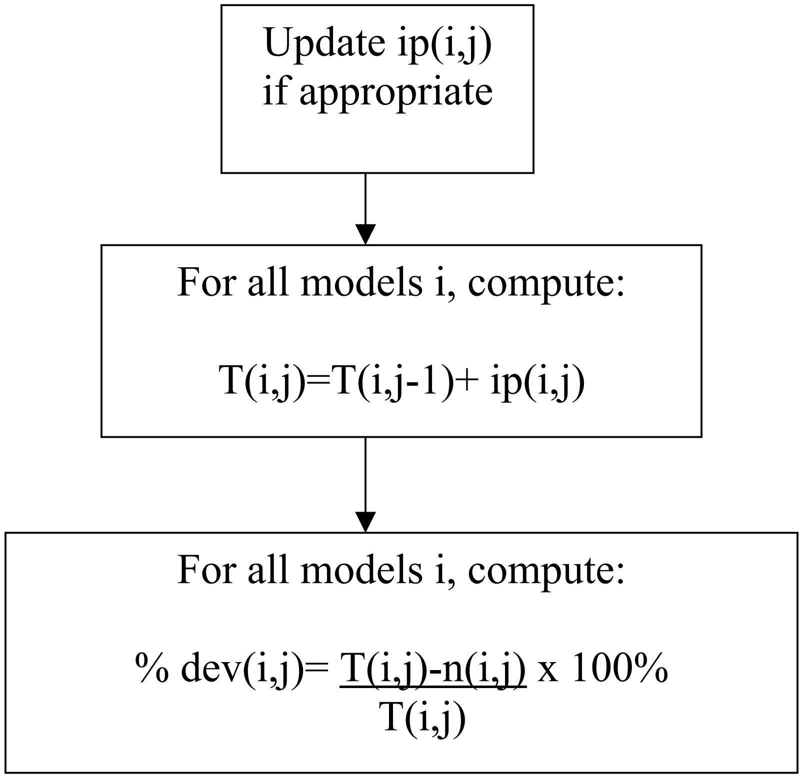
- No back to back Avalons
- No more than two moon-roofs in a row
- At least 15 other vehicles between two successive Right Hand Drive vehicles

The company was not able to achieve the expected leveling performance from their current practices. Also they were violating many assembly constraints, which was resulting in unbalancing of the assembly line. The major area of focus was the discharge from the selectivity bank. Currently they were relying on the manual selection of different models. An operating worksheet is given every month to the personnel at the decision point. This worksheet contains instructions on how to rotate between the models. These instructions are also designed to take into account various assembly constraints. So the scheduling is operated under static rules backed by the human judgment collected over a period of time to react to some very obvious situations. There was no system which can dynamically react to the changing conditions in the plant.

Objectives of the TMMK Study:

The study was aimed at investigating the current flow of entities by using the actual shop floor data and trying a modified goal chasing logic described in the figure 2.1. Also different inventory control techniques were followed to reduce the buffer size.

To cater for the dynamic nature of the plant instead of keeping the goal chasing percentages always constant they were modified at each car discharge event. The goal chasing percentages for different models are determined by the percentages of those model types in the pool of 1000 cars just behind (upstream) the selection point. Figure 2.2 is the flow chart for the same.



Where,

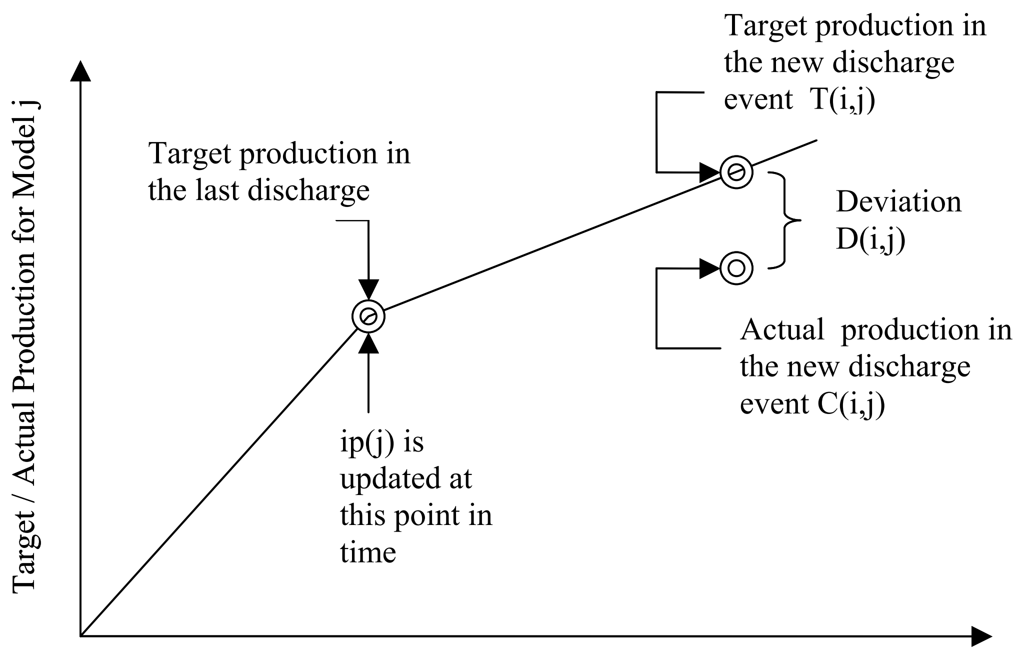
ip(i,j) = Ideal percentages for model i at discharge event j

T(i,j) = Current target quantity of model I that should have been discharged prior to time of discharge event j

n(i,j) = Actual quantity of model i of cars that have been discharged prior to time of discharge event j

% dev(i,j) = percent deviation from target for model i of cars at time j

Figure 2.1 Calculations for Goal Chasing Logic



ip = Ideal Percentages
j = Model Type
i = Time instant
T = Target production
C = Current Production

Figure 2.2: Dynamic Goal chasing Logic

Development of Simulation Model

To verify the effectiveness of the new logic simulation model was developed. Assembly constraints were also included in the model.

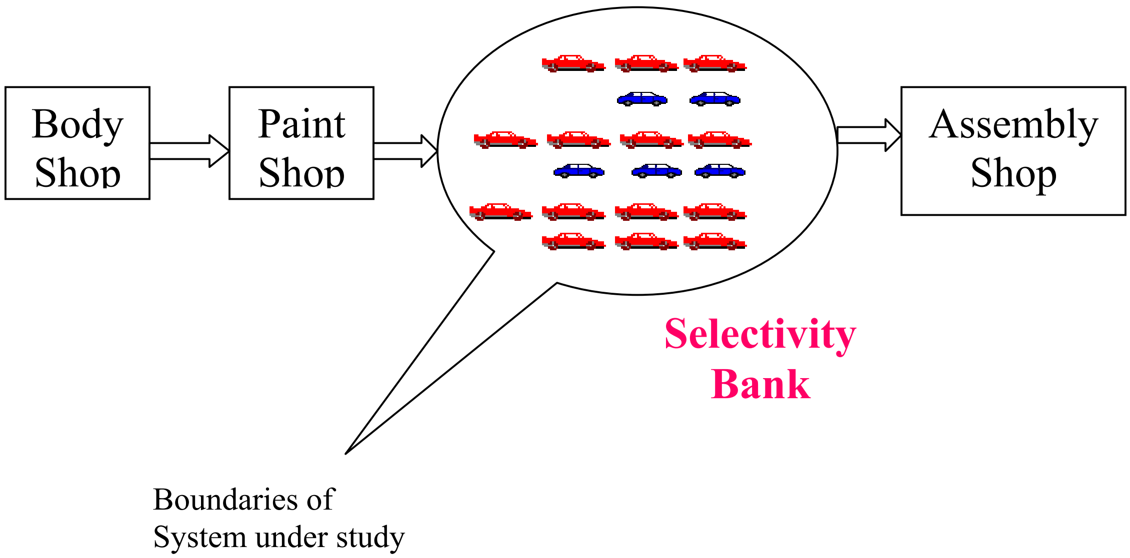


Figure 2.3: System Boundaries

Figure 2.3 shows the system bounds imposed on the simulation model. The performance of the whole plant depends upon how the individual departments are performing. In JIT the material flow is controlled by KANBANs so change in one part of the plant affects the material movements in the whole plant because they are connected to each other. So it is ideal that in order to study the performance, one should model the entire plant and carry out the simulation study. But in actual practice, it is not possible because the high level of complexity and time involved in such an extensive study. Also in most of the cases it is not required to carry out this kind of detailed study. So typically the simulation studies are always carried out by concentrating on one part of the system, which is of interest.

The following figure describes the overall working of the simulation model. Ones the deviations are calculated for all the models, they are ranked in ascending order. Higher deviation from the target means that the current number of cars produced for that model are less than ideal. So higher deviation model type is given higher priority. The top candidate model is then checked for availability as well as constraint satisfaction. The model is selected for discharge only if it satisfies all the assembly constraints

.

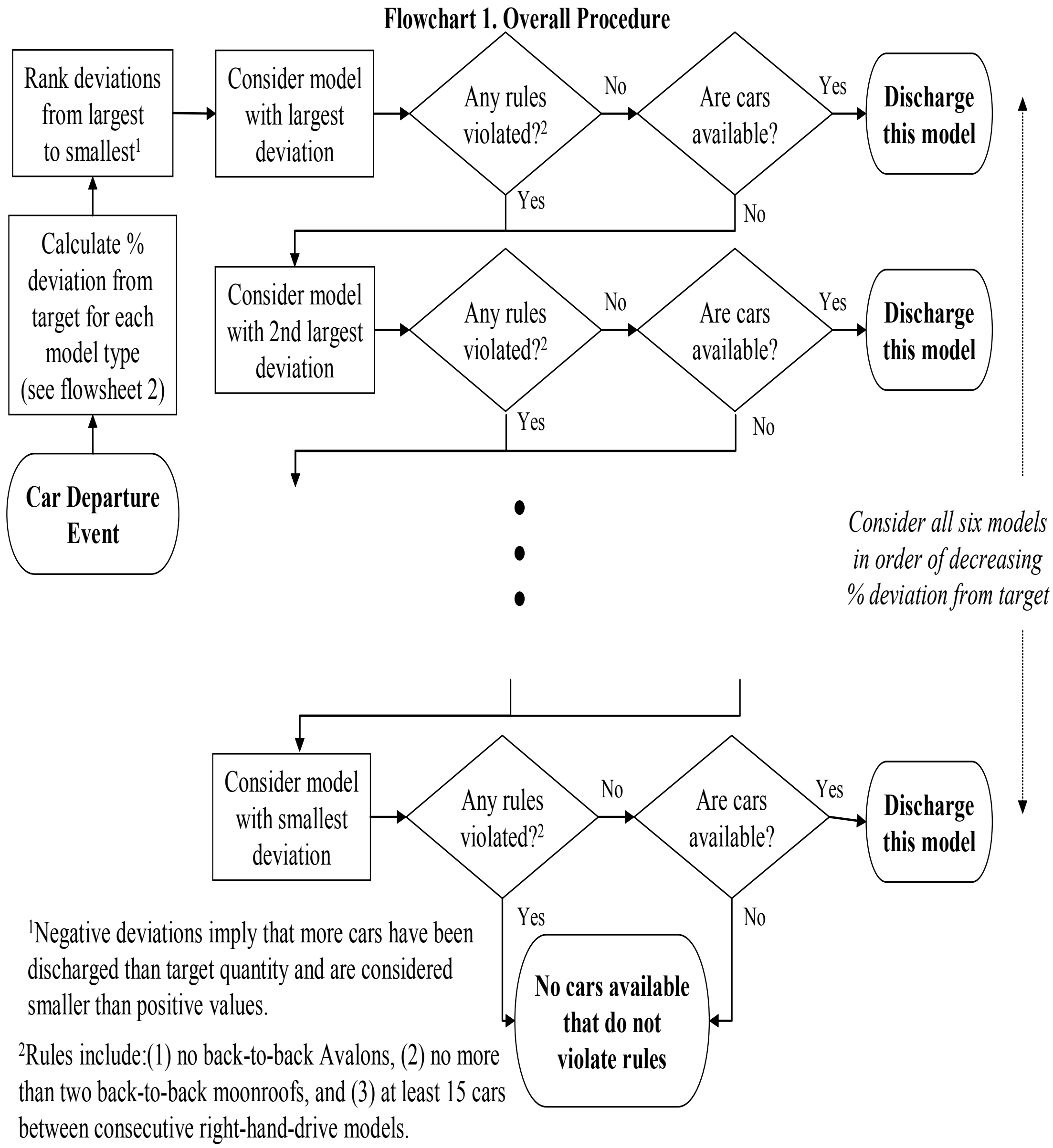


Figure 2.4: Overall flow chart for deciding the best model for next discharge

Results

Graphs in figure 2.5 and 2.6 show the comparison of leveling in the incoming stream of cars and the leveling achieved by existing method and the leveling that would be achieved if the proposed methods are used. The Y axis shows the variation in percentages over small time buckets

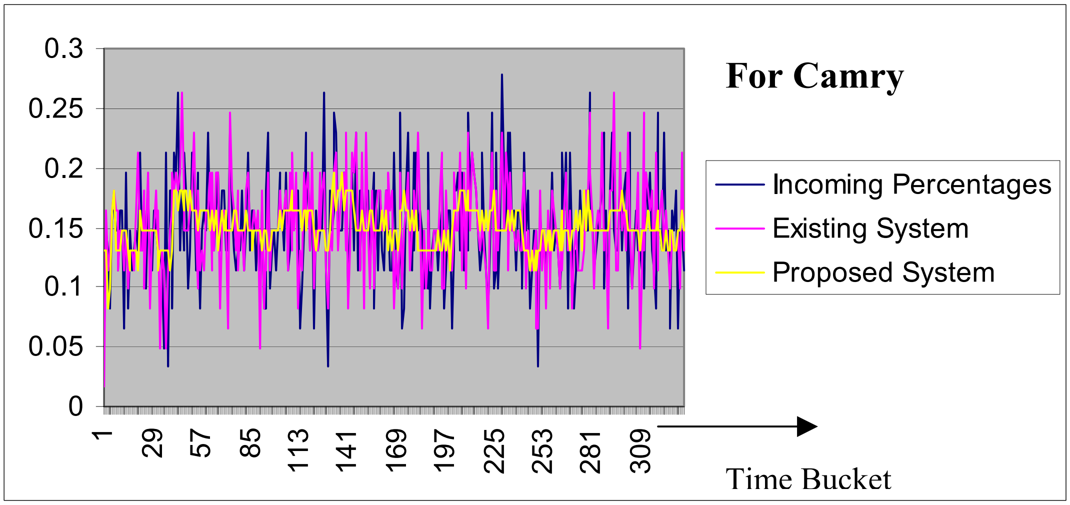


Figure 2.5: Leveling performance for camry

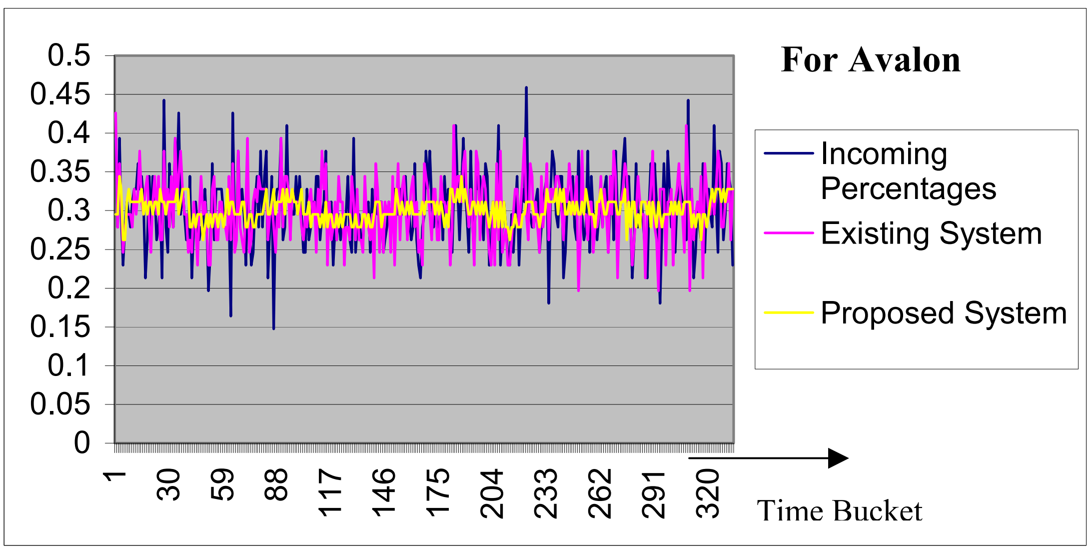


Figure 2.6: Leveling performance for Avalon

Remarkable improvement in the leveling performance is achieved by using the above simple logic. Also the number of rule violations decreased by a considerable number. The change in the leveling performance can be observed by the above graphs.

Insights

The main insight gained from the TOYOTA project is that if you keep the goal chasing percentages constant for a simple goal chasing algorithm you end up with a very disturbed sequence of cars which is not optimum at all. This occurs because of the very dynamically changing nature of the system. The system should react to these changing conditions and the goal chasing method should be modified to a dynamic goal chasing method. So the solution to the problem is found by updating the goal chasing percentages in real time based upon the stream of cars that are due to come in the selectivity bank .. It was found that with this dynamically changing goal chasing percentages the system is able to keep the % of different cars close to the desired percentages of respective models as compared to the current procedure. There is a clear advantage in keeping the goal chasing percentages changing based on the current status of the system.

Chapter 3: Review of current Literature

Introduction

Simulation modeling technique is used for many manufacturing applications. It is used to evaluate any modifications before they are implemented in the actual system. This reduces the downtime that might be associated with the changeover. It also helps to build greater confidence in managers and operators that the changes are feasible and are going to improve the performance.

There are many articles that deal with sequencing of mixed model assembly lines because these kind of assembly lines are used in many different areas apart from automotive. The literature associated with this topic mainly covers the following goals.

1) The goal of sequencing different models on the line is to produce them in accordance with the demand for those models in the market. The production of the models needs to be leveled over a small period rather than making them in batches (Heijunka). The models need to be fed to the line at constant rates over a short time interval.
2) Each finished product consists of many sub- assemblies and parts that are provided by the suppliers. In order for the suppliers to provide these parts consistently, their consumption need to be leveled.
3) The different models vary in total work content. They can be classified in ranges such as high work content, medium work content and low work content models. The other main goal is to schedule the models in such a way that balancing of the line is not disturbed. Also while designing the line, care should be taken to

distribute the work load equally over the various work stations on the assembly line

Case Study at Mercedes Benz Plant

One of the studies conducted by [2] David Graehl at Mercedes-Benz All Activity Vehicle (AAV) production facility involved the simulation study of whole plant by designing individual models, each representing one of the functional shops. The goal of this study was to investigate the operational policies in the AAV assembly plant and to determine the maximum possible throughput of the plant. The study also tries to point out the possible bottlenecks in the system and how buffers should be used in case of disturbances. A special consideration is given to the "Selectivity Bank" which is the buffer between the end of paint shop and beginning of the assembly shop. The body shop, the paint shop, and assembly shop are modeled using the SIMAN simulation language. The algorithms used in selectivity bank are comparatively complex to be modeled by SIMAN so the selectivity bank is modeled in the C++ language. C++ gives more flexibility and power for the modeling effort. The model uses the constraining rules to decide the discharge from the Bank. The study revealed that the Selectivity Bank remains full all the time. This implies that the assembly shop is not processing the bodies faster enough causing the bodies to back up in the bank consequently blocking the paint shop. Pointing out this problem, it is suggested to carry out further study of the assembly shop.

One of the main areas of focus when paint shops are simulated is the power and free conveyor system that transports the jobs through the painting operation. During the initial design of the paint system this system needs to be simulated and the various possible configurations are to be evaluated to ensure that the final layout is capable of meeting the desired throughput levels. Simulation studies like this are generally one portion of the overall decision making process, but they serve as the major criteria on which the final design would be based. David W. Graehl in his paper uses simulation for two purposes

1) to evaluate the feasibility of adding a new body style to the production line
2) to estimate the advantage of several proposed changes to the system layout.

The study helped the decision makers to get valuable insights regarding possible problems that might be encountered during operation.

Case study of Durr Automotive

[16] Durr automotive creates a software to experiment with variables including targeted levels of throughput, production schedules, product mix, buy-off rates shift patterns, process times and resource levels. They can also test the control logic before it is installed actually in the plant. They can introduce the data related to breakdowns and study its impact on the operation. They use powerful 3-D graphics to animate the movement of different entities and create a virtual paint shop to visualize it as it would be a real operation. Initially they were using simulation primarily as a sales tool but when they realized its power they started using simulation for making informed decisions which are backed by hard evidence rather than relying on guesswork. These efforts are specific to a plant , so the results obtained from any of these simulation studies are useful only for that plant.

In one of the studies [16], they created a simulation model for the paint shop of Rover. The problem on hand was to cater for the conflicting objectives in the paint shop. At first sight the demands for batching colors in the paint shop and a differing sequence for final assembly were insurmountable. The cars in the assembly were need to be batched based on different criteria than the ones used before the paint shop. A significant investment was planned to expand the painted body store (so called selectivity bank) prior to final assembly to enable re-sequencing after painting. The challenge for the simulation was to validate if this investment was necessary. Through the model operating protocol they achieved 99.5 feature batch integrity by dynamic order reallocation. This proved that the investment of 5 million to extend the painted body store was not required.

Case study of GM Holden, Australia

GM Holden [14] wanted to upgrade their current paint shop to cater for the increased capacity demands. The current option content variability had clearly outgrown the capabilities of current painting facility. In this plant once the vehicle painting is complete, the routing controller was sorting vehicle in a small four lane storage bank. The bank uses a simple dedicated lane approach to sorting vehicle models and options to assist downstream trim and assembly operations. At that time, this approach was adequate. However as demand, models and option contents proliferated this bank became one of the bottlenecks within the plant. The problems in the scheduling and sequencing in this case were same as in the above case. The vehicles were batched for color before the paint shop to reduce the number of purges and they some constraints imposed on the sequencing the vehicles for the assembly . The company was planning to introduce an AS/RS system to cope with this problem but the investment needed was very large so they wanted to try some other option one of which was to try large multilane selectivity bank housed in an existing building. GM Holden asked [14] Steven R. Kline Jr at SMARTEYE to perform simulations to determine the feasibility of the idea. After several simulation trials, the new idea was quoted and turned out to be significantly less expensive than the AS/RS solution. After a few months of fine tuning, the 15 lane bank performed all of the duties that were expected from ASRS. Along with the dynamic bank controls for color blocking and trim re-sequencing, GM Holden also wanted a database system that could gather and store historical data on color blocking, efficiencies, trim shipment history, production counts and other diagnostic information for the system. Just-in-time trigger points were also added from the bank control systems to the plant-wide scheduling system as vehicles exit the bank to trim to improve material disbursement and shipments to the plant.

Case study of Chrysler Corporation

[15] Tom Chase had developed a custom application called Centralized Vehicle Scheduler (CVS) for Chrysler Corporation. It significantly improves productivity at the final assembly plants around the world. Chrysler's application for sequencing vehicle production is based on the ILOG optimization suite. This application (CVS) has improved purge rates 10% to 20% , producing an annual savings of about $500,000 a plant which is more than $7 million annually for the corporation.Savings typically run at $12 per purge by reducing the cleanup time and conserving paint and solvents. Also the automaker expects to realize inventory reductions of up to $20 million by using ILOG components in option leveling throughout its production scheduling, achieving a significant improvement in personal efficiency as well.

Case Study of Nissan, Sunderland UK plant

In 1998 Nissan decided to introduce a new vehicle to European markets, the Almera. It was decided to manufacture it at the Sunderland plant which was considered as the most productive of all European automobile plants. [3] Nissan wanted to compare between the possibilities of constructing a complete new assembly line for the new model or making three models on two lines. Previously Sunderland scheduled weekly production on the basis of each shop. The schedule would reflect each shop's constraints and was coordinated from the control room where the process computers were based. Any glitch in the process led to the meetings between the shop managers who would devise an ad hoc solution to the sequencing issue which would then be managed by the control room. Under this approach, as many as 90% of the cars would required some kind of adjustment, from the control room. Most of the scheduling challenges were encountered in the before and after paint bays.

[3] Dennis Sennechael and lain MacLean along with Nissan a developed a solution using ILOG solver, an optimization software based on constraint programming. ILOG solver can quickly determine the optimal solution to a problem making it ideal for car sequencing application at Nissan. Users specify the constraints of a process such as parts availability, painting restrictions etc. and the software generates production schedule for orders that need processing. In designing the software system, 2500 possible constraints were identified. Multiple paths can be followed by the models. The path it takes depends on what makes most sense on any given day. The ultimate result was that the total

capacity of the plant was increased by 30%. Also only 5 % of the cars were now require intervention from the control room.

From all these literature survey it is confirmed that vehicle painting is one of the critical bottlenecks of automobile assembly lines. Delays on paint lines can adversely affect both throughput and productivity of the other shops. So the scheduling and sequencing associated with it has always been an issue of research and investigation.

Following comments were received from Mr. Neson Lee who is an experienced simulation consultant for Rapid Modeling Inc. at Cincinnati, Oh.

“ Significant work is required to be done specifically for the re-sequencing issue between paint and trim/assembly. This is a compelling problem, because many components coming to the line need to be pre-sequenced before arriving (e.g. - seats, engines, bumpers, etc.). Since a lead time must be allowed for the pre-sequencing of components; buffer size and lead time policies represent compelling opportunities for simulation modeling - optimization, and cost savings. These efforts can result in significant reductions in lead time and buffer size, generating significant savings in operating costs (e.g. inventory and labor) and capital for the system.”

Chapter 4: Development of The Simulation Model and Modeling Approach

Objectives

Simulation has been defined as " the process of designing a mathematical or logical model of a real system and then conducting computer based experiments with the model to describe , explain and predict the behavior of the real system. Most of the simulation studies are carried out before the implementation of the system or before implementing changes to the current system.

The problem considered here is a type of scheduling and sequencing problem. Mostly the Scheduling and sequencing tasks are done on day-to-day or even hourly basis. Because of the limitation on the processing capabilities of the computers, it was not possible till now to integrate simulation and scheduling. But with advancement in the computing and networking capabilities it is possible now to run long simulations within few minutes and come up with computer generated suggestions or sometimes computer made choices. One of the advantages of using simulation for scheduling is that most of the scheduling softwares consider deterministic times for processing and machine failures. Simulation can accommodate the probabilistic nature of these events. Also one can incorporate different constraints and decision algorithms easily into a simulation model.

One of the first things to be done while carrying out any simulation study is to create a clear picture of the problem under investigation and the issues to be addressed. This helps to decide the appropriate level of model detail. The complexity of the model should not be more than needed to meet the objectives. So the development of the simulation model was started by clearly defining objectives , goals and assumptions.

Following are the main objectives of the simulation model to be developed.

1) **Realistic**-

The model should be simple and all the unnecessary details should be avoided. In a real automotive plant there will be many other systems such as conveyors , robots, workers , transporters etc. If these details are added to the model they are not going to add a significantly more accuracy or information for the analysis.

2) **Versatile And Broad**

Although the layout configuration at each assembly plant is different there are certain features which can be identified as similar. Every plant has the four basic shops as explained earlier. The initial model developed for this problem was applicable just for the case of Toyota. It was modeled to depict the physical system implemented at the Toyota, Georgetown plant. While developing the model for the thesis it was decided that the model should be versatile enough such that any automobile facility should be able to use it. To achieve this objective, several changes were made to the initial model. Instead of using the real data from the Toyota factory, a model block was created that will generate a perfectly leveled stream of cars. Also the paint shop and the repairing in the paint shop is modeled just by simple DELAY blocks within Arena. The quality control at the end of paint shop is modeled by a simple DECIDE block. The percentage of cars that are rejected can be controlled through this decide block. The whole repairing process is modeled by a single DELAY block.

3) **User friendly and interactive**

The model is designed to make it easier to use by the end user even if much familiar with simulation modeling. The end user should be able to change the various parameters associated with the simulation study without changing the model much. Simple forms were created to interact with the model. The output is written to a worksheet . The user can do further analysis of the data using tools available in the spreadsheet software. Customized graphs can be constructed to see how the input parameters are affecting the performance measures.

4) Faster conclusions

Simulation studies should help the production shop to adjust nimbly to the changes in the product mix as the nature of incoming streams changes. The shop should be able to determine what kind of strategies and inventory levels should be used to cope with the changes in rework levels. It should be able to decide the optimum levels of buffer sizes suitable for different scenarios.

Decision Variables

One of the key achievements of the thesis is to identify the major parameters that affect the performance of the buffer in the described situation. This helps the user to keep track of those factors and keep them under control in order to achieve the desired performance.

From the different simulation runs the major factors that affect performance the most were identified.

1) **Probability Of Going Out of Ssequence**– This is determined by the current conditions in the paint shop. As explained earlier the production rate of a paint shop fluctuates. The probability of going out is expressed in terms of the percentage of cars that are rejected at the end of the paint shop and go in the rework shop.
2) **Buffer Size-** This is the capacity of the intermediate buffer in terms of the maximum number of cars that it can hold at a time.
3) **Selection Logic**- Selection logic is the objective function that governs the discharge of different models from the selectivity bank. They are simple mathematical formulas which will be described later in the chapter.

Performance measures

The definition of performance measure depends on objectives. In one case it might mean the keeping the buffer size as small as possible. In another it might mean the running of the line with most balanced utilization of people and machines. In still another it might mean keeping a constant and minimum throughput time.

The main performance measure chosen in the study is the leveling performance. The leveling performance is calculated by finding out the discrete individual values of spacing between two successive cars of same type and then finding out standard deviation of those values. Standard deviation for these values basically measures the variability of this spacing value around the mean. The smaller the value the more consistent is the spacing better is the performance in terms of leveling. Clearly leveling is the key performance measure of selectivity bank. If it can do it with a small buffer size, that is better.

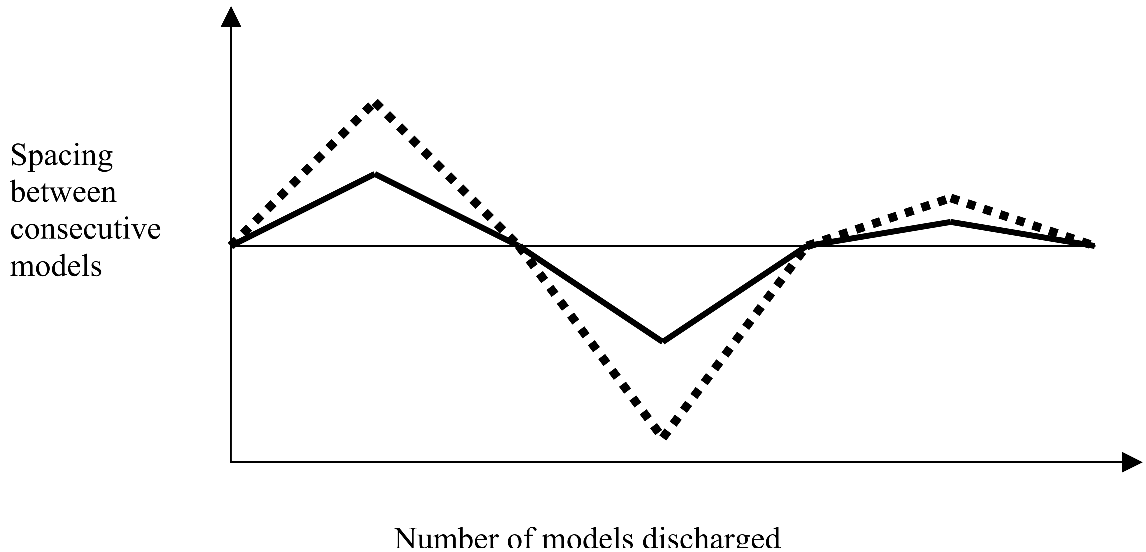


Figure 4.1: Significance of deviation of leveling

For example Figure 4.1 shows leveling obtained in two different scenarios. Both the series have identical values of mean but standard deviation of the dotted series is higher which is not good in terms of leveling. The mean in the long term is determined by the long term proportion of the models and it approximately equals the demand for that model.

The series represented by continuous line follows the mean more closely, which is what is desired.

In order to aggregate the performance of all the models in terms of a single value three more performance measures are defined.In order to weigh different models on a common basis there demands are aso taken in to consideration. They are

Q_i = Demand for model I

σ_i = Standard Deviation for model

μ_i = Mean of spacing values.

1) Demand Weighted –

$$Performance = \sum_{i=1}^{n} Q_i \left(\frac{\sigma_i}{\mu_i}\right)^2$$

2) Equally Weighted

$$Performance = \frac{1}{n}\left(\sum_{i=1}^{i=n}\left(\frac{\sigma_i}{\mu_i}\right)^2\right.$$

3) Inverse Demand Weighted.

$$Performance = \sum_{i=1}^{n} (1 - Q_i)\left(\frac{\sigma_i}{\mu_i}\right)^2$$

Note that the first performance measure reflects a priority of leveling a high demand models and the third performance measure reflects priority of leveling low demand models.

Another way of quantifying the performance is by using some economic measures. This can be done by using some relationship that converts the leveling performance into an equivalent cost penalty. This relationship might be linear or exponential or logarithmic. Giving a dollar value to the performance is always the best way for quantifying the gains achieved through the changes. It is easier for the managers to decide on the basis of difference in cost rather than difference of 0.5 in leveling because this abstract number has no economic meaning with it. Along with this, penalties can be charged for each violation of assembly constraints. Nonetheless, cost differentials associated until changes leveling are elusive to define.

Assembly Constraints

Assembly constraints are rules that prevent certain sequences of models on the assembly line. For example the models might be classified into high and low work content models. An Assembly constraint might prevent a tough model from being in order to prevent dynamic imbalance in the line

In the simulation model these constraints are entered in the form of “At Least” constraints. These constraints restrict the consecutive spacing of a particular model by the “at least value “ for that model. This means that if the “At least” constraint for a particular model K is specified as S then the simulation model keeps track of the number of vehicles sequenced after the last occurrence of model K. Model K is not discharged unless S number of other vehicles are discharged from the selectivity bank. In the absence of any such constraint the models are given freedom to discharge anytime the need arises. Because of the leveling nature of the objective functions, the value of spacing is maintained close to the natural spacing for these models (e.g.The spacing is maintained at 4 if the demand for the model is 25% in absence of any constraints.)

Assumptions

To create a generalized model without unnecessary details, several assumptions were made. Following is the description of these assumptions and the justification explaining why these assumptions do not unrealistically change the behavior of the system.

In the actual system the cars move over a conveyor and many other transportation systems. All the details of the conveyor are not modeled because those details were not going to help more to the main objective of the study. It takes time to transport a vehicle from buffer to assembly shop. But in the simulation model it goes there immediately. There is no time lag between the selection and the discharge. This assumption is not unrealistic because the variation in the time associated with this transportation is same for all models all the time. So even if the major parameters of the model are changed the distribution of this transportation time remain the same. Consequently the performance measures are not affected by including this detail.

In the real system the quality check takes place at several locations so cars go off line and come back into the main line at several locations but the main quality check takes place at the end of painting process where the cars are checked under a lighted booth. At this place depending upon the intensity of quality problem, the cars are sent back to major repair or spot repair. The percentage of rejected cars varies. To simplify the model it was assumed that the quality check takes place at a single location. Everything that goes off line eventually comes back into the line. It is very rare that a complete body is rejected. So the rejection at several locations can be aggregated into a single numerical value.

As mentioned above the repairs are of two types: major and spot. The nature of repairs for the paint problems are very diverse so sometimes it takes very short time to make a simple repair and sometimes it takes very long to repair. So the repair times are completely randomly distributed. Hence it is valid to assume that the repair times are exponentially distributed.

As the rejection rate at the end of the body shop is very small it was assumed to be zero. So one car comes every 1 min (or whatever the takt time of the system may be). Also the leveled stream of the cars is not much disturbed, so a sub-model was created that generates a leveled sequence of cars and in turn models the output from the Body shop.

The selectivity bank is generally a multilane structure. Each lane can carry any type of model. It is ideal to have one lane dedicated to one model so that any model type can be easily accessed, but it is not usually the case in practice. Sometimes a single lane can be shared by 2 or more low running models. This avoids the underutilization of lanes by low running models. To simplify maters, it was assumed that one lane is dedicated to one model. It is easy to accommodate the condition to send more than one model to a single lane but then the simulation model becomes customized for that configuration only.

Most of the new automobile plants these days are highly automated. The sensors, relays and barcode readers are spread throughout the plant. They collect the information about the current status of the plant and send it over to the MIS(Management Information System) or DSS (Decision Support System.) in real time. So the management always has the current picture of the system. It was assumed that information system is prevalent in the operations under study. This information system will collect and store the information regarding the flow of cars through the selectivity bank. This should enable the decision system to ask questions such as "Which models are currently stored in the selectivity bank?" " How many cars of each type are currently available?", and " What are the demands and productions of individual models?" Based on this information the DSS should be able to calculate the values of certain parameters for car selection. Also it is assumed that all this happens in real time.

Mathematical Formulation

All the heuristics in the model are in terms of measures that indicate deviation of the state of the system from an undesirable state, e.g. too few units of a particular model have been discharged or too many units of a particular model are in the selectivity bank. When making the decision regarding the choice of next model type, the decision maker logic in the simulation model checks the current values of the measures for each of the models. The car model whose current measure is currently has relatively highest value is chosen as the next unit for the discharge. The rational is that discharging this model type will be a god choice to reduce the deviation and thereby bring the system closer to a desired state.

Define,

m = *Number of models*

n = *Number of cars discharged*

T_j = *Target loading for model j*

A_j = *Actual loading for model j*

S_j = *percentage of cars of model type j in selectivity bank*

D_j = *Deviation of loading for model j from its ideal value*

Q_j = *Ideal demand for model j*

SR_j = *Percentage of cars of model type j in selectivity bank plus cars in*

Subject to constraint

Sp_j = *Spacing constraints for model j*

CSp_j = *Current value of spacing constraints for model j*

To satisfy a constraint

$$CSp_j \geq Sp_j$$

Note that,

$$T_j = Q_j \times n \qquad j = 1.....m$$

$$D_j = T_j - A_j$$

List of Objective functions

1) D_j

This objective function decides the model based on the deviation of those models from the target production.

2) $D_j \, x \, S_j$

Here the objective function is weighed based on the percentages of the model available in the bank. So if the deviation for a particular model is small but the inventory of that model is accumulated in the selectivity bank then the this function will increase the priority of that model. This function will try to keep relative balance between the percentage demand for the model and the corresponding inventory of that model in the selectivity bank.

3) $D_j \, x \, \frac{abs(Q_j - S_j)}{Q_j}$

This objective function ranks the model types based on the absolute difference in the demand for the model and the percentage of that model available in the selectivity bank.. This is not a good objective function and the reason for it will be explained later in chapter 6.

4) $D_j x \frac{S_j}{Q_j}$

In this objective function the deviation is weighted by the ration of Sj/Qj . Most of the time Sj is approximately equal to the Qj. So this function is expected to behave as the function 1

5) $\frac{D_j}{Q_j}$

This function is designed to give higher preference to the low running models This is evident from the fact that. at the same value of Di, as value of Qi is small for low running models, they are always given higher priority during discharging decisions.

6) $\frac{S_j}{S_j - Q_j}$

This objective function puts the difference between the percentage in the selectivity bank and demand in the denominator.. Again as Sj will approximately equal to Qj and the function is expected to perform similarly as the function 2.

7) $D_j x \frac{SR_j}{Q_j}$

This particular function takes into account the cars in the selectivity bank as well as the cars in the repair bank. This basically increases the time window width of the heuristics. Data needs to be collected from repair bank as well. This enables the system to take decision based on current status of a large part of system. This heuristics is expected to reduce the size of selectivity bank for achieving the same amount of leveling.

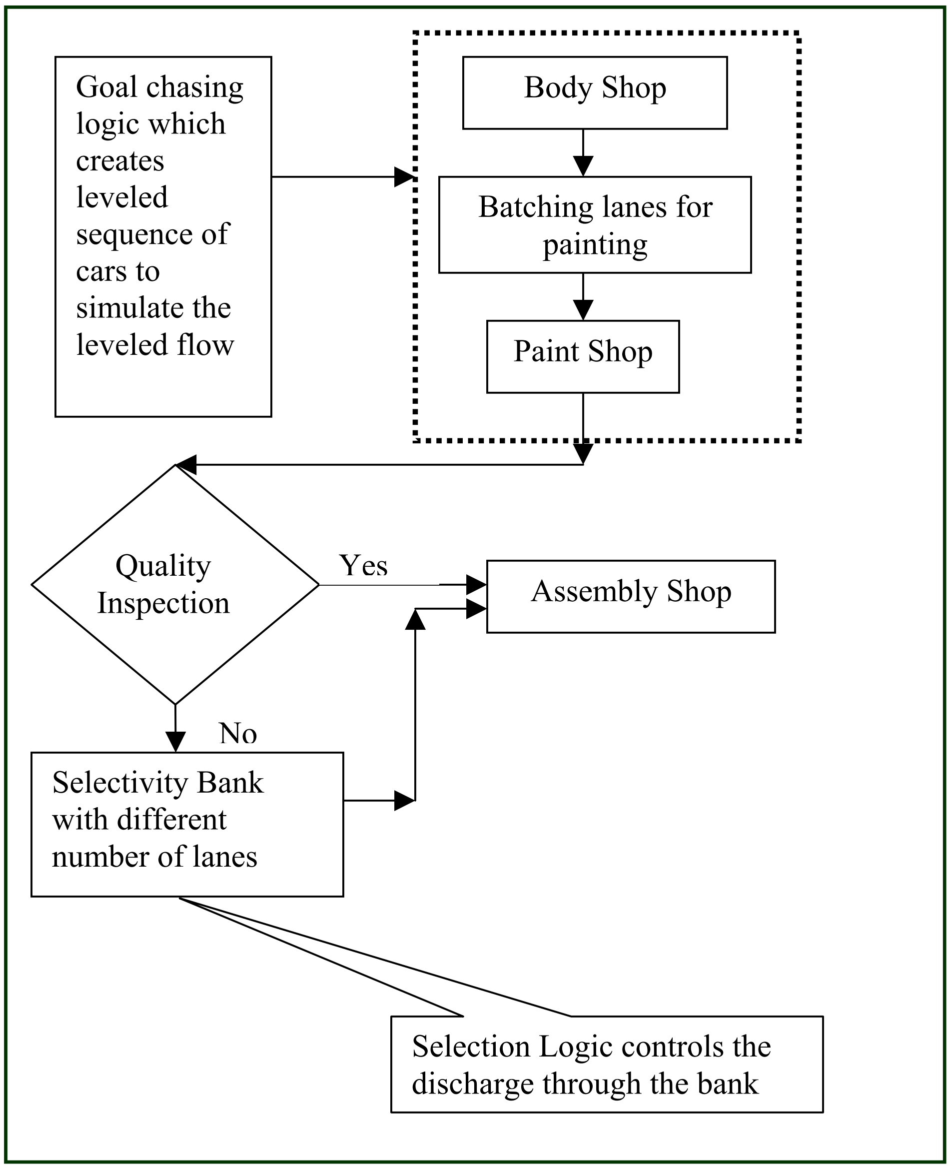


Figure 4.2: Overview of the simulation model

Chapter 5: Experimentation/Analysis/Simulation Runs

Variance Reduction

One of the objectives of the study is to compare performance of the different selection rules as regards to leveling. The comparison of rules should be made under the same conditions. This means that the input sequence of cars should be the same for different rules. Also the same cars should go offline and they should spend the same amount of time offline, even though they are randomly assigned they should be uniform over the runs. This helps to ensure that any difference in the observed performance can be attributed to the way each rule is working and not because of the difference in the random assignment of cars going offline and the delay they encounter there.

This is accomplished by assigning a series of random seeds to all the replications. Same series of seeds is used for another set of replications. This ensures that the same sequence of random numbers is generated and the same cars go offline and for the same duration of repair time.

The model attributes of the car are determined by a goal chasing logic. If the goal chasing percentages are constant this logic generates the same sequence of different models of cars. The logic designed for generating out the cars in a leveled manner is stable, so for a given set of conditions which is the demand pattern for models it will keep on generating a constant pattern of cars. For example if the logic generated out a pattern say 1-3-2-3-4 for the first 5 cars that matched Qj for those models, it will repeat the same pattern for rest of the simulation provided that the demand percentages for different models remain the same.

To achieve variance reduction, first the locations where the random numbers are generated are identified. The 2 locations where there is a need to control the sequence of random numbers are as follows

1) The first block where it is decided whether this particular car will go out or not. This decision depends on the particular value of random number generated and the current rejection rate. For example if the current rejection rate is 20% and the value which is generated by the uniform random generate between 0 and 100 is less than 20 then the car is rejected. The same car would be rejected in another set of simulations where a different logic is used but where other conditions like probability and buffer sizes are same.
2) This rejected car undergoes a repair. There is a randomly assigned time with this repair. Using the variance reduction the times associated with this repair are also the same if the fifth rejected car undergoes a repair for 23 minutes in logic 1 it will undergo repair for the same amount of time when the second logic is used.

The selection logic controls the output from the buffer bank and input to the buffer is controlled by the rejection and delay. So each logic is given a fair chance of selecting cars from the same input stream.

Need of experimental design

As there are so many different combinations of model parameters are possible, it is very time consuming to conduct all the experiments. In order to concentrate on specific issues or to answer certain questions some of the values of variables are not as useful as others. Keeping this in mind following design of experiments was formulated for this case study.

Table 1, Experimental Design

Number of Models	Model Distribution	Buffer Size	Probability of Rejection
Low (3)	Low	Low (30)	20%
Medium (6)	Medium	Medium (60)	40%
High (9)	High	High (90)	60%

Each parameter is varied in different levels Low, Medium and High. The corresponding values for these parameters are listed in the above table. The model distribution is included in order to study the performance of high runners and low runners under different conditions. It is necessary to study if certain rules are good or bad for low running and high running models. Demands for the individual models determine the model distribution in the experiment. The demands are plotted on the graph in descending order to visualize the distribution. If the graph has a steep slope then the model distribution is said to be high giving a high difference between a high running model and low running model. If the graph is almost flat then the model distribution is said to be Low.It implies that the demands for all the models are almost same. The medium stands in between the two.

Table 2 Demand percentages of low number of models

Model Number	High Distribution	Medium Distribution	Low Distribution
1	60%	50%	36%
2	35%	30%	33%
3	5%	20%	31%

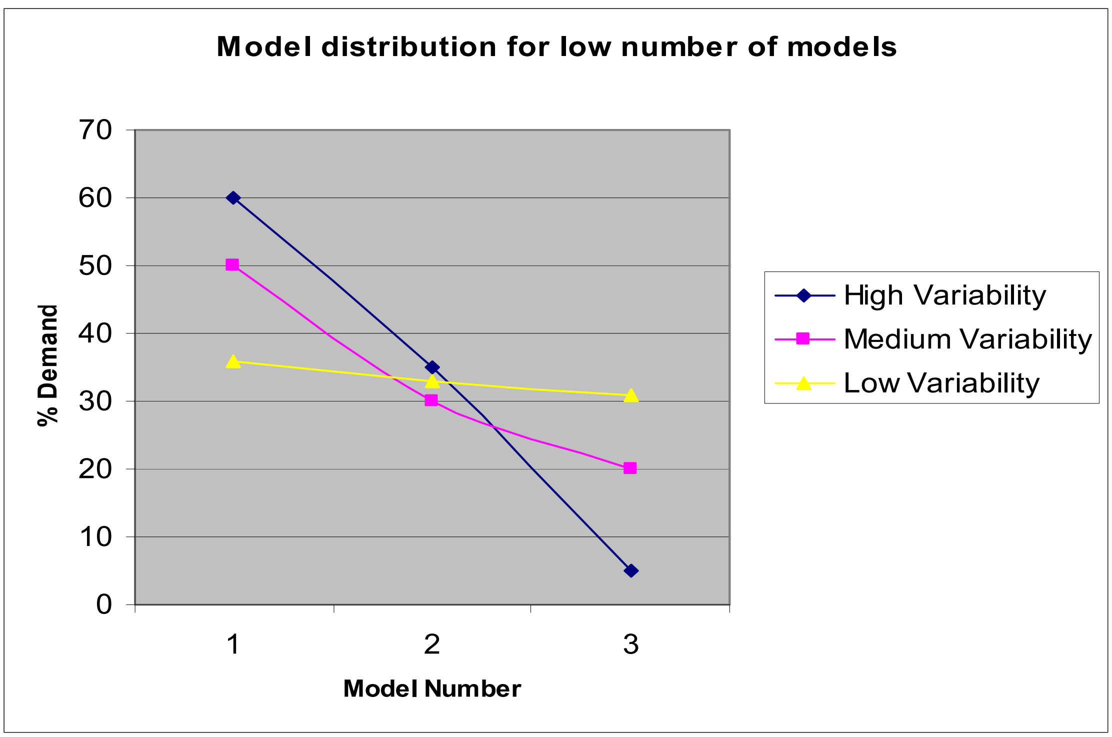


Figure 5.1: Graphical representation of model distribution for 3 models

Table 3 Demand percentages of medium number of models

Model Number	High Distribution	Medium Distribution	Low Distribution
1	47%	33%	20%
2	25%	19%	19%
3	15%	15%	17%
4	7%	12%	16%
5	4%	11%	15%
6	2%	10%	13%

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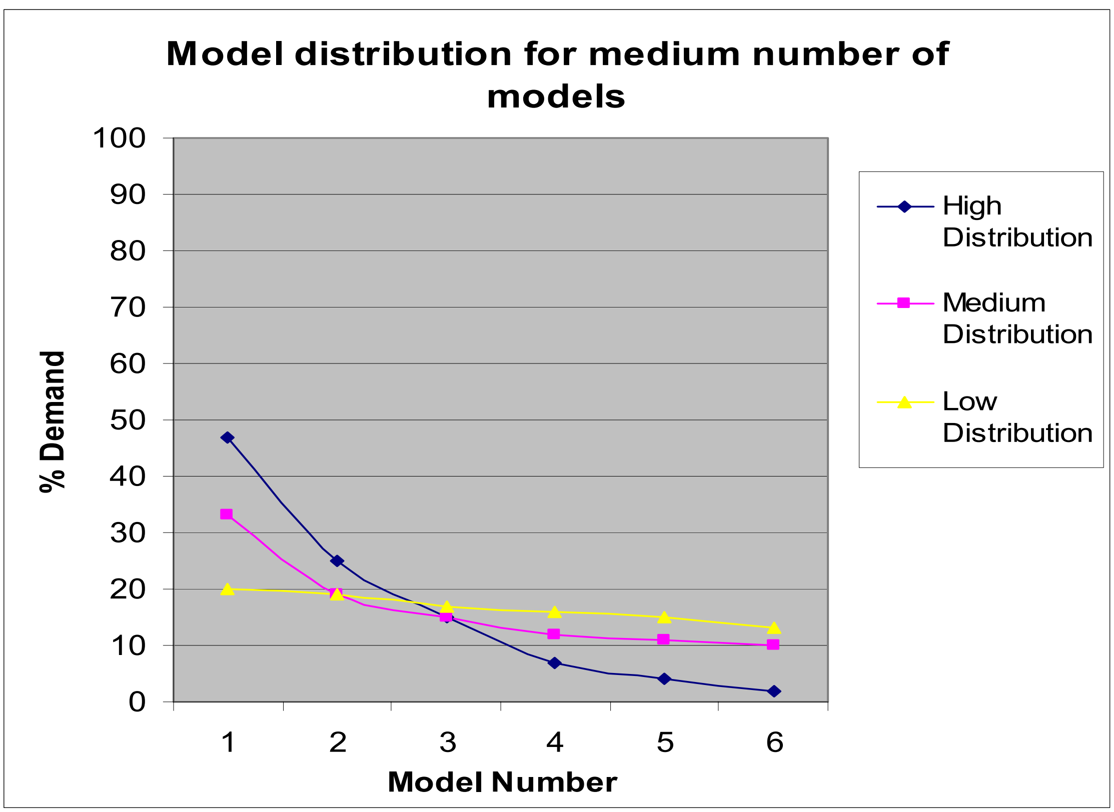

Figure 5.2: Graphical representation of model distribution for 6 models

Table 4 Demand percentages of high number of models for different experiments

Model Number	High Distribution	Medium Distribution	Low Distribution
1	39%	24%	16%
2	18%	17%	14%
3	12%	12%	13%
4	10%	10%	12%
5	7%	8%	11%
6	6%	9%	10%
7	5%	8%	9%
8	3%	7%	8%
9	2%	5%	7%

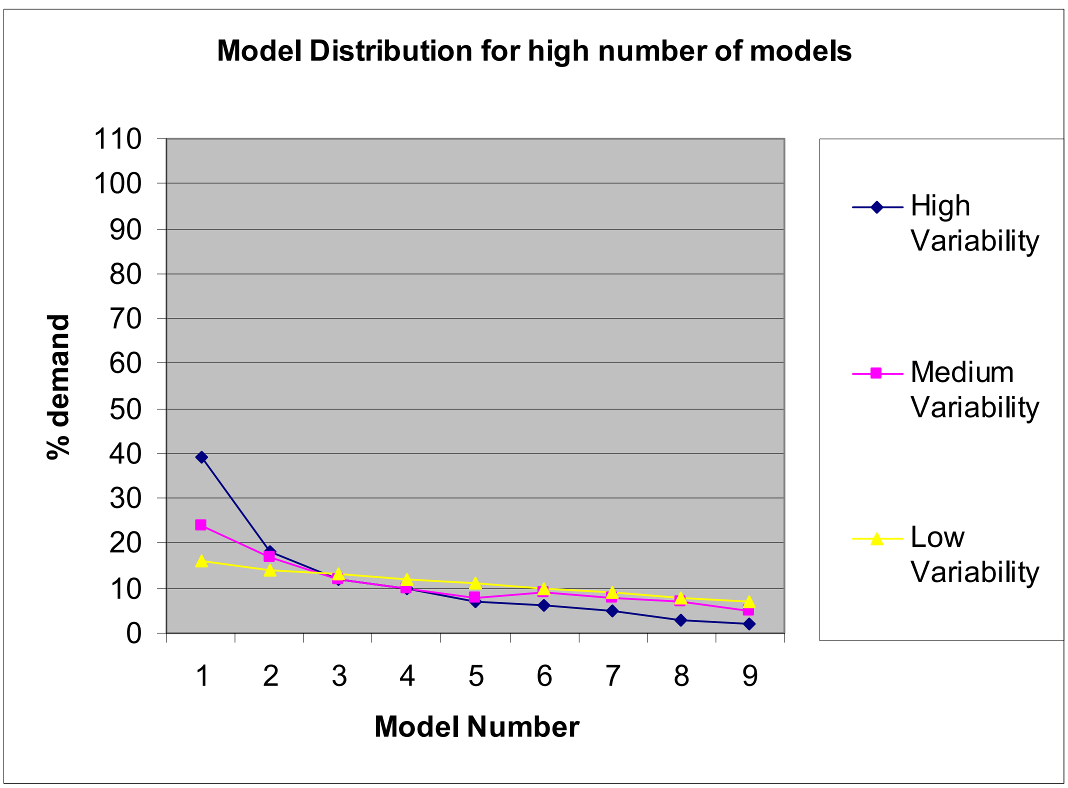

Figure 5.3: Graphical representation of model demands for 9 models

The buffer size is varied in two ways. In some experiments the buffer size is assigned values from the above tables. But in some experiments the buffer size is reduced continuously form a large value with a small decrement. The small decrease allows the study to exactly find the point from where the buffer size has no effect on the performance.

The probability of rejection is varied from a reasonable value of 20% to a very high value of 60%. The goal is to see how quality of painting affects leveling.

The figure 5.4 graphically describes the input and output parameters associated with the study. Some of the parameters like TAKT time are not considered for the case study. But they need to be incorporated in the study for experimenting with different system. There is a possibility of relation between the TAKT time and the time associated with the repair.

Calculation of some of the outputs such as standard deviation of spacing is incorporated in the simulation model and the user can find it in the output file generated. The equally weighted, demand weighted and inverse demand weighted functions need to be programmed in the spreadsheet application.

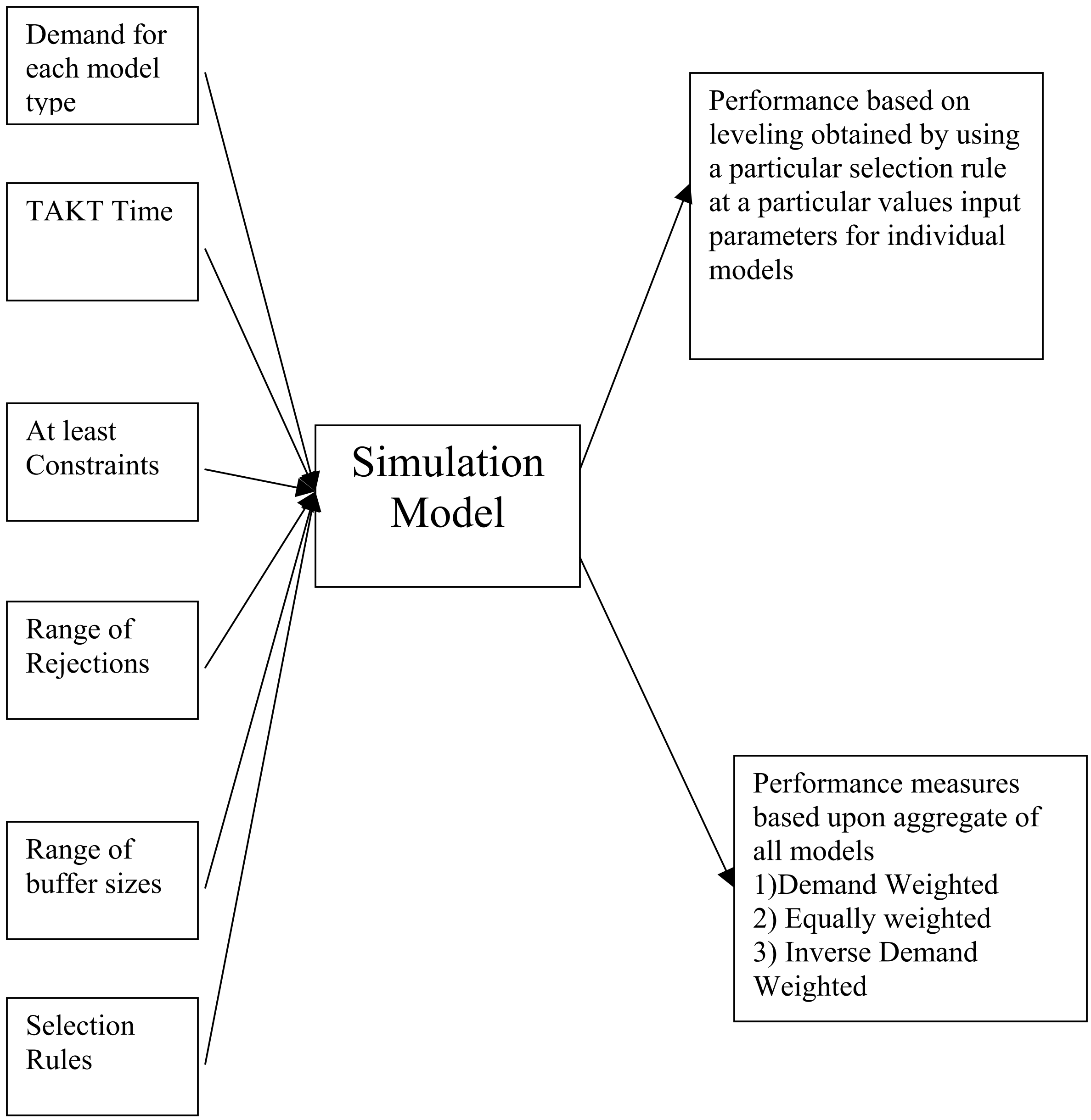

Figure 5.4: Experimental Parameters

Description of GUI

Figure 5.5 shows the Graphical User Interface developed for the model. This enables an user to enter the input information in an easy way. The main parts of GUI are as follows.

1) Number of models

2) Percentage of demands for these models:

3) Constraints

4) Range of values for probability of rejection (Minimum –Maximum and Step Size)

5) Range of buffer sizes (Minimum –Maximum and Step Size)

All the above inputs are plant specific. So the user has to conduct a study to precisely get the values of these parameters. The number of models can be determined by the major variations in the job specification from assembly point of view. Demands for the models can be obtained from the records in the marketing department. The constraints can be designed by dividing the models into high work content and low work content models. Probability of rejection depends upon the reliability of the equipment in the paint shop and the painting process overall. The minimum and maximum values of the probability of rejection can be obtained from the historical data maintained in the paint shop. Buffer size is the capacity of selectivity bank. In order to see the gradual effect of reduction in the buffer on the performance of the system small step size should be given. But small step in buffer size increases the number of experiments and consequently the simulation time. Given all this information the VBA code built in the model takes care of calculating the number of replications that need to run in order to complete the study. The model also writes the necessary output to a text file for the post simulation study.

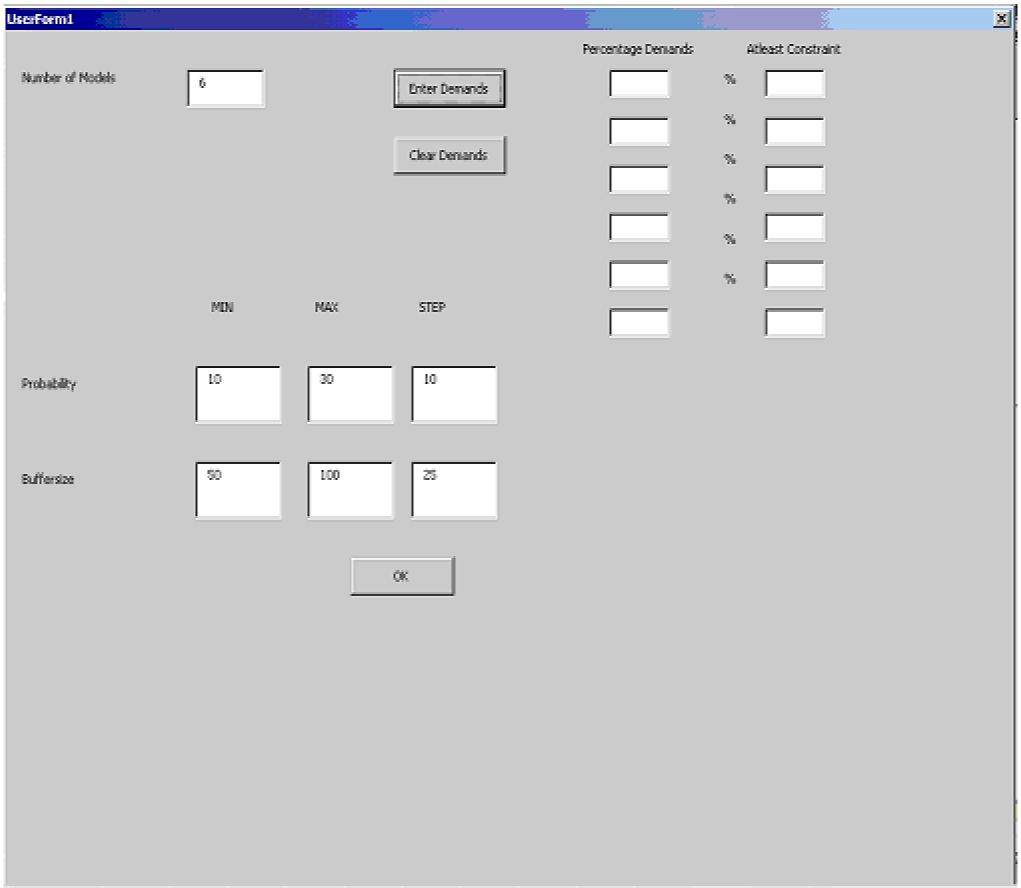

Figure 5.5: Screenshot of GUI

Chapter 6: Model Behavior / Conclusions for the case study under investigation.

The Effect Of Increase In Buffer Size On The Leveling Performance

As the buffer size increases, the leveling performance of the system increases. This phenomenon is irrespective of the selection rule being used. This is because of the fact that with larger buffer size the probability of finding the most ideal model increases. So at every discharge it is easier to follow the ideal leveling without violating any constraint. Even though this is obvious, it is not obvious what this buffer size is, just by knowing the value of all the parameters. As it can be seen this threshold value of buffer size varies from case to case. It depends heavily on the external factors in the simulation model. In the case study it was found that the selection rule makes a bigger impact on this threshold value than any other factor. Figure 6.1 to 6.4 shows this effect.

It is a goal in the Lean manufacturing philosophy to reduce the WIP on the shop floor in a JUST IN TIME manufacturing plant. Reduced WIP not only saves the floor space but it also reduces the flow time of the entities. From the simulation study it is found that beyond a certain value of buffer size there is no major change in the leveling performance so there is no value added in adding more cars to this buffer. Also it is found that below a certain value of buffer size it is impossible to maintain an uninterrupted flow of cars without violating one or other constraint. It is subject of further study of relaxing constraints one by one by giving higher precedence to one constraint than other.

The tool developed gives an excellent platform to get an insight into this phenomenon and a target value of buffer size that should be implemented.

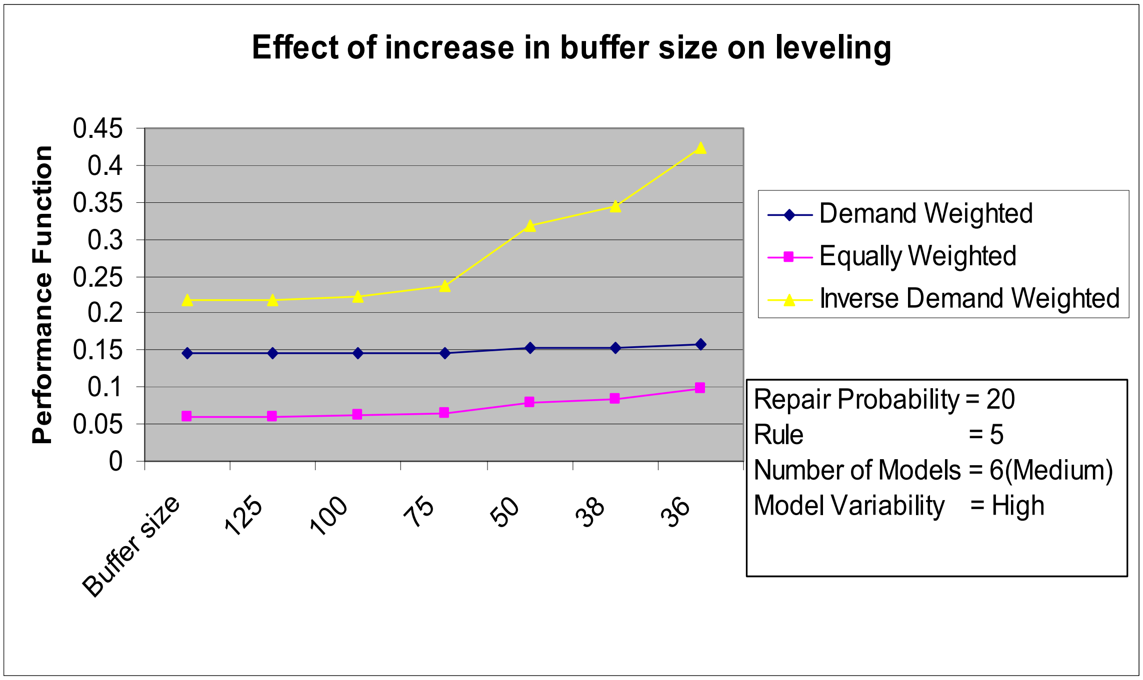

Figure 6.1: sample of performance as a function of buffer size

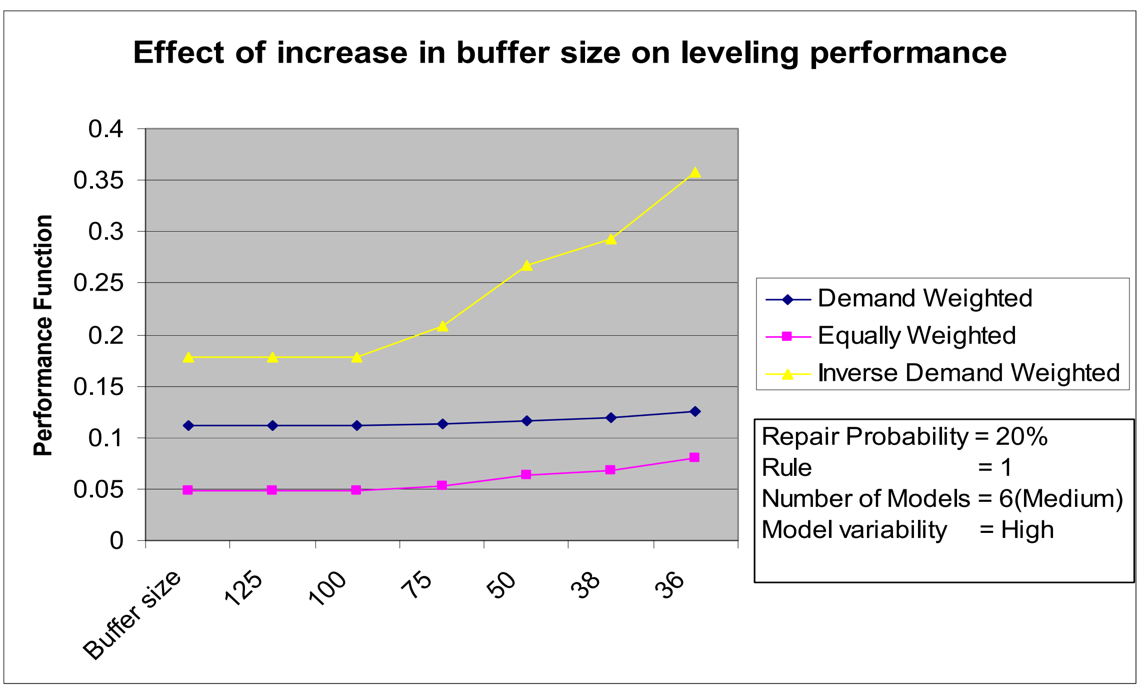

Figure 6.2 Sample of performance as a function of buffer size

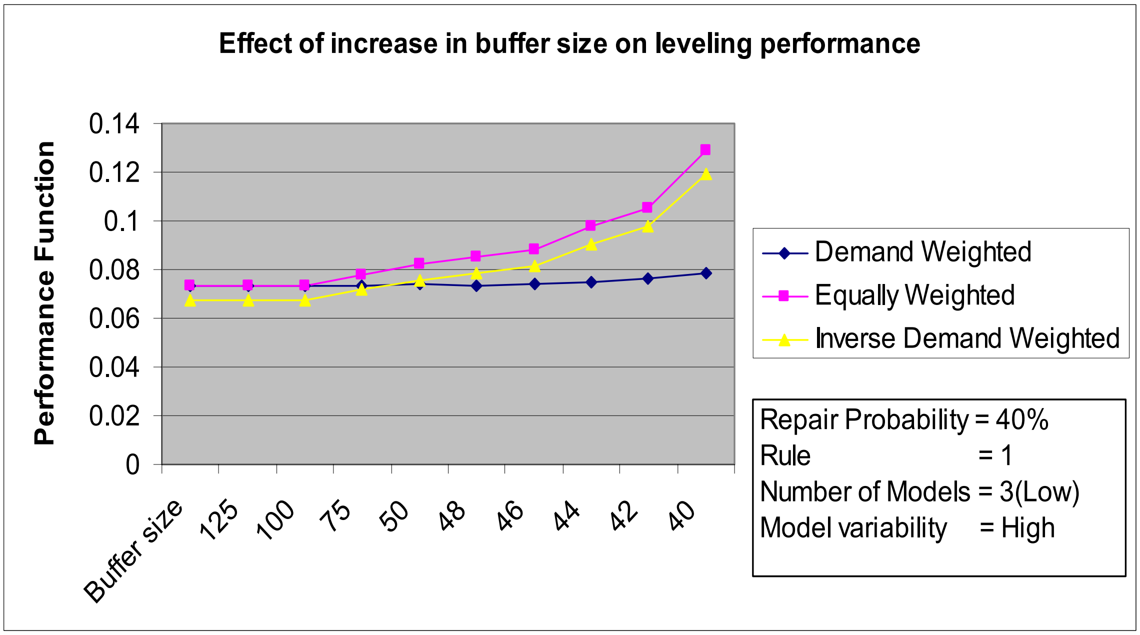

Figure 6.3: Sample of performance as a function of buffer size

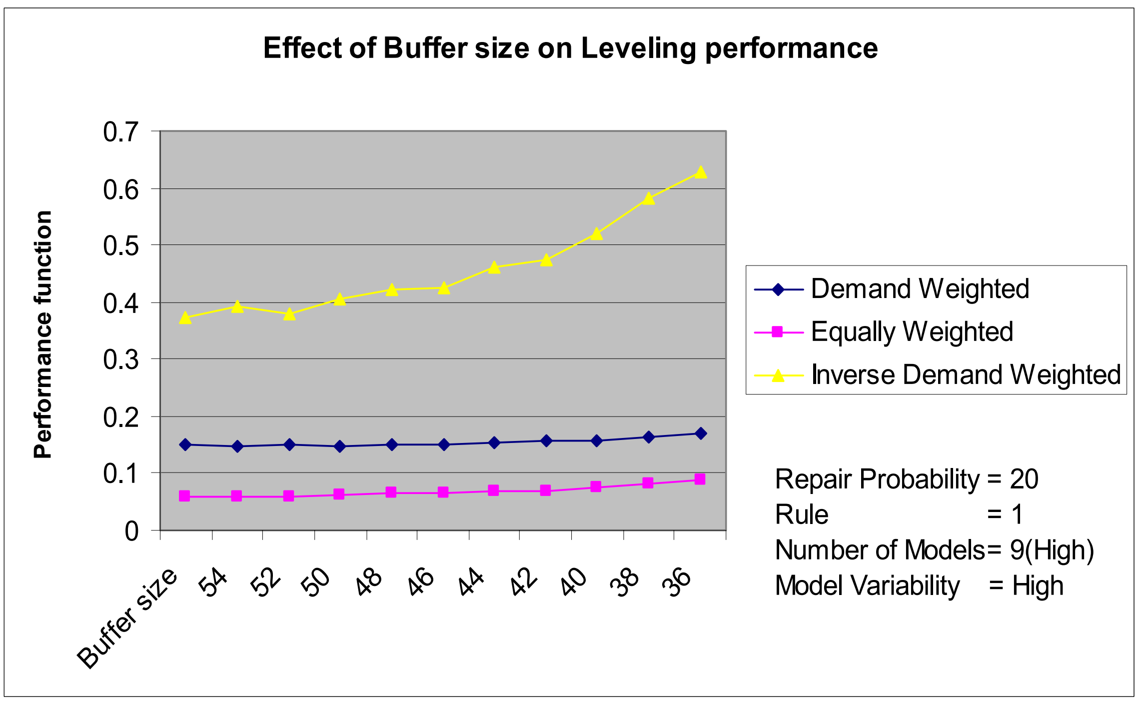

Figure 6.4: Sample of performance as a function of buffer size

Infeasible Constraints

One of the achievements of the thesis is identification of infeasible constraints. Infeasible constraints are those constraints, which cannot be satisfied. They arise because of the inherent nature of the system. A simple example of this would be, if you say at least 5 cars must be in between two successive appearance of a model and the demand for that model is 25 %, then the value of this spacing should be 5. But if such constraint is imposed on the system, then inventory of this model will be increase and will cause jam in the system. The simulation model helps to identify this kind of unpractical values of constraints.

Some of these constraints are not very obvious as shown in the above example because of the complex nature of these constraints which are not based on the model but are based on some of the model features which increase or decrease work content. As the model has sufficient animation capability, any bottleneck can be easily identified just by looking at the accumulated models at the selectivity bank.

In the study of the selectivity bank at TOYOTA, it was found that one model was getting accumulated in the bank. After analysis it was found that the constraints of not putting not more than two moonroofs in a row was the problem because the total percentage of moonroofs was more than $2/3^{rd}$ of the total demand. But this information was not readily available to the scheduler so he did not understand why he had to violate the moonroof constraint again and again.

Good rules for low running model

As you can see in figure 6.5 graph Rule 5 looks to be good for all the models . Also it is especially good for low running models such as model 5 and 6. It can be observed from the graph that models 5 and 6 register the least deviation when we use the 5th selection logic. This is obvious from the fact that the objective function for rule 5 is Di/Qi. As Qi is small for low running models the value of 1/Qi is high giving a higher priority to the low running models.

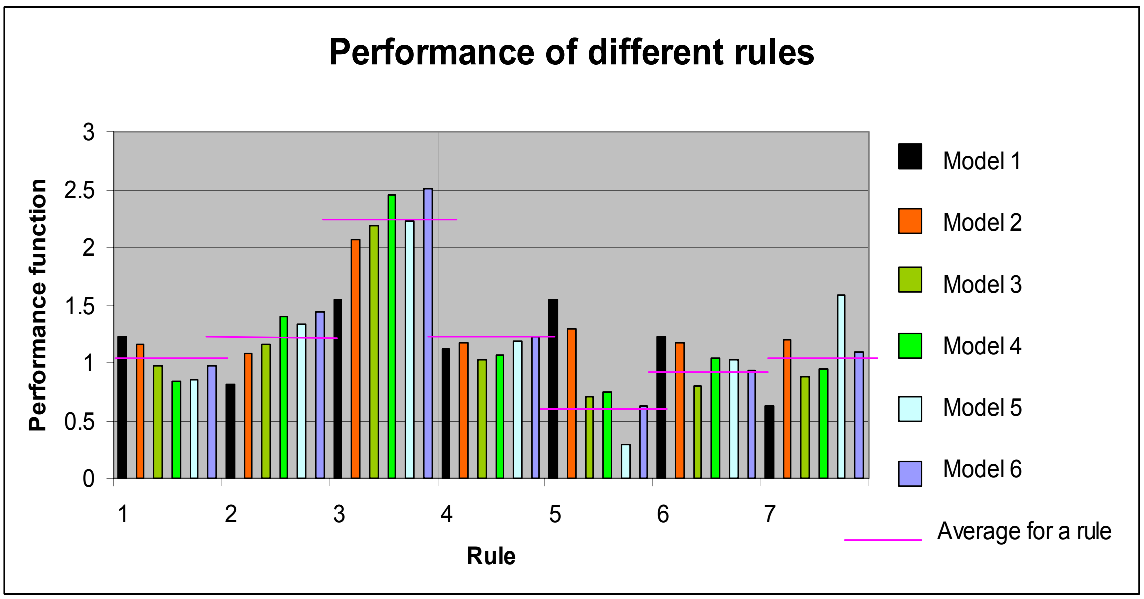

Figure 6.5: Graphical Representation of Leveling Performance As a Fucntion of Rules For Different Models

Following graphs (figure 6.6, 6.7,6.8) show the effect on the performance of low running models such as model 5 with respect to probability of rejection .The probability of rejection increases from 20 to 40 to 60 in the following graphs.

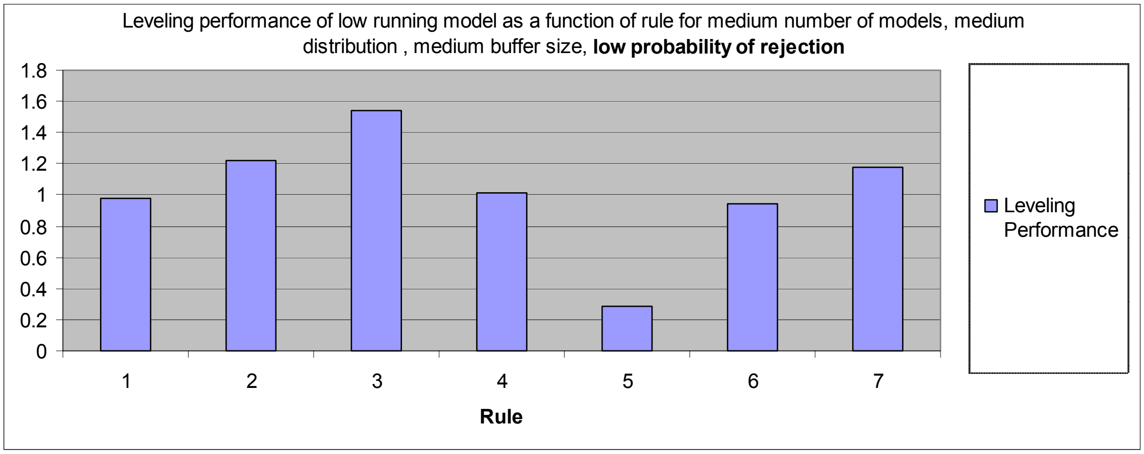

Figure 6.6: Relative Performance of Different Rules

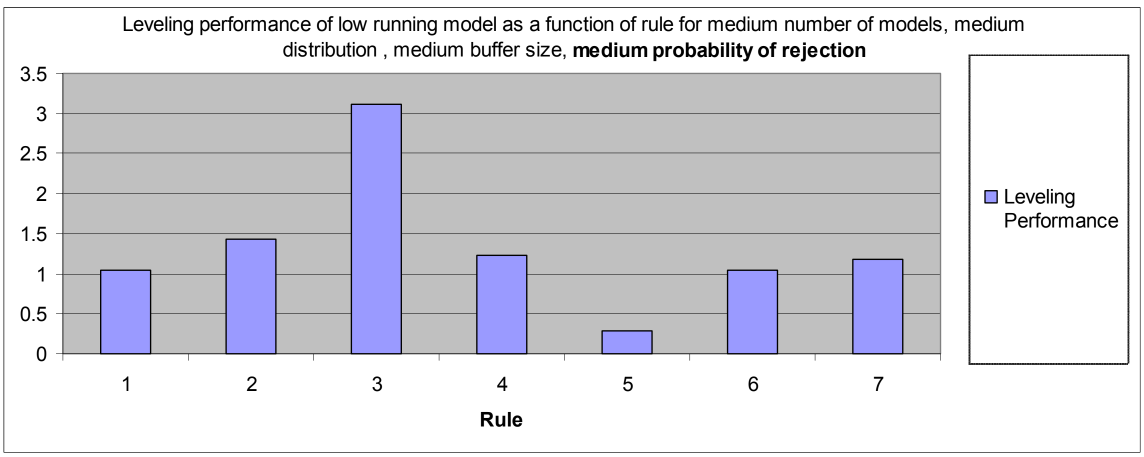

Figure 6.7: Relative Performance of Different Rules

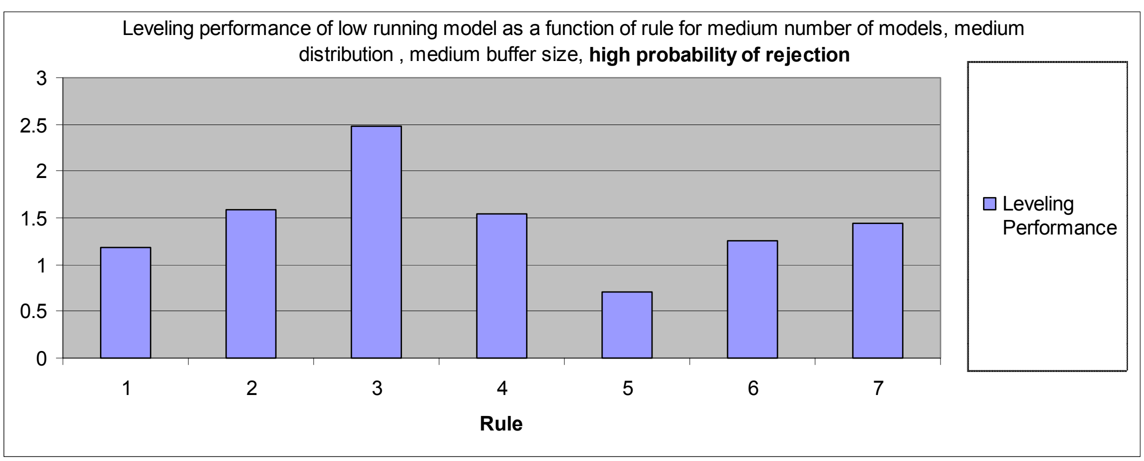

Figure 6.8: Relative Performance of Different Rules

Effect of increase in the probability of rejection on leveling

As the probability of rejection increases the average inventory of each of the models in the selectivity bank decreases. This reduces the probability of finding the best match in the buffer. The following graph shows the change in inventory of some models as the function of buffer size.

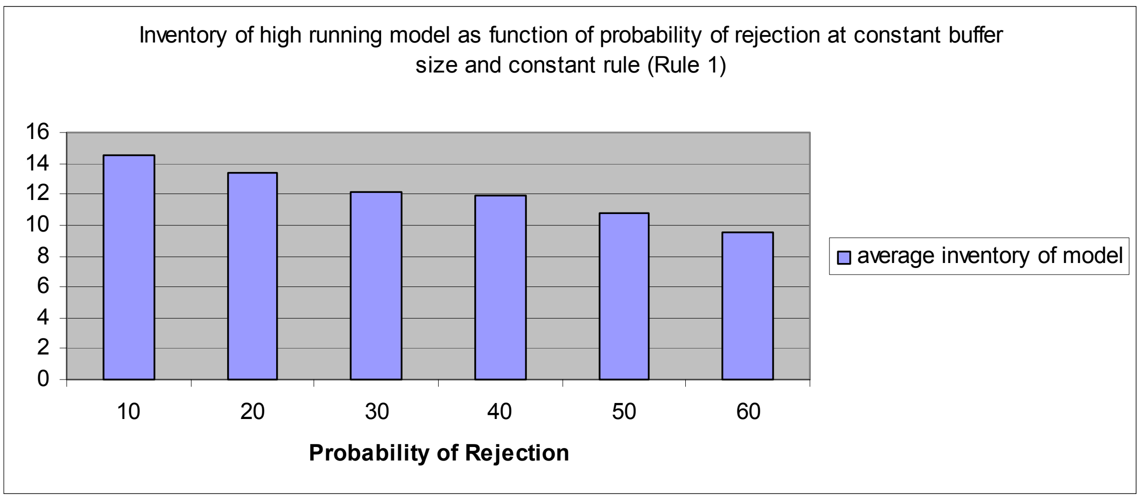

Figure 6.9: Probability of Rejection Vs. Average Inventory for High Running Model

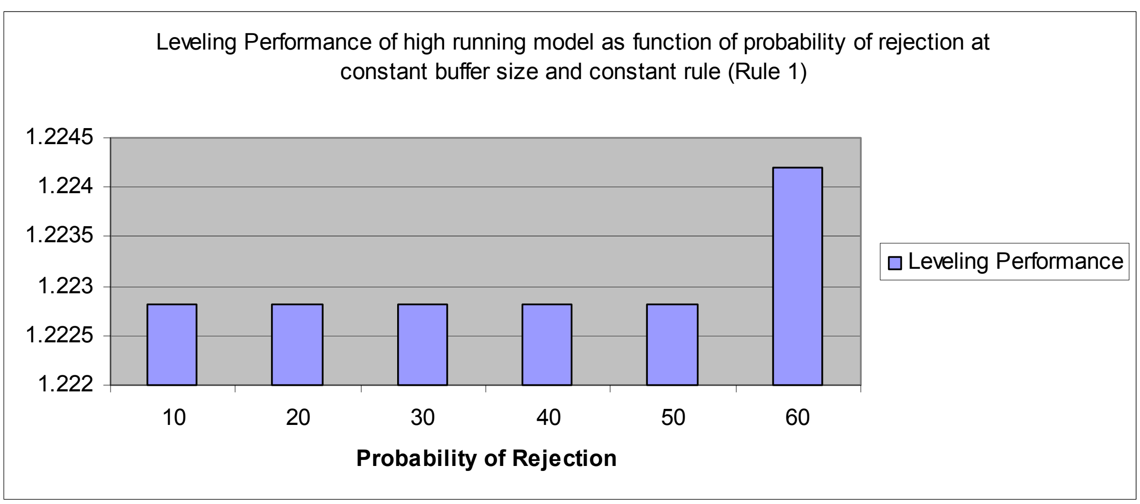

Figure 6.10: robability of Rejection Vs. Leveling Performance for High Running Model

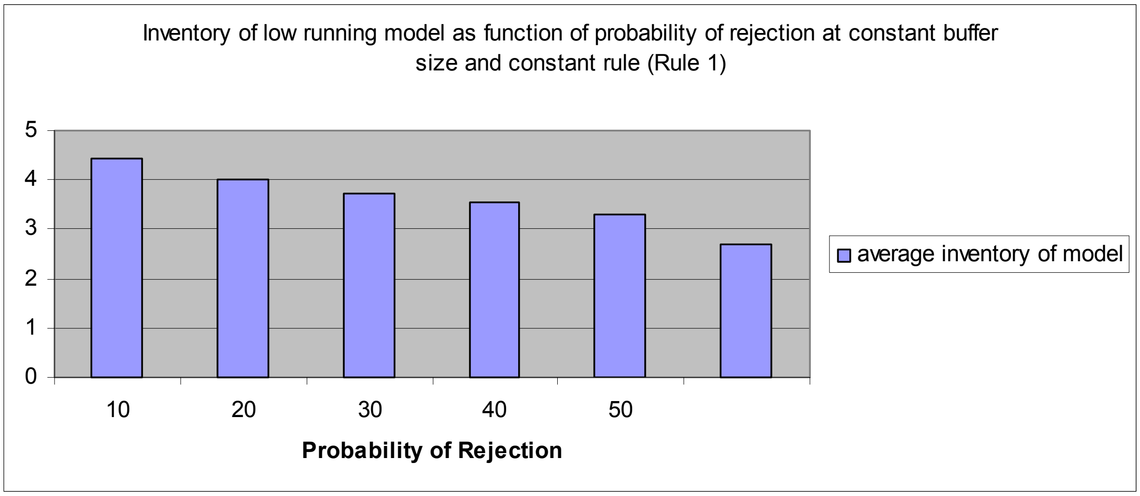

Figure 6.11: robability of Rejection Vs. Average Inventory for Low Running Model

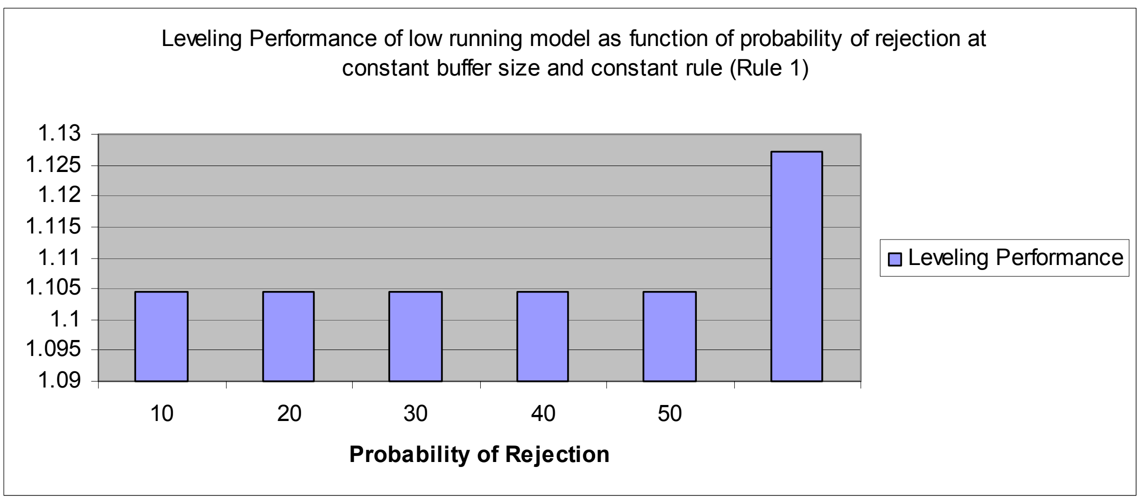

Figure 6.12: robability of Rejection Vs. Leveling Performance for Low Running Model

Performance of rule 7

The figure 6.13 shows performance of Rule 7 as compared to other rules at high probability of rejection .The rule performs well because it takes care of some other parts of the system such as the models in the repair bank as well as the models that are waiting to be discharged. The goal chasing percentages are updated by considering all of the above mentioned parameters. This rule was developed based on the insight gained in the Toyota study. As the state of the system changes dynamically during the operation, a rule which is more dynamic in nature works better than a static one. The rule provides a dynamic feedback to the controller of the system and keeps correcting the discharge to the optimum level.

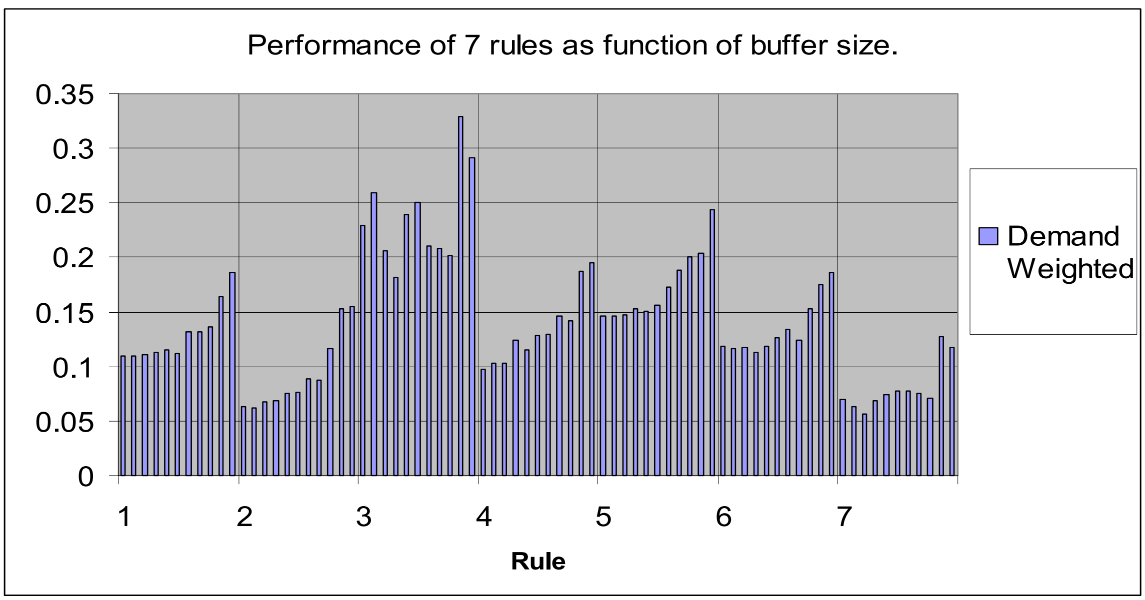

Figure 6.13: Relative Leveling Performance of Different Rules As Function of Buffer Size

The value of buffer sizes decreases from 70,60,50,40,38,36,34,32,30,28,26, between rules

Effect of atleast constraints.

The graphs in figure 6.14 and 6.15 are constructed after conducting two simulation experiments In one simulation experiment spacing for model 4 is not constrained. In the other experiment the spacing for model 4 is constrained very close to its ideal spacing. This will basically result in spacing model 4, close to its ideal spacing most of the time. So the value of deviation is reduced a lot. Similar observations were made for other models as well.

But there is another interesting observation that has been made. When one or two models are constrained strongly, they of course do well in terms of leveling, but it is achieved at the expense of deterioration in leveling of other models. This can be explained by the fact that it is not possible to remove the randomness in the model or bad qualities in the system. Efforts made for leveling one kind of model will be transferred to other models.

But this observation is good for low running models. The fact, many times the low running models will be the most important ones from the point of leveling because sub assemblies for the low running models may not be always available on the assembly line, and so it may present a problem if these models are scheduled successively.

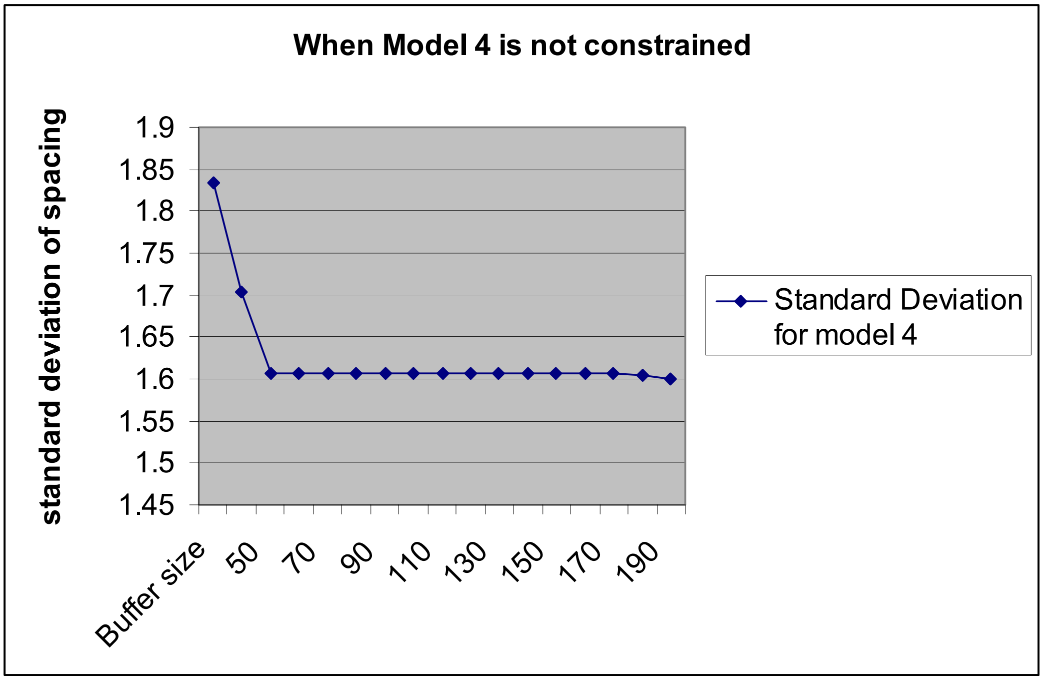

Figure 6.14: Leveling Achieved Without Constraining model 4

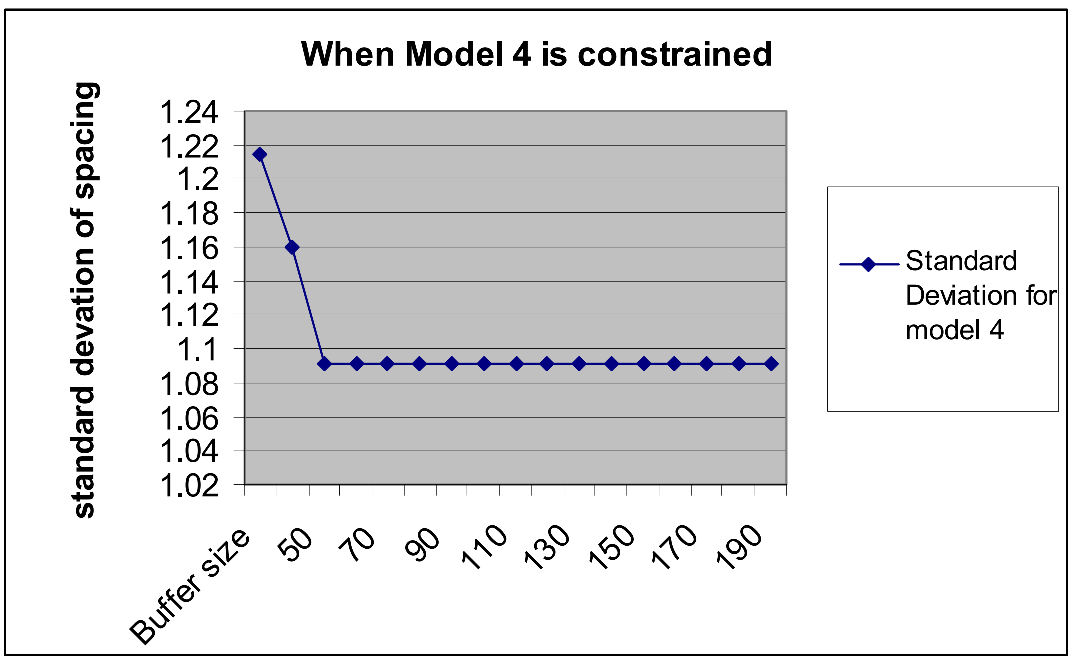

Figure 6.15: Leveling Achieved after Constraining model 4 Strongly

Cylic and Low Performance of Rule 3

Objective function for rule 3 is

Dj x abs (Qj – Si) / Qi

This is the worst kind of objective function that we considered. Ideally Qi and Si should follow each other closely to make sure that the cars are discharged in a proportional manner. Qi is constant in the model and Si keeps on varying. So if Si starts falling below its ideal value then the discharge for the model i should be restricted. But according to this rule, even though Si starts falling down then the value of Qi-Si will increase. This will result in increasing the discharge chances of that model. On the other hand when Si starets increasing above Qi, then it behaves as intended. This can be summarized in the following figure 6.16.

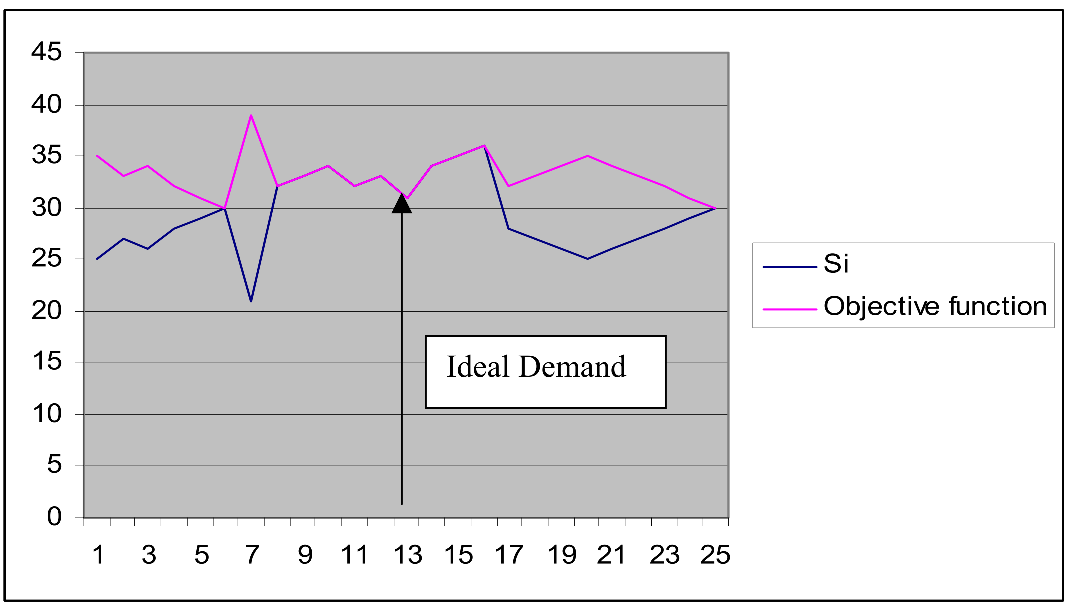

Figure 6.16: Cyclic Performance of Rule 3

Observed Findings

The simulation tool which is developed for this thesis helps to answer some questions of the planner or the scheduler of the system like" How to provide the assembly shop with a good order sequence?"

The optimum size of buffer depends on factors such as

1) The reliability of the upstream process - If the process is very reliable then you need a smaller buffer.

2) The number of model variations - If the number of models is very large and you want to level the models over time then you need a bigger size buffer even if the process is reliable. As model options proliferate it becomes difficult to always find the right car at the right time. Bigger buffers increase the chance of making the ideal choice at all the time.

3) The sequencing rule used - There are no perfect guidelines that can be used to design the perfect selection rule and there are no rules, which are perfect. Many heuristics can be designed which can be used to make decisions regarding sequencing. These heuristics can be designed keeping in mind the objective for decision making. Some heuristics which perform well for one objective may not perform well for the other objective, It is difficult to come up with some rule that can be universally used to achieve some objective. Even the same rule which is proven to be effective in one configuration of the system may not work well for some other configuration of the system for the same objective.

For low running models a small spike in the incoming stream does not affect the leveling performance. Performance of low running models is affected only when the spikes are really big. This is evident from the fact that low running models are required to discharge after a long time so if no car of this model type is received in long time then it is reflected in the output. This information can be used in prioritizing the repair work . If the controller finds that, the time for discharging a low running model is approaching but there is none available in the selectivity bank but there is one in the repair bank then the repair work of this model can be expedited.

In case of low number of models a good leveling is obtained despite an increase in the rejection or decrease in the buffer size. This can be explained by the observation that, when the number of models are low, the chances of having all the models in the bank at all the time is high , even the low running models.

As the above observations are based on simulation of various configurations, they can be used as general rules by a designer of the system of similar configuration. Although care has been taken to generalize the model as much as possible, the results might change for a system with dramatically different configuration.

APPEPNDIX

1) Arena model developed for the simulation study.

   This will require Arena 5.0 to be installed on the machine on which to run the model. The output data will be written in the file c:/something.csv.This file something.csv can be opened in MS-Excel to carry out further analysis.

   A user can give maximum 9 different models along with their atleast constraints. Probability of rejection can be given any value from 0 to 100. Buffer size can be varied infinitely but some values between 20 to 200 are practical ones.

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VITA

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