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MODELING AND SIMULATION DRIVEN RECONFIGURATION OF HIGH PRODUCTION VOLUME MANUFACTURING

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ABSTRACT

The benefits of lean manufacturing have been seen throughout the automotive industry, for several decades. Lean production of a complicated, discrete product has been proven to improve efficiency and lower cost. With the recent wave of lean production, other industries are making efforts to adopt the philosophy to reconfigure their production systems. In particular "Just in Time" (JIT) manufacturing philosophies can convert the factory form a "push" system to a "pull" system, reducing waste, inventory, thus increasing product visibility. But, in the high-volume continuous production process, do the benefits of implementing lean manufacturing philosophies outweigh the costs? Due to supply requirements, most plants are unable to disrupt production while the factory layout changes are being implemented. Can the reconfiguration and modernization of the production system be phased in without reducing the production? In this paper, we investigate the efficacy of stochastic process simulation techniques in answering such questions.

A series of simulation modules that enable redesign or reconfiguration of production systems and measure their performance have been developed. The simulation modules are general and flexible enough to model the production cycle, materials handling, operator involvement, failures/breakdowns and multiple part operations. Typically each module can be configured to simulate one flexible manufacturing cell. The simulation modules can be rapid configured and assembled into large-scale factory floor simulations that can be used to evaluate and optimize factory floor configurations. Sufficient care is taken that the simulations run much faster than real time so that the behavior of the production systems can be observed over long elapsed times. This methodology is implemented for to an actual high production volume factory. Several lean manufacturing techniques that reduce the work in progress inventory are tested for their effectiveness. Maximum production volume that can be achieved from the production line system is predicted using the simulations. Numerical examples pertaining to this case study are presented in this report.

Introduction

The benefits of lean manufacturing have been seen throughout the automotive industry, for several decades. Lean production of a complicated, discrete product improves efficiency and lowers cost by reducing waste and work in progress. With the recent wave of lean production, other industries are making efforts to adopt the philosophy to reconfigure their production systems. But, in the high-volume continuous production process, do the benefits of implementing lean

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manufacturing out weigh the costs? Due to supply requirements, most plants are unable to disrupt production while the factory layout changes are being implemented. Can the reconfiguration and modernization of the production system be phased in without reducing the production? In this paper, we investigate the efficacy of stochastic process simulation techniques in answering such questions.

Problem Description

Consider a very high volume production (100+ million/year) process typical of several commercial (e.g. fasteners, medical products, writing instruments) and military products (e.g. ammunition). Usually, these parts are not specialized, i.e. contain an array of options such as in automobiles. Therefore, the production of a simple high volume product does not inherently lend itself well to lean manufacturing methods. However there are elements of the lean manufacturing that can be adapted to a high production volume process and reap the benefits of low in-process inventory.

For the sake of illustration, a brass cylindrical case component is considered in this paper. The production consists of several traditional manufacturing process steps as follows:

1. Draw – a small brass cup is drawn into a cylindrical shape
2. Anneal – The cup is annealed and washed for the next process.
3. Draw- The cup is elongated in a 2nd draw step and trimmed off at the top
4. Anneal - The cup is heated, washed and dried for the 2nd time
5. Final Draw – The cylinder is now at the proper length
6. Pocketing – A small indentation is made in the end of the casing
7. Heading – the end of the casing is stamped flat
8. Wash – The cases are washed in a large batch
9. Head turn – a groove is cut around the base
10. Bottom Anneal – The casings are heated to increase body hardness
11. Taper – a series of dies forms tapers the neck and narrows the mouth of the casing
12. Wash – Cases are washed in a batch washer
13. Top Anneal – Final heating targeted at the mouth and neck to improve hardness

The baseline (existing and non-optimal) production line consists of 4 separate identical lines running (Line-A, Line-B, Line-C and Line-D). Each can be run individually, but the materials handling is integrative and can be transferred between the lines. The material from each machine is dumped into a single conveyor belt running between the process steps. So a part drawn on Line-A machine could then be annealed on a Line-B machine. Figure 1 shows the schematic of the process.

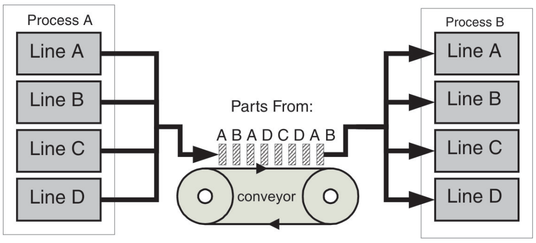

Figure 1: Product mixing between process steps

The conveyor belt system also causes a “push” feed system where materials are pushed from one machine to the next regardless of whether or not the machine can handle more parts. This often leads to an extreme backup of material at the slower or less reliable machines. Since this build up is inherent in the push system it has little chance of being alleviated. Each group of similar process machines are tended to by a single operator. The operator checks the machines are getting feed properly and the output products are not defective, at least by a visual inspection.

Updated Process using Lean Manufacturing Techniques

Lean manufacturing was developed by the Toyota Motor Company and has spread to automotive companies all around the world. Recently the methodology of lean manufacturing has influenced the manufacturing techniques of other industries. Lean production uses several tools in a systematic effort to increase efficiency and reduce waste. Some examples of Lean Manufacturing tools are:

- Using Just in Time (JIT) approaches to eliminate or reduce inventory. JIT production is spurred on by the customer’s order, reducing inventory by on manufacturing what is ordered. Reducing inventory is important because inventory is costly to store and makes locating defects and the source of the defects more difficult.
- The elimination of waiting time, which is normally caused by unbalanced cycle times, unplanned maintenance or quality problems, maximizes the efficiency of the workers and machines.
- Kanban carts are carts used for material handling. When an empty kanban cart is placed in a certain location, it works as an upstream signal that the machines downstream are ready for more materials. This reinforces the JIT approach to manufacturing.
- Minimizing or elimination of product transportation reduced costs because material handling is not a value adding activity. The use of kanban carts, which are a signaling system for JIT production, or use of machining cell layouts reduce material handling times. (Kalpakjian and Schmid, 2006)

The purpose of the tools is to identify wasted time, inventory, or labor and then reduce the waste. Benefits of reducing the wasted resources are the process steps run more efficiently and errors are found quicker, both resulting in lower costs.

The modernization of the process used for illustration will entail implementing some lean manufacturing methods. As this is a working factory trying to meet high production demands, the changes must be simple to implement, so not to stop production for any long period of time. Likewise, the factory would like to avoid purchasing new machines, so the changes must be implemented with the use of the current machines. Such constraints make a complete overhaul of the factory impossible. Therefore, the materials handling between the operations will be the focus for implementing lean manufacturing methods.

The effectiveness of the hypothesis of replacing the conveyors and bulk in-process inventory with smaller kanban carts will be tested. In this case each machine will be fed from a kanban cart and the processed materials will be output into a kanban cart. Besides being a means of transporting material a kanban cart works as a signaling device. If an operator places an empty cart in a designated area it is interpreted by an operator upstream to start production. The flow of materials will also be changed from a “push” system to a “pull” system. In a “pull” system the upstream machines only produce when they are signaled from the downstream machines. The pull system is a tool of lean manufacturing which reduced work in progress and allows operators to quickly locate the source of defects. In the current system, when defective cases are produced from one machine, they are mixed in with the quality cases. To avoid the tedium of picking hundreds of parts out of a pile of thousands, the whole mixed batch is scrapped. Having kanban carts to separate the product by which line the cases came from allows the operators to quickly identify the source of the defects and only scrap the cart with defective product.

The operators already present at the machining cells will be responsible for material handling, by transporting and emptying the carts. The kanban carts will have to be hoisted and the parts fed into the machine hoppers from above, since the existing machines are all top fed. This step will rely heavily on the operator involvement. As there is considerable potential for process improvement and reduction of inventory along with the risk of increased cost and reduction in production capacity, understanding the operations of such a line before building it is essential. Modeling and simulation techniques, when implemented appropriately, play a critical role in developing modern manufacturing processes. The subsequent sections of this paper present a detailed description of model development, simulations and use of the simulation results in designing the production process.

Simulation of High Production Volume Process with Lean Materials Handling Methods

Objectives

A primary goal for this simulation effort is to determine the production rate, resource allocation and the effect of machine breakdowns on an existing line that implements new materials handling methods. Since the changes are merely proposals at the moment, the model must be flexible to incorporate new ideas. The model will be easily altered to represent changes in the proposal. Each process group should be modeled in a self contained fashion so the processes can be arranged quickly and easily. The model would then be configured to match the proposed modernization of the factory using lean techniques. The modernized simulation would be run to gain an estimate of production rate and volume produced and the affects of proposed changes.

There are proven, well known benefits of lean implementation, such as the production of less scrap and the reduction of inventory, but to gather data such as specific usage and production rates, a computer simulation is necessary. The simulation is especially necessary when dealing with such high manufacturing volumes over long periods. The usage statistics acquired from the simulation will account for how each machine, operator, and kanban cart accounts for its time. Should the model yield production rates which are not high enough, the model can be reconfigured easily to adjust the cycle, transport, and repair times, along with the number of carts, operators and machines. The simulation is expected to model the factory activities for a minimum of a month, but a simulation time of closer to a year would be optimal. The simulation must run within a reasonable amount of time, so that a several simulations can be run over the course of a day.

Simulation Details

The factory model will be built in the computer simulation package “WITNESS.” WITNESS is a stochastic process flow simulation, with a layout similar to a flow chart, where each block is assigned a task and corresponding cycle time. WITNESS can be integrated with excel and produces simulation results in a spreadsheet or graphical format.

A key problem with the simulation is the number of cases involved. The factory estimates there are 5 million cases that are works in progress, but since there are no data acquisition methods, there is really no way of verifying that figure. What is known is that every year the factory produces cases in the hundreds of millions. There are 13 process machines per line, 4 lines and each machine's cycle time is an average of ½ a second per case. If each case was a separate entity that means the simulation would have to compute the path of 104 entities per simulated second, and that is not taking into account material handing, breakdowns or resource availability. The number of computations quickly overwhelms the computer system. In order to make a realistic model while still being able to run the simulation faster than real time, the cases had to be grouped and represented by an entity. The most logical grouping of the cases would be a kanban cart full of cases. The factory informed us about the capacity of the kanban carts it plans to use. A kanban cart has a constant volume, and since the cases remain roughly the same size throughout the processing, we decided to keep cart capacity at a constant 8000 cases throughout the simulation.

Module Development

Once the basic simulation unit is established the process steps can be put into place. The key to this model was flexibility. The model had to be rapidly configured and reconfigured to simulate different factory layouts. We began by making a trip to the factory and analyzing the operator and material handling steps surrounding each machining station. From these observations we could create a generic module that, with the correct configuration, could represent any machining cell found at the factory.

The simulation module is entirely self-contained, with resources, labor, machining and material handling. The cases enter through a material handling step (transport), conducted by the operator. From there the carts are lifted and emptied into the machine and returned to the kanban signaling post with an 8 step process (hoist). The batch of cases is worked in the machine as dictated by the input data. The finished batch is fed into a waiting kanban cart and delivered to the next module in the series. An example module is shown in figure 2.

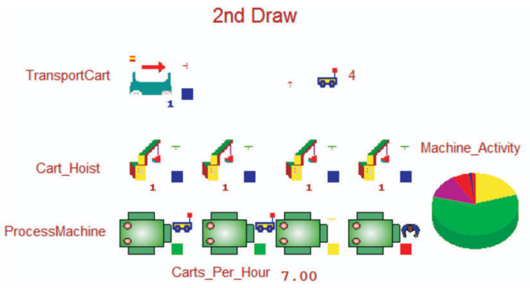

Figure 2: Example of Modeling Module: 2nd Draw Module

Using the fact that the factory is running four identical lines, similar processes from all four lines are grouped together into one module. Lean manufacturing requires quick isolation of problems, so even though the different lines share a module, the parts never mix while traveling to the next module.

Both the operators and the carts in each cell are modeled as labor resources. Most steps in the model require the attendance of an operator, cart or both. Each module is assigned at least one operator and multiple carts depending on the needs of the machines. The operator is not only required to move material. The operator is also responsible for repairs in his or her module. Both the hoist and the process machine have sudden jams in which it is the operator's job to rectify the problem. In order to cut down on computing time the carts are modeled as resources. If the carts were separate entities there would be wasted calculations joining and separating the materials to the carts. Entity carts would require the modules to interact more with each other; with one module disposing of carts created in another module. This increased interaction would increase the amount of time it takes to reconfigure the system. Since our goal was to make the module as autonomous as possible, modeling the carts as resources made the most sense.

The data inputted into each module was derived from cycle times of the current machines. The factory gave us the current cycle times, parts per cycle and number of machines. From these cycle times we computed the batch time to complete a cart full of cases. The results were organized into an excel spread sheet, under the heading of which module the data pertains. Along with the cycle times the database contained breakdown frequency (mean time to failure), repair time, and all the material handling times. As for the resources, the factory was not specific in the numbers. The factory estimated approximately 8 carts per module and one operator per module, except in the cases where the module contains over 4 machines. As a starting point for the model we generated the following list of modules with the corresponding number of machines and carts as seen in table 1.

Table 1: Module contents as requested by the factory

Process Module	# Machines	# Carts	# Operators
1st_Draw	4	8	1
1st_Anneal	4	8	1
2nd_Draw	4	8	1
2nd_Anneal	4	8	1
Final_Draw	4	8	1
Pocketing	4	8	1
Heading	4	8	1
Initial_Wash	4	8	1
Head_turn	12	8	2
Bottom_Anneal	4	8	1
Taper	12	8	2
Final_Wash	4	8	1
Top_Anneal	4	8	1

The database of operational data was integrated into the WITNESS model allowing for the modules to read their specific operational data when the simulation begins. With the modules all self-sufficient, they were then linked to one another in the order described by the factory. The final factory model can be seen in Figure 3.

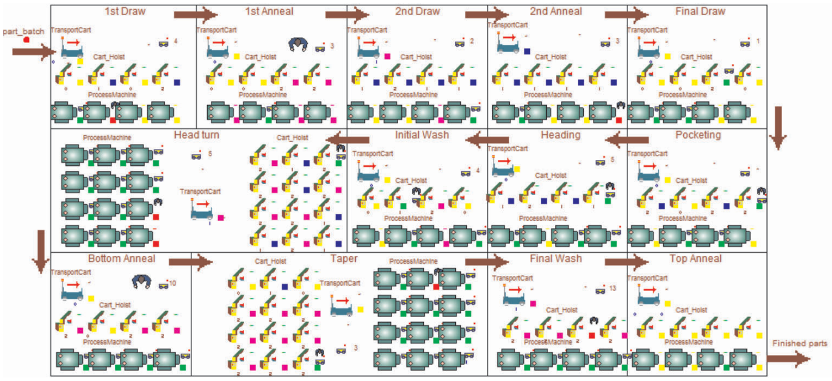

Figure 3: Completed Factory Model

Once the model was finished the testing could begin. The steps taken to speed up the simulation were apparent. The simulation ran over 30,000 times faster than real time. This rapid simulation speed made even year long simulations possible and practical. As a result we ran all simulations to roughly 1 year's working time which, excluding holidays and weekends, translates to 21,600,000 seconds. This simulation ran in about 10 minutes.

Recording production rates for machines before a steady stream of material reaches them often skews the results. This affect is combated in two ways in this simulation. Firstly a warm up period can be introduced; a period in which the simulation is running, but data is not being collected. We selected a warm up time of 32,000 seconds, the time it takes for the first cart full of cases to be moved through the entire line. The second feature that minimizes the affect of the system warming up is the exceptionally long simulation time. After a year of manufacturing, the effects of the inherently irregular beginning of the simulation have all but negated.

Once the simulation has completed the data from each machine and resource is extracted. WITNESS comes with an automatic spreadsheet reporting utility which summarizes the usage data for each simulation element.

Results and Discussion

Overall Production

The simulation, configured in the fashion proposed by the ammunition factory (Table 1), yielded the following results. The production numbers are shown below in table 2.

Table 2: Results of Simulation

Time (sec)	21600000
Carts Per Hour	5.06
batches pulled	30361
parts pulled	242888000
parts per batch	8000
Batches in Progress	138
WIP	1104000
Batches Finished	30223
Parts Finished	241784000

Over the course of a year the simulation predicts the factory will produce over 240 million cases. But the value of this simulation is not in the final part count, since the results will are not necessarily accurate. Instead the value comes from analysis and adjustments of the model to try different alternate configurations to produce the optimum results. To analyze the results we first look at the usage of the machines.

The machine usage is determined from the simulations. The machines usage consists of 6 categories:

- Busy – Time where the machine is processing casings
- Blocked – The machine waiting for machines downstream to complete their batches
- Cycle Wait Labor – The machine is waiting for an operator, a cart, or both
- Broken Down – The machine is broken
- Repair Wait Labor – The machine is broken and waiting to be repaired by and operator
- Idle – The machine is unused

The graph below (Figure 3) shows the frequency the machine is in each state.

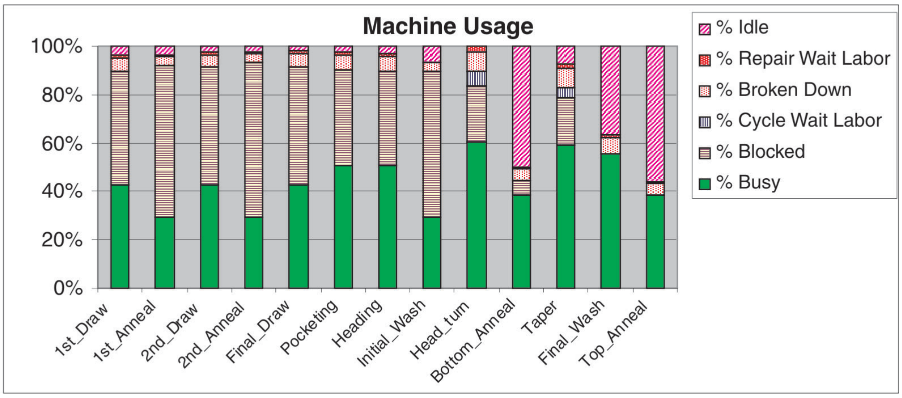

Figure 4: Machine Usage Data for Proposed Factory Arrangement

From these results, the inconsistency going from 'Head Turn' to 'Bottom Anneal' is clear. One of the principle ideas behind lean manufacturing is balancing the elements in the factory. The elements from the beginning of the line to 'Head Turn' spend a large portion of their time blocked. Meanwhile from 'Bottom Anneal', 'Final Wash', and 'Top Anneal' devote a large portion of time to being idle. Clearly something is causing this problem, it could be too few machines or too few resources only further analysis can make that determination.

Operator Usage

The operator usage results were much more consistent than the machine usage results. The operators in all the modules were busy approximately the same percentage of the time, as seen in Figure 4. In accordance with the lean philosophy of a balanced factory this graph suggests the operators are appropriately distributed throughout the factory.

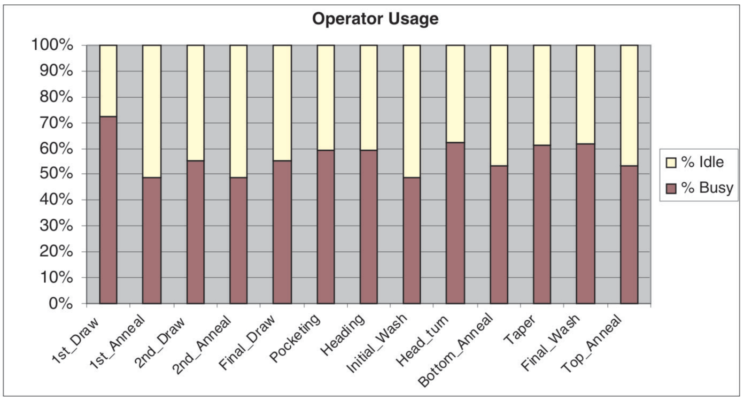

Figure 5: Operator Usage Data for Proposed Factory Arrangement

Cart Usage

The simulation showed the cart usage was not evenly distributed among the modules as seen in Figure 5. Two inconsistencies are immediately evident. Firstly the carts in the first 9 modules are extremely under utilized. Secondly carts in the 'Bottom Anneal' and 'Final Wash' module are in extremely high demand. This constant usage of the 'Bottom Anneal' and 'Final Wash' carts is undoubtedly causing the blockage of the first 9 modules and the unnaturally high idle time of the remaining modules. This over usage of carts does make sense. The carts in the

'Bottom Anneal' module are responsible for picking up the finished products from the 'Head Turn' module. The 'Head Turn' module has a total of 12 machines opposed to the regular 4. The same is true for the 'Final Wash' carts being used in the 'Taper' module.

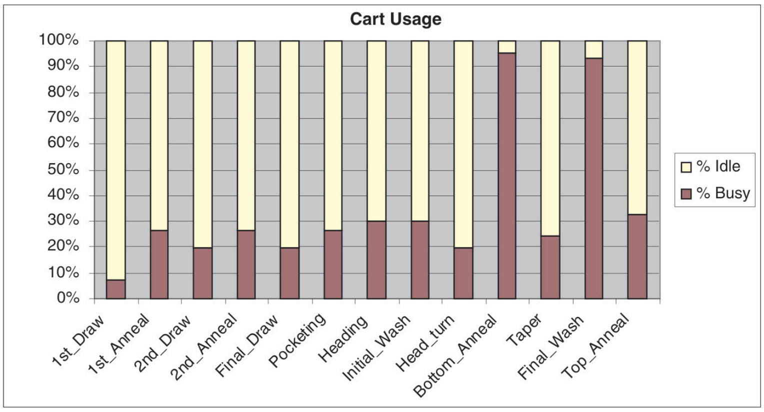

Figure 6: Operator Usage Data for Proposed Factory Arrangement

Optimizing the Model

To test the true value of the model we made adjustments to test if the results are affected in a positive manner. Since it is apparent that the carts were the cause of blockage and idle times, the best solution was to rearrange the carts accordingly. The original model started with 104 available carts, in the interest of cost, we did not change this total. We added carts where the usage was higher than average and removed carts from modules which under utilized the carts provided. The number of operators was kept the same. The reconfigured resources are shown below, in table 3.

Table 3: Rearranged Cart Quantities

Process Module	Original # Carts	Optimized # Carts
1st_Draw	8	4
1st_Anneal	8	4
2nd_Draw	8	4
2nd_Anneal	8	4
Final_Draw	8	4
Pocketing	8	4
Heading	8	8
Initial_Wash	8	8
Head_turn	8	8
Bottom_Anneal	8	20
Taper	8	8
Final_Wash	8	20
Top_Anneal	8	8
TOTAL	**104**	**104**

With the new configuration the model was run again for the same time period to test the affects of reconfiguring the carts. The machine usage results are shown below in Figure 6.

The new machine usage graph speaks volumes about the effectiveness of properly allocating resources. Overall the modules are more balanced causing less time blocked by absence of resources. The most concrete result is shown in Table 4. The final production numbers have increase by almost 80 million cases, without any costly new machines or even additional carts.

Table 4: Rearranged Cart Quantities

	Original	**Optimized**
Time	21600000	21600000
Carts Per Hour	5.06	6.98
batches pulled	30361	40071
parts pulled	242888000	320568000
parts per batch	8000	8000
Batches in Progress	138	115
WIP	1104000	920000
Batches Finished	30223	39956
Parts Finished	241784000	319648000

Concluding Remarks

The main challenge in optimizing this specific case was that the problem was highly constrained and has limited number of design variables. The factory could not experience downtime due to reconfiguration and the reconfiguration must use the existing machines. As the equipment and process flows are constrained by cost and manufacturability issues, only materials handling can be changed to optimize the line. Simulations have proven to be a powerful tool in assessing the efficacy deploying lean manufacturing concepts to materials handling. Though lean manufacturing is more commonly associated with the automotive industry many of these methodologies can be transplanted from a low volume, high complexity production line to high volume production line. Ideas such as maintaining a balance between cooperating machining cells and the use of a pull system opposed to a push system have proven to be unrestricted by production volume. The simulation has showed that a lean system can be used effectively in our factory example.

Using a model to try new ideas makes improving the factory layout much simpler with impressive results as demonstrated by simply reallocating existing carts. What makes the simulation more relevant is the flexibility to quickly reconfigure the model to reflect proposed changes or to optimize the system. A fast running, flexible model is the key to trying new concepts, such as lean manufacturing, while keeping the experimentation costs low.

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