International Journal of Industrial Engineering, 15(2), 176-184, 2008.

EFFICACY OF LEAN METRICS IN EVALUATING THE PERFORMANCE OF MANUFACTURING SYSTEMS

Mohammed Khadem[1], Sk Ahad Ali[2], and Hamid Seifoddini[3]

[1] Sultan Qaboos University,
P.O. Box 33, Al-khod 123,
Muscat, Oman

[2] Lawrence Technological University
21000 West Ten Mile Road
Southfield, MI 48075

[3] University of Wisconsin Milwaukee,
3200 N. Cramer St.,
Milwaukee, WI 53211, USA

Corresponding author's e-mail: {aali@ltu.edu}

The efficacy measure is an important indicator in lean performance measure. The research is to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of lean metrics in the production systems. A procedure for quantitative analysis of lean metrics is developed and the evaluation of the lean effectiveness in predicting the performance is presented. Lean metrics are embedded into simulation model so that the simulator is able to provide automatically lean metrics for the systems without any extra effort. The embedded lean simulation is used to investigate the significance of various improvement opportunities. This efficacy of these metrics for the performance measurement is a leading indicator for a manufacturing system. A validation is done to show the effectiveness of the proposed systems.

Significance: The efficacy of lean metrics in identifying the problems and underlying improvements needed to increase productivity in manufacturing and service systems.

Keywords: Lean Manufacturing, Efficiency, Efficacy, Lean Metrics, Lean Simulation.

(Received: 13 June 2006; Accepted in revised form 20 April 2007)

1. INTRODUCTION

Lean Manufacturing is an integrated approach to manufacturing of products (service) with the purpose of achieving superior quality, timely delivery and competitive cost leading to customer satisfaction. It is an operations management philosophy focused on reducing waste in a manufacturing system. Lean manufacturing is a performance-based process used in manufacturing organizations to increase competitive advantage. The concept of lean thinking (Womack and Daniel, 1996) originated from the Toyota Production System (TPS) developed in 1950s in Japan (Katayama and Bennett, 1996). Many industries are influenced by the principles of lean, along with its corresponding methodologies. Taiichi Ohno and Shigeo Shingo at Toyota originated lean manufacturing. It is now widely recognized that organizations using lean manufacturing methods have substantial cost and quality advantages over those still practicing traditional mass production (Liker, 1997). The goal of lean manufacturing is to reduce the waste in human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing world-class quality products in the most efficient and economical manner (Todd, 2000). Russell and Taylor (1999) define waste as 'anything other than the minimum amount of equipment, materials, parts, space, and time that are essential to add value to the product'. This study is to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of lean metrics in the production system including the development of a procedure for quantitative analysis of lean metrics and the procedure to evaluate the effectiveness of lean measure in predicting the performance of manufacturing systems.

A manufacturing measure is a standard that defines performance criteria for manufacturing process so that everyone in the organization is working toward the same goal. Lean metrics are essential elements for the success of lean manufacturing approach because it guides an organization on its path of transformation into a lean enterprise. Lean metrics involves visible performance measures, targeted improvement and team reward and recognition (Feld, 2001). These lean metrics have been developed outside academic environment and have not been systematically evaluated by researchers in the field. The performance measurement system (PMS) used in this situation works by separating overall performance of the process (time performance, cost performance, quality performance) into sub-tasks, which contribute to this process (Toni and Tonchia, 1996). While most of these studies have focused on a single aspect of lean and its performance implications (Hackman and Wageman, 1995; Samson and Terziovski, 1999; McKone et al., 2001), a few studies have explored the implementation and performance relationship with two aspects of lean (Flynn et al., 1995; Cua et al., 2001). Even fewer studies have investigated the simultaneous synergistic effects of multiple aspects of lean implementation and performance implication. A noteworthy exception is Cua et al.'s (2001) investigation of implementation of practices related to just-in-time (JIT), total quality management (TQM), and total preventive maintenance (TPM) programs and their impact on operational performance. There are little studies on the quantitative analysis of the lean measure in manufacturing systems. Most of the existing metrics have less links to production issues and more links to financial and accounting. Selection of effective metrics for performance measurement is the key to achieving stated goals. The traditional metrics for measuring productivity are throughput and utilization rate, which only measure part of the performance of manufacturing systems. They are not very helpful for identifying the problems and underlying improvements needed to increase productivity. Due to intense global competition, companies are striving to improve and optimize their productivity in order to stay competitive. Lean metrics enable to measure, evaluate, and respond to our organization's current performance in a balanced way-without sacrificing the quality. Properly designed lean metrics also enable to consider people related factors.

2. LEAN MANUFACTURING

Lean production in its purest form is nothing more than the combination of a myriad of tools and practices some of which were developed under the name of other management revolutions, such as TQM and JIT. Lean manufacturing uses tools such as kaizen, one-piece flow, cellular manufacturing, synchronous manufacturing, inventory management, pokayoke, standardized work, workplace organization and scrap reduction to reduce manufacturing waste (Russell and Taylor, 1999). There exists a surplus of different tools and techniques developed for different purposes and waste elimination or reduction (Green and Dick, 2001). Applying the tools and metrics is difficult due to the confusion and the lack of a systematic classification of their applications. The decade of 1990s was witness to many makeover of conventional manufacturing into lean approach. Many companies either transformed or created new cellular production system. There are also examples of how a complete factory could be designed in lean principles. Taj et al. (2000) shows a real example of designing a factory with a future in mind and Taj and Ghorashyzadeh (2003) address the strategic issues for planning lean manufacturing plants.

Traditional performance measurement systems are commonly based on cost and management accounting developed in the late nineteenth and early twentieth centuries. In recent years, vast changes have taken place in technology and production techniques that have made traditional performance measurement systems no longer useful. Maskell (1991) identified five main problems with traditional management accounting techniques for performance measurement, namely: lack of relevance, lagging Indicator, cost distortion, inflexibility, and hindrance. There are other reasons why there is a need for new performance measurement systems in manufacturing industries such as customers are requiring higher quality, performance and flexibility and management techniques used in production plants are changing extensively. The new performance measurement systems required by world class manufacturing enterprises should have the varieties characteristics (Maskell, 1991). Modern performance measures are not newly developed; however, it is necessary to replace their cost based performance measurement systems with ones that truly drive the production process since performance measures can also dictate behavior.

Thor (1994) proposes a "family of measures" approach that is well communicated complete consisted with reward and customer driven and performance measures should incorporate statistical concepts. Hall et al. (1991) state that how measures are used is just as important as what measures are used. The measures should motivate personnel to find and eliminate waste and inefficiencies and provide means to anticipate problems rather than simply reacting to them. Many studies have done on performance measurement and there is not always consensus among researchers. Past literature suggests creating performance measures based on satisfying a set of general criteria, however, these criteria seems inconsistent. Not much work has focused on a structured approach deriving manufacturing performance measures from a manufacturing system design and performance control perspective. This research addresses this problem and presents a systematic methodology for the effective performance measure of lean manufacturing.

3. LEAN METRICS

A measure of the extent to which a specific intervention, procedure, regimen, or service, when deployed in the field in routine circumstances does what it is intended to do for a specified population. An effectiveness assessment quantifies the extent to which a process produces intended results. To be effective and reliable, the chosen metrics need to have five key characteristics: aligned with business, actionable and predictive, consistent, time trackable (internal benchmark), and peer comparisons (external benchmark). Figure 1 gives a picture of the relationship of factory efficiency efforts with other production practices (Factory Efficacy Guidance US Air Force 2004).

A manufacturing measurable is a standard that defines performance criteria for manufacturing processes so that everyone in the organization is working towards same goals. Measurement drives the achievement of quality, cost, and delivery. In existing manufacturing systems most measurables have poor link to production issue however more related to accounting and finance. The baseline metrics are determined based off of the input of the as-is value stream map and the outputs are value-added ratio, takt time, lead-time, process time and pitch. These metrics are what will be the baseline measurement for the lean implementation. Metrics fall into two categories: primary metrics and secondary metrics. Usually in practice the primary measures are called lean metrics, which includes Dock-to-Dock (DTD) Time, First Time Throughput (FTT) Capability, Overall Equipment Efficiency (OEE) and Build-to-Schedule (BTS) Ratio. The secondary metrics includes days on hand inventory, value adding ratio, manufacturing cycle time, 5s diagnostic rating and square footage required. Only the lean primary metrics are considered for our research and analysis (Khadem 2004).In this section, the concepts of the fuzzy sets, particularly linguistic variables and fuzzy preference relation are briefly reviewed.

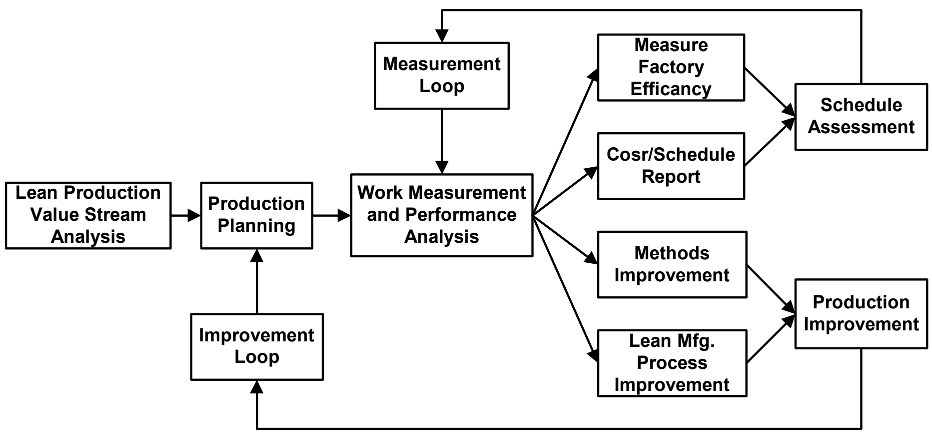

Figure 1. How the Factory Efficiency Practice Area Integrates with Other Practices

4. RESEARCH METHODOLOGY AND MODEL ANALYSIS

4.1 Research Methodology

A methodology is presented to determine the effectiveness of four primary lean metrics (DTD, FTT, OEE, BTS) in evaluating the performance of lean manufacturing system in terms of production rate, quality, machine utilization, tardiness, lead-time and inventory levels. In this paper lean metrics calculated and compared with simulation results, which provide estimates of the production rate, quality, machine utilization, etc. Parameters affecting the performance of production systems such as product mix, machine reliability, and production synchronization changed while values of lean metrics are calculated and compared to simulation results to observe the consistency or lack of it between the two measures. Figure 2 depicts the methodology of this study.

In lean manufacturing environment of advanced manufacturing systems, the flexible production line is designed to manufacture a variety of products in timely manner with minimal inventories. Such a system is composed of a number of workstations linked together by an automated transfer line. Furthermore, a computer program carries out the function of production scheduling, operation monitoring, and production control. A large number of factors are critical to the effective operation of such flexible production lines, including number of product options, the manufacturing operation of each product type, workstation capacity, the processing time of the operations at each station, material handling capacity at each work station, and overall material handling capacity.

It is necessary to build a more realistic model, one that can give more appropriate information, such as unexpected breakdowns of machines and absenteeism of labors. As production systems are characterized by high production diversity and customer demand for both excellent quality and timely delivery, it is necessary to analyze the production system to obtain an optimized outcome. The realistic simulation model development becomes essential and effective for designing and managing an assembly line, which needs to be highly flexible because of increasing complexity. Simulation has been commonly used to study the behavior of real world manufacturing systems to gain a better understanding of underlying problems and to provide recommendations for improving the systems. The re-configurable assembly line can provide flexibility for high-mix low-volume production, which is a growing customer demand.

Azadeh (2001) developed an integrated simulation model that generates a set of optimizing alternatives for a heavy, continuous rolling mill system in a full-scale steel-making factory and generates a set of optimum production alternatives. The model is designed to integrate with other workshops of the factory, locates the optimum solutions by a rule-based methodology. Sharma and Kim (2005) presents an empirical study using two or three-parameter distributions in place of best fit distributions in simulations of asynchronous production lines with finite buffers. Patel et al. (2002) discusses the methodology of modeling and studying the final process system of the automobile manufacturing process in order to develop an effective and efficient process to ensure the system throughput.

Choi et al. (2002) discusses the initial efforts to implement simulation modeling as a visual management and analysis tool at an automotive foundry plant manufacturing engine blocks. The optimum performances were identified through the use of scenarios by varying the number of assembly machines and processing time. Potoradi et al. (2002) describes how a large number of products are scheduled by a simulation engine to run in parallel on a pool of wire-bond machines to meet weekly demand. The frequently updated schedule redirects the line towards maximum demand fulfillment based on the latest status of the line. Leu and Chang (2001) investigates the effect of container size on a CONWIP production line processing multiple part types. It shows that smaller container sizes generally lead to shorter average flow time and smaller average WIP and may increase average flow time or average WIP.

Altiparmak et al. (2002) uses simulation metamodels to improve the analysis and understanding of decision-making processes of an asynchronous assembly system to optimize the buffer sizes in the system. Wiendahl, (1991) uses the simulation tools in the field of assembly planning, and due to different objectives of the different efforts in simulation, the tools are divided into the four-hierarchy classes of assembly shop, cell, station, and component. The study provides information on how the simulation tool can be used for designing any production line. Ramirez et al. (2000) presented how discrete-event simulation was used to identify potential problems and allowed solutions to be developed and enacted prior to production start-up. Several cell design alternatives for post-printing operations were evaluated before major capital investments and a final layout were made and resulted in effective equipment and labor force utilization, reduction of work-in-process and improved operational efficiency.

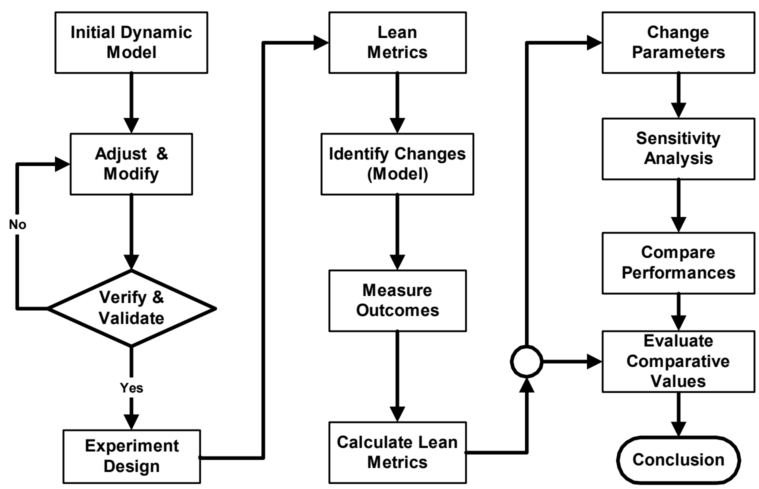

Figure 2. Flow chart of research methodology

To observe real manufacturing systems is expensive and sometimes cumbersome. Therefore, a simulation model is an easier way to build up models for representing real-life scenarios to identify bottlenecks, and to enhance system performance in terms of productivity, queues, resources utilization, and cycle times as well as lead times, all of which are important areas for today's manufacturing. The simulation study provides a clear picture of the performance of the drive production line under different possible production scenarios, including variations in demand, product mix, number of operators, operations of workstations, number of shifts, and other production factors. Simulation is being widely used for traditional performance measurements however limited research focuses on measuring lean performances. The different scenario analysis is done to see the performance of a re-configurable assembly line to accommodate today's market demand. The proposed assembly simulation model can be analyzed easily in terms of throughput, resource utilization, queuing, and WIP to understand the line behavior and to compare between various models and compare the lean performance with the traditional performances. This study presents an environment where the user can build up a more realistic model to analyze the assembly line to enhance system performance and predict the system behavior based on proper setting of lean metrics.

4.2 Modeling and Simulation of an Assembly Line

This case study was concerned of a sixteen-product family's assembly production line where the lean principles were implemented. These sixteen products are sorted in four series according to there sizes. These sixteen different products are assembled through a complex series of that are distributed across eight workstations and all sixteen products are also assembled on the same assembly line. The assembly starts at one of two starting points. After that all products go through all of the remaining workstations regardless of the series size. Workstations three is a primary testing station to make sure all connections have been made before the unit is powered up. This is workstation is fully automated. Workstation four and five add the various components that make the difference between models A, B, C, and D. Each product is then put through a functional test and is powered up under the load of an electric motor. The final workstation is packaging where finishing touches are made to the assembly and the product is packaged.

A modeling study was undertaken to create a model, which represented the current production layout with representative product flows. In any modeling study it is essential to start with a model that emulates the existing system and then to use this model to investigate further alternative strategies. A series of further models were developed using the Arena simulation software and this culminated in the development of a mode. The base-case run provided a general description of what may be considered as the inherent capability of the existing system which is shown in Figure 3. The traditional performance measure and lean measure for the base model is given in Table 1 and 2 respectively. From this data we see the line is running on its 70% of maximum capacity; according to Haywood-Farmer and Nollet (1994) the best operating point. The first time through (FTT) for the base model is 75% and where as overall equipment effectiveness (OEE) is 86%. Build to schedule (BTS) ratio is 72%. The equipment with the maximum OEE acts as the bottleneck of the whole manufacturing system.

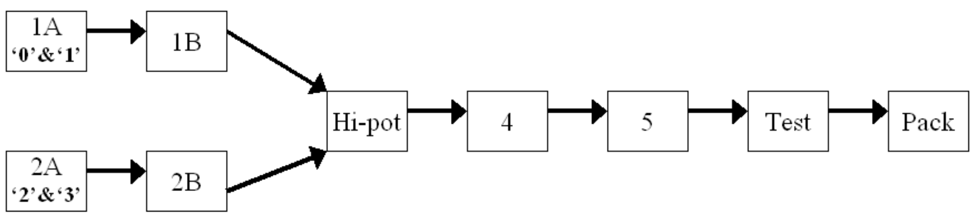

Figure 3. Manufacturing process outline (Scenario 1)

Lean Measures for Reconfigured Model

Flexibility is added to the assembly line and the performance measures for flexibility are shown in Table 1 and 2 for scenario 1, 2 and 3. It can be seen that OEE goes down around 16% and DTD time reduce 2% and FTT and BTS improves and approximately 2%. This flexibility reduces throughput time and improves the operator productivity. Adding a pre-assembly station (scenario 4) between stations 2A and 2B (bottleneck station) results shows a reduction in throughput (TH) time. OEE reduces significantly while FTT improves slightly. DTD time reduces approximately 20% and BTS ratio improves approximately 20%. Adding a station with the flexibility (scenario 5 and 6) improves the productivity significantly. To reduce the bottleneck at station 4, and 5 one more station added parallel to operation 5 (scenario 7) and results shows reduction in throughput time, bottleneck, and work in process inventory. It increases the productivity and balancing the line. In scenario 8, 9 and 10 where three revised processing times used and additional package station added. FTT productivity increases significantly. The results are for traditional performance and lean measure from where we can see there is a significant improvement in the measure and the line is more balanced.

	Scenario	FTT	OEE	BTS	DTD
Base Model	1	75	86	72	101
	2	76	71	73	100
	3	77	73	74	98.4
Redesigned Model	4	78	56	94	77
	5	78	60	95	76.6
	6	78	59	98	74.5
	7	79	76	98	74.4
Reconfigured Model	8	82	77	98	74.1
	9	87	75	99	73.9
	10	87	74	98	73.9

Table 1. Lean Measure different Scenarios

	Scenario	TH Time (min.)	Mean Utilization	Mean WIP	Operator Productivity
Base Model	1	77	69	34	8
	2	70	72	27	8

	3	68	73	22	9
Redesi-gned Model	4	61	68	26	11
	5	65	68	24	12
	6	66	70	11	12
	7	57	66	12	13
Reconfi-gured Model	8	65	68	16	13
	9	66	67	13	14
	10	66	71	18	15

Table 2. Traditional measure for different Scenarios

4.3 Efficacy Comparison

The base-case run provided as the line's existing capability. This is now taken as the production target for any improvement tasks to be implemented on the system when losses occur. The various improvement scenarios suggested may be tested using simulation, with the advantage of automatically gauging production improvement through the built-in lean metrics. As a demonstration, several losses are assumed to have occurred in the system (Khadem 2004), all at the same production shift. The randomly selected losses are limited to having an impact on availability and quality efficiencies only. Although performance efficiency is not directly manipulated, it fluctuates from the base-case in response to other losses occurring in the equipment or in upstream or downstream locations. To investigate the significance of various improvement opportunities on the system with the losses, ten scenarios of simulation runs are generated, each with a mutually exclusive set of improvement scenarios. Scenario 4, 5, 6 and 7 target availability and quality, respectively, each at a single workstation. Improvement scenarios in scenario 4 also include mutually exclusive sets, but target a combination of randomly selected losses in two locations.

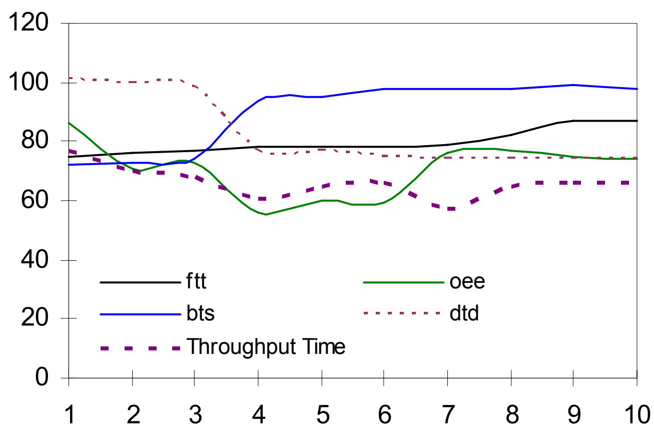

Figure 4. Lean measure comparison with throughput time

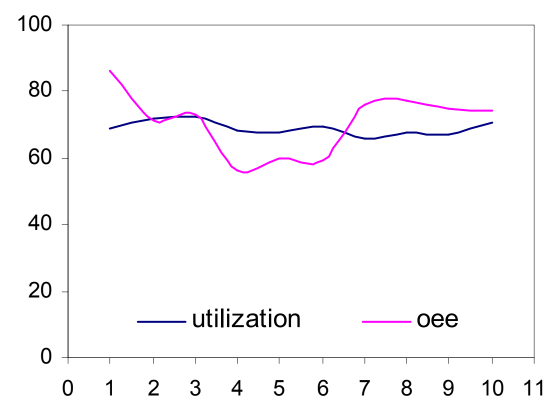

Figure 5. OEE comparison with mean utilization

Improvements on availability efficiency scenario 1 are conducted by eliminating the downtime losses at the selected workstations one at a time, therefore providing ten cases, as shown in Figure 4. The improvement is reflected by an increase in availability, which increases OEE. By comparing simulation results of the potential improvement scenarios, visual inspection of results in the above figure suggests that eliminating losses at hi-pot and functional test to reach the inherent OEE of 0.73 will greatly enhance productivity by increasing. In Figure 4 comparisons of lean metrics have done with the throughput time. It can be seen that balancing the line consideration significantly impacts the throughput time. After line balancing, throughput time is more stable.

Figure 5 compares mean utilization of the line with OEE. We see the scenario 1, 2, 3 where OEE improvements increase productivity and later scenario though OEE reaches its optimal for this system. Mean utilization of the line shows it best operating condition as it's on the range 65-70%. For base model OEE was 85%. The reason it is high on the base model that the assumptions were availability and performance efficiency 100% for the base model. Later scenarios the losses (machine downtime, operator availability) are incorporated. In scenario 4, 5 and 6 shows the best improvements in terms of cycle time, utilization. However in later scenario improves the flexibility and productivity for the system reducing the losses and OEE increases up to 73% as the line is more balanced which is expected for a highly reliable electronics assembly line like power drive assembly. Based on that we found the optimal configuration of the system. In Figure 6 compares DTD with throughput time and the author observed that its shows a trend in between DTD and throughput time. Improving the DTD improves the throughput time. Such behavior agrees with the discussion and conclusions of Huang et al. (2002). The equipment with the maximum OEE acts as the bottleneck of the whole manufacturing system. When the maximum OEE is higher than those of other units in the system, it will mostly determine the system performance. In Figure 7 compares the BTS with mean WIP inventories and shows that improving the BTS ratio decreases the WIP inventories.

These effectiveness metrics are embedded into simulation modeling so that the model is able to calculate automatically lean metrics for the system without any extra effort. Several group simulation runs are generated to investigate the significance of various improvement opportunities. The experimental results show that lean metrics is very effective in identifying the problems and underlying improvements needed to increase productivity.

The proposed simulation modeling with lean performance can improve the performance measurement of the manufacturing systems. These developed models can be applied in life examples to analyze the system performance more efficiently and effectively and can be easily used for line balance and identify the system behavior. Management can prevent any unexpected situations by proper analyzing the tradition and lean performances through the simulation models.

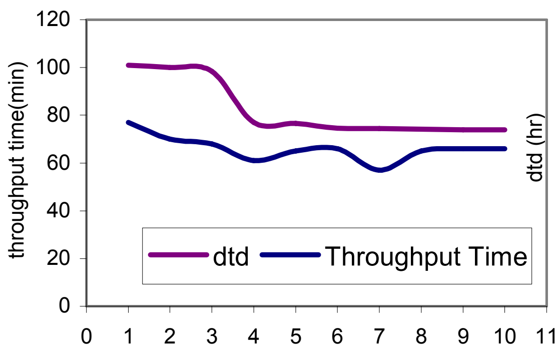

Figure 6. Comparison of DTD with Throughput time

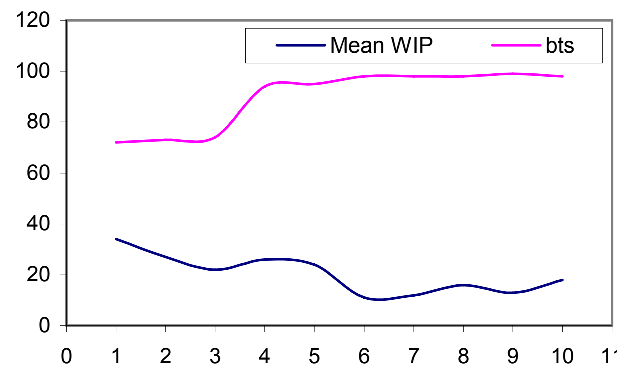

Figure 7. Comparison of BTS with mean WIP

5. CONCLUSIONS

The research has developed a quantitative analysis framework and a simulation methodology to evaluate the efficacy of lean metrics in the production systems. This study was successful in reaching its objectives in three aspects. First, a quantitative analysis of lean metrics has been developed in evaluating performance of manufacturing systems. Secondly, lean metrics are embedded into simulation models so that it can provide automatically lean metrics for the system without any extra effort. Simulation runs are generated to investigate the significance of various improvement opportunities. The experimental results show the efficacy of lean metrics in identifying the problems and underlying improvements needed to increase productivity. Lean metrics calculated and analyzed in the models in different scenarios. The results show that the efficacy of these metrics for the performance measurement of manufacturing system is the leading indicator for a manufacturing system. Finally, real systems are represented in the light of lean manufacturing systems and simulation and validated with real-life application and found significant improvement in production scenario. In this research only the primary lean metric was focused for the performance measure of the manufacturing system. Secondary lean metric may be considered for future research extension and there effect on manufacturing performance measure. One of the proposed extensions to this research would be to add lean metrics into simulation software as built-in functions so that the simulator is able to calculate automatically FTT, DTD, OEE and BTS for manufacturing systems.

6. REFERENCES

1. Altiparmak, F., Dengiz, B. and Bulgak, A.A. (2002). Optimization of buffer sizes in assembly systems using intelligent techniques, Winter Simulation Conference, Dec 8-11, San Diego, 2: 1157-1162.
2. Azadeh, M.A. (2000). Optimization of a heavy continuous rolling mill system via simulation', 7th International Conference on Industrial Engineering and Engineering Management, Nov 28-30, Guangzhou, 378-384.
3. Choi, S.D., Kumar, A.R. and Houshyar, A. (2002). A simulation study of an automotive foundry plant manufacturing engine blocks, Winter Simulation Conference Proceedings, 1: 1035-1040.
4. Cua, K.O., McKone, K.E. and Schroeder, R.G. (2001). Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. Journal of Operations Management 19(2): 675-694.
5. Feld, W.M. (2001). Lean Manufacturing: Tools, Techniques, and How To Use Them, St. Lucie Press, Boca Raton, FL.
6. Flynn, B.B., Sakakibara, S. and Schroeder, R.G. (1995). Relationship between JIT and TQM: practices and performance, Academy of Management Journal, 38(5): 1325-1360.

7. Green, M. and Dick, M. (2001). Baseline analysis diagnoses manufacturing, Lean Directions: The e-Newsletter of Lean Manufacturing, July.
8. Hackman, J.R. and Wageman, R. (1995). Total quality management: empirical, conceptual, and practical issues, Administrative Science Quarterly, 40(2): 309-342.
9. Hall, R.W., Jhonson H.T. and Turney, P. (1991). Measuring Up: Charting Pathways to Manufacturing Excellence, Business One Irwin, Il.
10. Haywood-Farmer, J.S. and Nollet J. (1994). Professional Service Firms and Total Quality Management: A Good Fit?, International Journal of Service Industry Management, 5(3): 5-13.
11. Huang, S. H., Dismukes, J. P., Shi, J., Su, Q., Wang, G., Razzak, M. A. and Robinson, D. E. (2002). Manufacturing system modeling for productivity improvement, Journal of Manufacturing Systems, 21(4):249-259.
12. Katayama. H. and Bennett. D. (1996). Lean production in a changing competitive world: a Japanese perspective, International Journal of Operation and Production Management, 16(2): 8-23.
13. Khadem, M. R. (2004). A comparative study of Lean matrix and traditional manufacturing performance measure, Ph.D. Dissertation, University of Wisconsin -Milwaukee.
14. Leu, B.Y. and Chang, S.H. (2001). The effect of container size on a CONWIP production line: a simulation study, International Journal of Industrial Engineering, 8(2).
15. Liker, J.L. (1997). Becoming Lean, Productivity Press, Portland, OR.
16. Maskell, B.H. (1991). Performance Measurement for World Class Manufacturing, Productivity Press, MA.
17. McKone, K.E., Schroeder, R.G. and Cua, K.O. (2001). The impact of total productive maintenance on manufacturing performance, Journal of Operations Management, 19(1): 39-58.
18. Patel, V., Ashby, J. and Ma, J. (2002). Discrete event simulation in automotive Final Process System, Winter Simulation Conference Proceedings, 1: 1030-1034.
19. Potoradi, J., Boon, O.S., Mason, S.J., Fowler, J.W. and Pfund, M.E. (2002). Using simulation-based scheduling to maximize demand fulfillment in a semiconductor assembly facility, Winter Simulation Conference, 2: 1857-1861.
20. Ramirez, M.T., Christian, P., Govande, V. and Zimmers, E.W. (2000). Design and implementation of a cellular manufacturing process: a simulation modeling approach, International Journal of Industrial Engineering, 7(4).
21. Russell, R.S. and Taylor, B.W. (1999). Operations Management, 2nd ed., Prentice-Hall, Upper Saddle River, NJ.
22. Samson, D. and Terziovski M. (1999). The relationship between total quality management practices and operational performance, Journal of Operations Management, 17(5): 393-409.
23. Sharma, A. and Kim, D.S. (2005). Effectiveness of using two and three-parameter distributions in place of "best -fit" distributions in discrete event simulation models of asynchronous production lines with finite buffers, International Journal of Industrial Engineering, 12(4).
24. Taj, S. and Ghorashyzadeh, Y. (2003). Strategic issues for planning manufacturing plant/facilities, Proceedings of the European Applied Business Research Conference, Venice, Italy, June 10-15.
25. Taj, S., Pfeil, J., Sullivan, D., Hutka, J. and Cochran, D. (2000). Designing a factory with a future in mind, Proceedings 7th Annual Meeting of the Production and Operations Management Society, San Antonio, April 1-4.
26. Thor, C. G. (1994). The Measures of Success, Wiley, NY.
27. Todd, P. (2000). Lean manufacturing: building the lean machine, Advanced Manufacturing, September 12, [http://www.advancedmanufacturing.com/leanmanufacturing/part1.htm].
28. Toni, A.D. and Tonchia, S. (1996). Lean organization, management by process and performance measurement, International Journal of Operations and Production Management, 16(2): 221-236.
29. Wiendahl, H., Garlichs, R. and Zeugtraeger, K. (1991). Modeling and simulation of assembly systems, CIRP Annals, 40(2): 577-585.
30. Womack, J.P. and Daniel T.J. (1996). Lean Thinking, Simon and Schuster, New York.

BIOGRAPHICAL SKETCH

Mohammad Khadem is an Assistant Professor in the Department of Mechanical and Industrial Engineering at the Sultan Qaboos University, Oman. He received B.S. in Mechanical Engineering from Bangladesh Institute of Technology, Khulna, M.S. in Mechanical Engineering from University of South Alabama and Ph.D. in Industrial Engineering from University of Wisconsin-Milwaukee. His research interests include simulation and optimization, decision support system, intelligent manufacturing system, lean manufacturing, flexible manufacturing system, logistic and supply chain and production planning and control.

Ahad Ali is an Assistant Professor in the Department of Mechanical Engineering at the Lawrence Technological University, Southfield, MI. He earned B.S. in Mechanical Engineering from Bangladesh Institute of Technology, Khulna, Masters in Systems and Engineering Management from Nanyang Technological University, Singapore and Ph.D. in Industrial Engineering from University of Wisconsin-Milwaukee. Dr. Ali was Assistant Professor in Industrial Engineering at the University of Puerto Rico - Mayaguez, Visiting Assistant Professor in Mechanical, Industrial and Manufacturing Engineering at the University of Toledo, Lecturer in Mechanical Engineering at the Bangladesh Institute of Technology, Khulna. Dr. Ali has published journal and conference papers. He is member of IEEE, IIE, INFORMS, and SME.

Hamid Seifoddini is an Associate Professor in the Department of Industrial and Manufacturing Engineering at the University of Wisconsin-Milwaukee. He earned B.S. in Industrial Engineering from Sheriff University of Technology, M.S. and Ph.D. in Industrial Engineering from Oklahoma State University. His research interests include lean manufacturing, part-family formation for cellular manufacturing, group technology, and reliability engineering.