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Simulation Analyzes Material Handling Requirements for a Major Automotive Supplier

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Abstract

Simulation now has a long record of improving operational efficiency and effectiveness in many areas – manufacturing, commercial transportation and logistics, health care, public-sector transport, service industries, and military operations. Historically, simulation's earliest successes appeared in the manufacturing sector. These successes began with attention to value-added operations (e.g., at machines often entailing high capital investments) and rapidly spread to the non-value-added but very necessary material-handling requirements within factories.

In this paper, we describe the simulation and consequent analysis of material-handling requirements for a major automotive supplier. Successful material handling operations must satisfy several compelling interests, including safety, timeliness, efficiency, and effective support of the actual manufacturing operations under conditions of tightly constrained financial investment and ongoing financial support. This successful simulation and analysis project helped the client enterprise accommodate needed production increases with reduced headcount and hence minimal or no cost increases, including those entailed by in new equipment and floor space.

Keywords
Logistics, material handling, discrete-event process simulation, assembly lines, inventory management

1. Introduction

Discrete-event process simulation has now established a superb record of its ability to improve the efficiency of queuing processes without extravagant over-expenditures on either equipment or personnel. Historically, this ability was first aggressively exploited in the manufacturing sector of the economy (Law and McComas 1999), and quickly spread from sole consideration of the value-adding machines to include the non-value-added but very necessary tasks of material handling. More recently, simulation usage has expanded to healthcare delivery, service industries, military operations, and transport systems. Examples of simulation applications in material handling and logistics are indeed numerous. For example, (Costantino, Di Gravio, and Tronci 2005) used simulation to improve distribution and delivery of medical oxygen all across Italy. In a more localized application, (Azab and Eltawil 2016) undertook a simulation analysis which greatly shortened truck turn time in a container terminal at a port. In a manufacturing context such as the present one, (Tokola and Niemi 2015) studied and improved the ability of cranes within an automated storage and retrieval system (AS/RS) to support an assembly process.

In the study presented here, the client is a Tier I supplier of vehicle components to the automotive and commercial vehicle segment (a Tier I supplier supplies vehicle manufacturers directly; a Tier II supplier supplies a Tier I supplier, etc.). Management of this company had already realized that manufacturing operations (and hence their internal material-handling support) needed significant expansion (close to 50%) to accommodate both increased quantity and increased variety of demand within the constraints of budget and space. Therefore, corporate managers and engineers sought the help of industrial engineering techniques, especially simulation, to suggest and evaluate improvements in the material handling aspect of factory operations.

2. Overview of the Manufacturer's Operations

The manufacturing plant to be simulated and analyzed in search of improvements is responsible for supplying components directly to the automotive and commercial vehicles economic segments. This facility currently runs more than twenty lines (counting both assembly and subassembly lines), and firm plans for the near future involve adding an additional eight lines. The building includes three basic components – an incoming warehouse storage area for receiving raw materials, the manufacturing plant containing the assembly lines, and an outgoing warehouse storage area where finished goods await shipment to customers. The assembly lines now operate based on a given production schedule and the dock area operates eleven hours, six days a week. Currently nine feeders (workers) carry material from the incoming warehouse area to both the subassembly and the main assembly lines. A stand-up "hilo" (a type of forklift vehicle; (Lane 2001)), so-called because its driver stands erect when operating it, picks (selects) finished goods from the production lines and takes them to the finished goods area; this hilo also picks empty containers from the finished-goods area and returns them to the production lines. Later two standard hilos take finished goods from the finished goods inventory area to the outbound shipping docks; similarly, these hilos transport incoming raw-material components from that dock and deliver them at an overflow area. A Bendi® (articulated forklift truck) is also used to replenish stock in the racks from the overflow area; this vehicle can carry two containers simultaneously. These additional lines have recently been tasked with raising production to nearly half again its current level; i.e., by nearly 50%. In view of the complexity already inherent in these operations (and this complexity will increase), plus the severe constraints on expansion spatially, the client requested a material-handling discrete-event simulation model encompassing the assembly lines, the subassembly lines, the FGI area, the storage rack area, and the dock area. The challenges of improving the logistics within this manufacturing process entailed using many of the thought paradigms documented in the excellent survey paper (Simeonov, Simeonovova 1999). In this context, it was important that issues of material flow and issues of facility layout be considered jointly; the importance of this integrated viewpoint has been cogently and appropriately emphasized in (Kane and Nagi 1997). Both the client and the consultants knew that economically efficient and successful manufacturing activities require well-designed, efficient, and robust material-handling support, as illustrated in much actual experience, e.g., (Galé, Oliveron, and Silván 2002). Tasks within this simulation analysis included:

1. Develop the future production schedules
2. Develop the future state layout for the dock and FGI areas
3. Determine material handling requirements and utilization of the feeders
4. Determine optimal finished goods, line side, and rack inventory levels
5. Design the tugger delivery system and its tugger routes (a "tugger" is a motorized vehicle, manned or unmanned, capable of pulling a "train" of carts coupled together)

In the current system, the feeders replenish, from the racks, the purchased parts as needed on the line. They are also responsible for returning empty containers to the subassembly lines. This configuration entails long walking distances for the feeders and intermittent starvation of the assembly lines due to the physically demanding work. The prospective redesign of the rack and FGI areas will allow the client company to store more material in the limited available space. Both the improvement in work methods (less strenuous and tiring) and the increase in inventory (without physical increase of space) will greatly reduce stoppages of the assembly lines, in addition to improving worker morale and reducing the risks of excessive fatigue, repetitive strain injuries, and accidents often partially attributable to these underlying causes.

3. Input Data and its Analysis

Extensive input data were required for the construction of this model. The client and consultant engineers worked collaboratively to collect these data. Concurrently with the building of the model, time studies were undertaken, and MODAPTS [MODular Arrangement of Predetermined Time Study] (Brisley and Eady 1982) used to assess the strenuousness of this work. These activities provided much of the manual cycle time and transit time data. Other data collected pertained to the operating speeds, carrying capacities, loading and unloading times, routes, and breakdown frequencies and durations of both currently used and prospective material handling equipment. Still other data pertained to the main assembly lines and their operations (cycle times, reliability, manpower requirements, etc.). The schedules for incoming and outgoing delivery trucks also needed to be collected, checked, and incorporated into the model. Significantly, the complexity and scope of the plant operations, coupled with the large quantity of input data to be collected, required that the consultant analysts spend two months on-site, working in concert with the client's production and industrial engineers.

4. Model Construction, Verification, and Validation

The model was built, after discussion among the clients and the analysts, using the AutoMod® simulation software (Rohrer 1999). This software excels at detailed material-handling simulation and contains built-in constructs for modeling material-handling equipment such as conveyors, forklifts, tugger trains, and automatic guided vehicles (AGVs). Furthermore, this software also provides, concurrently and almost automatically with construction of the model, construction of an animation (either two-dimensional or three-dimensional at a mouse click). A typical screenshot of the animation appears in Figure 1 below. Its companion software AutoStat® (Carson 1997) interfaces conveniently with AutoMod® and can perform extensive statistical analyses of simulation model output, thereby obviating the need for separate statistical software other than routine Microsoft Excel® charting and summarization capabilities.

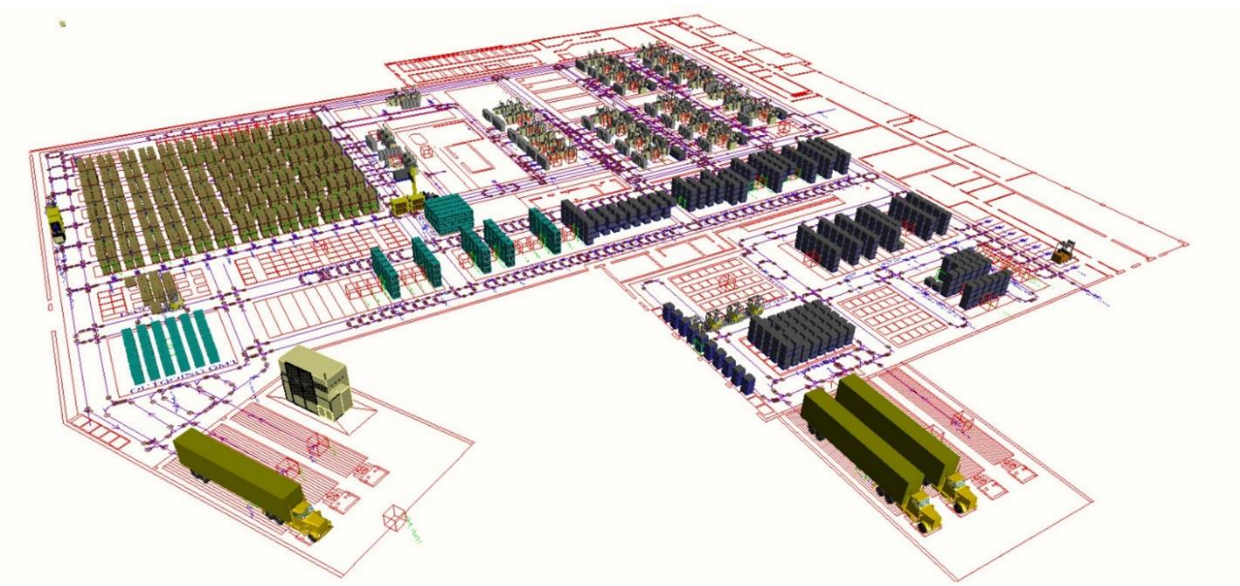

Figure 1: Model Layout (Incoming Warehouse, Assembly, Outgoing Warehouse) Built in AutoMod®

Since the model was large and complex, it was constructed modularly, with the various modules corresponding naturally to different operational parts of the manufacturing plant. Given the capabilities of AutoMod®, interfacing these modules was quite straightforward; each module was *independently* verified (examined in complete isolation from all other modules) and validated before interface (corresponding with work flow in the plant) with any module previously built. Multiple verification and validation methods were used (Sargent 2015), including:

1. Structured walkthoughs (Weinberg 1972) of code written within each module (simulation modeling work of even moderate complexity, undertaken in AutoMod®, requires the writing of code in a language rather like C++);
2. Viewing the animation with the client to ensure that all material-handling equipment followed pick-up, travel, and drop-off procedures as intended;
3. Allowing only very small numbers of entities (sometimes only one) to enter the model and then following model events on a stepwise basis;
4. Constructing histograms of all probability density functions used in the model and obtaining the client engineers' concurrence that these density functions were reasonably choices with respect to mean, mode, and range;

5. Provisionally removing *all* variability from each module and then checking its predictions against basic arithmetical computations;
6. Directional analysis – checking that when cycle times and/or downtime durations were experimentally increased, queue lengths increased and throughput decreased;
7. Checking that collisions between material-handling devices, or between a material-handling device and a stationary object (e.g., a machine or a wall) did not occur;
8. And, most significantly as a "capstone" verification and validation, achieving a close correspondence (within 4%) between performance metrics currently observed in the plant and those predicted by the model of the current system. The performance metrics thus used in verification and validation included time breakdowns for the material-handling equipment, especially the hilos. Total time for these hilos was triaged: (1) working (i.e., either carrying a load or traveling empty to a destination on request to pick up a load; (2) going to park (i.e., traveling empty to a parking location when no material-movement assignment was pending; and (3) parked (stationary and on-call at a location of repose). The time breakdowns predicted by the simulation model agreed well with observation for the hilos, and also for the Bendi®. An analogous verification/validation step was also successful for the warehouse pickers, the weekly feeders, and the tuggers.

Only after all these verification and validation checks were passed did the model achieve credibility with the client, and hence show readiness for modifications to assess the relative merits of proposed system improvements.

Additionally, the model was initially designed and then built to receive almost all of its input from a Microsoft Excel® workbook containing many worksheets. Likewise, the model sent all important output results to Excel® (in addition to displaying highlights thereof during animation). As examples, one worksheet contained all details of incoming truck schedules; another, all performance data pertinent to the tuggers; and another, all data on the routes of the tuggers. This incorporation of the spreadsheet software as a fundamental component of the simulation study provided four significant advantages:

1. The client engineers could conveniently and reliably change details of model input data within the Excel® workbook;
2. Writing custom Excel® functions and macros to control several complex aspects of the model logic was faster, simpler, and more "transportable" (relative to potential future use of the model) than implementing the equivalent logic in AutoMod® code;
3. The logic thus implemented within the Excel® workbook via VBA [Visual Basic for Applications] (Albright 2015) was more accessible and intuitively readable by the clients than AutoMod® code would be, increasing client confidence in the model;
4. The client engineers and managers were thus empowered to routinely and conveniently specify a variety of inputs to the model, examining a wide variety of potential improvements, using a run-time version of AutoMod®.

5. Results of the Simulation Model

The operations at this plant certainly called for running the simulation model on a steady-state basis (as contrasted with a terminating system such as a bank or a restaurant); after examination of the time needed for the system to "stabilize," the analysts chose a warm-up period of length twelve days followed by replications of length sixty days. Since the replications exhibited little variation, ten or fewer replications were needed to predict values of important performance metrics within gratifyingly narrow 95% confidence intervals.

Guided by the results of the study, the clients decided to:

1. Extensively rearrange raw materials stored in both the "incoming" warehouse area (stores raw material to be used for production) and the "outbound" warehouse area (stores finished goods to be shipped to vehicle assembly plants) for faster picking and put-away respectively;
2. Reallocate labor tasks: Originally nine feeders (workers responsible for bringing raw material from the incoming warehouse area to the production lines) were used; after the model exposed severe underutilization, only three workers were used – with no starvation of the production lines (contrast vividly shown in the graphs shown in Figure 2 and summarized in Table 1, below);

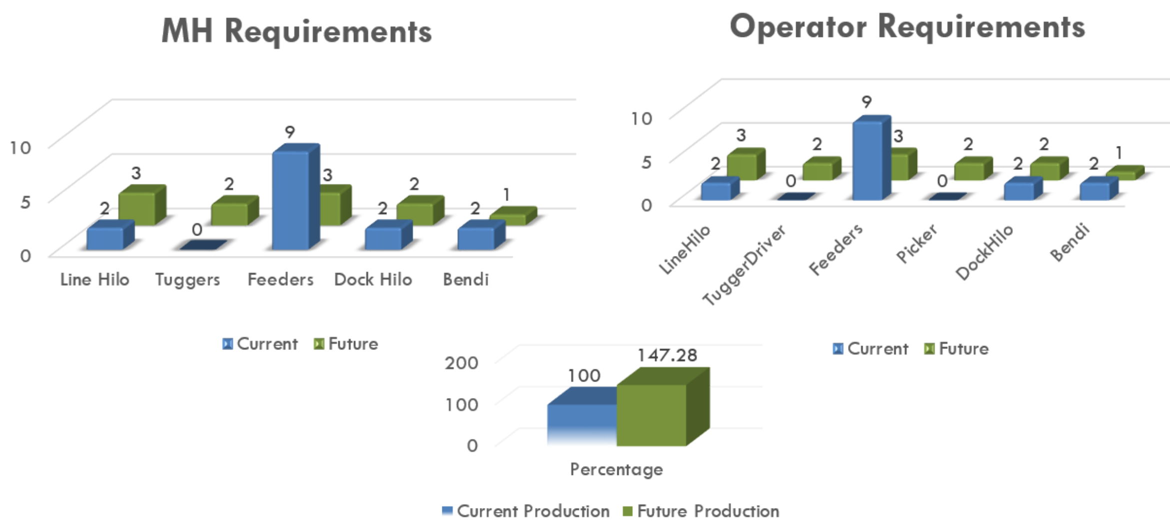

Figure 2: Comparative Graphs for Current and Future State Material Handling Requirements with Production Ramp-up

Table 1: Feeder Utilization – Current state Versus Future State

Current State						Future State					
Feeder Utilization						**Feeder Utilization**					
Index	**Working**	**GTP**	**Parked**	**Idle**	**Check**	**Index**	**Working**	**GTP**	**Parked**	**Idle**	**Check**
1	78.11%	0.01%	21.88%	22%	100%	1	41.13%	0.55%	58.32%	59%	100%
2	51.45%	0.02%	48.52%	49%	100%	2	39.44%	0.57%	59.98%	61%	100%
3	40.53%	0.10%	59.37%	59%	100%	3	27.94%	0.06%	72.00%	72%	100%
4	39.15%	0.15%	60.70%	61%	100%						
5	27.25%	0.08%	72.66%	73%	100%						
6	23.78%	0.05%	76.17%	76%	100%						
7	68.61%	0.00%	31.39%	31%	100%						
8	38.12%	0.06%	61.82%	62%	100%						
9	49.12%	0.10%	50.78%	51%	100%						

"GTP" = "going to park"

3. Reassign the six employees no longer doing the work in (2) to the recycling of packing materials and additional cleaning tasks, which improved working conditions and safety;
4. Since the demand for a large production increase involves not only "more production of the same items" but also production of new items, purchase and deploy a second stand-up hilo to transport finished goods from the production lines to the outbound warehouse area;
5. Exploiting space savings ((1) above) in the incoming warehouse area, move three docks for the unloading of trucks bringing raw materials, thereby reducing transport distance of these materials from truck to interim storage;
6. Reassign the docks in (5) to operate as outbound docks, again reducing transport time, cost, and risk of damage – this time, relative to outbound finished goods.

Furthermore, with respect to "5S" (sort, set in order, shine, standardize, sustain), this project made valuable contributions. For example, the study has pointed the way to lower inventory levels without risk of stockouts. The lower inventory levels in turn allow and encourage standardization of routes traveled by the hilos and tuggers, reducing the risk of accidents and lowering the training requirements and timing for subsequent new hires. A derivative of this standardization has been installation of new plant-floor signage, an example of which appears in

Figure 3 below. Consideration is being given to adapting the simulation model, with its animation, to the interactive training of material-handling workers to be hired in the future, analogous to the training in container terminals documented by (Cimino, Longo, Mirabelli 2010). Also, the study demonstrated how to increase production (and the variety thereof) by nearly 50% with only a 33% (from three to four) hilos.

Figure 3. Typical Tugger Route Sign Recently Installed on Factory Floor

6. Conclusions and Further Work

This simulation study, coupled with its ergonomics sub-study, provided valuable advice to the client engineers and managers concerning multiple ways to improve productivity, reduce capital expenditures required to do so, and achieve efficient usage of both production and storage space. The recommendations (1), (4), (5), and (6) above have already been implemented, and have resulted in the benefits predicted. Reallocation of the workers ((2) and (3) above) is pending. Additionally, the client plans continued use of this model as the production system evolves, plus additional simulation studies of other parts of corporate operations. Extensive documentation of the model, both internal and external, will support this continued use over an extended period of time and potential personnel changes.

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Biographies

Gabriel Carreño holds a bachelor's degree in Industrial Engineering (Texas State University, 2015) with a minor in applied mathematics. From January 2015 to May 2015 he worked for his Capstone Design Project building a material handling simulation model to optimize the warehouse of a major North American supermarket chain. In August 2015 he joined Production Modeling Corporation (PMC) in Dearborn, Michigan, as an Industrial Engineer. He has been working with various client companies through PMC on material handling, scheduling, and simulation projects using a variety of analytical software tools such as ProPlanner®**,** Preactor®, AutoMod®, SIMUL8®, Simio®, and Witness®.

Dinesh Patlolla holds a master's degree in Industrial Engineering (University of Tennessee, 2015) with a minor in statistics. He has a bachelor's degree in Mechanical Engineering (Jawaharlal Nehru Technological University, Hyderabad, India, 2012). From 2013 to 2015 he worked as a Graduate Research Assistant in the Department of Industrial and Systems Engineering and successfully defended his thesis: Integration of Maintenance into Design and Sustainability of Buildings. In September 2015 he joined PMC, Dearborn, Michigan as an Industrial Engineer. He is an active member of the Institute of Industrial and Systems Engineers (IISE) and the Society for Automotive Engineers (SAE International). A paper he authored won "the second best paper in applied case study category" in the IIE Annual Lean and Six Sigma Conference held in Orlando, FL, USA in October 2014.

Edward J. Williams holds bachelor's and master's degrees in mathematics (Michigan State University, 1967; University of Wisconsin, 1968). From 1969 to 1971, he did statistical programming and analysis of biomedical data at Walter Reed Army Hospital, Washington, D.C. He joined Ford Motor Company in 1972, where he worked until retirement in December 2001 as a computer software analyst supporting statistical and simulation software. After retirement from Ford, he joined PMC, Dearborn, Michigan, as a senior simulation analyst. Also, since 1980, he has taught classes at the University of Michigan, including both undergraduate and graduate simulation classes using GPSS/H™, SLAM II™, SIMAN™, ProModel®, SIMUL8®, Arena®, or Simio®. He is a member of the Institute of Industrial Engineers [IIE], the Society for Computer Simulation International [SCS], and the Michigan Simulation Users Group [MSUG]. He serves on the editorial board of the *Journal of Computer Engineering*. During the last several years, he has given invited plenary addresses on simulation and statistics at conferences in Monterrey, México; İstanbul, Turkey; Genova, Italy; Rīga, Latvia; and Jyväskylä, Finland. He served as a co-editor of Proceedings of the International Workshop on Harbour, Maritime and Multimodal Logistics Modelling & Simulation 2003, a conference held in Rīga, Latvia. Likewise, he served the Summer Computer Simulation Conferences of 2004, 2005, and 2006 as Proceedings co-editor. He was the Simulation Applications track coordinator for the 2011 Winter Simulation Conference. A paper he co-authored with three of his simulation students won "best paper in track" award at the Fifth International Conference on Industrial Engineering and Operations Management, held in Dubai, United Arab Emirates, in March 2015.

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