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SELECTING SIMUALTION ABSTRACTION LEVELS IN SIMULATION MODELS OF COMPLEX MANUFACTURING SYSTEMS

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ABSTRACT

Abstraction level of complex simulation models such as large manufacturing systems is always a critical factor in simulation projects. It not only helps define boundaries of a simulation model but also defines the complexity and resource requirements for the model. Many a times a simple looking model grows into a complex model because of incorrect choices in abstraction level. Developing the model in stages or steps of abstraction is sometimes a favored approach. In this paper we study and analyze 'why' and 'how' these choices in abstraction level of a simulation model at various stages in a project's life cycle results in answering the objective function more precisely. Using several automotive manufacturing case studies, We discuss the challenges relating to complexity and methodological issues, and the procedures involved in managing the same.

1 INTRODUCTION

Manufacturing lines are the mainstay of production centered organizations. Developing an efficient manufacturing line and bringing it to realization is the main task of manufacturing line engineers (Benjamin et al. 1998). A simulation model is a powerful tool for understanding the complex interactions of manufacturing operations. An accurate model helps identify the effects constraints on dynamic process (Scott 1994). The biggest challenge for a simulation engineer in terms of ensuring accuracy is selecting the level of detail to include in a model. In most cases, the levels of detail or abstraction overlap and hence making a binary decision proves near impossible.

This decision on abstraction levels also impacts software choice. Vasudevan et al. (2009) discuss software selection methods in detail. Improperly matching software and abstraction levels can lead to significant delays in the project timeline. Some simulation tools can be very easy to use when modeling assembly line workstations to study throughput, but can be extremely tricky to use when handling work-cell type robotic interactions or cross-transfer type conveyor systems to study acceleration parameters (Vasudevan et al. 2009). However, even after the right software choice is made based on a given abstraction level and objective function, varying the abstraction level and hence model design based on findings is an interesting challenge.

Since the advent of simulation, various authors have written documented use of multiple level abstraction in Simulation modeling (Law and Kelton 1991). The importance of abstraction level detail required in simulation based on goals is well noted by these authors. The level of abstraction of a model determines the amount of information that is contained in the model. The quantity of information in a model decreases with the lowering levels of abstraction. Thus a 'low level abstraction' model contains more information than a 'high level abstraction' model (Benjamin et al. 1998).

The significance of abstraction is further amplified by pressures on both time and costs of projects and does not allow the use of a 'safe' abstraction level that would have more than required details in the model . It hence becomes vital to model at the highest possible abstraction level that does not compromise in any way on the accuracy of outputs or ensuing decisions. That said, there is a need for models and modelers to be flexible with abstraction levels during projects. Koyuncu et. al (2007) discuss Dynamic Data Driven Application Simulations which are designed to switch abstraction levels during model run, but this technology is still in research phase and requires refining before it can be applied to everyday modeling projects in different industry environments. Vasudevan et al. (2009) describe five easy to classify abstraction levels as shown in Figure 1.

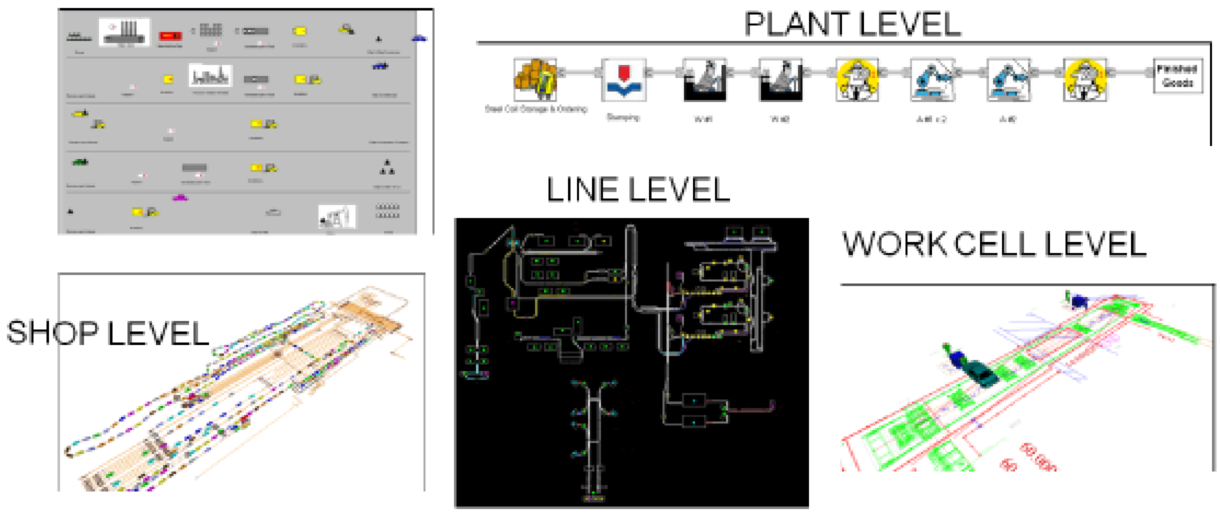

Figure 1: Simulation Abstraction Levels

This paper discusses abstraction levels in modeling an automotive final assembly line and changes in the same as a part of the project lifecycle. In this case, changes in abstraction level of a specific portion of the model was made as a consequence of the validation effort. The rest of this paper is organized as follows. Section 2 discusses the final assembly line under study and the associated model. A discussion of the changes needed in abstraction levels and modeling methodology follows in sections 3 & 4. Results of the revised model, conclusion and findings from the project are summarized in Section 5 and 6.

2 AUTOMOTIVE FINAL ASSEMBLY LINE – SYSTEM DESCRIPTION

The large automotive final assembly line under consideration has a designed capacity in excess 60 jobs per hour. Like all final assembly lines, the system accepts painted bodies into the Trim, Chassis and Flat top lines. Each of these lines have multiple manual and automated operations. Other associated processes include the Door Line (i.e. Doors on & Doors off) and the tire and wheel line, both of which feed the chassis directly. The front suspension line is fed with Engines from the Engine line and then feeds chassis as well along with the Rear suspension line. The IP build system, feeds the Trim line. The above described flow is shown pictorially as a flow chart in Figure 2.

The plant produces one model of vehicle, hence product mix complexities do not play a role in this model. Each of the 9 final assembly lines run at different speeds and use material handling systems intensively. However, these material handling systems all feed into a gross line speed with any associate downtimes. It is also assumed that the Flat Top line is never blocked i.e. pre-delivery and downstream areas are not the bottleneck of the system

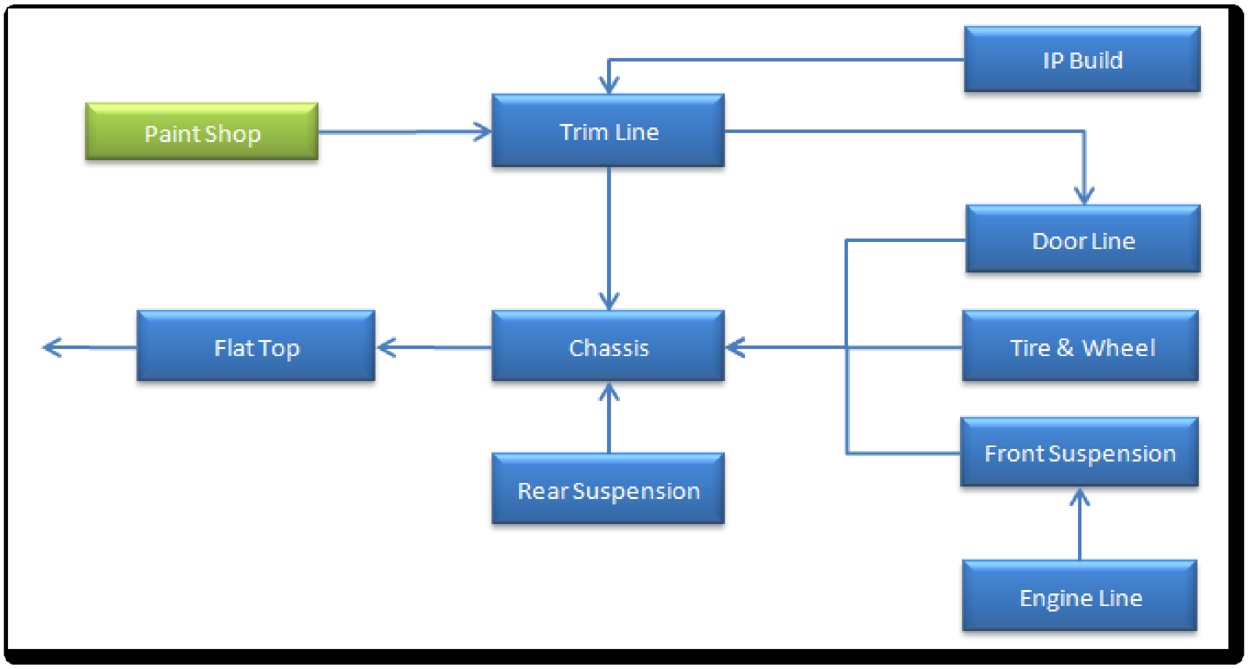

Figure 2: Final Assembly Line Process Flow

3 SIMULATION MODEL

A simulation model of the above described final assembly system was requested by the plant in order to be able to identify and eliminate system bottlenecks, study the impact of number of carriers, skids and clamshells on assembly line performance and conduct what-if scenarios to test the impact of future improvement efforts.

3.1 Modeling Approach

Based on the standard approach to simulation modeling at this specific organization and the fact that individual station cycle time variations were minimal did not play a major role in determining overall system throughput (only downtimes mattered significantly), it was determined that the model abstraction will be at a shop level i.e. individual stations will not be modeled. As mentioned earlier, given existent standards to simulation development and chosen abstraction levels, Simul8® was chosen as the modeling tool. Other reasons for choosing Simul8 included expertise in the tool among the simulation engineers as well as convenience and feature set offered by the tool.

Each of the aforementioned manufacturing lines were modeled as a conveyor section topped off by a single work center. The capacity of each conveyor section was one less than the capacity of the line (the work center accounting for that one station). This setup allows us to combine the ease of setting a conveyor line speed with accumulating several individual downtimes on a work center, thereby modeling the capacity and downtime effects on the line. Cross transfers were modeled as individual work centers with cycle times (equal to travel plus table drop time) that could push parts out only when adjoining work centers were available (i.e. Idle). A high-level screenshot of the model is shown below in Figure 3.

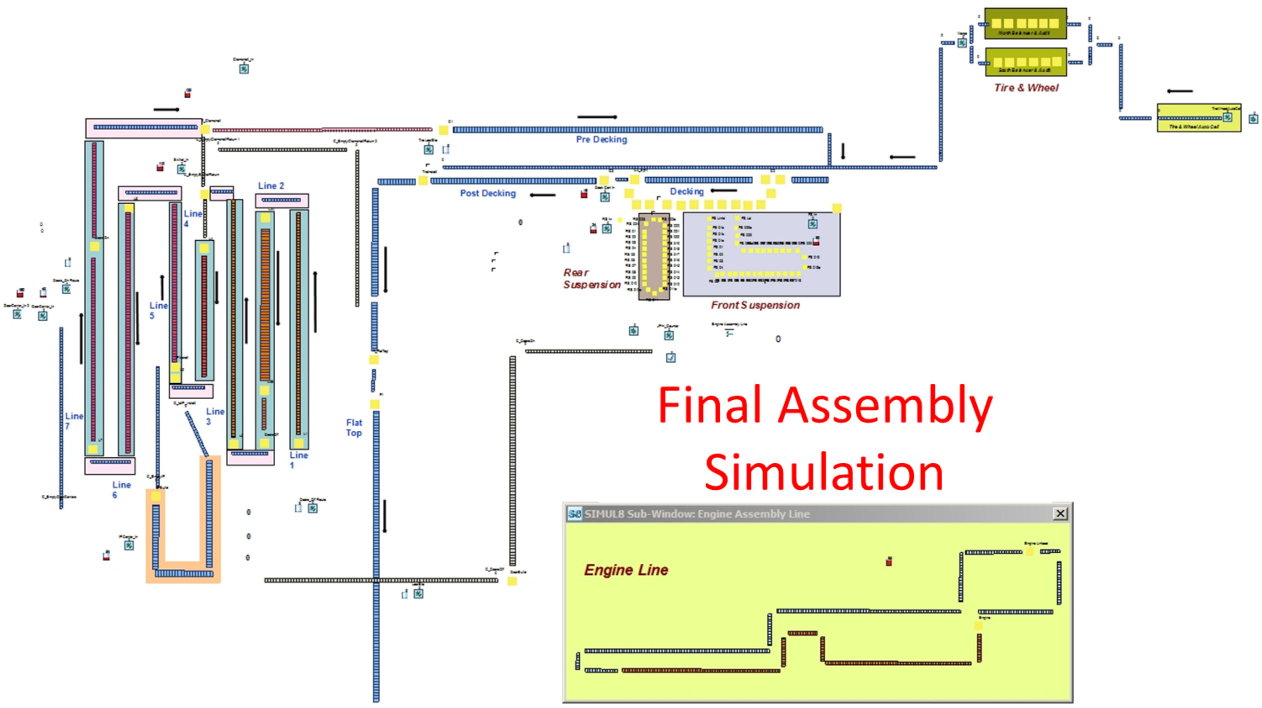

Figure 3: High level Simulation Model of Final Assembly Line

3.2 Verification, Validation and Model Results

Model verification was performed as a part of the model building process. At each stage, components of the model (each line) were run standalone and their throughputs were verified. As each of the components were assembled a basic standalone check for throughput validity was performed by comparing against theoretical calculations. Once verification was complete baseline results were assembled and presented to the plant. A throughput improvement roadmap was also built to identify the sequence of bottlenecks that needed to be broken to get to target capacity under different scenario settings.

Table 1 shows the throughput and findings from the simulation model. As we can see from table, the Door Build line featured as one of the top four bottleneck in each of the first four scenarios. However, plant studies suggested that the Door build line should in fact feature as the top bottleneck. Experienced plant personnel also agreed with this inference from the plant study. The model hence could not be directly validated in its current state.

Further investigation revealed that the Door build line were operated by a special type of conveyor system called the Powered Zone Roller (PZR) conveyor. The process in the door lines created the need to operate this type of a conveyor system. Time studies concluded that it was highly likely that the PZR system was causing certain delays that were not currently a part of the model. This hence called for a change in model abstraction level.

However the plant was also interested in studying the throughput of the system assuming that the PZR system was not a bottleneck. It was decided to approach the project in two distinct phases. Phase 1 would involve analysis of the existing model. Phase 2 would involve changing model abstraction level and including further information. Hence as a part of Phase 1, we completed the analysis of different scenarios in the existing model to study the effect of other lines, number of carriers and skillets on system performance. The results from these studies are shown in Figure 4.

Table 1: Scenarios and Finding from Existing Model

Scenario	Top Bottleneck	Bottleneck%	Throughput
1	Line 6	97.68	65.4
	Line 7	95.50	
	Chassis 2	94.97	
	DoorBuild	96.48	
2	Line 6	97.12	65.9
	Chassis 2	95.66	
	Flattop	96.36	
	DoorBuild	95.92	
3	Line 6	97.50	66.1
	Chassis 2	94.77	
	Flattop	96.75	
	DoorBuild	95.02	
4	Line 6	96.80	66.5
	Chassis 2	95.34	
	Flattop	97.34	
	DoorBuild	95.60	
5	Line 6	96.29	66.2
	Chassis 2	96.13	
	Flattop	96.84	
6	Line 6	96.40	66.3
	Chassis 2	96.24	
	Flattop	96.27	

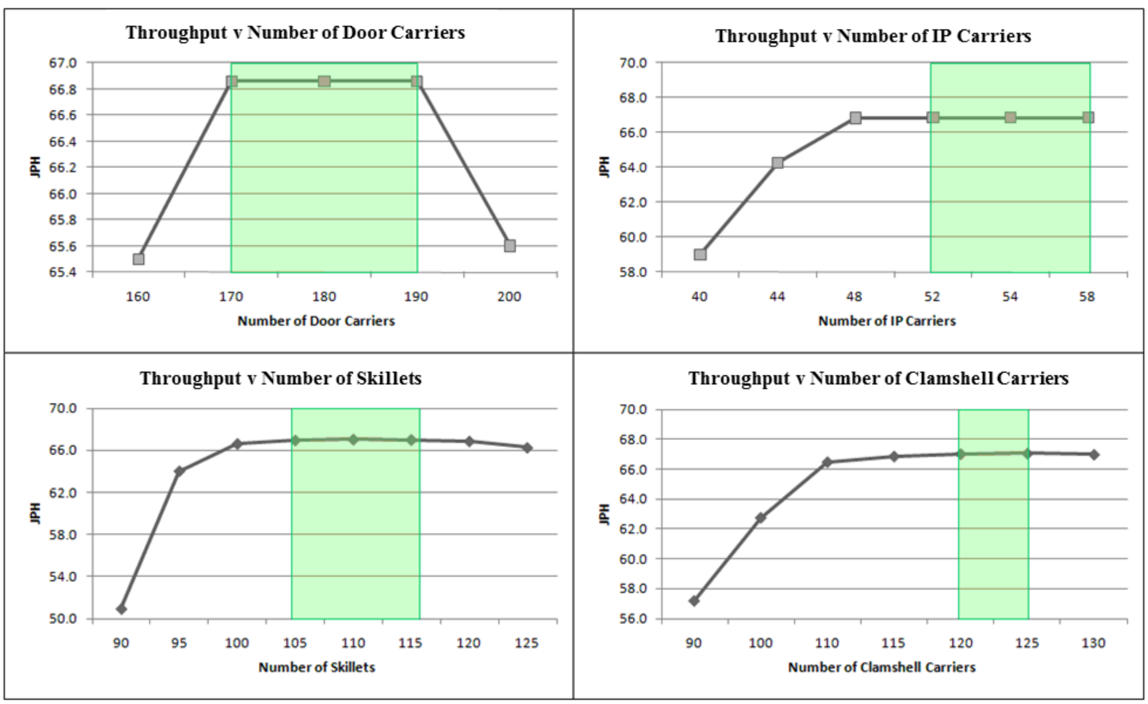

Figure 4: High Level Simulation Model Results

4 CHANGING THE ABSTRACTION LEVEL

As a part of Phase 2, the project team was faced with several choices on deciding which direction to move the project in. Increasing the level of information in the model, thereby moving into a line level model that considered station level information was the most direct approach. Another feasible approach was to build a separate model of the PZR system at a line/cell level and incorporate accurate information regarding its operation.

Each of the approaches had its pros and cons. For the first approach, The amount of data and information that will have to be collected to model an entire assembly line at the line level, was seen to be prohibitive. Modeling effort and cost would also be considerable. Advantages of taking this approach included the ability to study interactions between the PZR and rest of the assembly line system and the fact that the model would now be capable of reporting statistics by station. In the latter approach, the amount of data required and focused modeling efforts would result in a short lead time project, but we would lose the ability to study interactions and the dynamic effect of PZR operation on upstream and downstream lines.

After studying the pros and cons of the both approaches, and agreeing that cons outweighed the pros in both of these methods, the project time decided to go for a hybrid approach where the PZR system would be modeled into the existing simulation model. This would mean that there would exist multiple fidelities in the same model which in turn leads to inconsistency in data requirements across different parts of the model. However, this approach would guarantee the ability to study interactions as well as a comparatively low data collection and modeling lead time. The approach was also in agreement with the Theory of Constraints way of approaching a problem, by deep diving or working on only the bottleneck or in this case the 'problem areas'. Spending time & money in deep diving the rest of the model will prove futile from the point of view of project objectives. The rest of this section describes the PZR system in detail and the modeling techniques involved in simulating the same. Results from this partial low-abstraction (cell level) model are also presented.

4.1 PZR – System Description

The PZR system consists of high speed conveyor sections that follow a staggered motion approach using several in system sensors. Each section acts as a stop and go conveyor between workstations. Powered Zone Roller Conveyor (PZR) is a modular handling solution that allows parts to accumulated without contacting one another. Standard PZR are arranged in a series of "zones," with each zone driven by a bi-directional motor. Parts are driven out of a zone only when the next zone is vacant, so parts can accumulate without the need for pallets.

Flexibility of application distinguishes Powered Zone Roller systems from conventional floor conveyors. PZR Conveyors come in standard lengths, allowing a floor layout to be assembled more quickly. Application engineers can place PZR modules into layouts without lengthening and shortening every unit, as is required with most conveyor solutions.

4.2 Modeling the PZR system

This section discusses in detail the modeling of PZR system, challenges in modeling and steps taken to work around the same. As in all modeling efforts, the conceptual design of the model is critical. As a part of this conceptual design phase it was decided that a proof-of-concept model will be built to test the logic that runs the PZR conveyor. Once verified, the concept would be built into the actual working model of the final assembly line.

Upon understanding the PZR in more detail, it was seen that its working could be broken down into three logical rules that can then be programmed/implemented in the simulation model.

- When accepting parts, section(s) should not empty out
- When emptying parts, section(s) should not accept the part
- Section should hold part(s) to its capacity till the next section starts accepting part(s)

Once broken down to these three basic operational rules, the conceptual model was developed using a interval based monitor that served as a sensor to detect release and accept points for each conveyor section. During the model development stage it became evident that model run time would be adversely impacted given that we are adding detail, using continuous monitoring functions and increasing number of model entities (logical entities). Several additional variables were also required to store current state of system information.

An efficient way of incorporating this additional abstraction level was conceived using spreadsheets to store the current state of systems. Internal Simul8® spreadsheets were used for this purpose. Spreadsheet allow us to track information better and implementation of logic much more structured. Use of spreadsheet delivered two advantages over variables: first, the number of separate variables required in the model was reduced. Second, it made debugging easy from the perspective of tracking and adding watches. The speed of simulation was not compromised and improved significantly with the use of internal spreadsheets compared to using individual variable arrays.

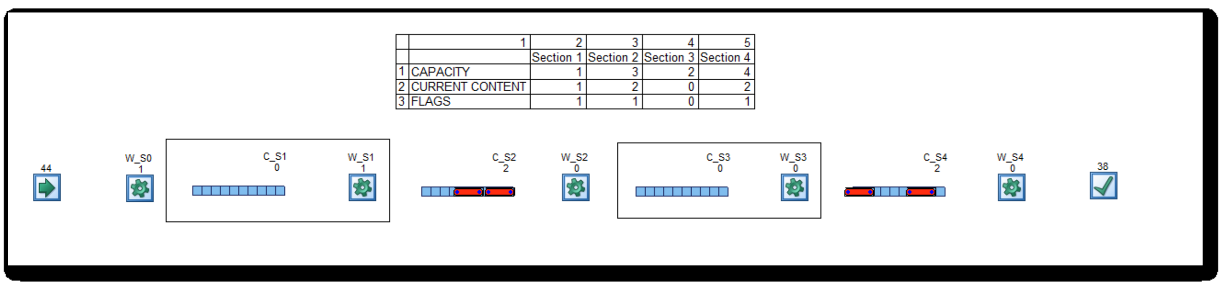

Figure 5: Conceptual Model to Test PZR logic

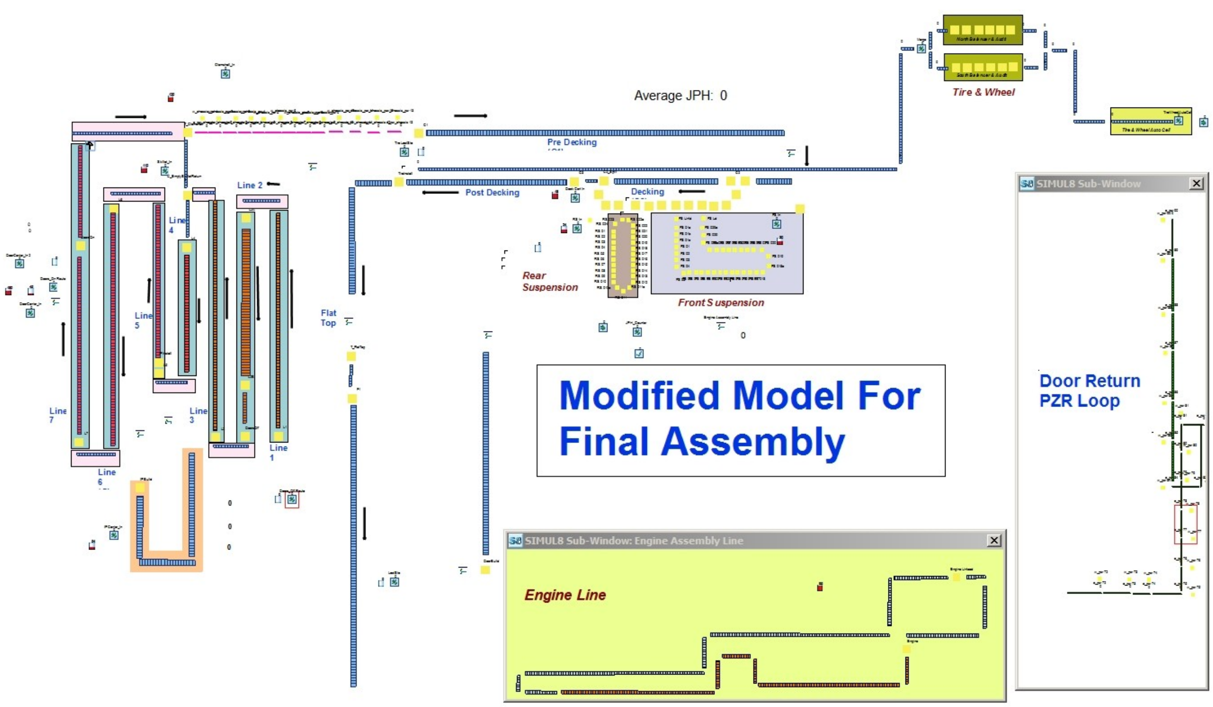

Figure 6: Simulation Model Screenshot - Final Assembly Model with PZR based Door Build Line

Once fully developed the proof-of-concept model was discussed with the plant team to ensure that the working of the PZR conveyor was to specifications. After obtaining their buy in, the logic was transferred to and implemented in the full blown assembly line simulation model. As expected, this revised model ran slower than the original one given that the monitoring interval could not be minimized or eliminated. Using an alternate software (material handling system focused) could have allowed the use of photo eyes as sensors and hence negated the use of continuous monitoring, but these high fidelity simulation tools, are generally slower for large models anyway (would have also required a lot of effort to build the whole assembly line in a more complex tool). A screen shot of this modified model is shown in Figure 6 and results are discussed in the following section.

4.3 Results & Validation

The addition of the PZR system to the model provided various insights into the dynamic nature of the final assembly system. The change in system behavior was in line with line observations and expectations from a standalone view, however system interactions and net system effects were difficult to predict and hence provided key insights to the plant in each of the different scenarios. For instance, the model did show a level of starvation on the line observed in the plant was expecting but baseline model throughput remained near constant. Though the Door Build line was not the bottleneck in the baseline model, it showed up as the primary bottleneck in several scenarios, which explains plant observations.

Results and data collected from different scenarios provided information and suggestions for modifications that could be carried out on the existing PZR system in the facility. Figure 7 shows the results from the modified model for clamshell experiments; which can be compared with the bottom-right graph in Figure 4 that has results from the high-abstraction level model. Number of clamshells required to achieve a 66.5 JPH throughput has reduced from around 110 carriers in the high level model to 105 carriers in the detailed model. It is further observed that the even with its working modeled in acceptable detail, the PZR system is not the system bottleneck.

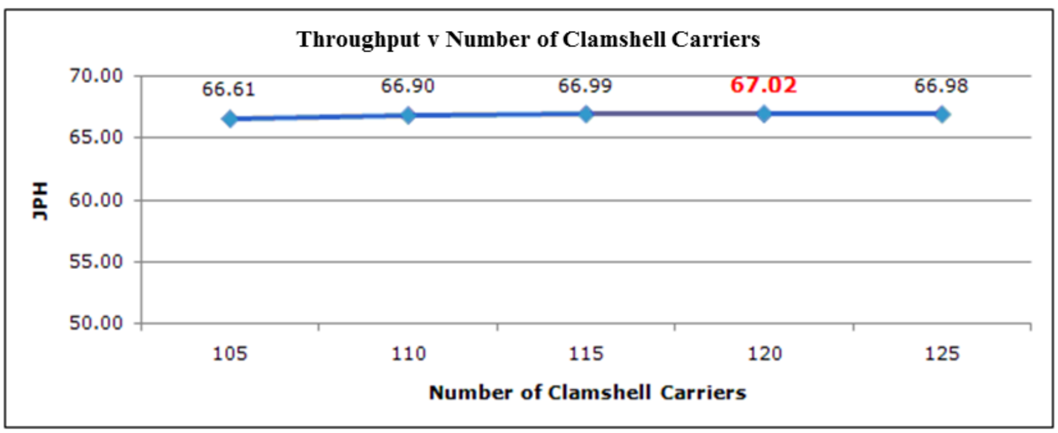

Figure 7: Result from Revised Model – Effect of number of clamshells on throughput

5 CONCLUSION

The simulation model of an automotive final assembly line has been presented in detail. Challenges related to changes in abstraction level during the project lifecycle have also been discussed. The importance of model validation becomes evident as a part of this paper. The need to modify abstraction levels i.e. add more detail arises often during validation. It is not advisable to change the abstraction level of the whole model in such cases. Techniques such as “five whys” and bottleneck analysis can help us in identified areas for a deep dive.

The presence of multiple abstraction levels in the same models does create data collection and documentation challenges, but trades off with time and effort requirements in case a decision is made to rebuild the model completely. There are four key take ways from this paper.

- Selection of abstraction levels should be based on project objectives and should not purely depend on the system itself
- Modelers should note adopt a safe-bet approach of putting more detail into the model than what is required. Models should be built at the highest level of abstraction possible without compromising accuracy.
- Analysis of high-level model results and TOC based tools can help in identify areas for adding model fidelity
- Changes to model efficiencies should be considered right from the conceptual phases when moving to low abstraction level models

Further studies on abstraction level will be made with every project undertaken. The process of selecting abstraction levels is still predominantly arbitrary. Being a part of an experienced consulting firm that works on large number of simulation projects across industry verticals, the authors are constantly trying to define generic methodologies that can be used for making abstraction level decisions.

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