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# **ENTERPRISE MODELLING IN SUPPORT OF METHODS BASED ENGINEERING: LEAN IMPLEMENTATION IN AN SME**

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## *Abstract*

**Popular ‘methods-based’ approaches to engineering enterprises include: BPR, Continuous Improvement, Kaizen, TQM, JIT, Lean and Agile Manufacturing. Generally the industrial application of such methods-based approaches leads to long lead-times, high costs, and poorly justified engineering projects that do not prepare the organization for future change. These outcomes are to be expected because (1) invariably Manufacturing Enterprises (MEs) constitute very complex and dynamic systems that naturally require complex design and change processes and (2) current methods-based approaches to organizational design and change are not analytically well founded.**

**Therefore the authors argue that a framework and modelling toolset are required to facilitate ongoing and integrated application of methods-based engineering approaches, providing underlying modelling structures and concepts to ‘systemize’ and ‘quantify’ key aspects of organization design and change. Unless suitable decomposition, quantitative and qualitative modelling principles are used to underpin an approach such as a Lean Manufacturing, deficiencies will remain. Often, MEs adopt the “we need be lean” mindset without holistic understandings of causal and temporal impacts of such philosophies on ME processes, resource systems and current and possible future workflows. Enterprise Modelling (EM) partially addresses the aforementioned problems and can support the development of robust understandings about current enterprise processes and potential capabilities of systems. However in general, current EM techniques are geared best to capturing and organizing relatively enduring knowledge and data about any given organization but are themselves deficient in respect to replicating and predicting dynamic system behaviors.**

**This paper presents a model driven approach to organization design and change in support of methods-based engineering, applying Lean Manufacturing principles, with a UK based bearing manufacturer. EM and various derivative Simulation Modelling (SM) views were generated to display system behaviors under changing scenarios.**

**Keywords: Lean, 5S, Takt time, Manufacturing Enterprise, Enterprise modelling, Simulation Modelling**

## 1.0 Introduction

In recent decades technological innovation has induced very significant change on the way that Manufacturing Enterprises (MEs) operate and compete. To support MEs in coping with changing business and production requirements, 'method-based' approaches to organization design and change including: BPR, CPI, Kaizen, TQM, JIT, PPM, Lean Manufacturing, Agile Manufacturing, etc, have been proposed and applied in many MEs. However, none of these management philosophies and production approaches could be said to be a panacea for success. With increasing pressure on MEs to remain responsive to changing market demands, whilst maintaining operational efficiency, arises the need for robust process understandings to enable effective implementation of improvement philosophies.

In general MEs are very complex entities: designed, managed and changed by people, by deploying people and technological resources in systematic, timely and innovative ways that generate competitive behaviors. Prerequisites to respond such change and deal with complexity are firm understandings of; the processes that are the focus of improvement and effects of change decisions. However, implementing change and dealing with associated effects can prove difficult when such an understanding is not intrinsic i.e. domains lacking structure and documentation.

This paper presents a model driven approach to organizational design and change. An Enterprise Modelling and Integration (EM&I) approach was deployed to model aspects of a Small to Medium sized Enterprise (SME) collaborating with the Manufacturing Systems Integration (MSI) research institute. The resultant models, especially in their simulation views provide basic frameworks for reasoning about enterprise systems behaviors under changing scenarios. The case instance reported is an SME that makes composite bearings to order, namely ComBear composite bearings. The focus objectives of the ComBear improvement project include (1) to create enterprise models (static & dynamic) to enhance the understanding of the enterprise processes and systems, and (2) to bring to bear on the process and systems models created elements of Lean Manufacturing concepts and tools with a view to achieving improved performance in the critical areas of lead time, process efficiency, resource utilization and consumption, and increased value generation.

## 2.0 Lean Manufacturing Philosophy Background

The Lean Manufacturing philosophy originated from Toyota Production systems in Japan and was pioneered by Taiichi Ohno (1912 -1990). The prime purpose of Lean Manufacturing is to eliminate manufacturing wastes (muda). Tapping [1] describes manufacturing wastes in terms of the so called seven deadly manufacturing wastes, namely: overproduction, waiting, transport, over processing, inventory, motion, and defects. Wastes in manufacturing are activities which absorb resources but create no value in return and they includes: mistakes which require rectification, production of items no one wants, unnecessary inventories, processing steps which are not needed, movement of people and transport of goods without purpose, people waiting because the upstream activity has not promptly delivered, goods and services that do not satisfy customer's requirements [2]. Lean Manufacturing is a systematic approach to identifying and eliminating wastes through continuous improvement, flowing the product at the pull of the customer in pursuit of perfection [3]. Hence the goal of Lean Manufacturing is to eliminate wastes by:

- Producing what the customer needs
- When required by the customer
- In the exact quantity needed
- Using resources only when needed

Womack & Jones [2] suggest five principles steps towards achieving Lean Manufacturing benefits namely:

1. Precisely specify value by specific product
2. Identify the value stream for each product
3. Make value flow without interruption
4. Let the customer pull value from the producer
5. Pursue perfection

The application and testing of some of these Lean Manufacturing principles in ComBear will be discussed later in this paper.

### **3.0 Enterprise Modelling and Simulation**

Enterprise Modeling (EM) approaches and supporting tools provide a structured view and grounding for change decisions, enabling the systematic hierarchical decomposition of an ME's processes, allowing contextual problem definition and specification. CIMOSA (Computer Integrated Manufacturing Open Systems Architecture) was developed by the AMICE consortium during a series of ESPRIT projects [4]. CIMOSA aims to help companies manage change and integrate their facilities and operations. It has been emphasized by [5], [6], and is considered by many authors to be the most comprehensive of current public domain EM approaches [7]-[9]. CIMOSA introduced a process-based approach to integrated EM, ignoring organizational boundaries, as opposed to various function or activity-based approaches, described in terms of their; function, information, resource and organizational aspects, and designed according to a structured engineering approach that can then be plugged into a consistent, modular and evolutionary architecture for operational use [7]. It presents a model-based approach to design, operationalize and manage an enterprise. The authors and their colleagues have been using CIMOSA in numerous research and industrial projects. Sets of CIMOSA conformant models are generated during projects and presented to industrial partners for verification. This serves three purposes; (1) to enable enterprises to understand, model, analyze their processes and operations, (2) to provide model developers with an accurate benchmark from which improvements can be derived, (3) to provide the management team with information to make effective decisions in response to change. For the constraints of this paper, the authors will not go in to great details and illustrations of CIMOSA models, but briefly introduce main modeling procedures followed and the model types produced.

#### **3.1 Establishing a Focus Modeling Domain, the Context Diagram**

After the broad aims and general problems for a case company have been identified, the modeler must define a scope within which the existing modeling tools will be deployed. EM in this case uses decomposition principles to handle model complexity, this constrains the modeler to model in abstraction and avoids modeling of the infinite complexity inherent to real systems. The modeling priority and emphasis is established through a model depicting the global objective, which is reasonably simple in structure and content. The primary focus is central and surrounded by the most relevant domains involved in objective realization. This is termed the Context Diagram, and is the first type generated. Additionally, it is necessary to have specified an area of concern when drilling down and to demarcate immediately unconcerned domain(s) to provide succinct models, representative of entry point and problem concerns. Marked domains are then treated as 'black box' thus not further detailed during model development nor when creating modeling scenarios for case companies.

#### **3.2 Problem Domain Decomposition, Interaction Evaluation and Structure Building**

The next modeling step deploys a mechanism for decomposition to break down the primary focus domain, CIMOSA modeling specifies a diagram to show relationship networks between those involved domains. The relations are interpreted in terms of inflow and outflow of; information, human resources, material and finance. Thus when a particular domain is subjected to internal change, one can deduce the inter-domain effects on connected flows and responses. This outlines the purpose for the Interaction Diagram. A subsequent type of diagram, termed the Structure Diagram, is used to decompose and build structure. This can also be used on each of the associated domains which have been identified to model in CIMOSA in the Context Diagram. The Structure Diagram takes each domain as a focus for further examination and decomposition in to a hierarchically structured set of processes. Both types of diagrams can be built on a subsequent level i.e. it is possible for a particularly complex domain to have several Interaction and Structure Diagrams for the purposes of providing a sufficient level of detail as required by the modeler.

#### **3.3 Sequential Precedence of Process Operations, the Ultimate Respondents to Change and Where Decisions Need to be Made**

Procedural steps thus far have served to decompose and structure domain contents. Now a more detailed level is reached, here actual sequences of process and constituent operations are assessed. Complete end-to-end process networks, comprising activities with associated information and resource inputs and outputs are represented using the fourth CIMOSA diagram type, the Activity Diagram. A numbering convention is followed to identify activities listed with their dependencies and routings. Also, an approximate duration is given through means of a timeline indicating when each step of operation will initialize and how long they operate.

From a model developer and theoretical perspective, the concepts, methodology and technology used in CIMOSA modeling and diagrams, can usefully decompose complex process networks into their component process segments. CIMOSA also serves to provide a means of documenting and visualizing associated flows of; activities, material, information, controls and so forth. Such model diagrams can support an ME's decision makers (i.e. company management teams and direct associated operators) who require increased information support from models. To achieve this, the models need to enable; (1) appropriate presentation format and structure to be readily understood by users (i.e. the decision makers) (2) efficient and equivalent information which can be quickly obtained from models, (3) quick, responsive and efficient development, if original model data is available, as per the end users' reference requirement, (4) a model format and building procedure that is flexible to various model iterations, transfer, and re-use.

### **3.4 Systemizing Methods-Based Engineering Using CIMOSA**

The authors propose that the use of EM, in particular CIMOSA and conformant approaches developed at the MSI Research Institute [10], in conjunction with methods-based engineering approaches will fulfill a two-fold requirement, these being: (1) the provision of a structured route to implementation of methods-based engineering philosophies, and (2) EM based improvements to be informed through well defined philosophies. Such static models can then inform the analysis of time dependant simulation models, allowing for the quantification of improvements with respect to: throughput, time in the system, resource efficiency and utilization.

## **4.0 Case Study**

### **4.1 Company Background**

ComBear is a rapidly growing SME based in the UK with global customers and stakeholders. Recently, ComBear completed a major enterprise engineering project when it created a second production facility, similar to its UK operational base, which is now located in South Korea. Further production facilities are being developed in other parts of the world including the US with a view to increasing market share. At both of its current manufacturing sites, ComBear manufactures a range of advanced composite products suitable for agricultural, marine, mechanical, pharmaceutical and food processing applications. In general terms, composite products are manufactured from reinforced plastic laminates composed of synthetic fabrics impregnated with resins and lubricant fillers. Final products are delivered to customers in a variety of form factors including, but not limited to: structural bearings, washers, wear rings, wear pads, wear strips, rollers, and bushes.

### **4.2 Problem Definition and Case Study Objectives**

ComBear's growth in the market of composite bearing manufacture has put the company under increasing pressure to produce products in larger volumes, shorter times, and at reduced costs. Approaching such challenges without considering organizational design and change has lead ComBear to compromise metrics fundamental to the customer i.e. on time delivery, product quality, and product costs.

The focus objectives of the case study were to: (1) create enterprise models to enhance the understanding of the enterprise processes and systems, and (2) bring to bear on the process and systems models created elements of Lean Manufacturing concepts and tools with a view to achieving improved, quantifiable, performance in the critical areas of; lead time, process efficiency, resource utilization and consumption, and increased value generation. Whilst Lean activities with ComBear are ongoing, to remain concise, the establishment of a 'pull signal' and reducing materials wastage will be discussed in this paper with particular emphasis on the raw materials production process.

### **4.3 Enterprise Modelling and Simulation at ComBear**

CIMOSA modelling constructs and representational formalism support decomposition of complex systems, in this case ComBear's processes, into sub systems that can be analyzed independently and later recomposed into a collective whole. The key processes in ComBear were identified and encoded to enable the realization of enterprise models. These were then validated by their management and production teams as being representative of the enterprise processes and associated resources. Exemplar diagrams follow, figure .1 shows a Context Diagram which was described in section 3.1. Figure .2 depicts an Interaction Diagram,

described in section 3.2, of ComBear's 'plan and control production' process, showing the flow of information and resources between associated processes.

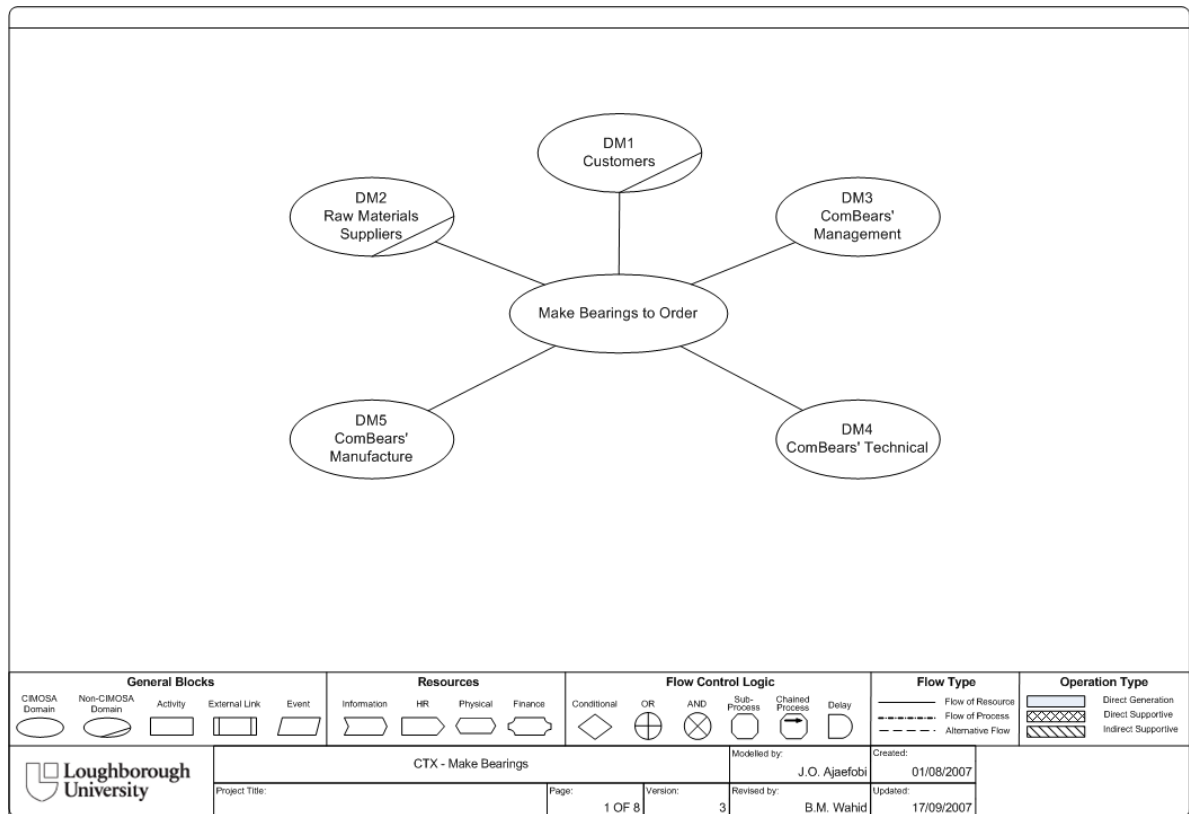


Fig. 1. Establishing a focus domain using the Context Diagram

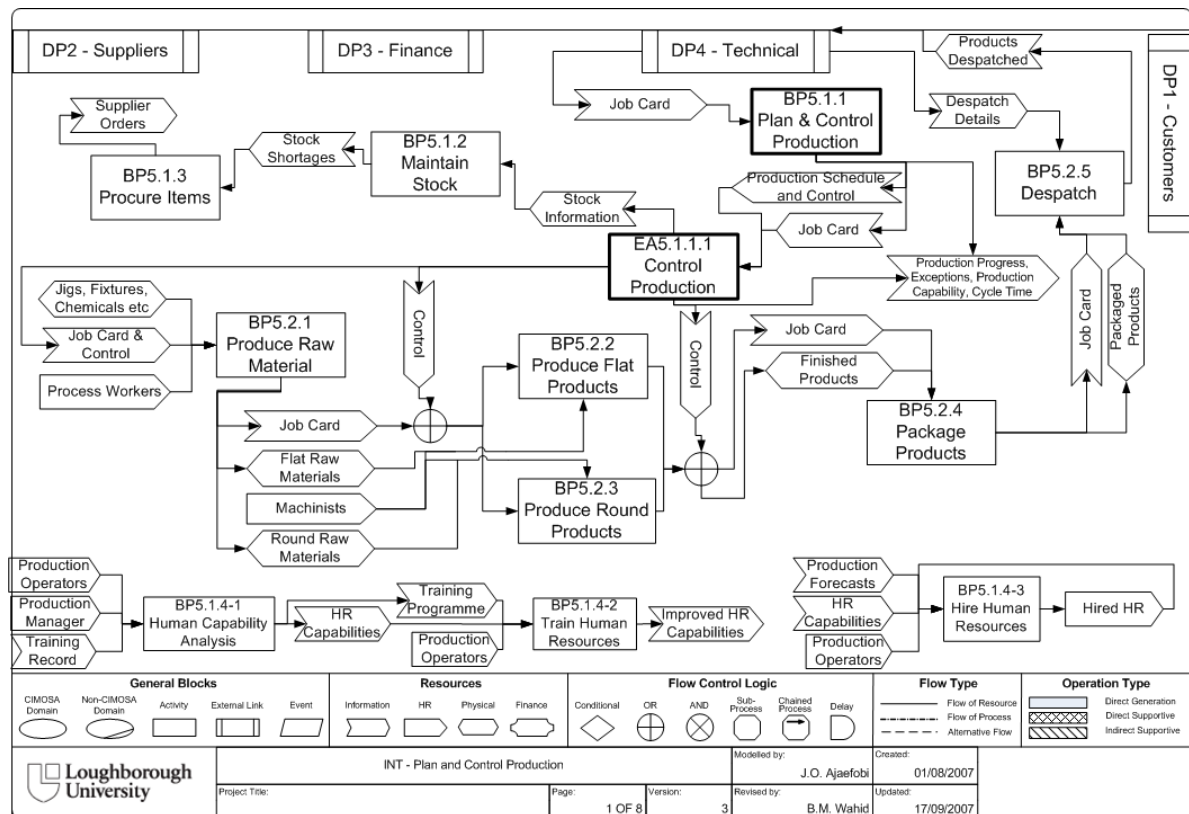


Fig. 2. Process and resource flows within a domain, the Interaction Diagram

Having developed similar static models of ComBear processes, at the further detailed ‘activity’ level, the next step in the project sought to operationalize the models by applying selected Lean Manufacturing measures to the processes in a simulation environment in order to observe current ‘as-is’ process behaviors and performance of the resource systems. The initial simulation environment was realized using Simul8® and further investigation is being carried out by another software, Lean Modeller®, to establish values (this is mentioned for completeness but is not within the scope of this paper).

Through analysis of static and simulation models in conjunction with discussions with ComBear’s management and production teams, it was decided that the focus of improvements should be in the production of raw materials that supply later processing shops. This was supported by the simulation model in figure .3 which indicates a very low percentage utilization of resources in the histogram as well as a large deviation in the time round narrow raw materials spend in the raw materials processing shop. Additionally, this part of the manufacturing process was manually intense hence offered the most scope for improvement.

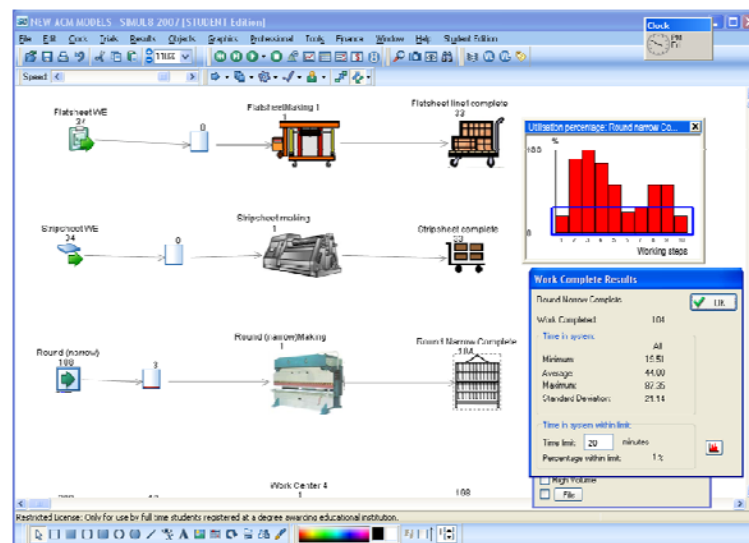


Fig. 3. Initial simulation model

The company’s production systems are a mix of make-to-order and engineer-to-order, despite the order book consisting of repeat orders. Whilst these are representative of pull systems, the pull signal itself i.e. the job card, is issued to the raw materials processing shop i.e. the start of production. This indicates that whilst production is based on firm orders, within the factory products are produced in a way more representative of a push system. ComBear had highlighted that there were increasing problems with late deliveries and also product quality, with products leaving site that were then found to be of insufficient quality by the customer.

Having created static CIMOSA models, to depict processes and provide common understandings, and simulation models to introduce time dependencies and thus quantify current practice (in terms of output, time in the system, and resource efficiency and utilization) indicating where to focus lean improvements, the next step was to deploy methods-based engineering to target improvements. Whilst improvements were targeted and made across flat, strip, and round raw materials, for the purposes of this paper only those made with respect to round narrow will be discussed.

#### 4.4 Lean Manufacturing Principles Deployed

Through use of analytical methods, guided by the model structures developed using EM principles and diagramming techniques, improvements were targeted to provide; effective process resourcing, product and tooling rationalization, reduced materials wastage, and workplace organization.

##### 4.4.1 Implementing Pull and Product Rationalization

In order to implement a pull signal within the organization, it is necessary to establish takt times for products i.e. demand driven requirements of ComBear. This can only be achieved if sound product classifications exist, these were established through the use of activity diagrams. It was noted that of the product classifications used by ComBear, processing characteristics provided an alternative and generalized classification of round, flat, and strip products. These general form factors exhibited distinct processing routes in the raw materials

processing shop. This rationalization of products allowed complexity to be minimized when establishing takt times.

Analysis of historical order information allowed takt times to be developed and broken down in to constituent takt times for each of the newly defined classifications by key processes i.e. produce raw material, produce flat products, produce round products, as defined in previously created enterprise models. With these times understood and visible to the production team, decisions could be exercised to enable adequate resourcing of processes to support production of what the customer needs, when required, in the quantity needed.

#### 4.4.2 Materials Wastage and Tooling Rationalization

The processes deployed in the production of raw materials require that the tooling, thus working dimensions, be within 2mm of finished dimensions to minimize the amount of subsequent machining effort required and material wasted. However this must be balanced with cost, space, and demand constraints. Currently, tooling is highly product specific and whilst this reduces material wasted, it does induce waste in terms of tooling stock. Other than dimensional constraints, there is no sound justification for the tooling sizes stocked in the raw materials shop. A distinction must therefore be made between the frequency of tooling use and a justification must be made for holding particular sizes and quantities. With the aforementioned points in mind, stepwise improvements have been delivered through the categorization of products in to; those that occur on a continuous basis and are core products (runners), those that occur regularly (repeaters), and those that are manufactured to specific requirements (strangers). The associated requirements for tooling sizes and quantities were extrapolated and as a result of these grounded considerations for stocking of tooling, significant scope for rationalization has been indicated. The authors would like to state that this is still an area of continued work, with similar improvements targeted for the other product types produced at ComBear along with effects on scheduling of production within the organization.

#### 4.5 Quantifying Improvements Through Simulation

The quantified effects of changes to the production of round narrow raw materials, as a result of implementing Lean compliant improvements and resourcing strategies, can be seen in the simulation model in figure .4. Comparing this with figure .3 shows that the worker utilization has increased as has the overall productivity of the system, this is now regularly achieved with 71% within the limit. The histogram indicates that a higher resource utilization percentage has been achieved, this is attributable to the increased availability of tooling i.e. operators are not waiting. The implementation of a pull signal (takt time) means that operators are more clear and informed as to the proceeding job, this is reinforced by the standard deviation which indicates that the production rate is more predictable.

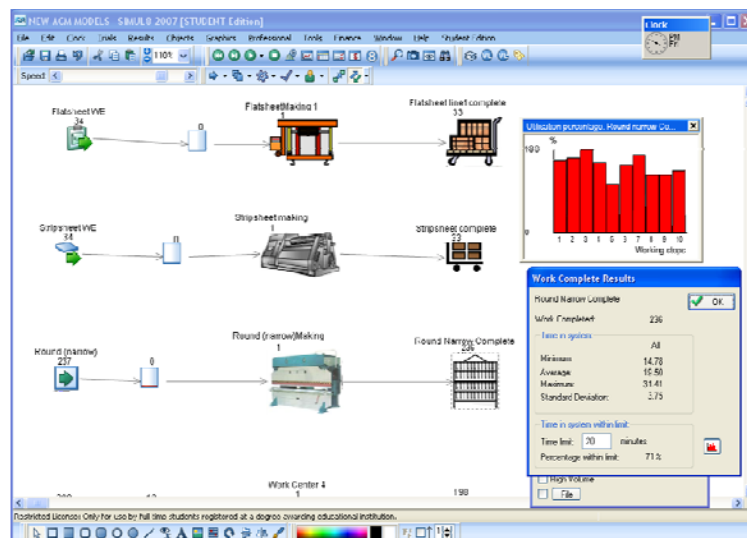


Fig. 4. Simulation model to quantifying improvements



## 5.0 Conclusions

The combined use of Enterprise Modelling (EM), Simulation Modelling (SM), and methods-based engineering allowed the authors of this paper to conduct a quantified, systematic and targeted Lean implementation based on; improved and verified process understandings, establishment of a pull signal, resource (human, tooling, raw materials) and product (establishing groupings) rationalization.

Whilst it is acknowledged that the research in the areas of Lean Manufacturing is well documented, it is however lacking in a structured and integrated means to realizing improvements. The authors can see the real benefits in the development of systematic support for methods-based engineering that guides users with generalized routes to implementation. The case study conducted has shown that the key to successful Lean and similar improvements is largely dependant on understanding of current practice and the causal impacts of change. Through the use of static and simulation modelling approaches developed at the MSI research institute, many of these impacts can be enacted and thus mitigated.

Improvements and methods-based engineering conducted were done so in abstraction from the real system, using EM and SM approaches. The project work with ComBear is ongoing and the next steps are to work on product classes to inform different stocking strategies based on the product type i.e. runner, repeater, or stranger. For example it may well be necessary to make-to-stock raw materials for less frequent products. Additionally, the interfaces between the raw materials shop and subsequent processes needs to be explored to further inform takt times thus fully implement a pull signal. Whilst classifications break complexity, there is a degree of variation within them, hence further variables will be used in order to further inform product sub-types.

Further suggested improvements are to be implemented and areas of investigation researched, the results of these efforts will be reported on in further conference and journal publications.

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