Proceedings of the 2011 International Conference on Advances in Supply Chain and Manufacturing Management
Kharagpur, India, December 16– 18, 2011

Optimizing In-plant Supply Chain in Steel Plants by Integrating Lean Manufacturing and Theory of Constrains through Dynamic Simulation

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Abstract: Optimizing steel plant operations on an ongoing basis is a complex task due to the nature of steel plant process which spans from discrete to continuous. Planning, scheduling, tracking, genealogy, monitoring and dispatch operations in such a situation becomes a challenge as they have to satisfy two potentially conflicting goals of increasing throughput and reducing inventory and costs. Combining the principles of Lean manufacturing and Theory of Constraints along with a supply chain management system like MES can provide the opportunity for plant optimization and better decision making. However this might be challenging due to the variability and complexity involved in the operational process on an ongoing basis. Coupling this with online dynamic simulation can yield the best results for plant operations optimization.

Keywords: Steel Plants, Lean Manufacturing, Theory of Constrains, Manufacturing Execution System, Simulation

1. Introduction

Optimizing steel manufacturing operations to satisfy throughput, lead-time and cycle time goals is a complex process. Integrated steel plants unit operations like raw material handling, iron making, steel-making, mills and finishing lines have varying flow characteristics ranging from continuous to discrete along with batch operations. Planning, scheduling, tracking, genealogy, monitoring and dispatch operations in such a situation to satisfy becomes a challenge as they have to satisfy two potentially conflicting goals of increasing throughput and reducing inventory and costs.

Supply Chain Management System using the theory of constraints can help in improving the throughput while providing real-time visibility in the steel manufacturing flow. On the other hand lean principles appropriately applied to steel manufacturing can reduce cost by cutting down WIP inventory/cycle times and shorten lead times and push the envelope to a global plant-wide cost minimization. It also has direct effects on improving quality. However, lean principles are constrained by assumptions of near perfect flow, standardization, minimal variability and minimal downtimes for maintenance - which are difficult to achieve in actual steel plant operations.

Combining the best of lean manufacturing and supply chain management systems provides the steel plant operations the opportunity to be globally optimal across throughput and costs. However, designing such a system analytically is intractable due to its complexity. Using discrete event system simulation we can effectively integrate SCM systems with Lean manufacturing for steel plant to determine the optimal level of operations. Simulation allows us to map out multiple future state scenarios of combined lean and SCMS operations for the integrated steel plant.

2. The Two Theories

We will discuss lean manufacturing and theory of constraints from the perspective of steel plant operations.

2.1 Lean Manufacturing in Steel Plants

Lean manufacturing is a business model that focuses on eliminating waste(that do not add value to quality) and providing quality products on time at lesser cost. Lean production is based on the concept of *kaizen*, or concept of continuous improvement, which stresses that routinely applying small incremental improvements over a long period result in significant improvement in quality. Kanban, a lean technique, is a system that creates a pull manufacturing system where upstream work centers receive signals based on requirements downstream. This provides flexibility to the manufacturing line.

In an integrated steel plant, the idea of Lean manufacturing would mean an uninterrupted continuous product flow through the entire value stream. In lean inventory is treated like cycle time, where more inventory means greater time it takes for an inventory to get its term. Reducing inventory and cycle time creates the urgency to eliminate these hidden wastes and waste-generating activities, by reducing the overall appetite of the system.

The traditional approach to implementing Lean technique in steel plants is difficult for the following reasons:

- Equipments are often large in size, making the rearrangement unrealistic
- Some processes need to be performed in large batches. In addition, as the size and weight of the products is large, the single piece flow becomes extremely difficult
- Substantial equipment set-up/changeover costs – not only in time and effort, but also in yield loss and equipment wear
- Bottleneck operations require some protective inventory to avoid a costly “out of metal” condition
- Some mills have a wide variety of routings, and multiple passes on the same equipment. Hence, traditional kanban controls may not be suitable
- Strong unions and/or less than cooperative labour relations make employee empowerment difficult to install and maintain
- Metallurgical constraints may limit how aggressively heat-up and cool-down cycles can be accelerated

(Hands-On Group 2000) provides a very good discussion on lean manufacturing in steel plants. Two basic methods which can be used in steel mills are

a. Installing Kanban controls and getting on-time: Applying Kanban creates a pull type system within the plant, where the system's demand is filled only on requirement. Kanbans provide an upper limit to the amount of inventory that is allowed between units, and thereby on the lead-time. Kanbans also put an upper limit on the number of potential defects. The reduction in inventory between the operations leads to fast detection of a defect which in turn makes it faster to ascertain the root cause of the defect.
b. Cutting planned lead times and getting on-time: This method aims at cutting out the excesses in the lead-times after reviewing the lead-times offsets for each operation. Cutting the planned lead times automatically cuts the inventory proportionally. Reliability is achieved by holding each department/operation accountable to achieve the operational due date. By cutting the lead-times in the planning system, the front-end operations experience a temporary drop in the workload, helping in reallocating the excess resources to some other short term project.

2.2 Application of Theory of Constraints using MES in Steel Plants

Today steel plants make extensive use of supply chain management systems. A supply chain management system is a key integrating element in the steel plant production system. Manufacturing Executing System (MES) plays a central role in In-Plant Supply Chain Management. The relation between Supply Chain Management and Management Execution Systems is shown in Fig. 1.

The key purpose of MES is to provide the integration and support in operational decision making, and its scope extends across the entire operational supply chain of the plant. Moreover, MES is being an execution system is integration both with Level 1 and 2 control systems and Level 4 and 5 levels of decision making systems providing end-to-end visibility for manufacturing decision making.

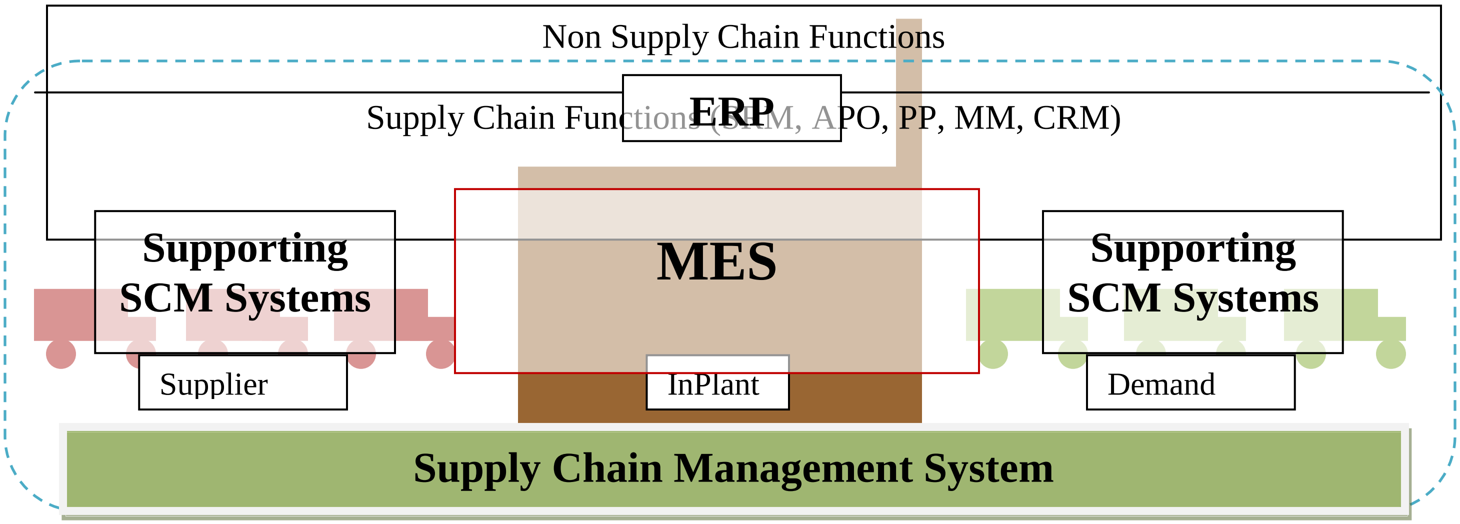


Figure 1- Supply Chain Management System

One of the important functions of MES is to provide better decisions around scheduling operations in the finite time horizon using Theory of Constraints as the underlying mechanism in the manufacturing execution system. There are five steps to application of the theory of constraints which is also applicable for finite capacity scheduling in steel plants. These are, identify the constraint, exploit it, subordinate everything else to it, elevate the constraint and avoid inertia when the constraint shifts.

(MCTS) provides a discussion of theory of constraints. In exploiting the constraint, the drum-buffer-rope scheduling technique and buffer management are used. In finding ways to elevate the constraint, the techniques of effect-cause-effect and the cloud diagram often are useful. The theory of constraints is a philosophy that has a lot in common with Lean but also has some critical differences. There are two basic differences. The first is that the theory of constraints accepts the existence of a constraint, at least temporarily, and focuses the improvement effort on the constraint and related workstations. The second is that the theory of constraints uses overlapped production (transfer batch not equal to the process batch) to schedule work through a batch production environment, while Just-in-Time provides no scheduling mechanism for a batch environment.

2.3 Similarities in Lean thinking and Theory of Constraints

There are many similarities between Lean thinking and Theory of constraints. Both of them recognize that in order to achieve and sustain the ongoing improvement, looking beyond the walls of manufacturing to include the rest of the enterprise is essential. And hence, they have expanded the scope to encompass principles and practices of the entire system to enable continuous system-wide improvement. Some specific similarities are summarized as follows:

a. **Focus on Value:** Lean thinking emphasises in delivering only those products and services that the customer values. Theory of Constraints also focuses upon increasing the customer's perception of value of your product or service.

b. **Understanding the Process Flow:** Lean thinking instructs the change agent to identify the opportunities for eliminating the waste from the system by walking the value stream from finished goods to raw materials. Theory of Constraints also starts by understanding the process flow and identify the weakest link in the system.

c. **Pull System:** Kanban principle of Lean thinking is consumption based replenishment system that pulls the material from downstream to upstream work centres. Similarly, the Drum-Buffer-Rope Production Planning technique as per the Theory of Constraints is a technique that maximizes the flow of product through the plant for which there is near term customer demand.

d. **Constant Improvement:** Lean thinking believes in continuous incremental improvements to eliminate wastes being generated in the value stream. Theory of Constraints also proposes a POOGI methodology that provides focus to improvement actions.

2.4 Differences in Lean Methodology and Theory of Constraints

Apart from the similarities mentioned above, there are many differences between these two theories. Some of them are summarized as follows:

a. **Underlying philosophy:** Lean thinking is based upon the philosophy that an organization is a collection of parts that can be systematically broken down, individually improved and put back together. While according to the Theory of Constraints an organization is considered as a system of interrelated parts that can only be improved systemically by focusing on the constraint-systems thinking.

b. **Objective:** The objective of the Lean thinking is to eliminate waste, i.e., reduce inventory and lead time to reduce the costs. But the objective behind the Theory of Constraints is to reduce inventory and lead time to gain competitive edge, enhance the capacity.

c. **Breadth of focus:** While the focus of Lean thinking is limited to process, i.e., design, order, fulfilment, project management, finance & measurement and distribution & replenishment, Theory of Constraints has much broader focus, including marketing & sales, finance & measurement, and strategy in addition to the focus of Lean thinking.

d. **Resource Management:** The Lean thinking strives to maximize the resource efficiency and it dedicates the machines and production lines to specific products. On the other hand, the Theory of Constraints segments the market, not the resources. It strives for maximum resource flexibility.

e. **Capacity:** While the Lean thinking believes in removing the excess capacity altogether and balancing the capacity to the rate of the customer demand, Theory of Constraints believes in removing the excess capacity, but keeping the protective capacity, unbalancing the capacity to maximize the constraint output based on the customer demand.

f. **Purpose of Inventory:** Lean strives to eliminate the inventory considering it to be waste. While TOC does not remove the inventory totally. It believes that excess inventory is waste – but some amount of inventory is required as it protects throughput against variability of supply and demand.

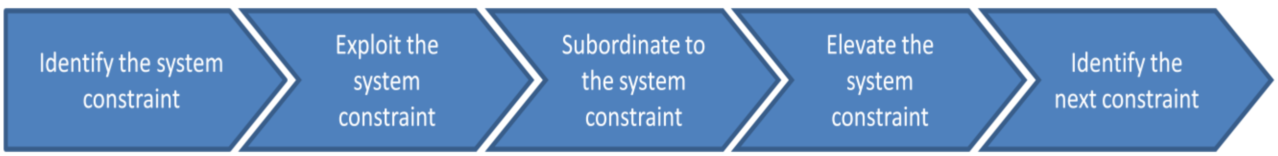
g. **Variability:** Lean strives to reduce variability in all places to zero while TOC believes that variability will always exist, and one needs to protect against it with time buffers and prioritizing the improvements using Buffer Management

h. **Measurement:** Lean redefines the traditional operational efficiency and managerial accounting measures around plant performance , i.e., the throughput is defined in units of volume, while the TOC redefines these around the company performance, i.e., the throughput is defined in terms of money

i. **Improvement Focus:** The improvement focus of lean is towards all work centres concurrently to improve the entire plant performance, while TOC focuses mainly on the improvement in the constraint

3. Applying Lean thinking and Theory of Constraints together in a Steel Plant

Combination of the Lean and TOC results is a highly focused and effective improvement approach aligned with the growth objectives of the business. A steel plant operation owing to its high setup, change over time etc for different product demands has several constraints that make direct application of Lean Principles difficult. Taking such a situation into consideration, Lean and TOC could be applied to a steel plant in 5 steps as mentioned below:



Step 1: Identifying the system constraint - Unbalance the capacity if required.

Step 2: Scheduling the constraint to maximize its performance while simultaneously satisfying the customer demand, applying lean tools and techniques like Kanban to the place that promises the fastest and most dramatic improvement and continually strives to remove waste at the constraint, and then manage time buffers and implement buffer management

Step 3: Subordinate to the system constraint – Application of Kanbans and pull systems, choking the release of material to the floor with the Rope, sacrificing the upstream work centre efficiency in case it is required to maximize the constraint output, and applying Lean tools and techniques to the work centers that hinder flow

Step 4: After all these improvement steps, if required, the plant can spend money to acquire additional capacity

Step 5: Identifying the next constraint and decide if we still want to improve it

The basic idea is to apply the TOC concept to identify and strengthen the weakest link of the plant, while improving the through put velocity using Lean concepts.

3.1 Simulating the Lean and TOC together using inputs from MES

Owing to the complexity of processes in Steel plants, it is difficult to integrate Lean and TOC together. Simulation can provide effective ways of foreseeing the effects of implementing Lean and TOC together. The lean and TOC approaches can be planned and used as an input while modeling the simulation program. Several simulation iterations can eventually help in coming up with an effective plan of implementation at plant level. MES is a very important tool that can support simulation by providing necessary data for simulation. The basic framework for simulation is given in Figure 2.

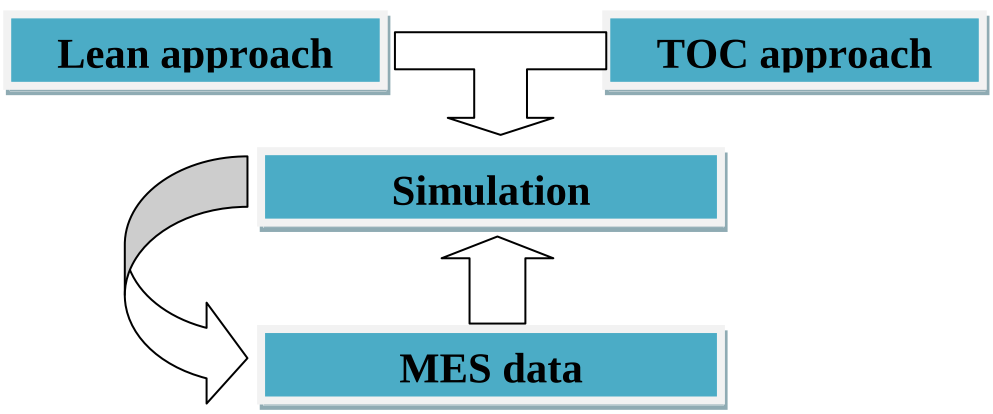


Fig.2 Basic Framework

The MES can collect real-time production information and execute optimized task to increase manufacturing efficiency, and is one of the typical shop floor control systems. Most of the components such as data collection services, control mechanism, and process planning functions in the MES can support the implementation of the on-line simulation.

On-line discrete event simulation is a computerized system capable of performing both deterministic and stochastic simulation in real-time or quasi real-time, to monitor, control and schedule caster, rolling and heats in steel manufacturing. On-line simulation integrated with the information systems can reach two powerful features: 1) reliable prediction of the future behavior of the shop floor and 2) the ability to emulate and/or dictate the control logic of a steel plant.

3.1.1 Advantages of Simulation

The advantages of simulation can be summarized as follows:

1. It can help the capacity planners to determine the lot sizes, release dates, and work calendars for resources by incorporating simulated scheduling constraints in the decision making
2. It can be initialized to the current state of the shop floor and a human scheduler can use it to predict the performance of alternative decision options
3. After the desired operational strategy and part mix are determined, simulation can interact in real-time with shop floor management.
4. Personnel can use simulation model to predict the order completion times for customers on-line
5. Simulation output can give feedback to the engineering function on the performance of the current design

3.2 Relationship between On-Line simulation and Supply Chain Management Systems

In order to implement the real-time process control, an on-line decision support system could be adapted to and integrated with the requirements of the MES functions. Subsequently, the on-line simulation can be combined with optimization tools for decision making and evaluation. A detailed control mechanism of the performance of the on-line simulation is described in Fig.3.

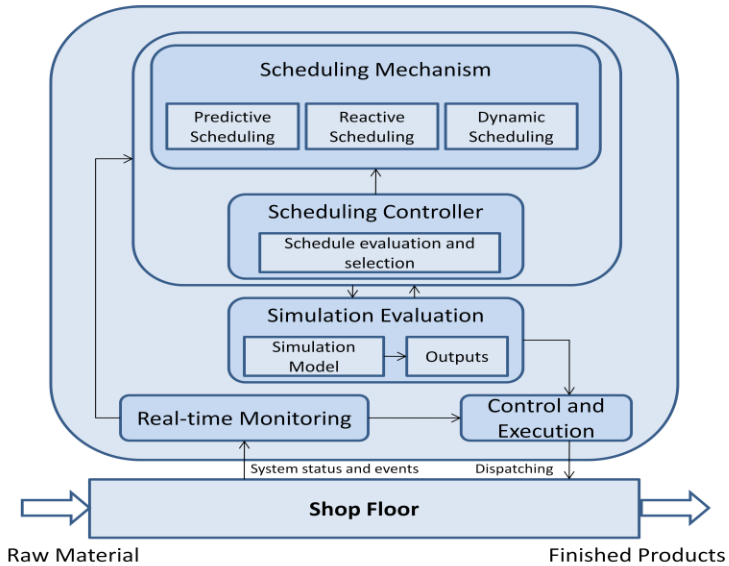


Figure 3 – The structure of a general on-line simulation system

A general on-line simulation system has four components:

1. Monitoring component – Receives events from the shop floor, and monitors the performance of the shop floor periodically
2. Scheduling controller – Selects the better scheduling approaches for further simulation evaluation based on actual manufacturing conditions
3. Simulation evaluation – Includes a simulation model constructed based on the physical shop floor status from the factory database
4. Control and execution component – Sends all scheduling control information to the shop floor and dispatches jobs to the machines

Now, let us see the functions of MES. According to MESA (Manufacturing Execution System Association International), the full functions of SCMS include: 1) resource allocation and status, 2) operation and detailed scheduling, 3) dispatching production units, 4) document control, 5) data collection and acquisition, 6) labor management, 7) quality management, 8) process management, 9) maintenance management, 10) product tracking and genealogy, 11) performance analysis.

The components 1, 5 and 10 can be seen as the monitoring components. Components 2 and 3 can be regarded as the scheduling controller components. Component 8 can monitor production and provide decision support to the operators for correcting and improving in-process activities and hence, can provide more powerful function than control and execution component in the simulation system.

Hence, it is clear that there exists a sophisticated relationship between on-line simulation and the MES. MES can provide more reality and exactly real-time information to the simulator which can ensure the simulator to solve the most correct production plan.

3.2.1. General MES framework includes simulation function

Figure 4 shows the general software infrastructure of MES.

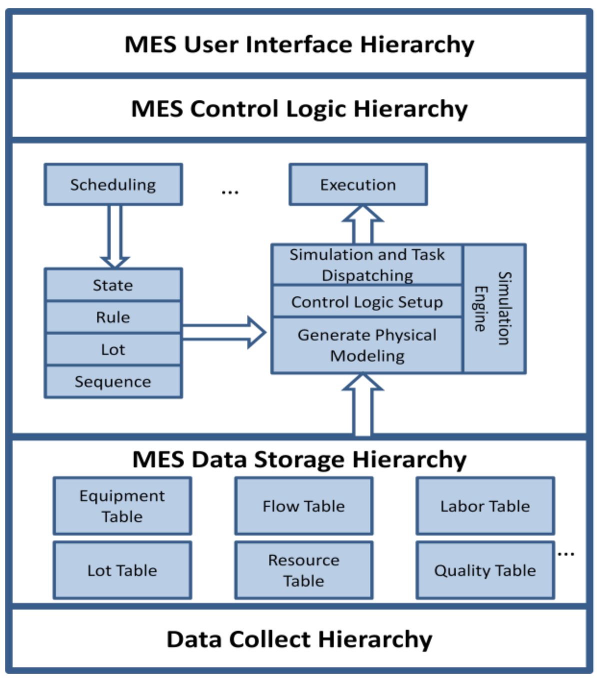


Figure 4 – General software infrastructure of MES include simulation function

The software infrastructure of MES can be classified as three hierarchies: User interface hierarchy, control logic hierarchy, and data storage hierarchy. User interface hierarchy is used to show the simulation modeling, simulation process and results. Control logic hierarchy includes three functional steps of simulation: model generation, control logic setup, and simulation and task dispatching. Data storage hierarchy supports the input and output of the simulation. Fig 5 shows the simulation and modeling phases in the MES components.

4. Conclusion

It is apparent that there exists a strong relationship between MES and simulation. These, combined with the Kanban technique and Theory of Constraints as discussed in the previous sections can be helpful in optimizing the steel plant operations where MES helps in collecting real-time production information, Kanban and TOC techniques help in providing various possible options to be simulated, compared and finally arriving at the optimized operations.

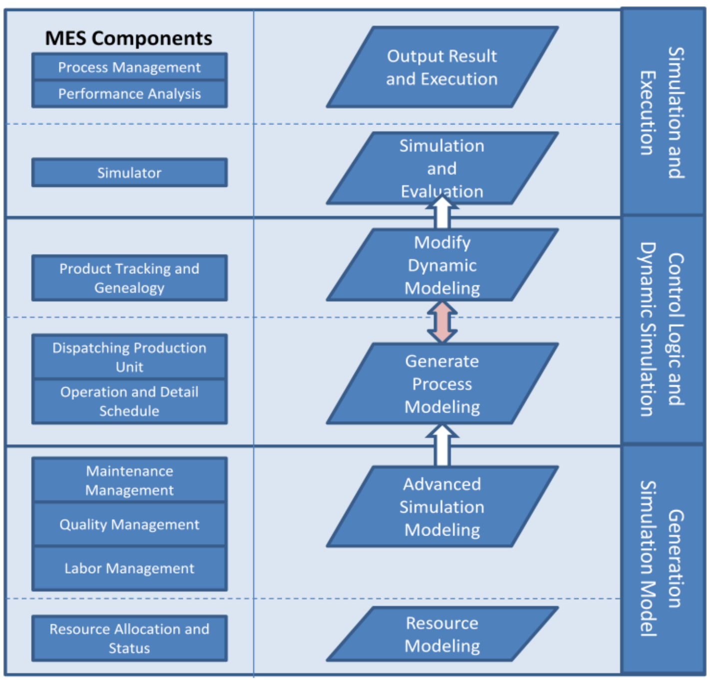


Figure 5- Modeling and Simulation phases in MES

References

Hands-On Group. "Running Steel Lean." *Hands On Group*. 2000. www.handsongroup.com.

MCTS. "Theory of Constraints". www.mcts.com/Theory-of-constrainsts.html.