Simulation Based Decision Support System (SBDSS) for the Vehicles Repair and Maintenance in Dynamic Business Environment

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Abstract

Maintenance support system is formed by all the needed support resources which are related and coordinated between each other to achieve certain objectives such as operational availability of the supported object during its life cycle. This paper describes the decision support system using simulation in the dynamic environment of vehicles repair and maintenance. The study illustrates a case relevant to repair and maintenance decision support system, in which different feasible scenarios has been modeled and modules developed for the analysis and improvement of the existing system. This is done by process mapping of the existing systems and modeling of the existing system in simulation language. Various feasible alternatives illuminated a pathway to significant improvements in customer service, management of work in process, resource utilization, over time and cycle time. It has been learnt that WIP and overtime are the major impediments in the system affecting the performance of the system which can be controlled by suggesting feasible alternatives.

Keywords
Automotive Repair Analysis, Decision Support System, Process Management, Repair and Maintenance Support System, Resource Utilization.

1. Introduction
Maintenance support system is an organic combination of the whole support resources needed for maintenance support and the corresponding management in the supported object's life cycle. It is the system formed by all the needed support resources which are related and harmonized between each other to achieve a certain aim (such as operational availability). There are peculiar requirements of maintenance support system for every set of industries. It depends upon type of machines, their working conditions, mean time between failures and many other tangible and intangible factors. An effective repair and maintenance support system should have in-built characteristics to reduce the down time of the equipment to minimum and continuous analysis for its improvement (Leo J, et la 2002). This research is about the repair and maintenance decision support system of vehicles and light trucks. Though there are many tools available for analysis of repair and maintenance support system e.g. TQM tools (Gunasekaran, P. Cecille, 1998) optimization techniques yet simulation is selected because simulation gives good insight of factors of interest (Navin. G, 2004). Moreover simulation models can be run for various alternatives. Because of many number of variable and solving of mathematical problem is quite cumbersome.

The system under investigated has been engaged in the repair and maintenance business of vehicles. This workshop provides repair, replacement and maintenance service for engine system, brakes, clutch, exhaust systems, steering, suspension, air conditioning and heating vehicle systems, denting painting and body work. At this particular workshop, it had been noticed that there is significant decline in productivity, efficiency, and profitability. Moreover there is an increase in operational costs, especially labor costs. Furthermore, lengthy service and waiting times, coupled with deterioration of service quality, were affecting customer goodwill. One of the problems is high turnover rate of service personals. The layout of the given system comprises of a reception desk coupled with inspection area to determine the fault. It has three repair bays as: Minor Repair Bay: The vehicles which require a short duration of repair are directed to this bay. Major Repair Bay: The vehicles requiring major repair are directed in this bay. It normally involves restoration of major assemblies in serviceable condition or replacement. Body Work Bay: The vehicles requiring denting, painting or ancillary body work are repaired in this bay. Sometimes it expands over days and quite often it requires one odd hour of repair. The objective of this study was development of modules of automotive repair shop, carry out analysis of systems to identify problem areas. After identifying the problem all feasible alternatives are to be modeled and analyzed for feasible solution. There are certain tangible objectives like minimize WIP, cycle time, overtime to optimize resource utilization. The case company was asked to include the cost factor in the analysis, but the management is of opinion that cost is not the major issue for them as they have ample number of customers in queue. This lead to reach us to use the performance measures in our analysis (however, the factors like cost cannot be ignored completely). However the intangible objectives like customer good will and satisfaction are dependent on tangible objectives. After comprehensive study of the problem and discussion with managers, desirable objectives of performance are: 1) Minimize Work in Process (WIP); 2) Minimize Cycle Time; 3) Minimize Over time; 4) Optimize Resource Utilization.

2. Literature Review

Using simulation as Decision Support System (DSS) has long being used. Simulation is imitation of the operation of a real-world process or system over time. Both the existing and conceptual systems can be modeled with simulation (Kelton, W. David, 2004). Simulation has long been an analytical tool of significant importance and power for process improvement (Navin Gupta, 2004). Discrete-event process simulation originally proved its worth and power as a process improvement tool within the manufacturing sector of the economy (Miller, 2000). Somewhat more recently, simulation has likewise become highly respected, and its use widespread, in various service industries (Herbst, 1997). Indeed, a variety of published results attest to the value of simulation within the service sector of the economy. For example, (Pichitlamken, 2003) used simulation to analyze a telephone call center handling both inbound and outbound traffic. (Palacis 2000) described the use of simulation to improve the business processing of accounting transactions within supply chains in the timber industry. (Nanthavanij, 1996) described an application in which simulation was used to improve services provided by car-park systems. Applications of simulation in logistics combat developments (Gregory H. Graves 2002) present three applications of how simulation was used within the U.S. Army Combined Arms Support Command in the design and analysis of current and emerging logistical systems in the Army. (Leo J. De Vin, 2002), worked on Simulation Based Decision Support for Manufacturing System Life Cycle Management. Discrete event simulation in automotive final process system (Vishvas Patel, 2002) is an important part of the entire quality assurance system in the automobile manufacturing process. Simulation modeling for a bus maintenance facility in which authors carried out process analysis of the system and suggested modifications to accommodate peak traffic (Manivannan Ramadass,2004). The Greyhound Lines Dallas Maintenance Facility was congested during peak operating periods. A stochastic model of this facility was developed to determine the resource requirements needed to provide adequate service during periods of peak demand. Representative sensitivity analyses were presented to discuss how this model was used to support facility sizing decisions. Conceptual model for fleet readiness by (Bernard J. Schroer, 2004) presented the conceptual model using process model for analyzing a vehicles fleet's readiness. The model is based on an extensive effort in value stream mapping of a real-world procurement environment. Use of simulation as decision support System (DSS) for automobile manufacturing supply chain simulation in the grids environment (Gary Tan Na Zhao 2003) is good piece of literature on the subject (Joseph C. Hugan2001) used simulation to evaluate traffic at an automobile truck plant. There is considerable interest in combining capacity planning, scheduling and discrete event simulation in the manufacturing environment (Hank,Czarnecki). Traditional methods of capacity planning and scheduling infinite capacity and static time calculations, quite often results are inaccurate and non-representative solution to very important questions (Thompson, 1993). Simulation is a better answer to these problems. The presented work is modeled in simulation which is explained in the upcoming section.

3. Process Mapping and Data Collection

3.1 Process Mapping

The process map of the system is constructed, so that we exactly know how customer report, how they are served and leave the system. Conveniently, services may be classified in either of two ways. From the customer's viewpoint, service sought is either periodic preventive maintenance (to maintain the vehicle in good operating condition) or repair maintenance (restore the vehicle to good operating condition). From the workshop management' viewpoint, service is classified into three categories as (1) minor repair (short duration), (2) major repair (long duration), (3) Body work. Typically, minor repairs are inspections and adjustments; major repairs are replacement or restorative work to one or more of the vehicle systems listed previously. The process map comprised seven main operations as shown in Figure 1.

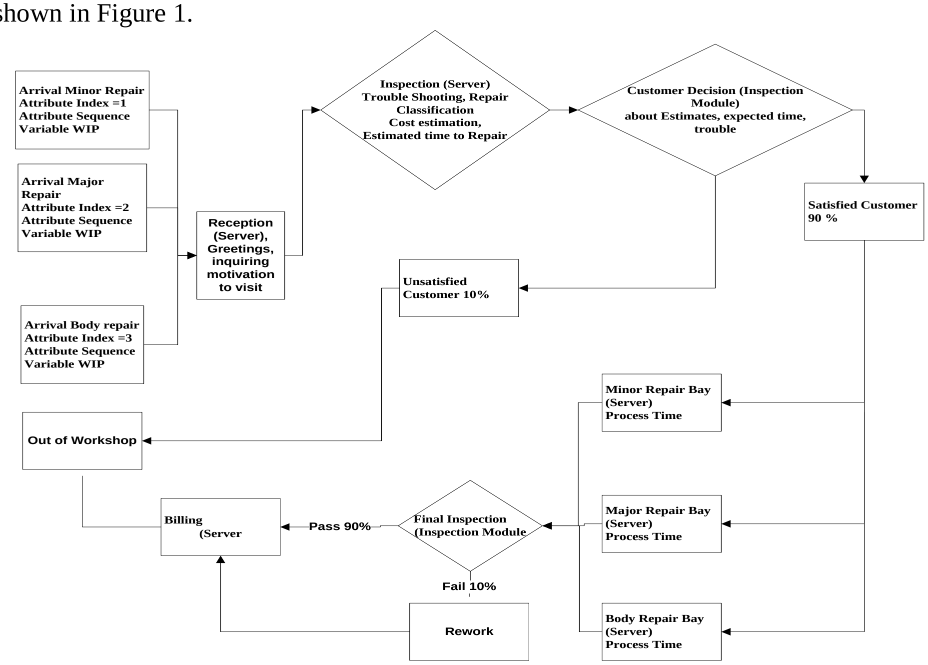

Figure 1: Process Mapping of the System and Outline of the Model

3.2 Data Collection Phase

Three types of data were examined/ collected, which is as: 1) Historical data covering over six months just prior to the beginning of the study. 2) Direct collection data covering twelve complete workdays (six days per week for two weeks) and 3) Customer Satisfaction Survey forms. These forms were personally given to and retrieved from every customer during those twelve sampled work days. Last two types of data collection encompass 100% sampling e.g. Process times were collected for all phases of the process map above. Data were analyzed, using the distribution fitter ("Input Analyzer") within the Arena^{TM} simulation software (Bapat, 2003). The Erlang, Triangular, Beta, and Weibull distributions fitted most observational data sets well.

4. Model Description

The simulation model was built using Arena and software not only provides tools for modeling and simulation of a wide variety to manufacturing, service and business systems but also has input and output analyzer modules to carry out analysis of input data and out put statistics. This model routinely used standard Arena modules such as *Arrive* (customer's vehicles enter the system), *Depart* (customer's vehicles leave the system), *Server*, *advance server*, *inspection* (vehicles undergo evaluation, repair, or inspection), or *Assignment* (attributes such as type of repair, sequence of repair and variable to calculate work in process assigned to a vehicle).

Logic modules for control of certain parameters have been used. As the system is quite complex, initially model was started for a simple system and one bay was added in the system and it was run for verification. Then 2nd and 3rd bays were added. *Sequence module* is used to direct the vehicles to their respective workstations. Three arrive modules have been used to create three separate entities each representing respective type of repair work i.e. minor repair, major repair and body work. Each category of entity has been assigned an attribute *Index* with a value of 1, 2 or 3, to keep track of each type of vehicle. Each repair resource is scheduled for eight hours from 9:00 A.M to 5:00 P: M, with 30 minutes lunch break from 12:00 to 12:30 P.M. The arrival of the vehicles has been controlled by a *logic module* which creates a controlled entity after every 480 min (8 hours); a variable pointer has been assigned to this entity whose value is increased by 1 after every 480 minutes. An array of 36 rows (12 working days, 2 weeks) has been used in expression module to store the values of batch sizes. It ensures that batch size remain 1 for initial 8 hours and 0 for remaining 16 hours of the day. Expression *batch size* with Index *pointer* is used in main arrive modules of all three entities so that vehicles report to the workshop only during working hours. *Set module* has been used to find quantity and cycle time of each category of repaired vehicle. A variable *WIP* has been assigned whose value is increased by 1, every time a vehicle report to the workshop and its value is decreased by 1 every time a vehicle is passed out of the workshop. Statistics module has been used to find statistics on cycle time, work in process, resource utilization and vehicle count. Model has been initially run for simple and constant values of inter arrival times and process times. The results verify the model as it was designed. Then, probability distribution expressions for inter arrival times and process times as obtained from ARENA input analyzer were used and model was run for 17280 minutes (12 days). The results obtained were discussed, verified and validated with the workshop management.

4.1 Analysis of the Base Case

Scenario-I

The Base Case Model after verification was run for two weeks time period (12 working days), with 10 replication each run. Data obtained for Base Case model run from day 1 to day 12 for cycle time, resource utilization and output statistics is tabulated. An insight into the data gives detail analysis of cycle times, resource utilization and work in process (WIP) statistics. The following statistics were collected and analyzed.

4.1.1 Cycle Time and Resource Utilization Statistics:

Figure 2 shows that cycle time for all three bays is constantly increasing from day 1 to day 12, which shows accumulation of significant WIP, causing this increase in cycle time. It is pertinent to mention that each bay was scheduled for 8 hours a day, with 30 minutes break in between. While scheduling the resources, *wait* option was used to ensure that work on the vehicle under progress at the time of closure of workshop is completed on the same day. As per this scheduling each resource was available for 31.25% of the time. Figure 3 shows that three bays, minor repair, major repair and body work are constantly going for the overtime as they are being utilized more than their availability.

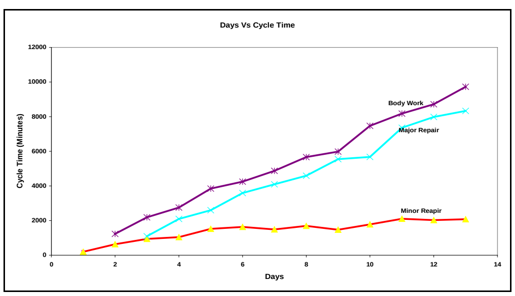

Figure 2: Days Vs Cycle Time

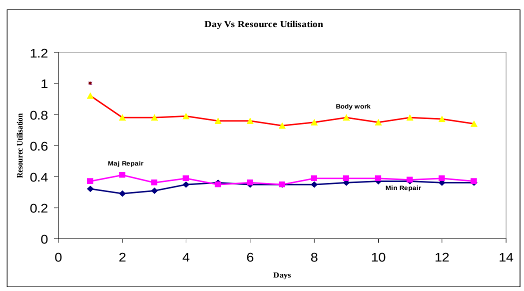

Figure 3: Days Vs Resource Utilization

4.1.2 Work in Process Statistics.

Accumulation of WIP is the main factor which is contributing to over utilization of the resources and increasing the cycle time. From the figure 4 we can see that WIP is accumulating with each passing day, and by the end of 12 working days, total 34 vehicles have been accumulated in the workshop. Figure 5 shows that minor repair and body work is the major contributor in increased WIP, having share of 15 and 13 vehicles respectively in overall WIP after 12 days.

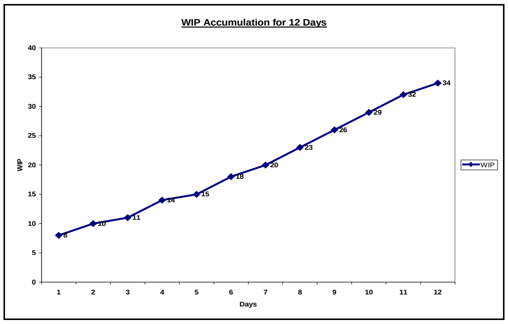

Figure 4: Accumulation of WIP

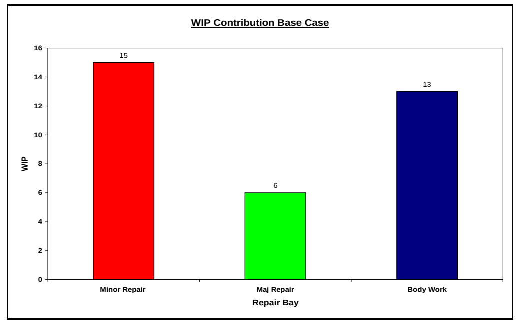

Figure 5: Bay Wise Contribution, WIP

4.2 Feasible Alternatives

Scenario-II

After having identified problem and analysis of existing results, it is concluded that there are three possible feasible alternatives or combination which can lead to solution of overtime and excessive WIP. These alternatives are:

1) Hiring of additional Service Personals: The number of bays cannot be increased due to space constraints, but in this scenario additional employees would be hired on a permanent basis. From the results and analysis of the existing system model, it is identified that minor repair and body work bays are the bottleneck resources; an additional workers already having the required skills to undertake such repairs could be hired. With the help of the additional workers, the process would presumably flow more smoothly than before, and this alternative reduces excessive WIP as well as overburden on employees. It could also be expected to improve customer satisfaction by reducing waiting times. One additional worker can well look after major repair and minor repair bays, because of similar nature of work in both bays. However separate additional worker will be required to tackle body work, because of different nature of work.

2) Use of Appointment System: In this alternative, customers are expected to make appointments in advance. A “Questionnaire Form” was used to evaluate the customers’ opinions concerning implementation of an appointment system and also to find the preferred time slot(s) for servicing. Implementing an appointment system would possibly guarantee proper workflow of the overall system, which in turn would ensure proper utilization of resources. Hence an appointment system would be expected to improve productivity, efficiency of labor utilization, and customer satisfaction. Though it may not be possible that 100% customer follow appointment system, yet we can expect improvement through this alternative. In this alternative, customers are expected to make appointments in advance. A “Questionnaire Form” was used to evaluate the customers’ opinions concerning implementation of an appointment system and also to find the preferred time slot(s) for servicing. Implementing an appointment system would possibly guarantee proper workflow of the overall system, which in turn would ensure proper utilization of resources. Hence an appointment system would be expected to improve productivity, efficiency of labor utilization, and customer satisfaction. Though it may not be possible that 100% customer follow appointment system, yet we can expect improvement through this alternative.

3) Additional Cross Training of Service Personals: With the aim of increasing personnel efficiency, a vigorous personnel-training program could be on a periodic basis so that a technician dedicated to one kind of job could be assigned another type of job if he is spare. Such an implementation presumably would decrease rework and excessive “Work in Process”. This decrease would improve utilization of resources, reduce waiting time of the customers, and thereby improve the overall productivity, labor efficiency, and customer satisfaction.

5. Comparison of Alternatives

From the simulation results of alternative 1 and 2 it was revealed that Body Work is contributing a major portion of WIP and overtime. A critical study of the data collected for body work bay was carried out again and necessary input from the service personals and management was also sought. An insight analysis revealed that there are clearly two different categories of body work, which if not differentiated may cause extra ordinary accumulation of work and overtime. There is large proportion of the vehicles which require minor body work. Work contents of minor body work ranges from 1 to 3 hours. While there are certain vehicles which required major body work spanning over days. So in alternative 3 an additional worker properly skilled to undertake minor body work was dedicated for minor body work. Major body work was completely separated from minor body work. During the trial simulation run it was revealed that this alternative has amazingly reduced WIP statistics. One other statistics of interest was that minor body work, worker after doing his required work remained idle for a good amount of time.

5.1 Analysis of Feasible Alternatives

Alternative 1, 2 & 3 were modeled and simulated with probabilistic values of inter arrival times and mean values of probability distribution of inter arrival time for appointment system. Instead of discussing the results of alternative 3 individually, results will be compared with base case, alternative 1 and alternative 2.

5.1.1 Cycle Time and Resource Utilization Statistics

Figure 6 shows cycle time statistics for different alternatives, minor work cycle time has reduces from 2025 in case of Base case to 872 minutes in case of alternative 3, which is quite desirable and satisfactory. As far as major repair is concerned cycle time almost remained constant. In case of major body work, again there is considerable improvement in cycle time which is reduced from 8715 minutes in case of base case to 6667 minutes for alternative 3. Cycle time of minor body work remained 556 minutes. Figures 7 give comparison of resource utilization for base case and different alternatives. Now in case of alternative 3, by splitting body work into minor and major body work, resource utilization has come well within available limits that is from 77% in case of base case to 27 % in case of alternative 3. In case of major repair it is 23 % and minor repair 21 %, while minor body work resource remained busy for 24 % of the time. It is important to mention that all the resource as scheduled remained available for 31.25% of the time.

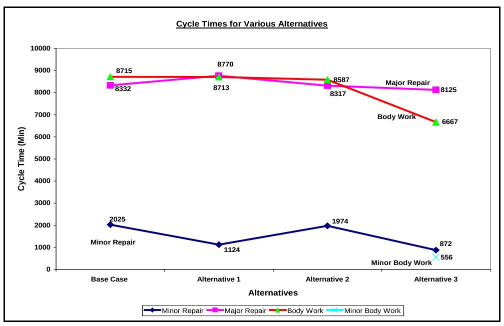

Figure 6: Cycle Times alternatives & Base Case

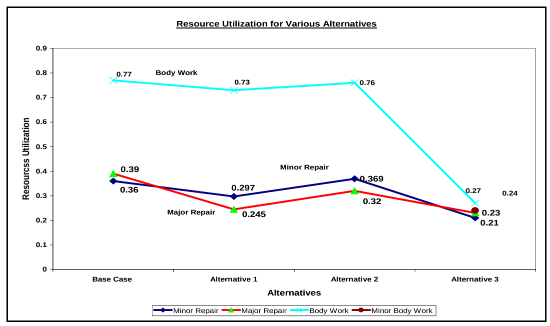

Figure 7: Resource Utilization Alternatives

5.1.2 WIP and Output Statistics

Body work and minor repair are the major contributory Bays in accumulation of WIP in Base Case and alternative 1 and 2. Figure 8 shows WIP statistics for base case and different alternatives. In case of major repair WIP is reduced from 6 to 3 (50%), In case of minor repair WIP is reduced from 15 to 8 (46%). WIP has reduced from 13 in case of base case to just 3(1 for body work and 2 for minor body work). Figure 8 shows that overall WIP statistics has reduced from 34 in case of base case to 15 for alternative 3. So there is overall 56% reduction in WIP.

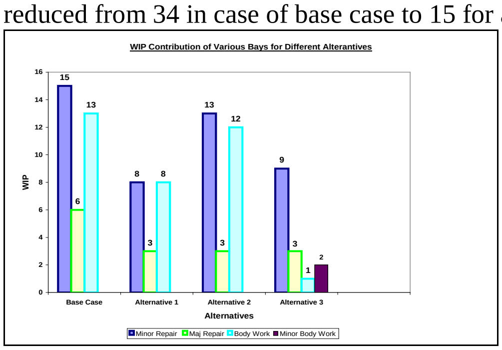

Figure 8: WIP for Various Alternatives

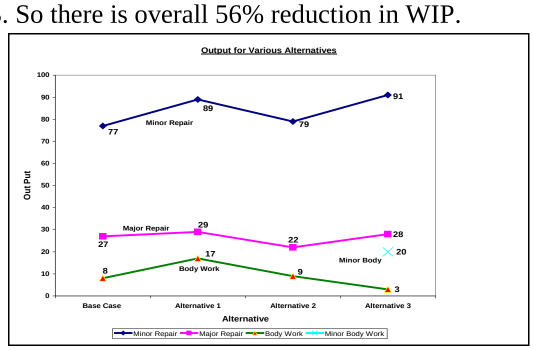

Figure 9: Output Statistics for alternatives

As far as output statistics are concerned, there is obvious improvement in case of Alternative 1 and 3 as compared to base case. Figure 9 show details of output for various alternatives.

5.1.3 Over-Time Statistics.

Figure 10 &11 shows over-time statistics for various alternatives, it is evident that base case model, major repair minor repair and body work bays are going for overtime, body work having largest contribution. Figure 10 shows weekly over time for various resources, in case of base case it is 84 hours per week, which is reduced to 60 ours for alternative 1, 72.5 hours for alternative 2, and 0 for alternative 3. Though alternative 1 eliminated the requirement of over time for major and minor repair bays, however body work still had large amount of over time. The problem of body work over time was solved by splitting it into minor and major body work as alternative 3. Results are given in figure 10 & 11.

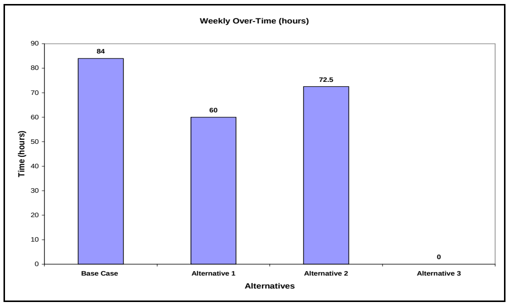

Figure 10: Weekly Over-Time Statistics

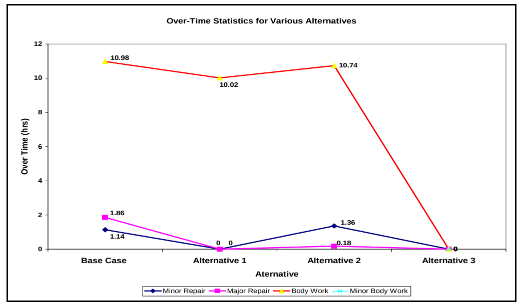

Figure 11: Over-Time Statistics

6. Conclusions

Simulation as a Decision Support System (DSS) for automotive repair workshop is developed and analysis carried out to identify bottlenecks. This showed that excessive WIP and over time are the major impediments which harm customer goodwill, labor efficiency and lower the productivity. Three feasible alternatives are modeled and analysis carried out among feasible alternatives. In first alternative two sufficiently skilled employs were hired to undertake extra load of major, minor repair and body work bays. Though this alternative reduced WIP to almost 42% of the Base Case, this reduction is observed in case of all three bays. However body work is still going for huge amount of overtime. In second alternative appointment system are suggested and modeled, that customer takes prior appointment of the repair work on their vehicles. WIP is marginally reduced (17%) as compared to Base Case. There is slight reduction in cycle time and resource utilization, but overall there is still significant over time for all three bays. Third alternatives is modeled by splitting body work into major and minor body work and additional cross training of workers are carried out so that they can switch their services to other bays if they are spare from their primary work. Result shows that alternative 3 gives most feasible solution. In alternative 3, encouraging results are achieved as almost 56% reduction in WIP as compared to Base Case. Work contents are more uniformly distributed between different resources and overtime is no more required. Simulation results as decision support system and analysis have given a tremendous insight of the systems involved. Statistics achieved form the results and their graphical analysis not only give extent of the problem due to excessive WIP, long cycle time over or under utilization of resources and Q time of entities, but also led to feasible alternatives to achieve desirable objectives. Different alternatives have been modeled and simulated to reach to a feasible solution. It has been learnt that simulation as DSS can be done for designing, process management, and improvement of repair and maintenance support system.

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