MODELING POWER AND FREE CONVEYOR SYSTEMS

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1 ABSTRACT

This paper establishes the groundwork to model power and free conveyor systems using AutoMOD II simulation software. A methodology to identify and model system parameters, control and routing logic, and sequencing product mixes is developed. A description of pitfalls, work-arounds, and other issues of concern in using AutoMOD to model power and free systems is presented. Recommendations for future enhancements and a comparison of power and free systems with state-of-the-art movement systems conclude the paper.

2. INTRODUCTION

Power and Free conveyor systems are a staple form of material handling in the automotive industry. With the recent trend towards agile and lean manufacturing techniques, the performance of power and free systems is, more than ever, critical to the overall performance of a manufacturing system. The newer automotive assembly lines handle several body types built on the same platform; and this places additional requirements on power and free systems such as selectivity banks and strip banks. The increased expectation from power and free systems has made it imperative that the workings of these systems be evaluated in detail. Modeling a power and free system will aid in predicting its performance under various conditions and, also, in the selection of control rules.

Power and free conveyor systems, in simple terms, consist of two tracks -- a power track and a free track. Central to a power and free system is a chain that continuously moves while supported by trolleys that ride on the power track. Spaced out at regular intervals on the chain are pusher dogs that engage with carriers that ride on the free track. A carrier consists of one or more trolleys. The dimension and weight of the load determine the number of trolleys that make up a carrier. Consider an example of a three-trolley carrier. A tow bar connects the leading and intermediate trolleys. A load bar connects the intermediate and trailing trolleys. The part being transported hangs off the load bar. The leading trolley has a power dog or duckbill and a hold back dog between which the pusher dog is trapped forcing the carrier to move forward. The trailing trolley has a beaver tail and when accumulating, the power dog of the next carrier engages with this beaver tail causing the carrier to disengage from the power dog. A trip-plate mounted on one of the trolleys activates limit switches placed along the track. These trip plates control the opening and closing of stops and also act as clearing limits. The position of this trip-plate has to be carefully modeled while simulating motion of carriers.

3. WHY MODEL POWER AND FREE CONVEYOR SYSTEMS ?

The throughput of a power and free system is a function of a multitude of factors. These factors include the placement of stops and control switches; the number of carriers; initialization strategies; traffic routing logic, the inter-arrival times of carriers at merges, the capacity of selectivity banks, and bias banks. The interaction of these factors is complex and coupled with operations such as loading and unloading; additionally other in-process operations such as welding further complicate the ability to predict the performance of such systems. Discrete event modeling is a versatile tool to study the performance of this system and study its behavior under various conditions.

3.1 Verification of traffic control logic

The time it takes for a carrier to move between stops is a function of several parameters. These parameters include chain speed, dog spacing, location of limit switches and control switches, the location of a trip-plate on carriers, etc. The positioning of limit switches to control the spacing of carriers on chain segments determines the inter-arrival time of carriers at stops. Though the inter-arrival times can be calculated with pencil and paper, their input on the overall throughput is difficult to estimate. Simulation is a versatile tool to study the effect of positioning limit and control switches and their effect on the ability of carriers to make cycle. Simulation provides a tool to study the motion of carriers out of stops and the cycle time available for loading, unloading or other operations at these stops.

3.2 Optimum number of carriers

Power and free systems are highly tuned systems and the number of carriers in a system directly influences the throughput of a system. An insufficient number of carriers can adversely alter the output of the system. Excess number of carriers can place undue stress on chains. Limit switches are used to control the spacing of carriers on chain segments. However, chains and drive motors are designed for specific loads and overload can lead to breakage and considerable downtime. Last, but not the least important, is the cost element associated with having excess carriers, chain lengths, control equipment, etc. Again, a model of a power and free system can help to quickly determine the effects of changing the number of carriers.

3.3 Bias banking requirements

Space restrictions, storage requirement between processes, float requirement, and other factors determine the need for bias accumulation banks. Biased accumulation refers to the fact that instead of carriers traveling end to end on a chain section they are angled and parallel to one another. In the three-trolley carrier example mentioned above, the trailing trolley is diverted into a parallel free track resulting in the load bar assuming an angular position. Considerable savings in space can be achieved by using biased banking to replace long section of straight-line chain segments. In order to maintain production through machine breakdowns, an effective strategy is to maintain a float (generally set to one-half hour to one hour of production) on the chains. The float has to be spread out along the length of the loaded section of the power and free system. Bias accumulation banks provide a means for storing float with minimum space requirements.

3.4 Throughput assessment

The bottom-line response of any system that is of interest to a manufacturing planner is the throughput of the system. The complexity of a power and free system results in difficult questions when changes to system parameters are contemplated. The availability of a model permits the user to optimize or perform a sensitivity analysis and study the effects of various system parameters on the output of the system.

3.5 Visualization

The animation provided by AutoMOD makes an excellent case for the motto "a picture is worth a thousand words." Visual aids go far in helping to comprehend solutions. The authors' experience shows that animation helps explain the working of a power and free system to their clients. The clients, in turn, find it an excellent tool to present their solutions to decision-makers and upper management. Animation is a tool for the modeler to ensure validity of a model. The power and free module in AutoMOD has superior animation capabilities and users, in conjunction with ACE, can develop quality presentations.

4. HOW TO MODEL POWER AND FREE SYSTEMS USING AUTOMOD

4.1 Control of carriers

Carriers in power and free systems can be modeled as (1) Carrier as controller, or (2) Load on board control.

3.2.1 Carrier as controller

The carrier is in control of its motion through the system when using this methodology. This is accomplished using built in features of AutoMOD such as work list, park list, load list, vehicle list, and search list. However, when using this methodology, modeling complex scheduling rules is cumbersome and an in-depth knowledge of these constructs is a necessary requirement. The authors' preference is the following methodology.

4.2.2 Load on Board Control

The motion of the carrier is controlled by commands issued to a load that resides on the carrier. Traffic control and routing are considerably simplified using this methodology. The load moves between processes while executing procedure actions.

The authors strongly recommend the use of 'load on board' control to model power and free systems. A short list of steps involved in developing a 'load on board' control for power and free systems include:

1. Define the power and free conveyor system and draw the chain sections.
2. Place stops and clearing limits on the chain sections.
3. Define a *named list* assigning a station where all carriers originate at the start of simulation. Return to the *Edit a Vehicle Definition* window and select the above *named list* for the *Carrier Start List.*
4. Connect the starting station to a process.
5. Clone loads equaling the number of carriers in the system to the above process.
6. Since a carrier is a territory in a power and free system, loads board a carrier automatically.
7. The motion of the carrier is controlled by issuing commands to the load on-board the carrier.
8. The load residing on the carrier can execute any action statement such as wait on orderlist, move into queue, move from process to process, etc.

4.2 Traffic control of carriers

Routing of carriers can be achieved using several strategies including the use of counters, orderlists and blocks. The authors' preferred strategy is the use of counters to implement traffic control logic. Counters are simple to use and need no *wait* statements. Incrementing and decrementing counters permits limiting the number of carriers on chain segment or route carriers through merges. Orderlists are preferred when product mixes are being handled on a given system. Sequencing a desired mix out of selectivity banks can be achieved using orderlists. Blocks are physical elements that are placed graphically in the layout. Blocks are quick and easy to implement. However, care is needed in placing the blocks accurately which otherwise could alter the routing logic.

The following pseudo-code illustrates an example of sequencing parts out of a selectivity bank.

/*pInit initializes the process pManager with only 1 load */

```
process pInit clone 1 load to pManager
```

/*PartRequestGenerator is a request generator that sends orders to pManager to execute certain actions. The order on oManager is backordered to ensure that each order placed, if not satisfied immediately is backordered and the sequence of request are maintained */

/ lai_PartType* is a load attribute of type integer describing a part type *oManager* is an orderlist that has only one load that circulates through it repeatedly */

```
process pPartRequestGenerator
        set lai_PartType to nextof(some custom sequence)
        order 1 load from oManager to pManager(lai_PartType+1)
        in case order not filled backorder on oManager
```

/*pManager is the sequencer or scheduler. Only one load is re-circulating in this process. The load waits on oManager to be ordered off by a load (from pPartRequestGenerator) requesting a particular action to be performed */

```
proc Manager
   if procindex is 1 then
        wait to be ordered on oManager
   if procindex > 1 then
   begin
        wait to be ordered on oPartSignal(procindex-1)
        order 1 load from oSelectivityBank(procindex-1) to pNextProc
        send to pManager(l)
   end
```

/* pSelectivityBank is a selectivity bank with different types of parts (lai_PartType) waiting on orderlist oSelectivityBank(lai_PartType) specific to the part. The part would be ordered off this list by pManager. The sequence of the ordering is determined by the backorder placed on oManager */

```
proc pSelectivityBank
    order 1 load from oPartSignal(lai_PartType)
    in case order not filled backorder on oPartSignal(lai_PartType)
    wait to be ordered on oSelectivityBank(lai_PartType)
```

/* The parts ordered out of the selectivity bank travel to the next stop on the chain and while exiting clone loads to pPartRequestGenerator to sequence the next part out of the bank */

```
proc pNextProc
    increment cNextProc by 1
    clone 1 load to pPartRequestGenerator
    travel to pf:NextStop
```

4.3 Biased accumulation banks of carriers

Biased banks are commonly used in automotive and other manufacturing plants and involve the biased accumulation of carriers in order to decrease the total length of accumulation. AutoMOD does not provide tools to directly handle biased banking. Two issues that need to be addressed while modeling biased banks are the chain parameters and the shape of carriers and loads. Chain parameters such as stopping and moving distances should be appropriately changed. To depict a realistic image of the carriers in the bank, create a new load type with the required shape and change the load type at the appropriate location.

To present a realistic view of carriers moving through biased banks change the load type when a carrier enters a biased bank. It is advisable for users to create a unique load for the following situations: a) empty carrier, b) full carrier, c) biased empty carrier, and d) biased full carrier. Model a biased carrier using the appropriate bias angle from drawings.

4.4 Modeling downtimes of Power and Free Chain Sections

Chain failures in power and free systems are as common as unexpected downtimes in other resources. AutoMOD provides no mechanism to readily model downtime. Modeling chain downtime on nonaccumulating chain sections is considerably easier than on accumulating chain sections.

4.4.1 Non-accumulating chain sections

Place a resource at a station located on the chain section to be brought down. Bring down the resource to halt the motion of all carriers on this section, effectively stopping the chain.

4.4.2 Accumulating chain sections

The authors are unaware of techniques available to realistically model downtimes of accumulating chain sections. Presented below is a workable, though inaccurate, methodology to model downtime. Place a resource at each station along a chain section and bring down all such resources simultaneously. However, this does not immediately stop the chain. Carriers moving on this chain section will continue to move and halt only when they accumulate behind a stopped carrier.

4.5 Layout

The process of developing a layout is considerably shortened when starting with an IGES file of the chain sections. Iges/Sim works extremely well while developing chain sections. Care should be taken in exporting the drawing from its native format to an IGES file. Each chain section should be maintained as a continuous segment without overlaps. The drawing should be to scale and maintain the coordinate positioning of the power and free system with respect to other components of the layout.

4. ISSUES IN MODELING POWER AND FREE SYSTEMS USING AUTOMOD

5.1 Converging Chains

Locating stations close to intersecting chains needs special attention in AutoMOD. Consider a transfer formed by the endpoint of chain # 1 intersecting chain #2. Carriers require a certain amount of space on the second chain before they leave the first chain. This distance equals the induction space of the transfer. This is a restriction peculiar to AutoMOD and this does not happen in reality. This prevents locating stations on the second chain close to the transfer. If a station is located close to such transfers, care should be taken to place this station behind the transfer by a distance greater than the induction space of the transfer.

5.2 Two non-accumulating chain sections forming a loop

A loop formed by two non-accumulating chain sections can lead to a deadlock at the transfers between the chain sections. When one of the chain sections comes to a halt, carriers on the other chain attempting to get on the stopped chain will halt and hence stop the second chain also. When the first chain comes up, carriers on this chain will attempt to move on to the second chain. However, the carriers cannot do so since the second chain has been brought to a stop thus leading to a deadlock. A simple fix to this problem is to place small segments of accumulating chain sections between the non-accumulating chain sections. The length of these chain sections should be slightly greater than the length of the carrier.

5.3 Chain length not an exact multiple of dog spacing

Situations where a single chain segment forms a loop can lead to the carriers being unable to maintain inter-arrival time. This is caused by the carriers having to wait for a dog before they can get through the transfer. A quick fix is to adjust the length of the chain so that it is an exact multiple of the dog spacing. The modeler should be aware of this problem when developing the layout for a power and free system and take steps to avoid its occurrence.

5.4 Modeling existing power and free conveyor systems

The topics discussed above apply to both greenfield and existing power and free systems. However, when modeling existing systems, special consideration is needed when specifying chain parameters. Wear and tear will cause dog spacing and chain speed to be quite different from nominal values. A common phenomenon in power and free systems is chain stretching. These discrepancies have to be accounted for while analyzing results from simulation.

5.5 Initialization strategies

The throughput of a power and free system is sensitive to the distribution of carriers along the empty sections and loaded sections of the chain. The distribution of carriers at the beginning of a simulation can influence the throughput of a power and free system. Initialization strategies have to be developed that are suitable for the system being modeled. Modeler will have to develop appropriate strategies in discussion with the designers of the system and test the accuracy of these strategies.

6. RECOMMENDATION FOR MODELING POWER AND FREE SYSTEMS USING AUTOMOD

This section discusses topics that will help users build an accurate model of power and free systems using AutoMOD.

6.1 Chain speed when it is a recurring decimal

The authors' experience shows that rounding-off chain speed can lead to inaccuracies in indexing and cycle times. Avoid this situation by using as many digits as AutoMOD will permit to represent chain speed as well as other numbers that users input. Consider as an example a power and free system that has to deliver 80 jobs per hour. This equals a cycle time of 45 seconds. Assuming a center-to-center distance between stops of 20 feet, in order to meet the 80 jph requirement, the chain speed must be set to (20/45 =) 0.444444 feet/sec or 26.666666 fpm. Rounding-off this speed to 26.67 will result in a cycle time greater than 45 seconds.

6.2 Chain synchronization

When joining two chain segments of different speeds, it is important to synchronize the two chains. Failure to do so can result in a carrier having to wait for a dog at a transfer before it move on to the next chain that runs at a different speed. This problem is avoidable by chain synching. The AutoMOD user's manual provides a detailed explanation of chain synchronization.

6.3 Combine chain segments to form a single chain

Care should be taken to model the chain segments exactly as they are laid out on a drawing. A chain segment on a drawing should not be broken into several segments in an AutoMOD layout. Segments that belong to the same chain should be combined to form a single chain. If not, carrier travel time will increase. At transfers, carriers wait to catch a dog on the next chain segment if chains are not synchronized.

7. CONCLUSION

Material flow is a major concern in the operation of manufacturing systems. The objective of material handling systems is to aid the overall manufacturing system. Movement systems add no value to the final product and every attempt should be made to limit motion and the usage of movement systems for in-process storage. An understanding of the working of a movement system is critical to predicting the performance of a manufacturing system. A discrete event-model aids in the analysis and evaluation of movement systems.

AutoMOD provides an excellent tool to model and study the behavior of power and free conveyor systems. Power and free systems, though only a small percentage of the overall material handling systems market, are popular in the automotive industry. Without doubt the automotive industry is the engine of North American economy and it is essential that better and more versatile tools be available to design and manufacturing engineers in the automotive industry. Subtle changes to the current version of AutoMOD will assist modelers in better predicting the performance of power and free systems. A long standing request from modelers using AutoMOD to study power and free systems is a wish to see pusher dogs in their animation. The mechanism of merges requires further refining to closely represent real-world power and free systems. An effective mechanism to implement downtime of accumulating chain sections need to be developed.

Recent developments in material handling systems cast a doubt about the viability of power and free systems in the future. Intelligent systems like electrified monorail systems (EMS) are increasingly popular with materials handling engineers and finding wider application in the automotive industry. EMS provide manufacturing systems with increased flexibility and appear to be an an ideal solution to the requirements of a lean and agile manufacturing system. However, experts in material handling systems are unanimous in their opinions that power and free systems will continue to play a big part in the automotive industry. With the automotive industry making rapid strides in developing countries, we can safely assume that the global market for power and free systems will grow considerably. Modeling of power and free systems will continue to grow and demands for improved tools will keep rising. ASI will not go wrong with any efforts to enhance the capability of AutoMOD to model power and free systems.