A Simulation Model for Mixed-Model Multi-Stage Assembly Lines

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Abstract: The standard flowshop sequencing and scheduling problem considers optimum processing of jobs through a number of work centres. Mixed model assembly is a type of manufacturing process in which a number of model variants are intermixed and processed simultaneously on the assembly line. The multi-stage is the number of different stages or levels required to produce a model. At the mixed-model multi-stage assembly plant sequencing and scheduling problems arise in production as the result of insufficient human resources in quantity or skill to operate each station at all times. The aim is therefore to find the sequence and resource allocation that allows the operations to be scheduled in such a manner as to allow the makespan to be minimised while also satisfying all precedence and resource constraints. This is achieved by the implementation and execution of a simulation model to solve the large sized resource allocation, sequencing and scheduling problem for a mixed-model multi stage truck assembly line. More then 50 stations with non-serial and serial convergent precedence requirements, about 80 workers and 12 trucks are sequenced and scheduled in the industrial application of the model. The processing times of jobs, the number of groups, the number of workers in each group and the allocation of stations to these specific groups are investigated as well.

Keywords: Simulation; Scheduling; Sequencing; Assembly line

1. INTRODUCTION

The standard flowshop sequencing and scheduling problem considers how best to process through a number of work stations in a sequence [see Koulamas, 1998; Murata et al., 1996; Ogbu and Smith, 1990; Reeves, 1995; and Taillard, 1990]. In reality however, standard flowshop problems rarely exist [Dudek et al., 1992]. Because the amount of processing required by an operation is generally dependent upon the level of resources allocated.

Mixed model assembly (MMA) is a flowshop type manufacturing process in which a number of model variants are intermixed and processed simultaneously on the assembly line. MMA plant sequencing and scheduling problems arise in production as the result of insufficient human resources in quantity or skill to operate a station. The main strategy is to improve production efficiency by shifting workers to various stations.

Therefore, the objective is to find the schedule, sequence and resource allocation that allows the operations to be scheduled in such a manner as to allow the throughput to be minimised while also satisfying all precedence and resource constraints. This type of **resource constrained flowshop** (RCF) has not been addressed frequently. Daniels and Mazzola [1994] have showed that the sequencing and scheduling problems concerned with the RCF is NP hard in the strong sense. Recently Burdett and Kozan [2000] have developed and solved a RCF model as an extensions of the standard flowshop problem.

Simulation models can be used to solve the large sized resource allocation, sequencing and scheduling problem for a mixed-model multi stage truck assembly line as well. Operations are scheduled in such a manner as to allow the throughput to be minimised while also satisfying all precedence and resource constraints. The reason for using simulation on this type of problems is that simulation may be more economical, safer and quicker than using the real system [see Pidd, 1996].

Atwater and Chakravorty [1996] outline the effects of having an inventory between stations in a serial production line and discuss the application of an inter-station inventory to a Just-In-Time (JIT) production process. Shi and Abourizk [1995] outline a method of optimising a large complex system. It involves a set of smaller simulation models and mathematical programming rather than one large simulation model. The optimal solution of a large and complex system can be located, by using the hybrid model presented in the paper, which combines simulation and mathematical programming.

2. ENVIRONMENT OF THE PROBLEM

A truck assembly is dynamic, interactive and complicated. Customised vehicles are produced and it is known as mixed model production [see Martinich, 1997]. Mixed model production involves producing different varieties of the same product on the same assembly line. Also task times vary, the following are some of the reasons why these tasks times may vary: variation in materials; workforce variation; material shortages; defects; mechanical delays; product differences; and lot-size differences.

These variations make the task times at the workstations stochastic in nature. This variation in task times may be represented by a probability distribution. Some of the probability distributions may not be standard probability distributions (like those used in queuing theory and other mathematical models), but simulation allows us to include these non-standard distributions into the model [see Robinson, 1994].

The system is also interactive, due to the fact that there is no in-process inventories. So if we have a work station called K which is busy and the previous work station called K-1 finishes processing a unit, then work station K-1 must stop production until K is ready to accept the unit.

Some of the latest research in the area of assembly line balancing, includes a paper by Pinnoi and Willhelm [1997] which outlines a set of models which incorporate issues that are relevant to both single product and multi/mixed product assembly lines. The paper presents a family of hierarchical models which incorporate a broad range of features that represent many aspects that are fundamental to assembly system design problems. Kusiak and He [1997] outlined design rules for agile assembly. The paper defines that the concept of agile manufacturing is driven by the need to quickly respond to changing customer requirements and be reconfigurable to accommodate changes in the product mix and product designs. Sawik [1995] presented a family of integer programming models for flexible assembly systems design and balancing.

The assembly line is complicated and the fact that there are sub-assemblies, furthers complicates the matter. Mathematical models cannot easily represent the complex interactions caused by random events. Random events that might occur are the main assembly going quicker than expected and has to wait for subassemblies, and machine breakdowns and some of the difficulties that are specified above. These reasons justify why a simulation model is worth doing for a truck assembly line. A simulation model or more notably a Visual Interactive Simulation (VIS) model showing an overview of a truck production plant, will demonstrate the frailty of local solutions and promote the implementation of total solutions [see Robinson, 1994].

3. THE MODEL

The aim of this research paper is the implementation and execution of a simulation model to solve the large sized resource allocation, sequencing and scheduling problem for a mixed-model multi stage assembly process.

The simulation model must be:
- adaptive to any changes in truck models e.g. new model, decreased or increased production of a particular model;
- able to be modified eg. new equipment is added which decreases production cycle time at a station
- allows sensitivity analysis;
- easy to update code and be well documented, so that there can be updated uses for the model; and
- accurate and meet the objective of the project.

A time interval between starting times of consecutive truck production is an important variable for the truck assembly line simulation model. This is also reflective on the demand for the trucks. The types of the trucks produced largely determines the extras which have to be put onto the truck, and how much processing time is taken at each work station.

Truck plants have a multi-skilled workforce and workers can work at several different workstations.

This fact had to be incorporated into the model. To develop the model the following questions had to be answered:

- What is the grouping of the stations that the multi-skilled work force worked at? That is, Where do workers with common skills work at?
- How many workers in total worked at the group of stations?
- How many workers at the one time had to perform a task at an individual station?
- What is the order in which the processes carried out and the time to start the subassemblies?

3.1 Distributions of the Data

Due to the fact that a truck assembly line is a mixed model production line, the subassemblies take different times to complete. Also, the task times on the sub-assembly lines and main assembly line vary even within the production of one model. So, the distribution of the task times for each different model at an individual station has to be determined. In addition, the distribution of the starting times of consecutive truck productions should be known. All of the above distributions will be inputs of the model. Demand forecasts for each type truck is input of the model as well. The outputs of the model will largely depend on these inputs.

3.2 Future Inputs for the Model

To say that future customer requirements will remain the same as they are now is not true. The marketplace can change due to customer requirements. This means that some of the above inputs may change due to a change in customer requirements, i.e. annual production may increase or a model is phased out. Also, the workforce may change due to hiring, retrenchment, and retirement or workers quitting their jobs, again this will require a change in the model. Another factor that might change the task times is if new equipment is bought and implemented in the plant. This means that changes that occur to the plant only require a modification to the model, rather than an entire new model being built. This would mean a saving in time and expenses for the track plant. Another event that could occur in the future is the release of a new model. If this occurs, then the task times will have to be estimated at each station. These estimated values could be placed in the model, so we can find out how this new model affects production.

3.3 The Simulation Language

The model was written in a simulation language called ARENA that can be used for discrete, continuous, and/or combined systems [Kelton et al. 1998]. The truck assembly line can be modelled using what is known as discrete-event simulation. There are two main files, model and experiment, associated with ARENA. The model file contains the simulation model and describes the physical elements of the system (machines, workers, etc.) and their interrelationship. The experiment file contains and specifies experimental conditions under which the model is run; including elements such as initial conditions, resource availability, type of statistics gathered, and length of run.

3.4 The Simulation Application

The simulation model for the assembly line has been applied at the Volvo Truck Factory in Brisbane, Australia. The tasks to be addressed within the simulation model were addition of the subassemblies, the investigation of process times and the number of workers at each station; and the analysis of the size and distribution of worker pools. The flow diagram in Figure 1 represents the Volvo Trucks Australia assembly line.

The number of truck models to be sequenced and scheduled is 12. Total number of workers is 80 and the minimum group number of workers required for each operation is one and the maximum allowed is 20. The data was collected 26 weeks in 2000 and includes the processing times required for a single worker at each of the work stations.

When creating a simulation model, the real system may need to be simplified or modified in order to implement the model without changing the main characteristics of the system. The real model would be too complex to implement if it was not simplified. For this reason the following **assumptions** are made: absenteeism remains below a certain level; machine breakdowns do not affect the production; and there are no shortages of parts.

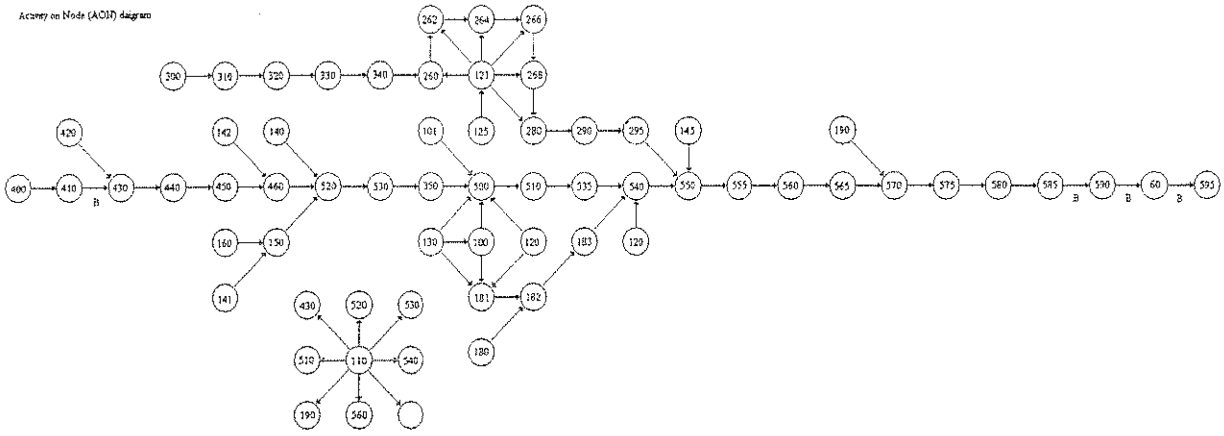

Figure 1. Volvo Trucks Australia assembly line flow diagram.

To make the simulation model more realistic, all subassemblies have been added to the simulation model. However, stations 121, 100, 120 and 130 were simplified due to their multiple outputs. It can be noted that station 110 was implemented with buffers to retain its multiple outputs.

There were a few **problems encountered** with the implementation of the subassemblies and worker pools. The two main problems encountered with subassemblies was with the implementation of stations with more than one output and stations with more than one input. Many stations that had more than one output were simplified except station 110 which was allocated buffers for each output. This solved the problem of stations with multiple output waiting to dispatch all output before the next truck could be processed. The problem of stations, which had more that one input (entity), was solved by including the batch block. The batch block matched and combined entities of the same truck model type to proceed to the station as one entity.

There were a few minor **modifications** to the number of workers and processing times at each station. Stations with longer processing times were allocated more workers if they contributed to blockages or bottlenecks in the assembly line. To reduce the variation in the processing times at stations, the triangular distribution was modified to *(0.95*t, t, 1.1*t)* where *t* is the estimated processing time.

3.5 Outputs of the Model

There have been many additions to the basic simulation of the main assembly line at Volvo Trucks Australia. Some of these modifications relate to the subassemblies, the worker pool and the number of workers and processing times at each station. For **Alternative 1**, there was one worker pool, the workers were collectively place in a large pool. This meant that workers were multi skilled and could be allocated to any station. However, in a real life situation this is not realistic. Generally workers can be allocated to maximum few stations. So, **Alternative 2** is created, this alternative contained twenty worker pools where the workers were allocated to between two and four stations. This allowed workers to be trained with specific skills for particular stations. **Alternative 3** was trialed with two worker pools. Thirty seven workers were allocated to the unskilled pool and another forty-three workers were allocated to the skilled pool. This allowed the unskilled workers to work on the main assembly line and the skilled workers to work at the subassembly stations.

Changes in processing time resulted in many changes to the simulation output. Effects of the five percent decrease in processing times are given in the following tables. Some of these changes were: the total number of trucks produced increased, the average time stations waited for workers noticeably
decreased; the time a particular truck spent in the system decreased, however, some times increased; and both station and worker utilisation slightly decreased. The outputs, which are obtained from the simulation, are given in the following tables:

Table 1. Number of Production of each Truck Model

Alternative \ Model	1	2	3	4	5	6	7	8	9	10	11	12	Total
1 Worker Pool	29	51	11	181	93	216	40	129	26	50	153	73	1052
2 Worker Pools	24	62	15	181	84	210	28	116	27	56	150	94	1047
20 Worker Pools	18	42	11	152	81	177	26	91	21	45	122	92	878
2 Worker Pools 5% Decreased	31	69	10	162	99	221	39	128	27	54	171	87	1098

Table 2. Trucks Time in System(as hours)

Alternative \ Model	1	2	3	4	5	6	7	8	9	10	11	12	Av.
1 Worker Pool	13.6	15.0	14.8	14.0	13.2	13.7	13.8	14.0	15.0	14.4	14.1	14.4	14.2
2 Worker Pools	12.8	13.2	12.4	13.4	13.9	14.1	15.1	14.5	14.6	14.0	14.8	13.7	13.9
20 Worker Pools	16.6	14.8	13.3	14.1	13.9	13.7	15.4	13.8	14.0	13.1	13.0	14.6	14.2
2 Worker Pools 5% Decreased	13.5	14.7	14.0	13.4	14.2	14.1	15.2	13.8	12.2	14.2	14.4	13.4	13.9

Table 3. Worker Utilisation

Alternative \ Pool	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Av. %
1 Worker Pool	79.5																				79.5
2 Worker Pool	74.6	83.5																			79.5
20 Worker Pools	69.5	52.6	47.6	43.7	40.8	55.6	52.6	65.3	69.7	55.3	89.7	41.7	79.7	70.2	68.6	18.6	55.6	53.3	75.1	74.8	59.0
2 Worker Pools 5% Decreased	74.1	81.2																			77.7

3.6 Station Utilisation

The problem with worker pools was to make them more realistic. Many different combinations of worker numbers and pool numbers were trialed. The results from these trials may be perused in Figures 3. Utilisation percentages of each work station have been determined by the simulation model. The optimum output was with workers in two pools. However, this is not very realistic. More analysis is being applied to this problem. Average work station utilisations are 79%, 78%,and 74% for alternatives 1, 2 and 3 respectively. A comparison of the each work station utilisation of alternative 1 to the alternatives 2 and 3 is given in Figure 3. As seen in Figure3, alternatives 1 and 2 have similar utilisation at the work stations, however, alternative 3 gives less utilisation at many of the stations (points close to the horizontal axis).

From these outputs, we can determine if there are any instances of bottlenecks in the system. Once we know about the outputs, we can vary the inputs to see what happens to the outputs, this is known as sensitivity analysis. The potential for sensitivity analysis is almost limitless and time is not [see, Robinson 1994, p.186], so we investigate what improvements can be made to any bottlenecks if we have any and vary key parameters, such as the arrival times of jobs and task times at potential bottleneck stations.

The model produced in this project has to also be capable of slight changes to the model to ask 'what if...?' questions. This is a lot cheaper than experimenting with the actual system itself. This is also known as sensitivity analysis, in which we may want to see how production may vary by changing a few policies, i.e. what happens if we have six people working at this station rather than five. All of the above issues have to be incorporated into the development of the model. That is, we have to have simulation code that is easy to update and well documented.

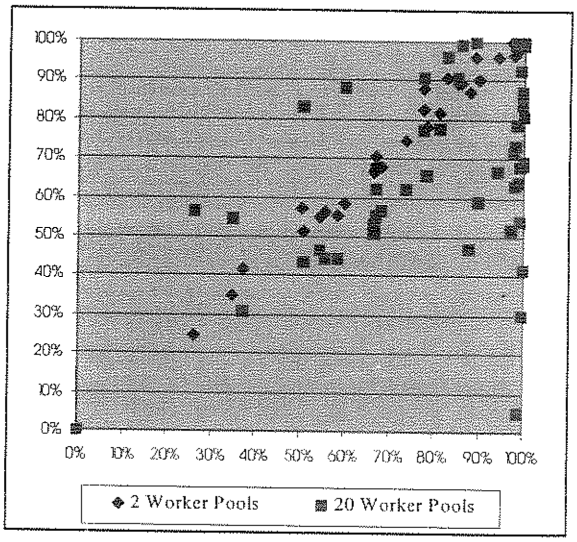

Figure 2. Comparison of the one worker pools' utilisations with the other alternatives.

4. CONCLUSIONS

The aim of this paper is achieved by finding the sequence and resource allocation using a simulation model that allows the operations to be scheduled in such a manner as to allow the makespan to be minimised while also satisfying all precedence and resource constraints. The simulation model is used to solve the very large Volvo RCF problem for a particular instance and to report the results of a significant numerical investigation case study. It can be noted that the simulation has been coded to allow easy extensions and modifications to the model. There are many aspects, which could be incorporated or extended in the current simulation model. These are as follows: in-process inventory; extended analysis of the size and distribution of worker pools; and inclusion of the more parallel and serial stations.

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