Proceedings of the 1997 Winter Simulation Conference
ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson

A SORTATION SYSTEM MODEL

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ABSTRACT

Automotive manufacturing is a complex task involving several steps of machining and assembly. Typically, larger components of an automobile such as the body, engine etc. are assembled over multiple systems. These large assemblies are transferred from one assembly system to another using conveyors. The conveyor/transfer system serves as a buffer and also serves to sort and re-sequence the components in a form that is required by the downstream operation. This requires the transfer system to be able to 'look ahead' at the requirements for the downstream operation and re-sequence the assemblies, if necessary. The sortation and re-sequencing part of the conveyor system is called a selectivity bank. The capacity requirement calculation and configuration design of these selectivity banks is difficult due to the randomness in the operation of, and the differences in schedules between the two systems it is connecting. Simulation is a valuable tool that is increasingly being used in the design, testing and upgrading of these systems. This paper presents the typical design issues of such selectivity banks, that are addressed using simulation. A case study is presented to elucidate the concepts and applications. The paper concentrates on automotive manufacturing systems but the concepts presented here are applicable to sortation systems used in several industries.

1 INTRODUCTION

Automotive manufacturing is a complex task with several automated functions. Machined or purchased components are assembled on sub-systems and the sub-assemblies are assembled together over final assembly systems. Sub-assembly production systems are connected to the final assembly systems using conveyors. Typically, in the automotive industry, production is first scheduled at the final assembly system. This production schedule depends on the market demand. The production schedule is then broadcast to all upstream operations. Thus, upstream operations can complete their tasks in a JIT (Just-In-time) mode or build a buffer of products based on the weekly or monthly schedule of the final assembly system. Based on the broadcast schedule, jobs enter an upstream operation, such as the paint system, in a certain sequence. This input sequence depends on the planned production schedule which again, is driven by the requirements downstream. However, if the paint system has a rework loop or a complicated process, then it is highly likely that the sequence in which the jobs entered the paint system, is altered. Thus, jobs will not be presented to the downstream operation in the originally planned sequence. Thus the output sequence from one assembly system may not be the ideal input sequence for the downstream assembly system.

To remedy the situation, buffers are provided between consecutive systems. Those temporary storage areas are usually accommodated within the transfer system although automated storage and retrieval systems are also common (Gunal et al. 1994). Transfer systems between assembly operations are typically automated or minimally manned and tend to be some form of conveyors. Thus the intelligence required for presenting components in the sequence required by the downstream operations becomes the onus of the transfer system.

The transfer system will have to be smart enough and flexible enough to provide the re-sequencing and handle all exceptions. To accomplish this objective, the transfer/buffer system takes the form of multiple conveyor lanes between the sub-assembly and final assembly operations. Components or sub-assemblies with differing attributes are sorted into lanes. Since it is physically not possible to have as many lanes as there are attributes, the sortation will have to be based on rules/schemes derived from knowledge of the schedule requirements for the downstream operation. These rules/schemes will have to be tested and optimized for minimum conflict downstream. The effectiveness of the rules chosen are also affected by randomness in the upstream and downstream operations. Such an intelligent system capable of conveying, sorting and re-sequencing sub-assemblies and operating based on a selection/sorting algorithm is popularly known as a selectivity bank. Selectivity banks become necessary in manufacturing systems where two operations need to be connected with the capability to sort and re-sequence parts in a manner suitable for the downstream operation.

Simulation has been extensively used for simulating automotive production processes. Examples of such successful applications can be found in Ulgen et al, 1994, Jayaraman and Agarwal 1996, Upendram 1996, and Graehl 1992. More specifically, with its inherent ability for modeling randomness, simulation is an ideal tool for evaluating different rule sets and for predicting the throughput capability of a selectivity system. It provides an easier option for evaluating different scenarios without affecting the current operation of the actual system. Simulation is also a less expensive option compared to actual controls programming and fine tuning of the real system. Furthermore, simulation software available today provide programming constructs and abilities that allow intricate operating details of such complex systems to be modeled with relative ease and accuracy. The remainder of this paper elaborates on the design issues and performance measures used for such selectivity banks and also substantiates the applications of simulation. A case study, based on a project performed by the authors, is presented in order to demonstrate all concepts.

2 SYSTEM DESCRIPTION

Selectivity banks consist of three or more sortation conveyor lanes between the sub-assembly production system and its downstream operation. Sub-assemblies are sorted between the lanes based on the following knowledge about the operation of such systems:

- Attributes of the sub-assemblies. These are also called options. An example of an option would be a truck body intended for a two-wheel drive automobile as opposed to that for a four-wheel drive automobile. The schedule for the downstream operation is a mixture of models with different attributes. For example, six four-wheel drive automobiles will be processed at the first station (and hence subsequent stations also) followed by two two-wheel drives followed by three four-wheel drives and so on. Based on the attributes carried, each sub-assembly or job will have to be sorted between multiple lanes.
- Rules for sortation. These rules are based primarily on projected schedule requirements of the downstream operation, as explained in the example above. Since sortation and re-sequencing is not possible past the selectivity banks, jobs will have to be sorted into the selectivity bank, carefully. To avoid conflict downstream, the rules for sortation will have to be carefully made up taking the schedule requirements downstream, into account.

Once jobs have been sorted into lanes based on rules, the next task will be the selection of a job from the output end of the selectivity bank. In reality, programmable logic controllers are used to make decisions regarding the job selection at the output end of the bank. A simple scheme is programmed into the controllers. The sub-assembly waiting at the front end of each lane is assigned a weight or "points." The relative weight or points are a function of the attributes of the sub-assembly and the rules to be satisfied. A penalty is included in the points system for breaking rules. A job that has the most favorable rating (highest points, in this case) is chosen as the next one to be routed downstream.

While there may be one sub-assembly that would be the ideal candidate, other sub-assemblies that are less than ideal can also be chosen. In other words, there may be three sub-assemblies with the attributes that would be potential candidates for selection. Only one of these three may be available at the front of a lane. This sub-assembly may satisfy 90% of the rules and hence will be chosen. Needless to say, in order to be able to select a required model with certain attributes, the sub-assembly should be available at the front end of one of the lanes. For this condition to occur, the sortation at the beginning of the bank should have been done with some intelligence about the requirements for the downstream operation.

Thus the input provided to the downstream operation is going to depend heavily on the input to the bank and the rules used to sort and re-sequence in the bank. If the required input sequence is not provided to the downstream operation, the overall system throughput is affected. Thus, the rules set chosen subject to a certain input sequence to the bank will have to be carefully evaluated prior to implementation. The number of lanes, the capacity of each lane and the conveyor speeds have an impact on the rules. Thus there are several parameters that affect one another. Simulation is an ideal tool for evaluation of different scenarios based on the values of the physical parameters and rules chosen for that scenario.

3 DESIGN ISSUES AND SIMULATION

As is evident from the above discussion, the system throughput capability depends on the effectiveness of sequencing at the bank. In summary, the following parameters affect the effectiveness of the selectivity bank -

- Configuration of lanes.
- Number of lanes.
- Capacity of lanes.
- Input rules - also known as sortation algorithms.
- Output Rules - also known as selection algorithms.

For a given schedule at the downstream operation, a certain set of rules for sorting sub-assemblies at the beginning of the lanes is optimal. A set of rules is programmed into the controller for making decisions. This program is not easily changed and it is preferable to make changes only rarely. Thus a certain rule set or sortation algorithm will have to be selected and implemented. Obviously, different rule sets need to be compared and fine-tuned, before selection and implementation.

Some of the performance measures used are:

- Throughput from the system.
- Congestion issues at the bank.
- Rules broken at the end of the bank. Inability to provide the downstream operation with the appropriate job, due to the sortation algorithms implemented and also due to lack of capacity.

Some of the factors leading to problems at the bank and loss of system throughput are:

- Inefficiencies at the upstream operation. This includes downtimes for operations, reject rates, repair and scrap.
- Changes in schedule at the downstream operation that have not been accounted for in the input rule set. A reason for a change in schedule might be the breakdown of an operation in the downstream system.
- An input rule set or sortation algorithm that does not account for problems at the upstream or downstream operation.

In effect, the throughput capability of the entire system will have to be measured subject to random inefficiencies in the upstream and downstream operations, a sortation algorithm and a selection algorithm. Discrete-event simulation is the only tool available that can take all the above factors into account. Also, animation is a valuable tool that helps in visual verification and helps identify potential congestion.

Inefficiencies such as downtimes can be modeled by fitting historical data to statistical distributions. Rejects at the upstream operation that lead to drastic changes in the sequence of sub-assemblies can be modeled using historical data. The times taken to repair a faulty unit engine can also be modeled based on historical or expected data. Once the model of the system is built, different input rule sets can be programmed easily. The output rules, based on the schedule of the downstream operation can be changed easily. The model can be altered in order to study different configurations of the selectivity bank and the number of lanes and their capacities can be altered easily. All the above analysis can be made with no impact on the current operation of the actual system. The case study presented in the following section serves to demonstrate these concepts further.

4 CASE STUDY

The system under consideration is a selectivity bank used for the sortation and selection of vehicle bodies. The bank exists between the paint and trim operations. Painted vehicle bodies are routed to the selectivity bank. At the end of the painting operation, certain vehicle bodies can be culled due to the quality of the paint. These bodies are then re-painted or finish painted manually. This condition leads to the original planned sequence being altered. The bank is used to re-sequence the bodies from paint, based on the sequence required by the trim operation. The bank consists of six lanes and each of the vehicle bodies have nine different attributes. A block diagram of the flow is shown in Figure 1

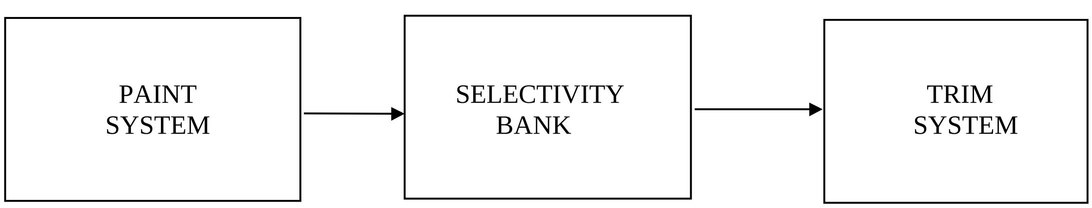

Figure 1 : Materials Flow Diagram For Case Study 1

A representative sketch of the configuration of the lanes in the selectivity bank has been shown in Figure 2. Each lane has a capacity of 6 vehicle bodies. At input point A, the lane selection decision is made and the vehicle body is routed to the selected lane. At output point B, the lane, from which the next sub-assembly will be drawn to route to the conveyor leading to the downstream operation, is chosen. Components are held in lanes using electronic eyes and mechanical stops. Decisions are made using Programmable Logic Controllers (PLC). Some lanes are dedicated to components with certain attributes pertinent to a high volume product. Other lanes might contain components with a mixture of attributes. The rules for sortation are based on the schedule requirements for the trim operation. These rules are pre-set. At the output end, there are selection rules. The jobs waiting at the front end of each of the six lanes are evaluated. The evaluation is programmed into the system based on a 'points' or relative weights program. The job with the highest relative weight is chosen. The selection decision is relayed to the appropriate mechanical stop and the job is released to be routed down the conveyor leading to the trim system. The next job waiting in the lane that was selected moves up to the front of the lane. The evaluation for the six lanes is made again.

A new product line was being added to the existing product line. This implied schedule changes and also a new set of rules used for sequencing trucks into and out of the bank. Simulation was used to verify the capability of the selectivity bank to re-sequence trucks to meet the new schedules. Also, the effectiveness of the new rules set was to be investigated. If the simulation proved that the required system throughput could not be met under the new conditions and rules, an alternate scheme was to be evaluated. If a feasible rule set could not be formulated, the option of adding another lane was to be considered - an investment of over hundred thousand dollars. Also, the new rules had to be investigated without affecting current production. A smooth transition was required from one schedule of operation to the next. Simulation was ideal for the application.

The model of the system was developed and analyzed using the AutoMod simulation software from Autosimulations Inc. AutoMod was chosen due to the constructs it provided for modeling power-and-free conveyor systems and the flexibility offered for programming different rules sets. Other examples of applications of this software can be found in Sathyadev et al, 1995 and Gunal et al, 1996.

The base model captured all the physical details of the system and a default rules set. The paint and the trim systems were 'black-boxed'. The rate and sequence of input to the selectivity bank was based on actual data defined by the planned schedules. It was assumed that the trim system would not block the selectivity bank due to any reason. The proposed rules set was incorporated and the model was simulated. The system throughput, and the number of rules broken, in order to provide a continuous supply of bodies to the trim line, were used as the performance measures.

From the simulation of the base model, it was seen that the required throughput could not be met based on the proposed rules set. In order to rectify the situation, some rules for the sortation at point A, were relaxed. The changes were made to the model and it was simulated again. Several iterations of the above process were made in order to come up with the optimal rules set that would help achieve the desired throughput.

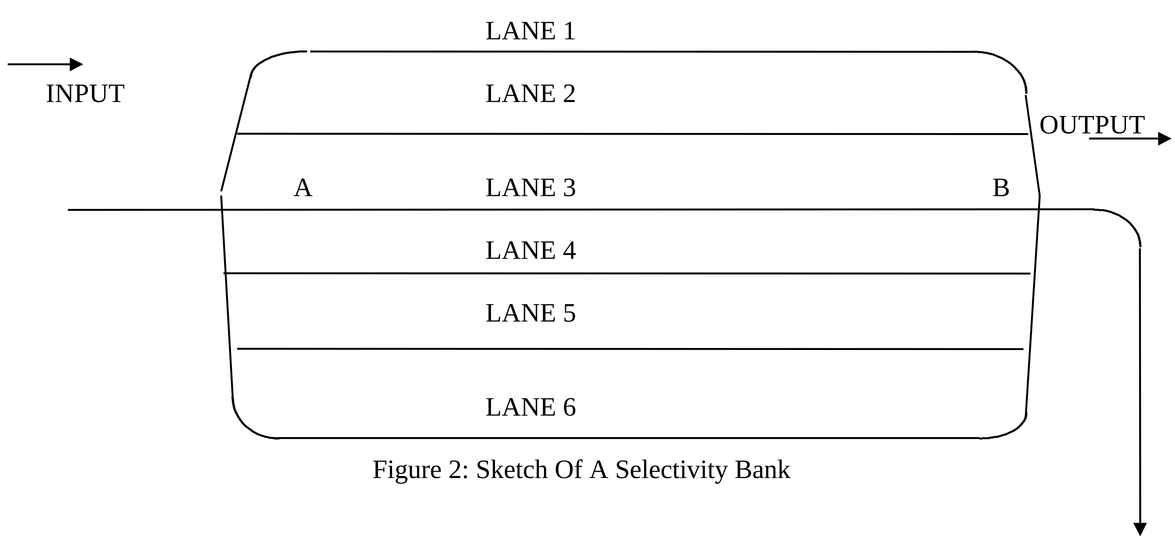

Figure 2: Sketch Of A Selectivity Bank

Once the optimal rules set was chosen, the feasibility of implementing this rule set in the real system was assessed. Thus the rules required for achieving the required throughput without compromising the schedule requirements for both systems was selected. Since a feasible rules set was defined from the simulation, the need for an additional lane and other physical modifications was obviated.

Simulation proved that the required system throughput could be met simply by modifying the current rules set. An additional lane or other physical modifications were not necessary. All this was made without any disturbance to the current operation of the actual system. The selected rules set were then incorporated in the Programmable Logic Controllers (PLC) for operation under the new schedule to accommodate introduction of the new product. Simulation was valuable to ensure continued operation and in avoidance of potential cost of over hundred thousand dollars.

5 CONCLUSIONS

Sortation systems and selectivity banks are used to connect major sub-assembly systems together in automotive manufacturing. These systems are used for buffering and also to re-sequence components in the order suitable for the downstream operation. These sortation systems are expensive to design and implement. Also, the sortation algorithms are continually changed over the lifetime of the system. Simulation is an ideal tool that can help in designing and fine-tuning these sortation systems. Some of the design and maintenance issues were discussed in this paper with relevance to simulation. A case study was presented to elucidate the issues with selectivity banks and to demonstrate the applicability of simulation. These systems are not exclusive to the automotive industry and is used in several manufacturing systems. Simulation will be a valuable aid in the design and maintenance of such systems.

ACKNOWLEDGMENT

The authors would like to thank Dr. Onur Ulgen, President of Production Modeling Corporation & Professor, Department of Industrial & System Engineering at The University of Michigan, Dearborn, for his encouragement, support and valuable comments towards writing this paper.

REFERENCES

Graehl, D. 1992. Insights into Carrier Control: A Simulation of a Power and Free Conveyor Through an Automotive Paint Shop, *Proceedings of the 1992 Winter Simulation Conference*, eds., J. Swain, D. Goldsman, R. C. Crain, J. Wilson, IEEE, Picataway, N. J., 925-932.

Gunal, A., E.Grajo, and D.Blanck. 1994. Generalization of an AS/RS Model in Siman/Cinema, *Proceedings of the 1994 Winter Simulation Conference*, eds. J. D. Tew, S. Manivannan, D. A. Sadowski, A. F. Seila, IEEE, Picataway, N. J., 857-865.

Jayaraman, A. and A.Agarwal. 1996. Simulating an Engine Plant, *Manufacturing Engineering*, Vol. 117, No. 5, 60-68.

Satyhadev, D., S.Upendram, E.Grajo, A.Gunal, O.Ulgen, and J.Shore. 1995. Modeling Power and Free Conveyor Systems, *Proceedings of the Autosimulations Symposium*, Autosimulations, Bountiful, UT, MON.MH3.1-MON.MH3.11.

Ulgen, O., A.Gunal, E.Grajo, and J.Shore. 1994. The Role of Simulation in Design and Operation of Body and Paint Shops in Vehicle Assembly Plants, *Proceedings of The European Simulation Symposium*, Society for Computer Simulation International, 124-128.

Upendram, S. and O.Ulgen. 1995. Methods for Implementing AGV Parallel Server Lane Selection Rules in Automod, *Proceedings of the Autosimulations Symposium*, Autosimulations, Bountiful, UT, MON.MH1-MON.MH1.14

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