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Effects of Human Stress on Reliability of Lean Systems – a Markovian Approach

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Abstract

Human resource elements play crucial roles in successful implementation and sustainability of lean journey. The impact of lean tools on human reliability is proposed through a markov model. Assuming the reliability level associated with certain work stresses, the model predicts Mean Time to Human Error (MTTHE) of the system which can be used to estimate a series of basic reliability metrics.

Keywords
Work Stress, Human Reliability, Lean Manufacturing, Markov Model

1. Introduction and Literature Survey

Efficiency and effectiveness along with quality are major drivers of change (Michie et al. 2014). Lean manufacturing focuses on waste elimination and achieving a flow with minimum use of resources including: material, machines, and personnel. This deals with systems additional components elimination, or making the system efficient, where efficiency is a measure of how economically the firm's resources are utilized. To improve operational excellence of a system, effectiveness should also be considered. Effectiveness is about outputs levels of the system. Lean Six Sigma aims at effectiveness for growth and not just efficiency to reduce costs.
Some lean initiatives have been designed to boost system's efficiency by increasing system's utilization. For example, in cellular structure the parts are grouped to enhance efficiency (Bhasin 2015). Reliability links the efficiency to the effectiveness. As an example, overall equipment effectiveness (OEE) metric contains both efficiency (quality) and reliability (availability) elements. Sawhney et al. 2010). So, to increase total effectiveness of the system, reliability and efficiency must be improved simultaneously. In other words, the system must be scrutinized from a reliability perspective along with the resource utilization aspects. Drohomeretski and his group (Drohomeretski 2014) show that reliability is dominant competitive priority compare with innovation, cost, flexibility, quality, speed. They surveyed 91 companies in Brazil which are implementing lean, Six Sigma or Lean Six Sigma (LSS).
There are several surveys showing that lean principles cause fast paced, high intensity, high stress environments although implementation means and cultural factors have vital impacts on the success of lean (Ohno 1988), (Parker and Slaughter 1988). Human resource management is playing a key role in lean (Gollan et al. 2015), (Vivares-Vergara et al. 2016). Karim and Arif-Uz-Zaman described personnel function through lean teams (Karim and Arif-Uz-Zaman, 2013). The importance of HRM factors and cultural change in transition process during lean implementation is explained in other study (Martínez-Jurado et al. 2014). They have focused to indicate HRM aspects that contribute to overcome worker's unwillingness and resistance to lean production. The impacts of five main groups of HR factors (training, communication, rewards, and job design and work organization) on four implementation phases were identified. HR related factors as lean obstacles have been considered by some researchers (Jadhav et al. 2014), (Bhasin 2012), (Marodin and Saurin 2015).
Most of HR-related barriers affect the system's efficiency and effectiveness metrics through reliability of the system. Personnel reliability along with material, equipment and schedule reliabilities are four components which determine system's reliability (Sawhney et al. 2010). Great care should be taken in selecting the measures or metrics, used to assess, evaluate outcomes of personnel reliability. Focusing on assessment of personnel reliability measures, assist us to make a plan to achieve the desired performance metrics (Sawhney et al. 2010). Various lean

initiatives affect personnel reliability in a different pattern. In this research, we have focused on stress level of the human operator caused by work intensity of the lean implementation. Work intensity is the proportion of time actually spent performing production tasks. Following lean manufacturing approach, work intensity increases. This raises job demand and stress. Stress escalation also may cause reliability reduction. Stress causes absenteeism, increased medical costs and higher turnover (Kvarnstrom 1997).
The curve shows that stress does not have a thoroughly destructive impact on effectiveness, but optimal human performance levels require a moderate stress level. Otherwise, at a very low stress, duties will become monotonous, therefore human performance will not remain at its highest point (Dhillon 1989).
One part of this study is to go through the framework of today's methods of human reliability analysis (HRA). The first generation methods that are quantitative such as THERP and HCR, as well as the second generation which are more qualitative like CREAM and SPAR-H, and new dynamic HRA methods and recent improvements of individual phases of HRA approaches.

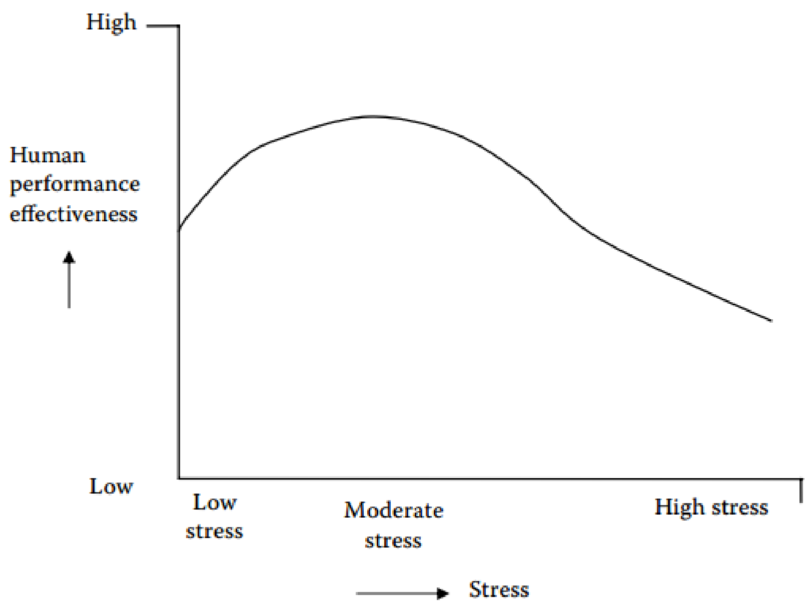

Figure 1: Human performance effectiveness versus stress curve (Dhillon 1989)

First generation assessment methods were the first to be developed to help risk assessors predict and quantify the probability of human error. These methods have identified human as a mechanical component, therefore ignores the aspects of dynamic interaction with the working environment. Human Error Rate Prediction (THERP) is based on the same assumption (Miller and Swain 1987). First generation approaches encourage investigators to decompose a task into its components and then consider the potential effect of modifying factors such as time pressure, equipment design and stress. Then the elements are combined to determine Human Error Potential (HEP). This class of assessment methods emphasis is on quantification, in terms of success/failure of the action, with less attention to the root causes and reasons behind human behavior. THERP method is based on classification of human behavior divided into skill-based, rule-based, and knowledge-based, compared to the cognitive level. In this method, wrong actions are divided into errors of omission and errors of commission, which represent, respectively, the lack of realization of operations required to achieve the result and the execution of an operation, not related to that request, which prevents the obtainment of the result. The base of THERP is event tree modelling, where each limb represents a combination of human activities, influences upon them, and results of these activities. Other techniques of first generation are: human error (JHEDI), probabilistic human reliability analysis (PHRA), success likelihood index method (SLIM), and operator action tree system (OATS). Among all above mentioned techniques, THERP is the most popular one that is compatible with probabilistic risk assessment (PRA).
Second generation human reliability assessment methods first introduced in 1990. Unlike the first generation techniques that were behavioral, they are more conceptual. The main specification of these techniques are qualitative assessment of human errors, in other words the main causes of the errors instead of their frequency are identified. In order to find the root causes of the errors, the interaction of human resources with production process must be studied. Cognitive models developed in this classification represent the interaction of the operator personal factors

like stress with the current situation normal system, abnormal conditions. Also, models of man-machine interface, which reflect the control system of the production process focusing more on the context that could lead to such errors of intention, are in the same group. The most notable of these were “A Technique for Human Error Analysis” (ATHEANA) (Cooper et al. 1996) and the Cognitive Reliability Error Analysis Method (CREAM) (Hollnagel 1998). CREAM is a more straightforward technique that has had mixed reviews, although currently is used in the nuclear industry. Other techniques are Cognitive Environmental Simulation (CES), Connectionism Assessment of Human Reliability (CAHR) and Method for assessing the completion of operator’s action for safety (MERMOS). The literature shows that second generation methods are generally considered to be still under development but that in their current form they can provide useful insight to human reliability issues.
Third generation techniques are emerging based on the previous tools, such as HEART model. It is designed to be a quick and simple method for quantifying the risk of human error. It is a general method that is applicable to any situation or industry where human reliability is important.
assessment and reduction technique (HEART), absolute probability judgement (APJ), justified human error data information

2. Methodology

The probability that an item will perform its intended function for a specified interval under stated conditions is regarded as reliability. There are three main aspects in the definition that can express the system reliability. In other words:

$$Reliability = f(Throughput, Time, Work\ Conditions) \tag{1}$$

In the equation, throughput can be regarded as the function of a system in the previous definition.
Lean implementation, can increase the throughput of the system by decreasing the cycle time, but based on working conditions, personnel may complain about the working environment stress that results in reliability reduction. According to Dhillon (Dhillon 2013) human reliability is defined as the probability that a job or task will be successfully completed by personnel at any required stage in system operation within a required minimum time.

$$Human\ Reliability = \frac{Actual\ Work\ Performed}{Expected\ Work\ to\ Be\ Performed}(1 - HEP)\left(1 - \frac{Wasted\ Time}{Expected\ Total\ Time}\right) \tag{2}$$

HEP not only contains the element of human limitations, but also other environmental factors. HEP is calculated based on HEART model and it is equal to (Williams 1985).

$$HEP = \frac{Number\ of\ Errors}{Number\ of\ Error\ Opportunities} \tag{3}$$

HEP is calculated for the purpose of evaluating the probability of a human error occurring throughout the completion of a specific task.
Human error is defined by Dhillon (Dhillon 1989) as the failure to perform a specified task (or performance of a forbidden action) that could lead to disruption of scheduled operations or result in damage to property and equipment.
Based on Meister’s (Meister 1964) classification human errors can be regarded as the followings:

- Operating errors
- Design errors
- Maintenance errors
- Fabrication errors
- Inspection errors
- Contributory errors

As it was mentioned, there are several methods for assessment of human reliability. It is worthy to see how the implementation of lean could change the reliability of human in the system. The main lean principles based on the definitions of (Shingo 1989), (Schonberger 1989), (Ritzman et al. 2004), and (Suzaki 1987) are as the following and the impact of that principle on the stress of human resources are explained.

2.1. Setup Reduction

Cycle time reduction is one of the objectives of lean manufacturing. One of the main parts of cycle time is setup time. By minimizing the setup time, cycle time can be reduced as well. Setup time reduction is a key to lot size reduction but shorter period of times needed for setup enables the operator to do these tasks more repetitively. Melamed's results (Melamed et al. 1995) showed that more replications increased stress in his respondents.

2.2. Inventory and Waste Reduction

Waste is a product or an activity that does not add any value to the product from customer prospective. Inventory as a safety stock can be regarded as waste in a production system based on the fact that it does not have any value added to the customers. For the manufacturing operators it is completely different. If inventories between workstations are allowable, then the operator can manage the pace of work and have some time to relax. Inventory reduction also increase the stress of not finishing tasks in their takt times (the average unit production time needed to meet customer demand). Therefore, cutting down the inventories and wastes magnifies stress.

2.3. Kanban Pull Signals

According to (Conti et al. 2006) study, normally lean manufacturers provide low levels of job control. Using poka-yoke process designs, standard products are built. Operators perform their job tasks, with automatic signals "Kanban". Researchers show that lower levels of control, makes the working environment more comfortable. So, the lower the control levels, the less the stressful the working environment would be.

2.4. Supplier Partnerships

One of the emphasis of the partnership is to deliver the high quality parts on time. This can be a relief for workers stress, as they are sure that needed materials are coming in an appropriate amount of time so they can use them to produce required items.

2.5. Continuous Improvement Program

According to TPS technique (Schonberger 1982), after achieving a smooth operating line, excessive resources such as operators should be removed so the manufacturing process becomes leaner. But to keep the output the same, workload must be divided to existing resources. This method of implementation increase the stress of workforce undoubtedly.

2.6. Cell Design

It enables the manufacturer to produce different items in a shorter lead time using less amount of inventory. With implementation of cell design, manufacturing line works smoother and workers of each cell have increased workload and cannot remain idle for short times. Also, if more than a worker is working in a cell, if a co-worker does not show up a day, others should do his tasks, therefore the pace increases and leads to stress inflation.

2.7. Total Quality Management (TQM)

Based on Delbridge study (Delbridge 1992), lean production has an interconnected flow that reveals any defective source, which inspire blame culture. Based on the feedback from others, operators may be blamed and have stress of being blamed by others.

2.8. Poka-Yoke or Design for Assembly (DFA)

Shingo (Shingo 1989) invented a method to avoid intentional mistakes. He also distinguished between errors and mistakes, meant that error couldn't entirely be avoided, but the mistakes that occur in production intentionally must be eliminated. He defined Poka-Yoke as a tool for achieving zero defects and eventually eliminating the need of quality control inspections. According to Hinckley (Hinckley 2001) classification methods of mistakes, one category of mistakes is stress factor, which is caused by workload, occupational change or frustration. The point of Poka-Yoke is to find the best available solution to the problem, so it can be regarded as a factor that causes the working environment more comforting.

2.9. Total Preventive maintenance (TPM)

This is aimed at improving the reliability, consistency and capacity of machines through maintenance (Ohno 1988). TPM creates an environment where people have the authority, resources and time to make realistic decisions within established boundaries, and this makes those people more productive. TPM also generates self-esteem to the workplace. So TPM itself can be regarded as a factor which makes working environment more comforting. However, if the working condition is distressing, people are not able to implement TPM thoroughly right.
Standard Operating Procedures (SOPs)
According to (Hsieh and Hsieh 2003), there is a negative relationship between job standardization and stress, because it helps workers to have consistency in their tasks allocated by the manager. Therefore, no role conflict occurs, also any required information can be accessed easily.
The effect of each of the above mentioned factors on the working environment is explained. Some may increase stress among the personnel which can influence reliabilities. The goal of this paper is to present a model that can find out the reliability of human resources in a system which the conditions are changing during time.

3. Model

As it was mentioned in the previous section, each lean principle has different effect on the stress level which may affect system reliability. Some of them like Kanban, makes the work environment more comforting, on the other hand, setup time and inventory reduction makes the working condition more distressing. Depending on the combination of lean principles using in each stages of an implementation project, 3 states may occur in the system as the following figure. The system is reliable when no human error is made, in other words, when the system is in states 0, 2, 4. The reliability of human resources reflect its impact on the error rates in different states of the system, λ_1, λ_2, andλ_3 which are their error rates in low, moderate stress, and extreme stress respectively, in a way that $\lambda_2 \leq \lambda_1 \leq \lambda_3$ (Dhillon 2013).

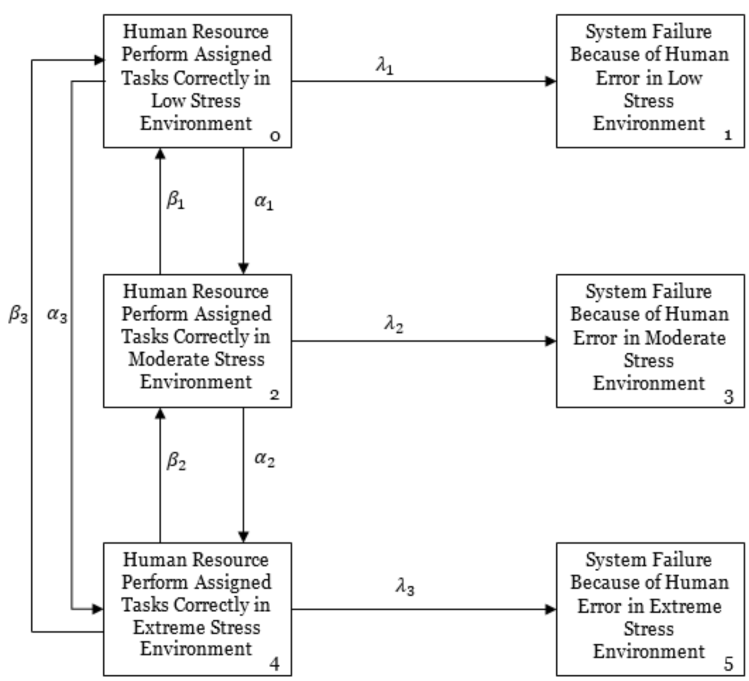

Figure 2: System States Diagram (Dhillon 1989)

3.1. Assumptions

- Human errors are statistically independent and have constant rates.
- The rate of changing between states is constant and is determined based on the system performance.
- System is considered in a continuous period of time.

3.2. Parameters

- $\lambda_1, \lambda_2, and \lambda_3$ are human error rates in low, moderate stress, and extreme stress respectively and $\lambda_2 \leq \lambda_1 \leq \lambda_3$.
- $\alpha_1, \alpha_2, \alpha_3$ are transition rates from states with lower stress level to the states that are more distressing.
- $\beta_1, \beta_2, \beta_3$ are transition rates from states with higher stress levels to the states that are more comforting. The transition rates are dependent to the sequence of the implemented lean initiatives during the time. These rates are case dependent and can be altered during time.
- $P_i(t)$ is the probability that system is in state *i* at time *t*.

$$\frac{dP_0(t)t}{dtP_0(t)t} + (\lambda_1 + \alpha_1 + \alpha_3)P_0(t) = P_2(t)\beta_1 + P_4(t)\beta_3 \tag{4}$$

$$\frac{dP_1(t)t}{dt} = P_0(t)\lambda_1 \tag{5}$$

$$\frac{dP_2(t)t}{dt} + (\lambda_2 + \alpha_2 + \beta_1)P_2(t) = P_0(t)\alpha_1 + P_4(t)\beta_2 \tag{6}$$

$$\frac{dP_3(t)t}{dt} = P_2(t)\lambda_2 \tag{7}$$

$$\frac{dP_4(t)t}{dt} + (\lambda_3 + \beta_2 + \beta_3)P_4(t) = P_2(t)\alpha_2 + P_0(t)\alpha_3 \tag{8}$$

$$\frac{dP_5(t)t}{dt} = P_4(t)\lambda_3 \tag{9}$$

Initial condition is that at the starting point (*t = 0*), system is in state 0. So $P_0(0) = 1$

$$P_0(s) = \frac{(s + k_2)(s^2 + k_5 s + k_6)}{s^4 + k_{12}s^3 + k_{13}s^2 + k_{14}s + k_{15}} \tag{10}$$

$$k_1 = \lambda_1 + \alpha_1 + \alpha_3 \tag{11}$$

$$k_2 = \lambda_2 + \alpha_2 + \beta_1 \tag{12}$$

$$k_3 = \lambda_3 + \beta_2 + \beta_3 \tag{13}$$

$$k_4 = \alpha_3 k_2 + \alpha_1 \alpha_2 \tag{14}$$

$$k_5 = k_2 + k_3 \tag{15}$$

$$k_6 = k_2 k_3 + \alpha_2 \beta_2 \tag{16}$$

$$k_7 = \alpha_1 \beta_1 + \alpha_3 \beta_3 \tag{17}$$

$$k_8 = \alpha_1 \beta_1 k_5 + \beta_1 \beta_2 \alpha_3 + \beta_3 k_4 + \alpha_3 \beta_3 k_2 \tag{18}$$

$$k_9 = \alpha_1 \beta_1 k_6 + \beta_1 \beta_2 k_4 + k_2 k_4 \tag{19}$$

$$k_{10} = k_1 + k_2 \tag{20}$$

$$k_{11} = k_1 k_2 \tag{21}$$

$$k_{12} = k_5 + k_{10} \tag{22}$$

$$k_{13} = k_6 + k_{11} + k_5 k_{10} - k_7 \quad (23)$$

$$k_{14} = k_5 + k_{11} + k_6 k_{10} - k_8 \quad (24)$$

$$k_{15} = k_6 k_{11} - k_9 \quad (25)$$

After substituting this values to the main equations we have:

$$P_1(s) = \frac{\lambda_1}{s} P_0(s) \quad (26)$$

$$P_2(s) = \frac{\alpha_1(s^2 + k_5 s + k_6) + \beta_2(\alpha_3 s + k_4)}{(s + k_2)(s^2 + k_5 s + k_6)} P_0(s) \quad (27)$$

$$P_3(s) = \frac{\lambda_2}{s} P_2(s) \quad (28)$$

$$P_4(s) = \frac{\alpha_3 s + k_4}{s^2 + k_5 s + k_6} P_0(s) \quad (29)$$

$$P_5(s) = \frac{\lambda_3}{s} P_4(s) \quad (30)$$

We know that the reliability of the system equals to the summation of the probabilities that system works correctly under any conditions. Therefore, we have:

$$R(s) = P_0(s) + P_2(s) + P_4(s) \quad (31)$$

Based on (Dhillon 2013), mean time to human error is:

$$MTTHE = \int_0^\infty R_s(t)\,dt \quad (32)$$

MTTHE is the mean time to human error, and $R_s(t)$ is the system reliability function in time t. By applying Laplace transformation, we have:

$$MTTHE = \lim_{s \to 0} R(s) = \frac{k_2 k_6}{k_{15}}(1 + \frac{\alpha_1 k_6 + \beta_2 k_4}{k_2 k_6} + \frac{k_4}{k_6}) \quad (33)$$

Where $R(s)$ is the Laplace transform of the system reliability. In the remainder of the paper, the plot shows the effect of human error rate in moderate stress level on mean time to human error, using the following data:

$\lambda_1 = 0.005, \alpha_1 = 0.4, \alpha_2 = 0.5, \alpha_3 = 0.3, \beta_1 = 0.6, \beta_2 = 0.5, \beta_3 = 0.7$

Figure 3 shows MTTHE for fixed λ_3 and variable λ_2. Lower levels of λ_3 as expected always lead in beigger MTTHE. Increasing λ_2 decreases the impact of λ_3.

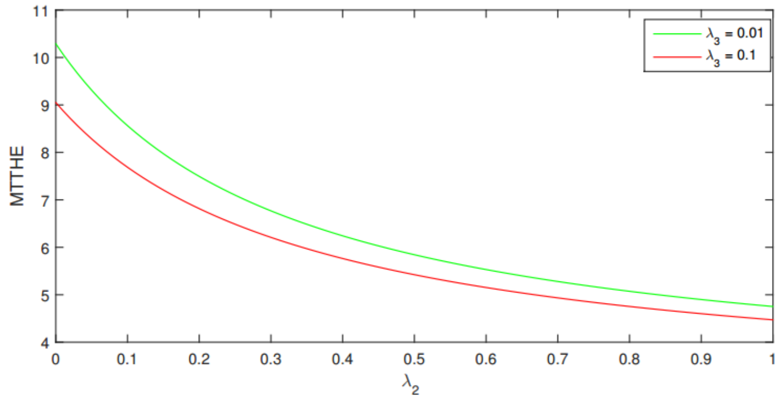

Figure 3: Mean Time to Human Error Plot

4. Conclusion

One of the main components that affect reliability in lean systems is personnel subsystem which refers to workforce capabilities and skills. On the one hand the lean production system assures that the workforce is the most important link of the entire system. On the other hand, employees complain that lean implementation causes a decline in their working conditions. They also express that the stress factor is often so high that not only affects the morality of personnel, but consequently the reliability of the system. The effect of each lean concept on human reliability is studied and their relationship is explained based on the surveyed literature. Based on the combination of lean tools that are chosen to be implemented in each phase, stress level might be increased or decreased. The reliability of lean systems can be measured from personnel prospective based on the presented model and framework, also the mean time to human error can be calculated, so backup resources can be planned to assist in the system for the times that personnel is about to make mistakes.

Predicting system's performance changes resulted from lean tools implementation can guide managers to apply control actions to mitigate risk. For example, they can plan for training workers to reach desired level of stress. Also this study guides decision makers in scheduling the implementation sequence of lean tools.

References

Kvarnstrom, S. Stress prevention for blue-collar workers in assembly-line production, in: Stress prevention for blue-collar workers in assembly-line production, OIT, 1997.

Ono. T., Toyota production system: beyond large-scale production, Productivity press, 1988.

Parker, M., Slaughter. J., Choosing sides: Unions and the team concept, South End Press,1988.

Dhillon, B., Human errors: a review, Microelectronics Reliability 29 (3): 299–304, 1989.

Sawhney, R. Subburaman, K. Sonntag, C., Rao, P. R. V., Capizzi, C., A modified FMEA approach to enhance reliability of lean systems, International Journal of Quality & Reliability Management 27 (7): 832–855, 2010.

Miller, D. P., Swain, A. D., Human error and human reliability, Handbook oh Human Factors, New York, John Wiley & Sons 219–250, 1987.

Cooper, S. E., Ramey-Smith, A., Wreathall, J., Parry, G., A technique for human error analysis (atheana), Tech. rep., Nuclear Regulatory Commission, Washington, DC (United States). Div. of Systems Technology, 1996.

Hollnagel, E., Cognitive reliability and error analysis method (CREAM), Elsevier, 1998.

Dhillon, B. S., Human reliability: with human factors, Elsevier, 2013.

Williams, J., Hearta proposed method for achieving high reliability in process operation by means of human factors engineering technology, in: Proceedings of a Symposium on the Achievement of Reliability in Operating Plant, Safety and Reliability Society, Vol 16, 1985.

Meister, D., Methods of predicting human reliability in man–machine systems, Human Factors: The Journal of the Human Factors and Ergonomics Society 6 (6): 621–646, 1964.

Shingo, S. A study of the toyota production system from an industrial engineering viewpoint, Japan Management Association 107, 1989.

Schonberger, R. J., Japanese manufacturing techniques: Nine hidden lessons in simplicity, 1982.

Ritzman, L. P., Krajewski, L. J., Klassen, R. D., Foundations of operations management, Toronto.: Pearson Prentice Hall, 2004.

Suzaki, K. New manufacturing challenge: Techniques for continuous improvement, Simon and Schuster, 1987.

Melamed, S., Ben-Avi, I., Luz, J., Green, M. S., Objective and subjective work monotony: Effects on job satisfaction, psychological distress, and absenteeism in blue-collar workers. Journal of Applied Psychology 80: 1-29, 1995.

Conti, R., Angelis, J., Cooper, C., Faragher, B., Gill, C., The effects of lean production on worker job stress, International journal of operations & production management 26 (9): 1013–1038, 2006.

Delbridge, R., Turnbull, P., Blyton, P., Turnbull, P., Human resource maximization, Reassessing Human Resource Management, 1992.

Hinckley, C. M., Make No Mistake! An Outcome-Based Approach to Mistake-Proofing, Productivity Press, 2001.

Hsieh, Y.-M., Hsieh, A.T., Does job standardization increase job burnout? International Journal of Manpower 24 (5): 590–614, 2003.

J. Michie, P. Sparrow, C. Cooper, and M. Hird, Do we need HR?, repositioning people management for success: Springer, 2014.

S. Bhasin, "Lean management beyond manufacturing," New York, NY: Springer International Publishing, vol. 10, pp. 978-3, 2015.

E. Drohomeretski, S. E. Gouvea da Costa, E. Pinheiro de Lima, and P. A. d. R. Garbuio, "Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy," International Journal of Production Research, vol. 52, pp. 804-824, 2014.

P. J. Gollan, S. Kalfa, and Y. Xu, "Strategic HRM and devolving HR to the line: Cochlear during the shift to lean manufacturing," Asia Pacific Journal of Human Resources, vol. 53, pp. 144-162, 2015.

J. A. Vivares-Vergara, W. A. Sarache-Castro, and J. C. Naranjo-Valencia, "Impact of human resource management on performance in competitive priorities," International Journal of Operations & Production Management, vol. 36, pp. 114-134, 2016.

A. Karim and K. Arif-Uz-Zaman, "A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations," Business Process Management Journal, vol. 19, pp. 169-196, 2013.

P. J. Martínez-Jurado, J. Moyano-Fuentes, and P. Jerez-Gómez, "Human resource management in lean production adoption and implementation processes: success factors in the aeronautics industry," BRQ Business Research Quarterly, vol. 17, pp. 47-68, 2014.

J. R. Jadhav, S. S. Mantha, and S. B. Rane, "Exploring barriers in lean implementation," International Journal of Lean Six Sigma, vol. 5, pp. 122-148, 2014.

S. Bhasin, "Prominent obstacles to lean," International Journal of Productivity and Performance Management, vol. 61, pp. 403-425, 2012.

G. Almeida Marodin and T. A. Saurin, "Managing barriers to lean production implementation: context matters," International Journal of Production Research, vol. 53, pp. 3947-3962, 2015.

Biography

Roshanak Akram is a PhD student in Department of Industrial and Systems Engineering at the University of Tennessee, Knoxville. Born in Iran, she got her BSc in Industrial Engineering from “Amirkabir University of Technology (Tehran Polytechnic)” after which she started her graduate studies in Supply Chain and Logistics at the “University of Tehran” before joining Dr. Rupy Sawhney’s “Center for Productivity Innovation (CPI)” group at UTK. During her PhD carrier, she has completed research projects related to reliability of lean systems, manufacturing improvement, packaging optimization, cost analysis, and parallel machine scheduling. Roshanak’s main research interests include optimization, lean manufacturing and reliability.

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students. He has published significant journal papers, conference papers and has submitted for 5 patents. His funded research projects are in the millions of dollars. He has worked with over 200 companies and is a recipient of various awards (Boeing Welliver Fellow, Alcoa Faculty Award, IIE Lean Teaching Award, Reuben Harris Award, and Accenture Teaching Excellence Award).

Vahid Ganji is a PhD student in Department of Industrial and Systems Engineering at the University of Tennessee, Knoxville. He received MSc in Manufacturing Engineering from University of Tehran. He has been working on operations management, operational excellence and reliability research projects since 2011. He conducts theoretical research to study the relationship between operational decisions and lean production systems' performance.