In K. Cheng, H. Makatsoris and D. Harrison (Eds.)
'Advances in Manufacturing Technology XXII'
Proceedings of the Sixth International Conference on Manufacturing Research, ICMR08
Vol. 2, pp. 849-858. Brunel University, London, UK, 9-11 September 2008.

SIMULATION SUPPORT OF LEAN LAYOUT CONSIDERATIONS FOR NEW PRODUCTS: A CASE FROM LARGE SCALE PRODUCTS

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Abstract

Planning a new production line for a product presents many opportunities to build best practice techniques into the new system. Set against the unknown quantities may be certain requirements for the production system to be lean, to have the flexibility to respond to market changes or make use of existing equipment of factory space. The unknown quantities can include: anticipated demand volumes, assembly and processing sequences, the specific production processes, lead-times of parts and components and even late changes to the product design after manufacturing/production decisions have been made. Simulations of a production system can be used to consider different scenarios and compare how well alternative approaches meet the defined requirements.

Uncertainties over production strategies, such as with a new production system, raises questions over which order to apply the use of simulation and layout optimization techniques. In addition, simulations of 'to-be' systems based on data from non-production prototypes and manufacturing estimates presents considerable challenges to the modeler to provide valuable decision support.

This paper considers the particular case study of simulation support for pre-production layout planning within significant cost and space constraints. The manufacturer in this case required that the production system remain lean while flexible enough to meet fluctuating demand volumes. While factory floor space was constrained, manufacturing equipment did not need to be fixed in place, allowing workspace flexibility. The paper describes the simulation issues overcome and the project structure used to produce various models for consideration of different manufacturing issues.

The 6th International Conference on Manufacturing Research (ICMR08)
Brunel University, UK, 9-11th September 2008

Keywords: Simulation, Lean manufacture, Layout planning, New product introductions.

1.0 Introduction

Simulation is a valuable tool for testing a wide range of manufacturing scenarios and potential changes to a system. The accuracy of the outputs of any simulation is driven by the data used to create the model, and as such when models are built using incomplete data or estimated values, the feedback that the simulation provides must be considered limited. When production has yet to begin for a particular set of processes it may be possible to estimate values or for the 'to-be' system or extrapolate test data for the purposes of building models, however this also leads to accuracy issues for the models concerned.

Lean manufacturing as a philosophy provides a basis for companies and supply chains to deliver value to customers through eliminating waste from production activities, and many tools exist for analyzing and improving existing production processes and facilities. Building lean concepts into a production system from it's first inception presents many opportunities for engineers to impact the levels of waste generated in the production process (however it must be noted that improvement activities should still take place once production begins). When presented with the opportunity to design a new production system, efforts to establish the best possible set-up and layout of the production system are made, and where feasible simulation tools can be used to support this process.

This paper considers how simulations can be used to support manufacturing layout planning in the face of incomplete 'to-be' data. A brief outline of the associated literature in the areas of lean manufacture and simulation is followed by a description of the methods that may be employed in modeling different manufacturing scenarios and some of the challenges that are faced in using estimates and test data for simulations. The paper closes with a case study manufacturer planning a new production system based on data from prototype products with cost and facility space constraints. Conclusions are drawn on how the authors supported the company's decisions on how the production system should be set-up using simulation tools.

2.0 Literature Survey

The following sections provide a brief outline as to the associated literature in the areas of lean manufacture and simulation.

2.1 Lean Manufacture

The concepts and mindset associated with lean manufacturing are now very familiar as a philosophy first conceived within the Toyota Production System (TPS) [1]. Many lean implementations fail, as the philosophy requires a mindset change and for cultural underpinnings of the company to be sympathetic to the changes that lean manufacture demands. Although there have been suggestions [2] of the application of 'fractal' lean concepts to points of production where flow and waste reduction can be most benefited without entire production systems undergoing the move towards lean manufacture.

The many tools used to highlight lean manufacture may be considered as largely related to analysis and mapping, one of the most simple analysis tools is lead-time mapping, which tracks, quantifies and prioritises the cumulative steps which contribute the total lead time. The concept behind the mapping is to highlight the main causes of delay in the products lead time by arranging the production steps which are commonly displayed chronologically in a Gantt chart format, into a Pareto format [3]. By severing the process step dependencies and focusing on the lead-times, those process steps which may contribute the greatest time savings can be focused upon. Process activity mapping is a name given to the process analysis style of mapping which originated in industrial engineering [4] which may be summarised thus:

- The study of the flow of processes
- The identification of waste
- Consideration of whether the process can be rearranged in a more efficient sequence
- Consideration of a better flow pattern, involving different flow layout or routing
- Consideration of whether everything happening at each stage is necessary and the result should superfluous tasks be removed

Value Stream Mapping (VSM) is a lean tool, and like all lean tools has the underlying motive of eliminating waste, it provides a visualisation of the physical and information flows through a particular value chain [5] and is very widely recognized in industry.

2.2 Simulation Support

Simulation projects generally follow a common set of steps [6] – [9]. The case for building simpler models allowing for easier changes and disposal of models in favour of newly released technology is a compelling one [10]. Sources that indicate that most simulation projects follow a similar form are generally in agreement in terms of the major steps that define the work. These key elements are outlined below [7]-[9], [11], [12] the approximate proportions indicated for each element of individual projects having been described [11].

Problem Definition and Analysis ~ 10% each

A written statement of the problem-solving objectives, understood by all involved, and it is *the* problem that needs solving.

Data Gathering and Validation ~ 10 to 40%

The models input parameters are specified and data collected relative to the model detail. The data is checked to ensure it is both appropriate and representative.

Model Construction ~ 10 to 40%

The model is built from either a simulation language or a simulator, it should be a simplified representation of reality, though including enough detail to provide a good approximation remembering that this will be used for problem solving.

Verification and Validation ~ 10%

Verification determines whether a model correctly performs as intended, and validation establishes the credibility of the model, ensuring there is a correspondence between the real system and the model-typically by collecting and comparing data from both.

Experimentation ~ 10 to 20%

Experiments are planned to efficiently produce meaningful output data from experimental test runs. The conditions that produce a change in results can be altered and contrasts between alternatives highlighted.

Analysis of Results ~ 10%

Statistical procedures should be implemented to measure performance, including estimates of errors where possible.

Recommendations ~ 5%

Documentation of the model is good practice to avoid any duplication of effort, assumptions made in the model should be noted and if suitable, the model should be implemented.

There are several forms of simulation that differ depending on the modeling focus and the processes under study. Discrete events are instantaneous actions that occur at points in time, while dynamic simulations are models that are influenced by time [7]. Discrete event simulations can however be used to describe a system as it progresses through time, and is widely used for manufacturing applications [13]. More effective communications between the user and the simulation analyst, so that both have an improved understanding of the problem, was a key reason in developing visual simulation tools [14]. This communication aid being recognised [15] as crucial when dealing with large teams or when presenting a concept. Simulating the system and using this tool to assist in the determination of the new layout (as opposed to determining layouts first) has been described [16] as preferable when operational policies are not predetermined, such as with a new production system.

3.0 Modeling Manufacturing Scenarios

Any simulation is at some level an abstraction of reality. Recognising this and understanding the level of detail that is appropriate to the system under consideration are key to successful simulation projects. A straightforward method to drive the modeling process to meet these objectives comes from a clear problem definition to establish exactly what it is the simulation sets out to achieve.

Too often modelers are asked to provide models of a system without clearly defined and agreed aims, objectives, and deliverables. The intention is that the models created may be used in a variety of different "what-if" scenarios to deliver many answers regarding changes in the production system. Such a tool would be invaluable to a company, however the difficulties in creating such a model, are often too much to overcome. A model capable of reflecting many different aspects of the business whilst exhibiting robustness to change would invariably involve vast quantities of data to be available or collected Additionally, construction of such a complex model would be time consuming to the extent of becoming obsolete.

The case for simple models, focusing on a particular set of problems is clear. In such instances, models can be quickly updated when fresh data becomes available or a new modeling technology comes to market. By making the models as simple as possible, validation of the outputs of the model is simplified and management decisions can be swiftly supported. A portfolio of models that reflect the issues that the manufacturer wishes to address, driven by clear definitions of problem areas, allows complex manufacturing systems to be represented by relatively straightforward models. Working from multiple models presents different working issues that must be considered.

The goals that the simulation sets out to achieve must be clearly structured and ideally broken down so as to assist in dividing the problem up into workable modeling areas. For greatest consistency, the model building activity should be undertaken by an individual, however given time, resource and practicality constraints, often the simulation process will involve a number of people or even multiple teams. In such instances great efforts must be made to clarify the stated aims of the simulation, and that all the modelers have a clear understanding of the methods by which the models will be built. The assumptions made in creating the model should be clearly documented and be consistent with assumptions made for all the models built for the system, likewise the variables that form the basis for the simulation should be explicitly outlined and consistent with the set aims of that particular model. Experiments using various models can contrast different scenarios where appropriate with a limited number of pre-selected variables driving the differences between the models. Assumptions should be kept consistent between models for this form of experiment in order to keep results meaningful, while competing manufacturing strategies (where the assumptions may be different) can be compared provided the differences between each model's construction are explicitly outlined alongside the results.

4.0 Challenges in Modeling 'to-be' Systems

Most commonly, modeling is undertaken on existing systems, in manufacturing particularly as part of Value Stream Mapping (VSM) processes, the incumbent system is referred to as the "as-is" system. When considering what the production system will become after a change is frequently termed the "to-be" system. As with any process which forecasts future systems or events, there are many difficulties associated with establishing the facts that will accompany a "to-be" system. Even more challenging cases exist where rather than improve upon an existing system, an entirely new production system is planned, with no opportunity to compare against previous operations or process data. As such, modeling a 'to-be' system means that risks associated with inadequate, incomplete or unavailable data threaten the success of the simulation project. Some approaches to reducing these data availability risks may be described as:

- **Use of comparison data**
  Where available, the use of data from similar processes or systems should be considered and substituted if given appropriate weighting and noted as an assumption of the proposed system performance.
- **Limiting the effect/impact of the data shortfall**
  In some instances it may be feasible to reduce the effect of the shortage of data through how the problem considered is framed. In limiting the impact on simulation accuracy, this practice will accordingly limit the benefits of the modeling undertaken by impacting the scope of what issues are explored.
- **Updating models as data becomes available**
  As the project progresses, information relating to equipment testing, product trialing, prototyping etc. may become available. By changing the models to reflect the most up-to-date information available risks to the simulation accuracy incrementally reduce, however risks to the overall manufacturing project may not be improved depending on when in the project the data becomes available!

The authors assert that there is no straightforward method to compensate for a lack of data when building models. However the value to be gained from undertaking simulation means that when it is possible to mitigate for the shortfalls in data availability then efforts should be made to make best use of what information *is* available to deliver useful decision support for developing the new or improved system.

5.0 Case Study

The issues previously outlined that surround simulation support of manufacturing activities based on 'to-be' data are illustrated further through the consideration of the following case study. The particular product considered is sensitive, therefore this paper has focused on the generic manufacturing aspects and no reference is made to any specific product or company details.

5.1 Background

Company X has a long established track record in manufacturing a wide variety of products, however current market conditions have caused the company to consider a new product as a potential revenue stream for the business. Several prototypes of the product have been created and the final design specifications are being finalized. The prototyping of two of the products have also been used to provide baseline processing times for the individual operations. A number of issues exist in using this data faithfully, through considerations such as operations that occur for prototypes may not happen during production and delays for parts that were not available as the supply chain was not yet adequately in place.

Estimates have also been made regarding anticipated demand and the production volumes (<10 / month) that will be required and space within the manufacturing facility earmarked for production. One of the key features of this new production system is that it requires no dedicated tooling equipment to be installed within the factory. The product will not require any transfer lines or dedicated machines so that the separate workstations will have a reasonably high degree of flexibility, however the production system will be required to have volume and product flexibility [17] to cope with changes in the initial period. A number of the operations do not have a fixed precedence and so the sequence of those operations can be altered to balance the production system.

Priority constraints for the company have been identified as production costs, as the product targets a new market there is some uncertainty as to pricing and profit margins. This uncertainty means that the company is keen to learn as much as possible about the costs associated with each potential manufacturing strategy. From a practicality point of view, the product itself is reasonably large and so the movement of the product and its constituent parts through the assembly system presents some issues, in addition to limiting the physical space available for workstations within the facility. The factory floor space outlined for production consists of half of an existing facility, with the possibility to expand to fill the whole factory should the business case and demand for the new product deem it necessary.

5.2 Project Structure

The modeling for this project was undertaken principally by staff at Loughborough University's Centre of Excellence in Customised Assembly (CECA), supported by other modelers from the university's Manufacturing Systems Integration (MSI) research group. The project had around 10 engineers with different backgrounds in modeling techniques and tools working with the company, and a considerable amount of coordination and time dedicated to clear communication between these modelers of the manufacturing issues was required. The modeling activity was broken down as described previously into a range of "problem areas" with small focused simulations being undertaken to address particular issues. Deconstructing the manufacturing issues began with consideration of the overall space limitations, with three scenarios drawn up; firstly the production system being implemented into half the factory (as initially intended), an alternative where the full factory is utilized and a blue skies comparison where no space limitations were placed on the system. Each of these scenarios had alternative workstation configurations suggested to present 9 alternative production layouts. These models formed the basis upon which experiments were performed to establish assembly sequences, capacity constraints, resource issues etc. An outline overview of the modeling areas and the structure of the simulation project is provided in Figure 1, below.

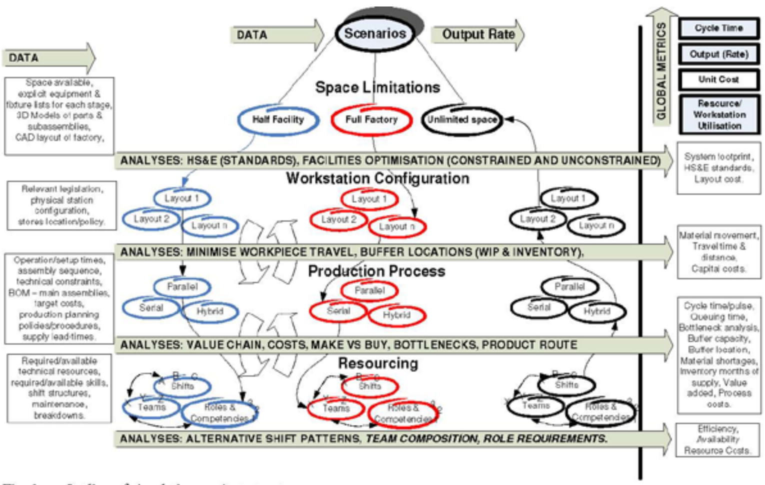

Fig. 1. Outline of simulation project structure.

The different modeling areas were undertaken by those members of the CECA and MSI teams that had expertise within those manufacturing fields, and regular consistency meetings and cross checks were undertaken to ensure the models were built in a compatible and comparable manner. The output metrics from each of the models outlined in figure 1 were kept consistent and as a baseline included cycle times, the system output rate, unit costs and resource utilization. Each of the models was subject to a range of analyses which included lean tools to assess how well the layout and assembly scenario performed for that model's given assumptions (e.g. half factory floor, with layout configuration 1 etc.) In addition, 3D models were generated from product CAD and factory layout plans to compare workstation configurations suggested from the modeling efforts and to establish how the production layout would fit within the space available.

5.3 Management of Simulation Issues

As anticipated with a project of this size and nature a wide variety of complexities had to be overcome. Data availability was a particularly constraining factor, with insufficient operation timings etc. recorded from the prototyping process. Collection of data from within the facility was also problematic, given the sensitive nature of the company's other products and restrictions on the time modelers could spend on site. These information issues caused significant concerns when it came to the accuracy of data that was used to drive the models, which identified where inadequate data was being incorporated into the simulation and flagged this next to the output results to remind the modelers of the confidence in the data. Fortunately, a final round of pre-production prototypes has been scheduled which presents opportunity to gather specific information relating to each operation as it is trialed. A program of data collection and information capture has been prepared and will provide improvements to the initial models created. Difficulties persist in the data not reflecting production information that could be collected were the full working system in place, however this updated information will be incorporated into the existing models to build greater confidence in those areas flagged as being subject to uncertainty.

Updating models as new information becomes available enables the modeling team to provide the most accurate simulation support possible as changes occur as the production system is prepared. Unfortunately this means that decision support early in the project was largely strategic and detailed feedback of the working of the system was necessarily broader than hoped. Additional problems to overcome updating of models were compounded through the distributed nature of the model building in this project. With each update in available information, the new data had to be analysed, disseminated and changes to modeling constructs agreed amongst the teams prior to undertaking the required changes. Communication is a key element to the success of this project and a close collaborative working environment has been established between the teams. Most of the personnel have worked together in the past, however working meetings and the overall project environment have been structured to allow open and clear communication of modeling issues as any member of the teams raise them.

A selection of analysis tools have been used to feedback information in conjunction with the various modeling scenarios. Each scenario (as indicated in figure 1) has in addition to the accompanying model, five analysis methods applied to the proposed production layout to assist in decision support for the company. These methods consist of mappings of the layout (through spaghetti or string diagrams), detailed consideration of the processes (through lead-time maps, process activity mapping and estimated value stream maps as described in section 2) and cumulative costs (through creation of a cost time profile [18] accumulated through production). Examining the processes in this way further confirms the assumptions that have been made accompanying each model, where processing times or resources have been estimated or appear dubious then they can easily be flagged here for future reference to explain any particular results of the modeling activity. Finally a matrix approach (as with Pugh's concept screening [19], [20]) is to be applied iteratively to compare the various layout scenarios. Selection criteria (such as layout cost, flexibility or system throughput) are set, against which the proposed layouts are scored by the team until a consensus is reached as to best alternative. Before discarding any layouts, improvement processes may be used to generate a hybrid design, which is modeled analysed and submitted for the next round of selection.

6.0 Conclusion

This paper has highlighted the wide range of issues faced when simulation is employed to support the launch of a new production system. Limitations from the lack of available reliable data relating to the proposed processes are significant, and while there are ways of mitigating against the impact of such shortfalls of data (notably in the case study presented by acknowledging the shortfall exists and building models flexibly to be updated as new information becomes available) there can be no replacement for comprehensive information available early in the project timescale. CECA and MSI's engineers continue supporting the company's decisions on how the production system should be set-up through the analysis of the proposed layout scenarios using simulation tools. Final examination of the selected layout and the extent to which the analysis methods and models assisted the company will be forthcoming in mid 2009 once the production system has been realised.

Acknowledgement

The authors wish to acknowledge the assistance and support of, CECA, HEIF and Company X.

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