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# Aligning Skills in Personnel with the Lean System's Requirements

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To the Graduate Council:

I am submitting herewith a thesis written by Anjushree Bangre entitled "Aligning Skills in Personnel with the Lean System's Requirements." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

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# Aligning Skills in Personnel with the Lean System's Requirements

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*For my parents Ma and Dada, brother Arjun and sister-in-law Kavya.*

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*"If you're not prepared to be wrong, you'll never come up with anything original".*

*- Ken Robinson*

*"I have not failed. I've just found 10,000 ways that won't work".*

*- Thomas A. Edison*

# Abstract

The sustainability of lean systems for long term is a major concern across various organizations implementing lean manufacturing methods. This issue can be attributed to inadequate infrastructure, inefficient process management, unsuitable personnel management methods and strategic tools. There is a strong need for addressing the risks for lean system sustainability. The resolution of the risks from a 'soft side' (people) perspective has not been addressed. The primary focus of this study is on the people-related risks.

The current study elicits a five-phase approach to enhance the implementation of the lean system by accounting for these risks. The first phase classifies the requirements of the lean system into six subsystems and proposes the precedence of lean activities within each subsystem. The second phase identifies the risks for the sustainability of the subsystems by categorizing these risks into Personnel, Material, Equipment and Schedule. The third phase uses expert opinions based on a survey to quantify risks. The fourth phase addresses the resolution of the people-related risks. The mapping of these risks with the required skills in personnel is proposed. A Lean Personnel Alignment Model (LPAM) is presented to align the identified skills with lean requirements in order to sustain lean implementation.

# Table of Contents

# List of Tables

# List of Figures

# Chapter 1

# Introduction

## 1.1 Overview

The intense competition among the global competitors to deliver high quality products with comparable costs has prompted several manufacturing firms to adopt a lean manufacturing approach. The idea of lean, as derived from the Toyota Production System (TPS), supports 'flow' or 'smoothness of work', in a manner that best meets customer demands, empowers employees and ensures the growth of the organization while emphasizing optimal resource utilization. Although lean systems are extensively implemented, companies continue to face difficulties in sustaining long-term success. About 95% of the lean implementations failed in the manner in which they were practiced in manufacturing organizations (Ransom, 2008). Glasgow et al. (2010) reported that 62% of the lean initiatives in health care failed due to the lack of stakeholder acceptance. A multitude of literature on lean implementation (Rubrich, 2004), (Schlichting, 2009) and consulting companies performing lean transformation, such as the Society of Manufacturing Engineers (SME), have estimated the success rate of real lean transformations across various manufacturing organizations to lie below 10%. This leads to the question of why most companies fail to sustain their lean improvements.

It is hard to sustain lean efforts in the long term due to inadequate infrastructure, inefficient process management, unsuitable personnel management methods and strategic tools (Bateman and David, 2002). The substantial failure in sustaining lean indicates the need for addressing the risks in lean systems sustainability. Any deviation from the principles of the Toyota Production System, where an employee fails to focus on improving the production process based on customer needs and product quality, is defined as a risk for lean sustainability. People significantly affect the utilization of manufacturing resources while performing lean activities, such as the preventive maintenance on the equipment, planning schedule requirements and routing materials on the production floor. An example of the role of people in lean implementation sustainability can be found in the work of Scherrer-Rathje et al. (2009). They explored an extensive lean implementation case study of a large, global organization named Machinery, Inc. in 1997. This company implemented lean systems to improve their manufacturing inefficiencies. Despite their initial successes (six months) with lean practices being applied to the production of machines, their lean project was ceased due to a lack of organizational support and subsequent senior management reorganization. The senior management took a hands-off approach to the lean implementation effort, which made it difficult for the employees to manage the project by themselves and stay focused on the lean implementation efforts. The employees were not motivated to start another lean project and reverted to conventional manufacturing methods. As a result of this, the productivity of machines and the resource availability was significantly affected. People are the key drivers for identifying ways to improve the production process and hence lean is commonly termed as the "people-centric" approach. The most commonly observed people-related risks include resistance to change among long-time employees, lack of top management support, alienation of line leaders, non-compliance with the standard operating procedures, lack of technical skills or job-related capabilities in workers, lack of responsibility among employees to complete their assigned tasks, elevated physical or mental stress levels, absenteeism of personnel and tardiness. Neglecting these people-related risks jeopardizes the sustainability of an organization's lean efforts and makes it difficult to develop a culture that strives to achieve continuous improvement. The different characteristics in people, such as people skills, human behavior and engagement, are studied in order to achieve a sustained lean culture (Pearce and Pons, 2012). The resolution of risks from a 'soft-side' (people) perspective can thus be addressed by utilizing one of these characteristics. Skills are defined as the ability to perform certain lean tasks well. The skills required in personnel can be broadly categorized under two main types: technical skills and people skills. The soft (people) skills are highly important within an employee-based environment as people constantly interact with one another to build a sustainable work culture. In a lean environment, the people skills typically involve real time performance management, root cause problem solving and the ability to lead small teams in looking for ways to improve operations through coaching and personnel development. The progress of an organization towards success lies in its ability to harness the skills of all its employees. Lean is a knowledge-intensive process and is dependent on the skills of people (Drew et al., 2004). Skill identification helps to hire people with appropriate skills as well as drive employee reward and compensation systems. Employees in such compensation systems would earn higher pay as they learn more skills and help with the assignment of workers to cells (Bidanda et al., 2005). The Toyota model of 'recruitment and selection process' identifies some of the key people skills/dimensions such as Teamwork, Initiative, Communication, Problem solving and Practical learning required in shop floor personnel. The association of some of these people skills with specific lean tools in the Toyota Production System (TPS) can be studied in literature. For example, (Bidanda et al., 2005) mentioned that the flexibility of the workers and their ability to work in teams is essential for the implementation of the cell layout. A sustained implementation of the TPS requires a complete understanding of the association of soft skills with all lean tools.

However, there has been no specific mapping or alignment of people skills with a majority of lean tools in the TPS. An organization's approach to implementing lean has to align with the skill sets of its employees. This ensures employee engagement towards continuous improvement. This thesis provides an insight on the people-related risks for lean sustainability by mapping these risks with the identified key people skills required in personnel.

## 1.2 Problem Statement

The Toyota Production System (TPS) fails to account for people-related risks such as lack of skills/capability, physical or mental stress and absenteeism while implementing a variety of lean tools/practices. This results in the lack of a culture for sustaining lean implementation.

A possible fix to address these people-related risks would be to look at the skills in personnel and align them with the requirements of the lean system. Further, an organization's approach to implementing lean has to align with the capability and skill sets of its employees. Any misalignment of these skills with the organization's lean approach creates a crucial cultural gap and leads to the failure of sustainable lean systems.

This thesis presents the functional decomposition of the TPS into six subsystems namely Operational Fundamentals, Enhancing Workplace Capability in Design, Standard Operations, Consistency, Flow and Production Scheduling and Motion, in order to assess thoroughly all the people-related risks for lean sustainability. The effect of people risks on other critical manufacturing resources within the TPS such as material, equipment and schedule, is also examined. The researcher proposes a Lean Personnel Alignment Model (LPAM) to align the skills in personnel with lean system requirements. The alignment of skills will help organizations in deploying personnel with appropriate people skills for sustaining a designated lean activity.

## 1.3 General Approach

This study was undertaken in four phases with the objective of aligning the skill sets of personnel with the requirements of the lean system. These phases are outlined in Figure 1.1.

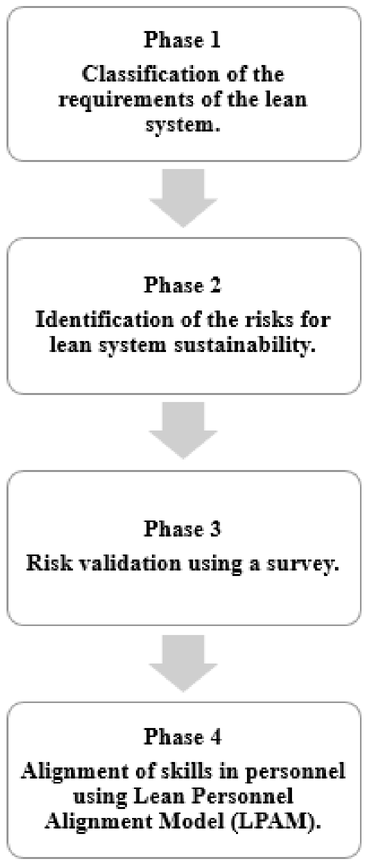


**Figure 1.1:** Research Framework Implemented During the Study
Source: Self-Generated.

**Phase 1: Classification of the requirements of the lean system**

A functional classification of TPS based on continuous flow path for products is developed. This provides an in-depth understanding of the requirements of a lean system. The TPS is categorized into six functional subsystems: Operational Fundamentals, Enhancing Workplace Capability in Design, Standard Operations, Consistency, Flow and Production Scheduling and Motion.

- Operational Fundamentals : These comprise of a key group of lean activities/tools such as Teamwork and Quality circles, Product Families, Value Stream and Kaizen, that are necessary for operating all the other activities in different subsystems.

- Enhancing Workplace Capability in Design : This subsystem deals with the interaction between the workplace and the functions performed by a worker using lean activities such as 5S, Cell Layout, and Multifunctional Workforce.

- Standard Operations : This subsystem deals with lean activities such as Standard Operating Procedures, which promotes the implementation of a set of clearly defined activities and standardized procedures for machines and their operators.

- Consistency : This subsystem ensures quick response to identification and correction of mistakes in a lean process using lean activities such as Total Productive Maintenance, Autonomation, and Quality Assurance.

- Flow: In this subsystem, the researcher studies lean activities such as Setup Reduction, Line Balancing, and One-piece Production, Reduction of Lot Size and Reduction of Lead Time, that are implemented in order to achieve flexibility to respond to customer demands.

- Production Scheduling and Motion : This subsystem consists of lean activities such as Production Smoothing, Pull system/Kanban and Just-in-time Production, to deal with the sequencing and transit of products within a production area.

The categorization of TPS into subsystems provides information on the precedence of lean activities within each subsystem.

**Phase 2: Identification of the risks for lean system sustainability**

Each of the subsystems of TPS, as determined in Phase 1, and their logical set of activities, are analyzed based on the risks for the lean system sustainability as follows:

- <u>Operational Fundamentals</u> : The major risk for the Operations Fundamental subsystem is lack of technical skills/capability in personnel.

- <u>Enhancing Workplace Capability in Design</u>: The sustainability of this subsystem is affected by a number of risks: high mix of products in material, poor layout design for material, absenteeism in personnel and unplanned maintenance in equipment.

- <u>Standard Operations</u> : The major risk for the sustainability of Standard Operations subsystem is non-compliance with Standard Operating Procedures (SOP) in personnel.

- <u>Consistency</u> : A number of risks, namely defective material, non-compliance with SOP in personnel, inappropriate behavior in personnel, unplanned maintenance in equipment, planned maintenance in equipment and malfunctioning equipment affects the sustainability of the consistency subsystem.

- <u>Flow</u> : This subsystem faces a number of risks such as, defective material, poor layout design of material, large batches of material, planned maintenance in equipment, physical or mental stress in personnel.

- <u>Production Scheduling and Motion</u> : The sustainability of this subsystem is impacted by a number of risks: material misplacement, high mix of products in material, improper procurement of material and complex routing of material.

These risks were identified during the literature review process, whereby the researcher studied the existing body of knowledge on the subject to determine the most suitable risk factors for this study. Due to the overlapping of the risks within each subsystem, the risks for lean system sustainability were categorized into Personnel, Material, Equipment and Schedule in this study.

**Phase 3: Risk validation using a survey**

The researcher developed a survey questionnaire and invited employees working as operational and lean professionals in the manufacturing industry to respond. The survey (attached in Appendix A) focused on rating the importance of each of the identified risks in personnel, material, equipment and schedule. The risks were thus validated.

**Phase 4: Alignment of skills in personnel using Lean Personnel Alignment Model (LPAM)**

This thesis specifically targeted the people-related risks as people significantly affect the risks in material, equipment and schedule. The soft skills required to address people-related risks are identified and mapped using Analytic Hierarchy Process (AHP) technique. The misalignment of these skills with the requirements of the lean system causes the system to fail. The researcher proposes a Lean Personnel Alignment Model (LPAM) to align the identified soft skills with lean requirements and thus addresses the risks for sustainability of lean systems.

## 1.4 Assumptions

The key assumptions of the study are deduced from the four phases of the general approach. The assumptions are :

1. The risks for lean system sustainability are determined by the detailed classification of the Toyota Production System (TPS) into subsystems.

2. The flow effectiveness of the lean system is affected by the risks for lean system sustainability ($H_0$).

3. The risks are validated using experts' survey method and their responses represent a random sample of the relevant population.

4. The mapping of the people - related risks with the soft skills ensures a sustained lean implementation.

## 1.5 Significance of the Study

The Lean Personnel Alignment Model (LPAM) integrates the requirements of a lean system with the firm's personnel requirements. The alignment of the skills in personnel with the requirements of the lean system enables an organization to structure its lean efforts with respect to the capability and skill sets of its employees. A skill-based assessment can be designed to analyze the job-specific skills of employees. This helps organizations select employees with the required skill sets to perform a specific lean activity. By recruiting the right people for the job, an organization can achieve employee engagement and empower its workforce to participate equally in the firm's continuous efforts towards improvement (Pearce and Pons, 2012). The study of people skills helps to resolve the people-related risks and thus provides a means for sustaining lean implementation.

## 1.6 Structure of the Thesis

This thesis arrangement is presented in the following manner: Chapter 2 provides a comprehensive literature review of the initial understanding of the risks affecting lean sustainability. It also studies the personnel skills associated with lean tools. Chapter 3 presents a conceptual framework for integrating the requirements of the lean system with people skills. Additionally, it provides a detailed risk analysis of the lean system, discusses the research hypothesis and presents the Lean Personnel Alignment Model (LPAM). Chapter 4 provides a detailed approach for validating the identified risks and the necessary skill sets in personnel. It further validates the mapping between the people-related risks and the skill sets in the LPAM model using Analytic Hierarchy Process (AHP) technique. Chapter 5 summarizes the findings of the study and evaluates the impact of the findings. The author also discusses the scope and suggests how the study can form the basis for further research.

# Chapter 2

# Literature Review

This chapter is divided into two components of the literature searches. The first focuses on the risks for the sustainability of the lean system with respect to different critical resources such as People, Material, Equipment, and Schedule and presents the different approaches explored for studying and assessing the risks. The second component of literature search discusses the alignment of people skills with lean tools using the Toyota model of 'recruitment and selection process' as a reference.

## 2.1 Identification of Risks in Lean Sustainability

Lean implementations have been unsustainable in some organizations. Approximately 50% to 75% of the lean manufacturing implementations in the United States have failed to sustain. The major hurdles to sustaining lean according to Lean Enterprise Institute (2008) were identified as follows: (1) backsliding to older methods of working after initial progress, (2) resistance of middle management to adapt to lean changes, (3) inability to understand the importance and benefits of lean tools, (4) lack of crisis to start lean implementation, and (5) resistance among shop floor employees to incorporate innovative ideas. There is a need to study causative factors, or 'risks,' in lean sustainability to improve the rate of sustainability in Lean implementations (Bayo-Moriones et al., 2008). The first step in this process is the systematic identification of risks. Risks in lean have been presented in the literature using interchangeable terms such as difficulties, barriers or impact factors (Marodin and Saurin, 2015). In the context of lean manufacturing, risks affecting lean can be categorized into the four categories of manufacturing resources, (Smalley, 2006); (Sawhney et al., 2010) namely: Personnel, Material, Equipment, and Schedule.

The literature surveyed for the purpose of identifying the risks for lean system sustainability was based on key search terms such as People-related risks, Material-related risks , Equipment-related risks and Schedule related risks respectively and was mainly carried on the Google Scholar and Scopus databases. Table 2.1 lists the literature surveyed in each category. The consideration of the risks under these four categories provides a method for addressing lean sustainability issues by integrating lean systems with the principle of reliability (Sawhney et al., 2010). The identification, assessment and prioritization of the risks helps to minimize the detriments of uncertain outcomes in lean implementation.

Material risks manifest at all locations in the production cycle, from the procurement of raw material to the routing of the finished product. Monden and Talbot (1995) identified that the procurement process exposes an organization to risk in terms of the operational costs and production hold-ups. He also determined material misplacement to be a potential material-related risk which translates into added expenditure and lost time. The manufacturing defects prevalent in a material hazardously impact its use and is a major material-related risk (Kilpatrick, 2003). The parameters, such as batch size, product mix, layout design and routing, impact the material flow. Producing material in large batches increases the downtime associated with the machines (Kilpatrick, 2003). An increase in the product mix considerably decreases the direct labor productivity and quality of the product manufactured (MacDuffie et al., 1996). An improper layout design often results in a longer lead time due to the change in the employee's range of jobs (Monden, 2011). Complex routing affects the movement of the material in the production area (Harris et al., 2004).

Equipment risks affect the overall effectiveness of the equipment, machinery or the installments at work. Nakajima (1988) determined the time and cost of lost production associated with the equipment-related risks such as, equipment on planned maintenance/changeover, unplanned maintenance (machine breakdown) and malfunctioning equipment. Planned maintenance poses a risk in terms of the expenditure involved with the frequent change of parts and labor costs. Unplanned maintenance is highly inefficient, causing sudden breakdown of machinery and lost revenue. Malfunctioning equipment undermines workers' safety and causes severe industrial hazards.

The risks in scheduling significantly impacts the duration of a planned lean project on sequencing the schedule of the parts and capacity planning. Monden (2011) identified non-adherence to schedule requirements and fluctuations in the customer demand (extraordinary orders) to be the schedule-related risks affecting the smooth operation of a system.

Personnel risks have been found to be the largest category of risk factors in literature. This is because of the importance of people-related factors in lean sustainability. People-related risks are prevalent from upper management to the worker level. Motwani (2003) identified people-related risks such as the lack of technical knowledge in supervisors and leaders and physical or mental stress in the workers in an automotive company. Scherrer-Rathje et al. (2009) found similar risks in personnel such as not encouraging operator's autonomy and lack of organization support in a longitudinal study of a food company. People-related risks commonly observed at worker level are non-compliance with standard operating procedures, physical or mental stress, absenteeism and inappropriate behavior. Non-compliance with standard operating procedures (SOP's) in personnel is a huge risk to an organization because not all workers conform to the written SOP's and because of this process anarchy occurs (Ohno, 1988). Emiliani et al. (2005) observed elevated physical and mental stress levels in shop floor personnel due to increased worker turnover and time lost due to accidents. Employee absences cause disruptions to the production process and cost organizations millions of dollars each year (Rabakavi et al., 2013). Inappropriate behavior in personnel, such as tardiness, fighting, foul language, insubordination, and rudeness, affect the environment of mutual trust between employees and management as well as among different work teams (Čiarnienė and Vienažindienė, 2012). People-related risks significantly impact the smooth functioning of other resources such as Material, Equipment, and Schedule. People are the most valuable asset in any organization, but also regarded as the most vulnerable asset (Taylor et al., 2013). People can undergo breakdown or damage just like machinery and material. However, people are harder to repair and the consequences can be far more serious. Therefore, people-related risks need to be addressed. The study of people-related risks helps to identify the expected behaviors/ skill sets in personnel when dealing with these risks.

## 2.2 Organizational Approaches to Studying Risks

Historical evidence and industry practices suggest risks to be perceived as something intangible and not measurable (Hubbard, 2009). Severity and probability are critical to risk analysis when the event is common and easier to estimate (Pearce and Pons, 2012). Methods to analyze risks can be widely categorized as expert intuition, expert audit, simple stratification methods (basic scales e.g., for heat or risk maps), weighted scores , traditional financial analysis , calculus of preferences (expert judgment) and probabilistic models (e.g., Monte Carlo Analysis) (Hubbard, 2009). A limited number of publications link "Lean" to "Risk" as in the context of risk management. There has been a considerable effort to studying risks affecting lean implementation using innovative frameworks and manufacturing techniques (e.g., core competency based framework and emergent manufacturing methods.) Parry et al. (2010) developed a methodology for lean implementation using the core competence theory to reduce the risk of damaging a company's key resources and abilities. Ahmed et al. (2007) identified the key risks affecting the utilization of the emergent manufacturing resources in order to meet the customer delivery dates. The risk

**Table 2.1:** Risks Affecting Lean Implementation.

| Risks | Risk category | Literature reference |
|---|---|---|
| Non-compliance with Standard Operating Procedures(SOP) | Personnel | (Ohno, 1988) |
| Lack of technical skills/capability | Personnel | (Motwani, 2003), (Emiliani, 2005), (Papadopoulou,2005), (Achanga et al., 2006), (Black, 2007), (Sim, 2009), (Pierce ,2009), (Scherrer-Rathje et al., 2009), (Farris et al., 2009), (Turesky, 2010), (Boyle et al., 2011) |
| Physical/mental stress | Personnel | (Papadopoulou, 2005), (Motwani, 2003), (Emiliani, 2005), (Sim,2009), (Pierce,2009), (Turesky, 2010) |
| Absenteeism | Personnel | (Rabakavi,2013), (Kara et al.,2002) |
| Inappropriate behavior | Personnel | (Duque, 2007) |
| Improper procurement of material | Material | (Monden, 1995) |
| Material misplacement | Material | (Monden, 1995) |
| Defective material | Material | (Kilpatrick, 2003) |
| High mix of products | Material | (MacDuffie, 1996),(Monden, 1995) |
| Large batches | Material | (Kilpatrick, 2003) |
| Poor layout design | Material | (Amri et al., 2016) |
| Complexity of routing | Material | (Harris, 2004) |
| Planned equipment maintenance | Equipment | (Nakajima, 1988) |
| Unplanned equipment maintenance | Equipment | (Nakajima, 1988) |
| Malfunctioning equipment | Equipment | (Nakajima, 1988) |
| Non-adherence to schedule requirement | Schedule | (Monden, 1995) |
| Extraordinary orders | Schedule | (Monden, 1995) |

assessment of a lean implementation was closely related to the use of risk and reliability methods, acknowledgement of risks for sustaining lean systems and the use of program management system (Pearce and Pons, 2012). These can be explained in detail as follows:

1. Use of FMEA (failure modes and effects analysis), Sawhney et al. (2010) developed a risk assessment value (RAV) for determining the risks affecting lean systems using modified FMEA for four critical resources: Personnel, Material, Equipment, and Schedule.

2. Use of Monte Carlo analysis in ship yard process (Kolić et al., 2011).

3. Matching of lean systems strategy to risk identification, Justin (2006) made use of systems engineering approach to optimize the risks in a complex system.

4. Use of the Program Management system/ process, Wilson (2004) studied the risks affecting lean implementation using project management methods.

A comparison was drawn between risks and lean process cycles (Alimohamadi and Seddigh, 2009) and the applications in lean were used to determine and resolve the risks in construction projects (Qiu, 2011). Supply chain focused modeling and simulations were used for the mitigation of risks (Shukla et al., 2010), (Hallam, 2010). There were also recent studies in supply chain risks comparing large and small enterprises (Thun et al., 2011). However, all these works discussed minimizing the detriments of a single, specific aspect of a lean system (e.g., specific processes or supply chain). The studies did not perform any structured risk analysis of a lean implementation apart from a bounded optimization. Pearce and Pons (2012) proposed the integration of risk management with lean practices using the application of AS/NZS ISO 31000 and a representative case study from the manufacturing sector. Further, a lack of understanding of the relationships between the risks in lean implementation created an important gap in the literature. The development of a classification scheme helped to identify the relationships between risks, as it grouped similar risks into the same category (Aloini et al., 2012). Marodin and Saurin (2015) proposed a model for compiling 14 risks affecting lean implementation based on the literature review of 14 studies and then categorized the risks into three dimensions namely: (1) Process management, (2) Managerial support and (3) Shop floor involvement.

There have been independent studies assessing the risks affecting lean implementation in terms of different categories (Motwani, 2003), (Marodin and Saurin, 2015). However, the study and categorization of risk factors into Personnel, Material, Equipment and Schedule within a single study is non-existent. This thesis presents the classification of the Toyota Production System (TPS) in order to determine all the risks for lean sustainability in detail and then categorizes the identified risks , thus providing a method to design and improve the reliability of the lean system.

## 2.3 Data-Driven Assessment of Risks

Risk factors affecting lean implementation have primarily been investigated with empirical evidence of the impact of one risk or several risks emerging from the in-depth case study. A few studies mentioned risks that appeared in one case study each, as not encouraging operator's autonomy (Scherrer-Rathje et al., 2009) and lack of commitment of senior management (Crute et al., 2003). Single company case studies have provided less evidence about the generalization of risks within a large number of companies. Surveying 202 plants, Boyer (1996) suggested that management support affects lean implementation process. In contrast, Angelis et al. (2011), who surveyed 1400 operators in 21 plant sites suggested that workforce support impacts lean implementation. Although empirical evidence supported both these studies, they focused only on one risk and further exploration was required to gain empirical evidence about the relationship between the risks in implementing lean. The survey-based research was employed to gather empirical evidence about the relationship between the risks (Malhotra and Grover, 1998). Survey of subject matter experts, from different industries, helped to enrich the perspective on the risks. The non-random choice of companies for surveys and the search for companies that were already known to the researchers is a commonly used strategy in the studies on lean implementation (Marodin and Saurin, 2015), (Boyle et al., 2011), (Eroglu and Hofer, 2011), (Taj and Morosan, 2011). Shah and Ward (2007) used a sample with participants drawn from courses and training events when they conducted a survey on lean implementation since it was necessary that the respondents had experience in the subject. Survey research contributes to the advancement of scientific knowledge in different ways (Babbie, 1990), (Kerlinger, 1986). Accordingly, researchers often distinguish between exploratory, confirmatory and descriptive survey research (Pinsonneault and Kramer, 1993), (Malhotra and Grover, 1998), (Filippini, 1997). Exploratory survey research is used during the early stages of the research to gain preliminary insight on a topic and forms the foundation for an extensive in-depth survey (Forza, 2002). Confirmatory survey research is employed when the knowledge of a phenomenon has been articulated with the help of well-defined concepts, models and proposition (Forza, 2002). Descriptive survey research is utilized for understanding the importance of a certain phenomenon and studying the distribution of the phenomenon in terms of a population. The descriptive survey method provides useful hints for theory building and refinement (Malhotra and Grover, 1998), (Wacker, 1998). The thesis focuses on descriptive survey research method to contribute to the general body of knowledge in the area of risks affecting lean implementation. The most commonly used inferential statistics in survey data analyses are t-tests (compares group averages), hypothesis testing, analysis of variance (ANOVA), correlation and regression. Advanced techniques, such as exploratory factor analysis, cluster analysis and multidimensional modeling procedures (Gavin, 2008) , (Hinkin, 1998) are mostly used for categorizing the survey results into groups.

## 2.4 Alignment of Lean Risks with People Skills

There have been numerous practical methodologies to address the risks affecting lean systems (Pearce and Pons, 2013). One such widely used methodology is modified Failure Mode Effect Analysis (FMEA). Risk Prioritization of Lean System (RPLS) tool used for FMEA prioritizes the risks affecting the manufacturing resources, such as people, material, equipment and schedule, to achieve a sustained lean implementation. The FMEA approach performs a gap analysis by evaluating the actual operational conditions of lean system based on the required conditions (Sawhney et al., 2010). However, the resolution of people-related risks affecting lean implementation has not yet been addressed solely from the 'people' perspective. The people-related factors, such as behavior, skills and engagement, could be utilized to tackle people-related risks (Pearce and Pons, 2012).

People skills form the key driver for the lean system's operation (Drew et al., 2004). Further, there is an association of the skills required in personnel with different lean tools. Workers' flexibility, combined with the ability to work in teams, is essential for cellular manufacturing (Bidanda et al., 2005). A versatile and well-trained worker is necessary for achieving Shojinka (multifunctional workforce) (Monden, 2011). The emergence of Total Productive Maintenance (TPM) has mandated that operators, maintenance workers, and engineers collaborate and work with one another (Witt, 2006). Effectively implementing Single Minute Exchange of Dies (SMED) requires shop floor workers to have fundamental skills such as teamwork, flexibility, and attention to details (McIntosh et al., 2000). The literature surveyed for the purpose of identifying the association of soft skills with some of the lean tools was based on key search terms such as, lean skills model, and people skills in cell layout. It was mainly carried on the Google Scholar and Scopus databases. Table 2.2 lists the skill sets associated with some of the lean tools and their corresponding references in literature.

There has been no specific mapping or alignment of the necessary people skills with

**Table 2.2:** Important Skill Sets Required to Implement Lean Tools/Techniques.

| Lean tools/techniques | Skill sets | Literature reference |
|---|---|---|
| Teamwork & Quality circles | Ability to learn, Observation, Problem-solving | (Liker ,2008) |
| Cell layout | Commitment to excellence, Self-management, Teamwork | (Al-Mubarak et al.,2003), (Hyer,2004), (Meredith,2004) |
| Multifunctional workforce | Multi-tasking, Flexibility, Ability to learn | (Monden,1995) |
| Single minute exchange of dies | Teamwork, Flexibility, Initiative, Attention to details | (McIntosh,1996), (Dillon,1985), (Monden,1995) |
| Line balancing | Multi-tasking, Leadership | (Monden ,1995) |
| Quality control | Leadership, Initiative, Communication, Problem-solving | (Monden ,1995), (Deming,1982), (Liker,2008) |
| Autonomation | Attention to detail, Communication | (Monden,1995), (Liker,2008) |
| Total productive maintenance | Teamwork, Collaboration, Communication, Co-operation, Flexibility | (Cooke,2000), (Witt,2006), (Besterfield et al. ,1999), (Sahin ,2000) |
| Scheduling | Problem -solving, Teamwork, Multi-tasking, Communication | (McKay et al.,1992), (Berglund ,2007), (Monden,1995) |
| Plan for every part | Problem-solving, Teamwork, Multi-tasking | (Bjrk,2004), (Monden,1995), (Liker ,2008) |
| Kanban | Problem- solving, Teamwork, Multi-tasking | (Storhagen,1995), (Nadal,2006) |

the majority of the lean tools in the TPS. Therefore, there is a need to determine the necessary people skills and align these skills with lean tools.

There has been a considerable effort to identify the necessary team skills and individual skills required in shop floor personnel. Meredith Belbin (2011) examined the interpersonal skills of shop floor personnel working in a team and identified nine key team roles which are essential for achieving team building among personnel. The team role model helped to identify the potential strengths and weaknesses of individuals within a team. Liker and Hoseus (2008)' s Toyota model of 'recruitment and selection process' identified nine dimensions/skills required in shop floor workers. The Toyota model was utilized to select shop floor workers based on their individual ability to perform certain lean tools well. These dimensions/skills were as follows: Team Orientation, Initiative, Oral Communication, Problem Identification, Problem Solution, Practical Learning, Work Tempo, Adaptability and Mechanical Ability.

- Team Orientation: measured group cohesiveness and team members' co-operation in facilitating a group process.
- Initiative: measured an individual's ownership quality for assessing the task at hand.
- Oral Communication: measured the effective expression of ideas and information in individual or group situations.
- Problem Identification: identified problems and studied cause-effect pattern to secure relevant data.
- Problem Solution: measured the ability to solve problems based on logical assumptions.
- Practical Learning: measured the ability to assimilate job-related information quickly.

- Work Tempo: measured the ability to perform a designated activity with a specific tempo.
- Adaptability: measured the ability to work effectively in varied environments involving various tasks, responsibilities or people situations.
- Mechanical Ability: measured the ability to perform mechanical tasks.

This thesis uses the Toyota model of 'recruitment and selection process' as a reference to identify key skills in individuals.

The mapping of people-related risks with their corresponding skills ensures the sustained resolution of people risks. Analytic Hierarchy Process (AHP) technique could be used for mapping the people-related risks to the skills. AHP is a widely used decision making technique to find out the best alternative among a list of criteria in order to attain a goal (Saaty, 1995). In comparison to other decision making techniques, AHP uses human judgments through expert-surveys to compare alternatives of the designated criteria or sub-criteria. It allows decision makers to choose the best among a multitude of alternatives and provides a quantitative justification for their choice (Ravikumar et al., 2015). Kiatcharoenpol et al. (2015) used Analytical Hierarchy Process (AHP) to prioritize the relative importance of the 12 critical factors for successful lean implementation in small scale industries. The priority of critical factors was interpreted using the AHP technique for the following reasons:

- AHP is an apt tool for determining priority with respect to different dimensions.
- It does not require statistics or probability theory and provides a perception of reality.
- It is a long-standing methodology to evaluate important factors in other research.

The researcher in this study employs Analytic Hierarchy Process (AHP) technique for mapping people-related risks with skills. The skills are evaluated as alternatives over the different people-related risk criteria to determine the most important skill for a particular people-related risk.

A thorough literature review on the risks for lean system sustainability and the alignment of lean risks with people skills thus indicate the absence of a model that classifies the Toyota Production System(TPS) and connects it to people skills. This thesis presents a Lean Personnel Alignment model (LPAM) which aligns the skills in personnel with lean system requirements.

# Chapter 3

# Methodology

This chapter presents a detailed approach to the classification of the Toyota Production System (TPS) into subsystems in order to understand its functional requirements. The risks associated with each of the subsystems is studied and further categorized into people, material, equipment and schedule. The author also discusses the development of a survey instrument to validate the risks and presents a Lean Personnel Alignment Model (LPAM) to align the skills in people with the requirements of the lean system.

## 3.1 Classification of the Lean System

The Toyota Production Systems (TPS), often referred to as a socio-technical system, comprises of some lean management philosophies and practices. The classification of the TPS into a set of subsystems provides a road map for understanding its functional requirements. Each of these subsystems consists of a group of lean tools which represents a specific objective of the TPS. The priority for the implementation of these subsystems is proposed. The logic for connecting a group of lean tools in a specific subsystem is presented to be sequential in a manner with the precedence requirements. The subsystems obtained upon the classification of the TPS are Operational Fundamentals, Enhancing Workplace Capability in Design, Standard

Operations, Consistency, Flow and Production Scheduling and Motion respectively. The entire TPS system, with the highlighted subsystems, is presented in Figure 3.1 below.

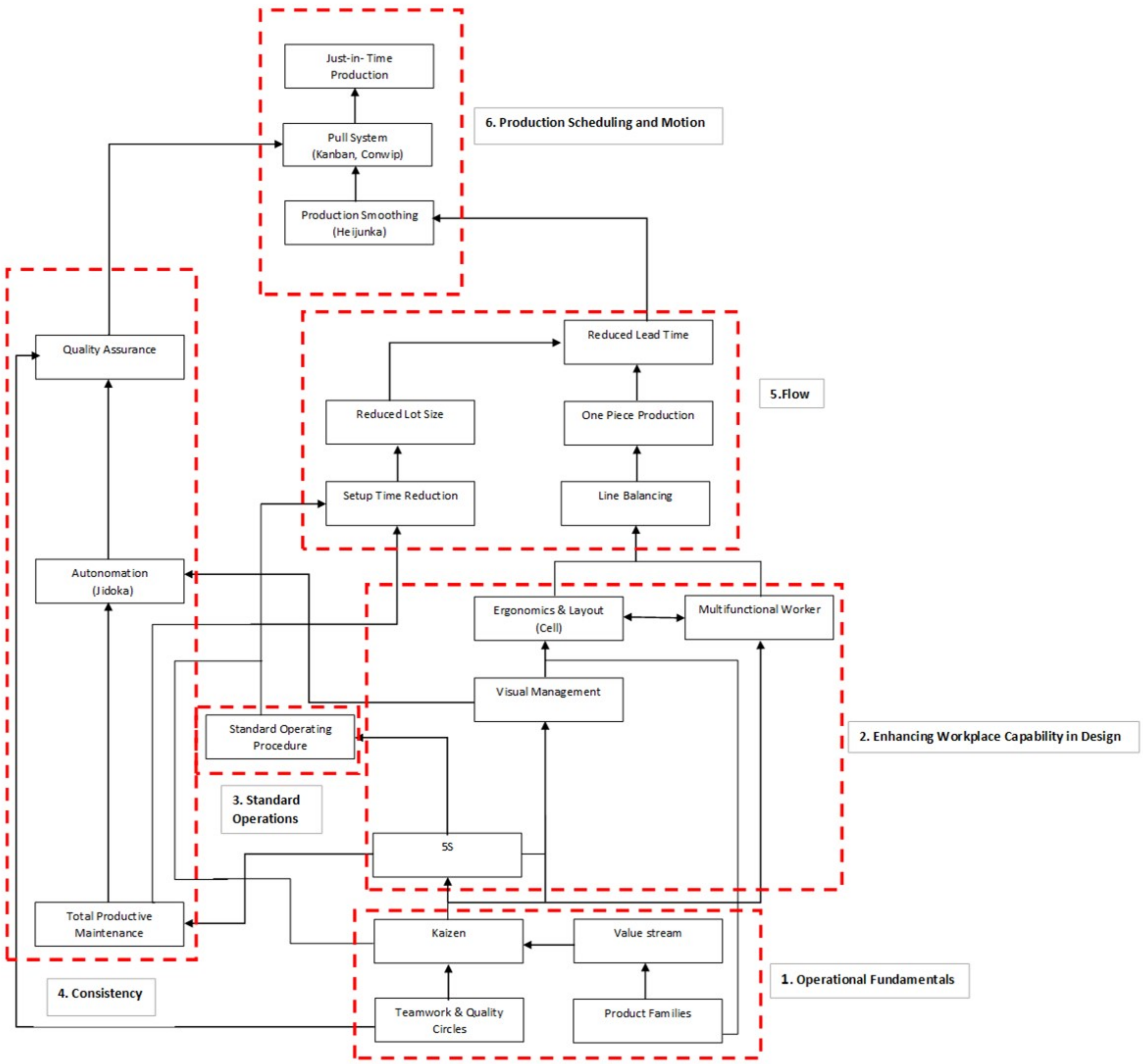


**Figure 3.1:** Classification of the TPS.

The six subsystems are explained in detail as follows:

1. **Operational Fundamentals**: is composed of a key group of lean activities, such as Teamwork & Quality Circles, Product Families, Value Stream and Kaizen, which are necessary for operating all other activities in different

subsystems. This subsystem addresses the business needs of an organization and stresses the importance of people working within a team. It represents a set of activities that help in understanding a lean process, stabilizing the variations within the process and working in a team to shape a continuous improvement culture. Operations Fundamentals subsystem provides input to subsystem 2, 3, 4, 5 and 6. Achieving Kaizen or Continuous Improvement is the ultimate objective of this subsystem. Kaizen provides a baseline for identifying where value can be created and sustained. Kaizen is dependent on Value Stream and Teamwork as well as Quality Circles, as they help in identifying the opportunities for eliminating wastes and non-value added activities. Value Stream is dependent on Product Families passing through a production process. Product variants form the units of analysis for Value Stream from the downstream step just before the customer. Operational Fundamentals subsystem is outlined in Figure 3.2. The critical resource for all the lean activities in this subsystem is people.

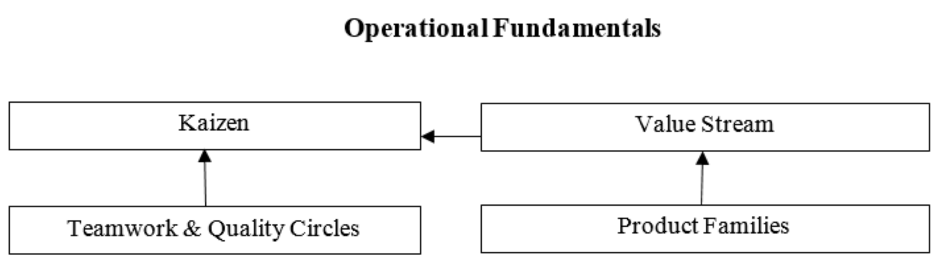


**Figure 3.2:** Operational Fundamentals Subsystem.

2. **Enhancing Workplace Capability in Design**: is composed of a group of lean activities, such as 5S, Visual Management, Cell Layout and Multifunctional Worker which promote the interaction between the workplace and functions performed by a worker. This subsystem focuses on improving the productivity and efficiency of the available resources in the organization by the systematic elimination of wastes. It represents a set of activities that help to eliminate

workplace inefficiencies, high stock levels, and inappropriate process flows by establishing a balanced workload for each production area. Enhancing Workplace Capability in Design subsystem provides input to subsystem 3, 4, 5 and 6. Achieving a well-designed work layout or Cell Layout equipped with a Multifunctional Worker is the ultimate objective of this subsystem. Cell Layout having a Multifunctional Worker, ensures higher productivity and quality of product flow. A Cell Layout is dependent on Visual Management and 5S techniques as they help in eliminating waste and optimizing material, people and information flow. Visual Management is dependent upon 5S for overcoming work flow challenges such as safety, quality, waste and employee morale. A visual workplace serves as a key force for displaying the necessary information at all points of action. Enhancing Workplace Capability in a Design subsystem is outlined in Figure 3.3. The critical resources for all the lean activities in this subsystem are People and Equipment.

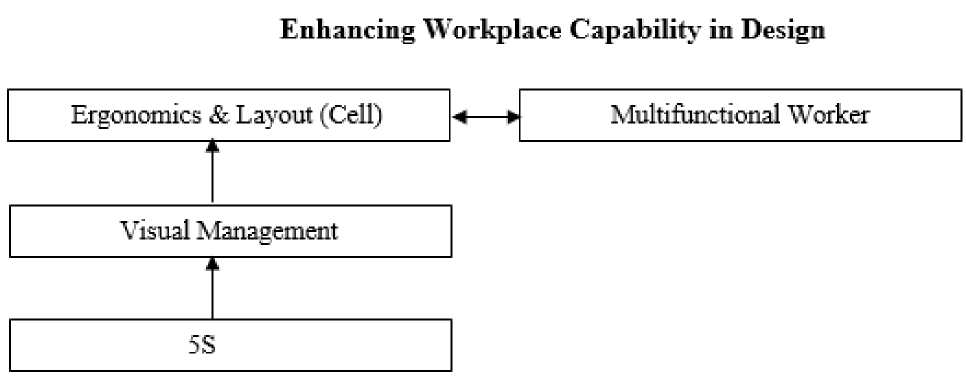


**Figure 3.3:** Enhancing Workplace Capability in Design Subsystem.

3. **Standard Operations**: is composed of a lean activity, namely Standard Operating Procedures, which promote the implementation of a set of clearly defined activities and standardized procedures for machines and their operators. This subsystem focuses on maintaining a routine of Standard Operations in the organization in order to shape a continuous improvement culture. The SOP's

help to achieve efficiency, quality output and uniformity of performance upon compliance with the industry regulations. The Standard Operations subsystem provides input to subsystem 4, 5 and 6. Achieving SOP is the ultimate objective of this subsystem. The Standard Operations subsystem is outlined in Figure 3.4. The critical resource for the lean activity in this subsystem is people.

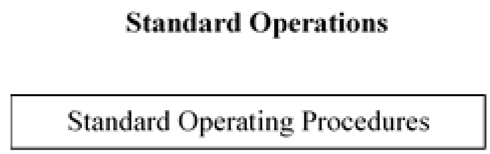


**Figure 3.4:** Standard Operations Subsystem.

4. **Consistency**: is composed of a group of lean activities, such as Total Productive Maintenance (TPM), Autonomation and Quality Assurance, which ensures a quick response to the identification and correction of mistakes in any process. This subsystem focuses on ensuring the improved quality of a manufacturing product or a performed service in an organization by adhering to a set of defined quality criteria or the customer's requirements. It represents a set of activities that help in achieving effective utilization of resources, improved customer satisfaction, quality and lower costs of failure. The Consistency subsystem provides input to subsystem 5 and 6. Achieving Quality Assurance is the ultimate objective of this subsystem. Quality Assurance ensures the desired level of quality in manufactured products. Quality Assurance is dependent upon Autonomation and Total Productive Maintenance as they help in maintaining and improving the performance of production systems through the machines, processes, and employees. Autonomation is dependent upon Total Productive Maintenance for maximizing the operational time of the equipment and empowering personnel with the ability to detect defects through the line. The Consistency subsystem is outlined in Figure 3.5. The critical resources for all the lean activities in this subsystem are People and Equipment.

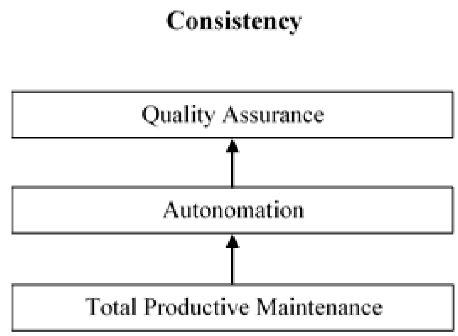


**Figure 3.5:** Consistency Subsystem.

5. **Flow**: is composed of a group of lean activities, such as Setup Reduction, Line Balancing, One-piece production, Reduction of Lot Size and Reduction of Lead Time, which are necessary for achieving flexibility in order to respond to customer demands. This subsystem focuses on ensuring an improved Work-In-Process (WIP) flow through production with minimal (or no) buffers between the manufacturing process steps. It represents a set of activities that facilitate a faster turnover of orders and on-time delivery of products. The Flow subsystem provides input to subsystem 6. Achieving Reduction of Lead Time is the ultimate objective of this subsystem. Reduction of Lead Time ensures the delivery of better quality products on a timely schedule. It is dependent on Reduction of Lot Size and One-Piece Production as they help in reducing inventory and variability of product flow. Reduction of Lot Size is dependent upon Setup Reduction (Shingo's Single Minute Exchange of Dies) to reduce or eliminate the changeover time. One-Piece Production is dependent upon Line Balancing to level the workload across all processes in a Cell Layout and to remove bottlenecks and excess capacity. The Flow subsystem is outlined in Figure 3.6. The critical resources for all the lean activities in this subsystem are People and Material.

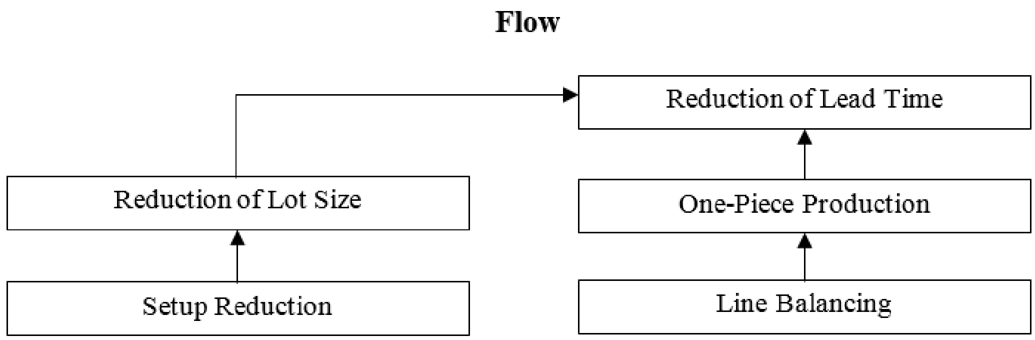


**Figure 3.6:** Flow Subsystem.

6. **Production Scheduling and Motion**: is composed of a group of lean activities, such as Production Smoothing, Pull System/Kanban and Just-in-Time Production(JIT), which is necessary for dealing with the sequencing of orders and controls that facilitate the transit of materials between the production areas. This subsystem focuses on ensuring a uniform distribution of the production volume and mix evenly over time. It represents a set of activities that help in achieving a smooth flow of product and reduced inventory costs. Achieving Just-In-Time Production is the ultimate objective of this subsystem. Just-In-Time Production ensures that the parts are produced based on the customer demand. JIT is dependent upon the Pull System/Kanban as it helps to determine the status of the production system and inventory by accounting for the daily demand changes. The Pull System/Kanban is dependent on Production Smoothing for maintaining the quantity of production variance in a production line. The Production Scheduling and Motion subsystem is outlined in Figure 3.7. The critical resources for all the lean activities in this subsystem are People and Material.

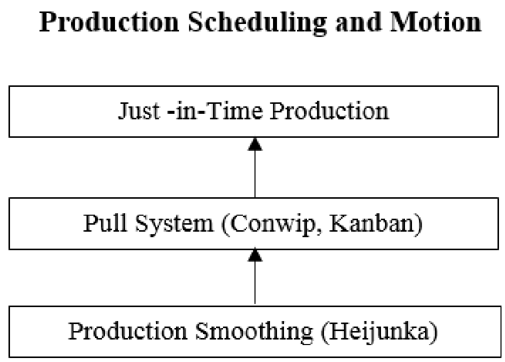


**Figure 3.7:** Production Scheduling and Motion Subsystem.

## 3.2 Risk Analysis of the Lean System

The classification of the TPS into subsystems in the previous section helps to understand the lean system's implementation and operation better. Although lean efforts are geared towards enhancing the smooth flow of raw materials through production processes, sustaining the lean system long-term is a major concern (Bhasin and Burcher, 2006). The ability to sustain lean improvements in a system can be enhanced by improving the reliability of the system's components (Sawhney et al., 2010). The present study used the concept of reliability by studying the risks impacting the flow effectiveness of the lean system and categorizing these risks into four components of reliability: people, material, equipment, and schedule. The risks were identified rationally using a literature search. The risk analysis was performed with respect to all the lean subsystems. However, due to the overlapping risks in different subsystems, the identified risks are specifically grouped into Personnel, Material, Equipment and Schedule.

**Flow Effectiveness with respect to Personnel**: The workforce is comprised of personnel and their skills are required to implement lean (Sawhney et al., 2010). The flow of a production material on a manufacturing line is impacted by the following people related risks (as shown in Figure 3.8): Non-compliance with standard operating procedures, Lack of technical skills/capabilities, Physical or mental stress, Absenteeism and Inappropriate behavior.

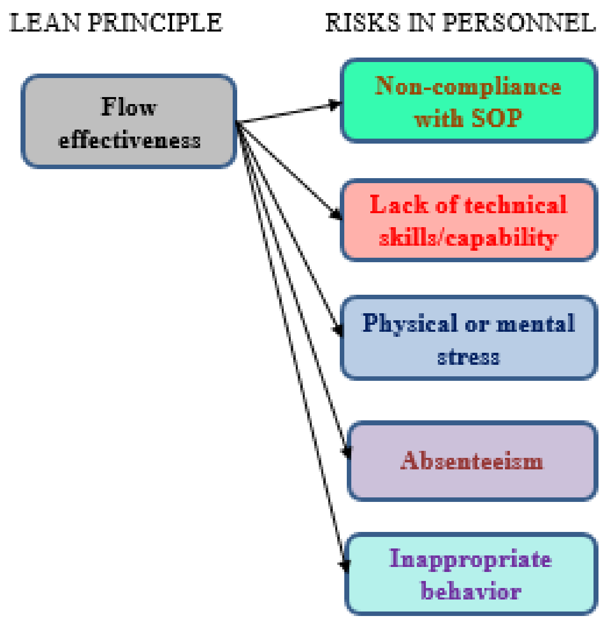


**Figure 3.8:** Risk Analysis of Personnel.

- **Non-compliance with Standard Operating Procedures**: The Toyota Production System relies on creating standard worksheets listing the standard methods for each procedure in the plant. Non-compliance with standard operating procedures (SOP's) creates a huge margin for error because all workers do not conform to the written SOP's. Thus, process anarchy results.

- **Lack of Technical Skills/ Capabilities**: Lean process-oriented initiatives should be implemented by the front-line workers (Liker, 2004). However, the problem is with the lack of workers' technical skills or capabilities to perform these process-improvement initiatives at the project level. To identify Muda (i.e., non- value-adding activities), the front-line workers need certain basic technical skills and capabilities to design and operate a lean system.

- **Physical or Mental Stress**: Toyota's one-minded approach to several lean practices has created obstacles to workforce efficiency and capacity utilization (Lurie, 1987). Lean production results in elevated stress levels in employees, increased worker turnover and time lost due to accidents. Furthermore, it has a negative impact on the operators' health and performance (Papadopoulou and Özbayrak, 2005).

- **Absenteeism**: Workers' adequate attendance level allows an organization to meet its objectives. Employee absences are both costly and disruptive. Productivity losses, due to employee absenteeism, cost millions of dollars to an organization each year (Hausknecht et al., 2008).

- **Inappropriate behavior**: It is important for an organization implementing a lean culture to ensure that its personnel behave in accordance to the guiding principles and maintain a climate of mutual trust amongst each other (Fernando and Cadavid, 2007). Inappropriate behavior among personnel includes tardiness, non-compliance with the top management and insubordination. An organization can effectively curtail the risk of inappropriate behavior in its personnel by providing an open-minded approach and supportive behavior.

**Flow Effectiveness with respect to Material:** Material comprises of raw materials, works-in-process (WIP), and finished goods (Sawhney et al., 2010). The flow of a production material on a manufacturing line is impacted by the following material-related risks (as shown in Figure 3.9): Improper procurement of material, Material misplacement, Defective material, High mix of products, Large batches, Poor layout design, and Complex routing.

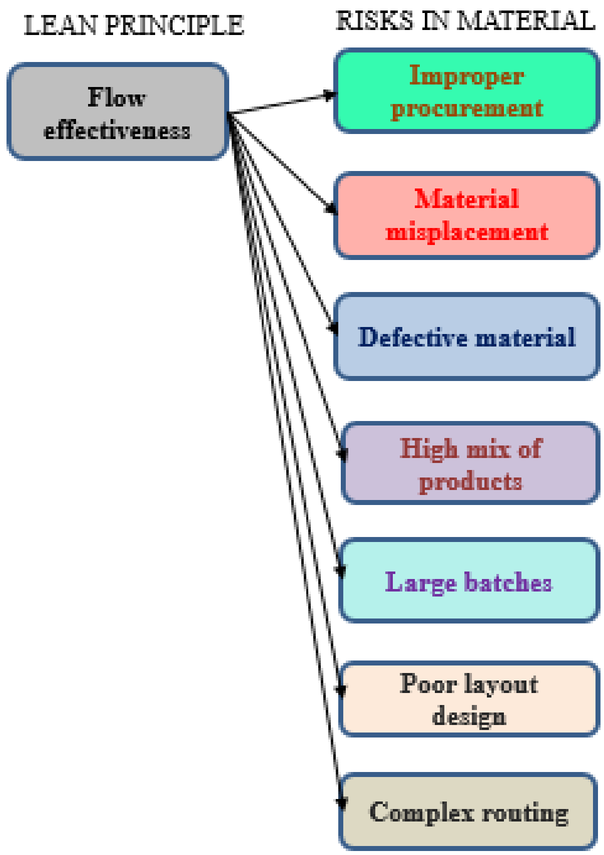


**Figure 3.9:** Risk Analysis of Material.

- **Improper Procurement of Material** : Bad procurement and inventory control lead to operational costs in areas of holding cost, obsolescence, dead stocks, and production hold-ups due to stock-outs and dormant stock (Monden, 2011). Unreliable vendors that miss delivery dates or deliver the wrong items, can slow down or halt a manufacturing process (Jeyaraman and Kee Teo, 2010). Therefore, the procurement process involves multiple risk factors.

- **Material Misplacement** : Misplaced inventory translates to added expenditures. Inventory management systems are not perfect as there is always some operator error wherein the material is thrown away or broken (shrink), misused or misplaced.

- **Defective Material** : A manufacturing defect exists if the product departs from its intended design, although significant care was exercised in making the product (Kilpatrick, 2003). A product that escapes the manufacturer's quality controls in a flawed condition leads to its failure during use, and could possibly cause injury to the user.

- **High Mix of Products**: Complexity of parts and options decreases the direct labor productivity and quality as production workers face a complex variety of parts and less likely combinations of parts to install (MacDuffie et al., 1996). Balancing the assembly line for consistent cycle times at each workstation also becomes more difficult due to multiple models and various option combinations.

- **Large Batches**: Producing material in large batches is inefficient because of the associated downtime. The downtime between batch runs substantially increases with an increased number of machines and complexity of production process (Kilpatrick, 2003). The idle time of machines is longer as operators reconfigure them for each new batch produced.

- **Poor Layout Design**: Failure to account for ergonomic interventions in layout design can cause work-related stress injuries and decrease productivity. Improper layout design can often result in longer lead time due to the change of each employee's range of jobs (Monden, 2011).

- **Complex Routing**: Routing prescribes the plant's work flow and includes the following: layout, temporary locations for raw materials and components, and materials handling systems. Complex routing leads to using improper material-handling systems for purchased parts to support the cells (Harris et al., 2004).

**Flow Effectiveness with respect to Equipment:** Equipment comprises of primary and auxiliary machines used in lean systems (Sawhney et al., 2010). A production material's flow on a manufacturing line is impacted by the following equipment related risks (as shown in Figure 3.10): Planned maintenance, Unplanned maintenance, and Malfunctioning equipment.

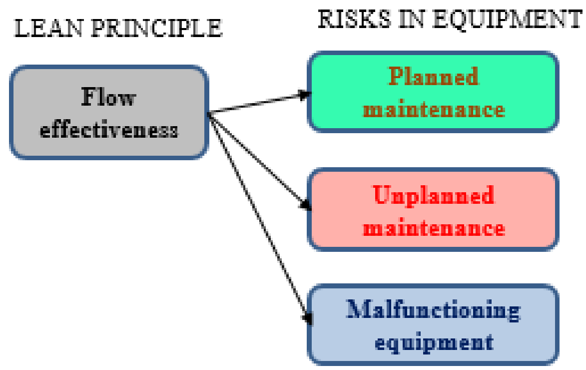


**Figure 3.10:** Risk Analysis of Equipment.

- **Planned Maintenance**: Planned maintenance is proactive maintenance work scheduled to occur on a regular basis. It is less reliable than condition- based maintenance. Furthermore, it is more expensive due to the frequency in which parts change and labor costs (Singh et al., 2013).

- **Unplanned Maintenance**: Unplanned maintenance is performed without planning, and it is related to breakdown, repair, or corrective work. Unfortunately, it is unavoidable. This type of maintenance is highly inefficient, causing sudden breakdown of machinery and lost revenue (Nakajima, 1988). It has the disadvantage of unplanned stoppages, excessive damage, spare parts problems, high repair costs, excessive waiting and maintenance time, and excessive troubleshooting problems (Jain et al., 2012).

- **Malfunctioning Equipment**: Equipment malfunction is one of the major risk factors impacting equipment performance. Defective machines lacking adequate safety features or warnings often undermine workers' safety and are tremendous industrial hazards (Nakajima, 1988).

**Flow Effectiveness with respect to Schedule**: Scheduling involves the ability to forecast, plan, and schedule a production system (Sawhney et al., 2010). The following schedule-related risks impact the flow of production material on a manufacturing line (as shown in Figure 3.11 ): Non-adherence to schedule requirements, Extraordinary orders, and High mix of products.

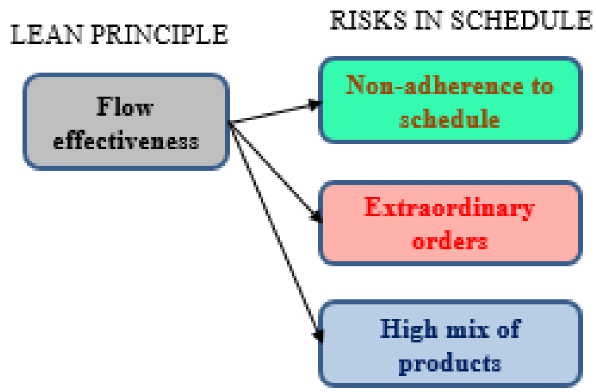


**Figure 3.11:** Risk Analysis of Schedule.

- **Non-adherence to Schedule Requirements**: In manufacturing, scheduling is an approach to understanding how much work can be produced in a certain period taking into consideration limitations on resources, such as people, material, equipment, and schedule. Non-adherence to the schedule requirements hinder the progress of a lean process throughout the plant. Improper sequencing of the parts is a consequence of non-adherence to scheduling (Monden, 2011).

- **Extraordinary Orders**: Lean processes should be adaptive and adjustable to absorb changing demand. Companies aim to reduce work in progress (WIP), optimize value streams, and gain profit. Inaccurate demand forecasting severely impacts an organization's profitability and survival.

- **High Mix of Products**: The complexity of parts and options affects adoption to the production schedule (Monden, 2011). Inappropriate product mix may lead to underutilization of capacity, overproduction, or failure in timely delivery (Gauri, 2009).

## 3.3 Survey Development

A survey questionnaire was chosen to validate the risks affecting the sustainability of the lean system. Hypothesis testing procedure was adopted to test the significance of the relationship between risk variables and flow effectiveness of the lean system. The null hypothesis indicates a significant relationship between the risk variables and flow effectiveness of the lean system. The alternative hypothesis indicates that there is no significant relationship between the risk variables and flow effectiveness of the lean system.

$H_0$- null hypothesis ; $H_1$ - alternative hypothesis ; $\alpha = 0.01$

$H_0$: Risk factor affects flow effectiveness ; $H_1$: Risk factor doesn't affect flow effectiveness. Table 3.1, below, presents the hypothesis tested in this study.

The hypothesis testing would be carried out at a level of significance, $= 0.01$ using One-Sample T-test and the Wilcoxon test. This is discussed in detail in the Validation chapter. Purposive sampling technique was utilized to achieve a moderate level of external validity and generalize the results obtained from the survey (Rosenthal and Rosnow, 1991). The survey questionnaire was grouped into two sections. Section 1 was designed to categorize respondents based on their relevant experience in lean projects, educational qualification and the primary area of employment. Section 2 was divided into four main categories of questions for Personnel, Material, Equipment and Schedule respectively.

There were a total of 18 questions in section 2; each question captured information on the 18 risk variables developed from the risk analysis. The survey questionnaire had a total of 22 questions out of which four questions were about the demographics of the respondents and was a part of Section 1. The relationship between each of the 18 variables and the flow effectiveness of the lean system was studied (as shown in

**Table 3.1:** Null Hypotheses for Testing the Interaction between the Risks and Flow Effectiveness.

| Risks | Affects flow effectiveness |
|---|---|
| Non-compliance with SOP in personnel | $H_{01}$ |
| Lack of technical skills/capability in personnel | $H_{02}$ |
| Physical/mental stress in personnel | $H_{03}$ |
| Absenteeism in personnel | $H_{04}$ |
| Inappropriate behavior in personnel | $H_{05}$ |
| Improper procurement of material | $H_{06}$ |
| Material misplacement | $H_{07}$ |
| Defective material | $H_{08}$ |
| High mix of products | $H_{09}$ |
| Large batches of material | $H_{10}$ |
| Poor layout design for material | $H_{11}$ |
| Complex routing of material | $H_{12}$ |
| Planned maintenance of equipment | $H_{13}$ |
| Unplanned maintenance of equipment | $H_{14}$ |
| Malfunctioning equipment | $H_{15}$ |
| Non-adherence to schedule requirements | $H_{16}$ |
| Extraordinary orders in schedule | $H_{17}$ |
| High mix of products in schedule | $H_{18}$ |

Table 3.1). The survey questionnaire made use of the five-point Likert scale ranging from 1 being "Strongly Disagree" to 5 being "Strongly Agree". (Likert, 1932). A pre-test study was carried out, and the identified risk variables were reviewed for their appropriateness by 15 lean practitioners. The risk variables were then modified based on the practitioners' feedback. The final survey instrument (Appendix A) was adopted based on the reviewer's consensus. The detailed survey design and the analysis of the risk variables are explained in the Validation chapter.

## 3.4 Lean Personnel Alignment Model(LPAM)

The LPAM model developed in this study aims to align the skills in personnel with the requirements of the lean system. The framework for the LPAM model is outlined in Figure 3.12. This model addresses the following objectives:

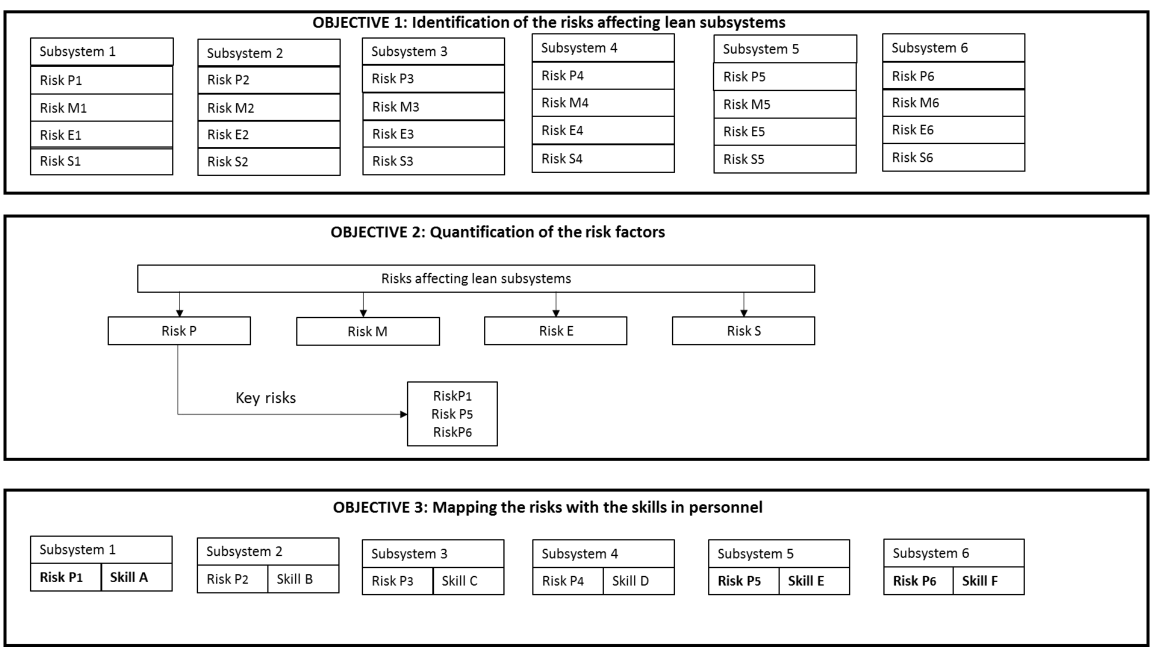


**Figure 3.12:** Framework for Lean Personnel Alignment Model.

1. **Identification of the risks affecting the lean subsystems**: Qualitative risk analysis tests are carried out on each lean subsystem to identify the risks.

Several techniques can be employed when performing qualitative risk analysis, such as Brainstorming, Interviewing, Delphi method, SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, Risk rating scales and use of historical data (Kindlinger, 2012). The impact of the risks typically affect the elements of the lean system, such as schedule, resources, cost, quality, and performance. The risks were identified rationally using a literature search.

2. **Quantification of the risk factors**: The identified risk factors are validated using expert-surveys. A specialized group of experts in the operation management and manufacturing fields are approached.

   Expert evaluations allow for the inclusion of all the risks affecting the lean system. Inferential statistics are employed to validate the risk factors. Exploratory factor analysis (EFA) techniques can also be employed to categorize risks (Marodin and Saurin, 2015). Validation of the risk factors for system failure enables the risk factors to be quantified and monitored.

3. **Mapping the risks with the skills in personnel**: The skills associated with the operation of the lean tools are gleaned from a thorough literature survey. The Toyota model of 'recruitment and selection process' could be used as a reference for integrating skills in personnel with lean design (Liker and Hoseus, 2008). The mapping of the people-related risks with the skills helps to deal with these risks and sustain lean implementation. Analytic Hierarchy Process (AHP) technique is utilized to map a set of skills with the identified people-related risks. The skills are evaluated as alternatives over the different people-related risk criteria to determine the important skill and the relative importance of all the skills under consideration. AHP technique uses expert judgment to provide a priority ranking of all the alternatives in terms of their overall preference.

The detailed analyses of the LPAM model are presented in the next chapter.

# Chapter 4

# Validation

This chapter provides a detailed interpretation and analysis of the survey data. It is divided into three sections namely survey details, validation of risks and mapping of risks with skills. The first section discusses the preliminary analysis carried on the survey items which includes sample size selection, data coding and collection methods, data screening procedures, reliability analysis of responses, demographic study of the survey respondents and descriptive statistics of the data set. The second presents the quantification of the risks using inferential statistics while the third validates the risks to skills mapping in the Lean Personnel Alignment Model (LPAM) using the Analytic hierarchy process (AHP) technique.

## 4.1 Sample Selection

One of the goals of this study is to validate the hypothesis stating that the flow effectiveness of the lean system is impacted by the risks for lean sustainability using a survey questionnaire. The survey respondents consisted of lean experts at different levels of management and were not limited to those who implemented the lean process successfully. These respondents were sought because of their extensive experience in working on the lean projects. The mailing list for industrial practitioners was obtained by researching the industry and academic sectors in depth. The industrial sector consisted of some of the local manufacturing companies in Knoxville and lean consultants all over the world. Lean forums and consortia as well as university research groups worldwide comprised the academic sector. The mailing list included the email addresses and job titles of 103 industrial employees. The respondents were identified as consultants, managers and employees.

## 4.2 Sample Size Justification

The questionnaire was designed to filter out responses of participants who did not have project experience in lean. A total of 74 responses were obtained from the targeted population of 103 respondents. These responses were from people who had project experience in lean manufacturing for at least a year. Furthermore, data screening procedures rendered 35 responses to be valid for the study. This means that only one-third of the total responses were utilized for this study. The percentage of the total valid responses is shown in Figure 4.1.

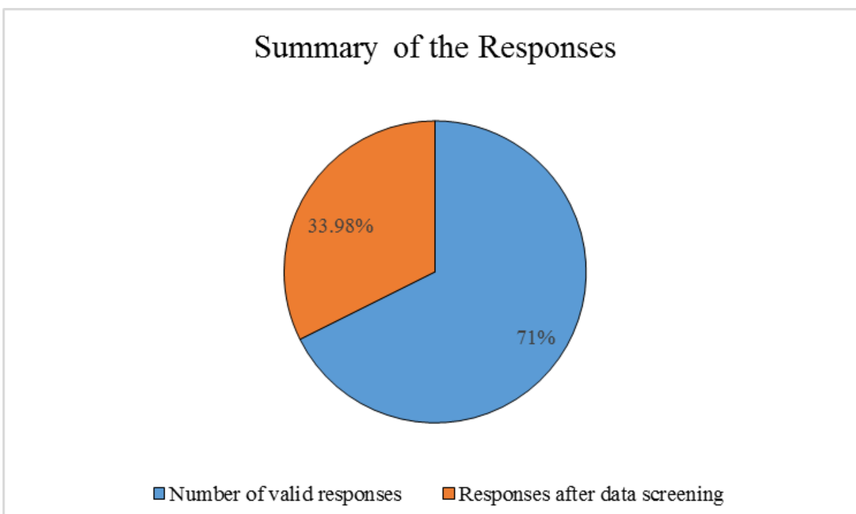


**Figure 4.1:** Summary of the Responses.

Power analysis tests are generally used to determine the required sample size for conducting a survey (Kish, 1965). This study used power analysis as a confirmatory measure for justifying the existing sample size. The required sample size is calculated using the following formula:

$$n = (z_{\alpha/2}\sigma/E)^2$$

where n: required sample size

$z_{\alpha/2}$: z- score for 99% C.I= 2.58

$\sigma$: average standard deviation on the responses = 1.06

E: margin of error = 0.5

$$n = [2.58 * 1.06/0.5]^2 = 30$$

The required sample size obtained from power analysis was 30 and the study used a sample size of 35 responses. The existing sample size is greater than the required sample size in this case, which makes it easier for gaining reliable insights about the total population size.

## 4.3 Item Coding and Data Collection

The survey data was administered with the help of the University of Tennessee, Office of Information and Technology (OIT), via Qualtrics survey software package. The survey responses were stored in the Qualtrics server. As a result, the downloaded data required formatting, such as removing the unused columns and recoded values. The data-coding steps listed below were followed to make the data ready for screening:

1. **Saved files with a format mmddyyyy.sav:** This was a simple, yet effective way to track changes in the dataset and served as a useful backup.

2. **Deleted the excess columns :** The unwanted columns (V1, V2, V3, V4, V5, V6, V7, V8, V9, V10, V11, V12, V13, V14, location latitude, location longitude and location accuracy) were generated as a result of the syntax used by the UT OIT Qualtrics server. Deleting these excess columns for analysis was important.

3. **Used the required information:** For capturing responses on the conceptual questions, the descriptive and demographic questions were eliminated.

4. **Used a unique test variable :** Each question was identified with a unique test variable. For example, Q1_1 in the extracted dataset was renamed as Test Variable 1_1.

The purpose of the survey questionnaire was to obtain information (and incorporate it into the research evidence) on the risk factors affecting lean implementation by categorizing them into the four components of reliability: personnel, material, equipment, and schedule. The questionnaire was categorized into four sections, one for each of the reliability components. It had a total of 18 topic questions and four demographic questions, which took approximately 15-20 minutes to complete. The data-collection process was conducted from December 2015 to March 2016.

## 4.4 Data Screening

The data-screening procedures ensured that the data was clean, reliable, and valid to conduct further statistical analyses. This section of the chapter addresses some of the issues related to blanks or unengaged responses, missing responses, and data outliers. The survey questionnaire was sent to some of the lean manufacturing companies in Knoxville; 35 valid responses were obtained from the survey. The unengaged or blank responses were eliminated because they would have affected the results. The following discusses the various issues and the data-screening procedures used:

- **Blank responses :** Detecting blank responses requires case-screening procedures in which the threshold of missing values for a particular question is less than 5% or 10% (Hair, 2010), (Lowry and Gaskin, 2014). The following steps were executed to identify the blank responses in the data:

  1. The data was entered in an Excel sheet with the variable names.
  2. Blank responses were checked for using the command = COUNTBLANK (B2:B36) for each question.(See Table 4.1.).

**Table 4.1:** Variables with Blank Responses.

| Variable | Blank Responses |
|---|---|
| Q1_1 Non-compliance with SOP in personnel | 2 |
| Q2_1 Improper procurement of material | 2 |

The questionnaire had an approximate of 11% of blank responses.

- **Unengaged responses :** Detection of unengaged responses on a survey required a thorough examination of the standard deviation of the responses obtained from the questionnaire. The standard deviation of the responses from all the individuals in this study were found to be equal to or greater than 0.5. It can thus be inferred that the respondents were highly engaged while taking the survey and this is shown in Figure 4.2

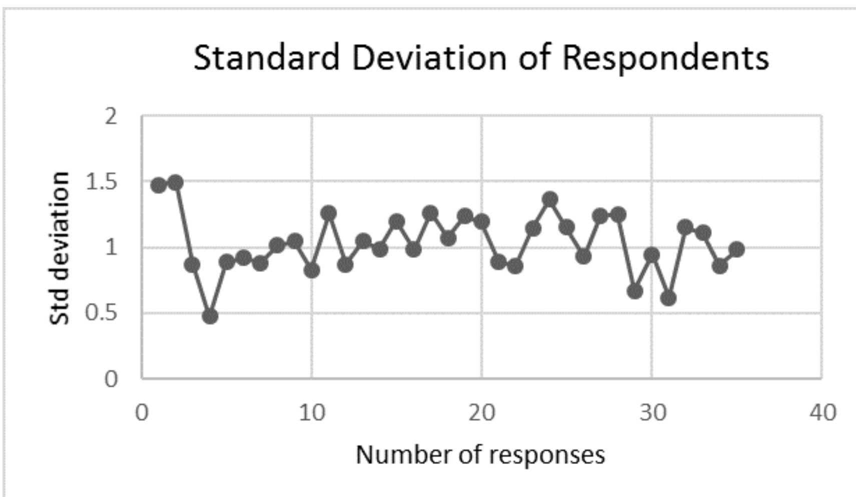


**Figure 4.2:** Standard Deviation of Respondents.

The standard deviation of each of the 35 responses was checked using the command in Excel=STDDEV.P(B2: GT2). The decision was made not to flag any of these data points and to regard them as valid responses.

- **Missing data :** Some of the responses in the questionnaire had missing values for a few questions. Missing data generally appears when a respondent either purposefully or inadvertently failed to answer one or more questions.

Rates of less than 1% of missing data are considered trivial; 1-5% manageable; 5-15% require sophisticated methods to handle; and more than 15% severely impacts any kind of interpretation (Acuna et al., 2003). Missing data is always a major problem because most analytic software procedures require observations on all individual variables and will use list-wise deletion (i.e., deleting all the variables when any single variable listed in the procedure is missing) by default. Missing data on different items accounts for the loss of a fifth or more of the total sample; significantly reducing statistical power (Dennis et al., 1997). Missing data can be replaced using mean (if normal), median (if skewed), or mode (if categorical) if only a few percent (<5%) of the data is missing. When the goal is to compare several groups, doing this replacement within each group is often desirable.

To avoid bias issues and to ensure enough data points were included in this study, the questions having missing values greater than 10% were imputed using the median replacement method. Further, to impute these values in SPSS, the Transform, Replace Missing Values command was used. As a Likert scale was used in this study, utilizing the median replacement method was more relevant. (See Table 4.2.)

**Table 4.2:** Subset of the Imputed Missing Values Table.

| Result variable | Number of Replaced Missing values | Creating function |
|---|---|---|
| 1_1 Non-compliance with SOP in personnel | 2 | MEDIAN(1,1,ALL) |
| 2_1 Improper procurement of material | 2 | MEDIAN(2 1,ALL) |

- **Outliers :** The outlier analysis for the survey items in this study did not exhibit any deviating behavior because of the selection of extreme points (1 or 5) on the Likert scale (Lowry and Gaskin, 2014).

## 4.5 Reliability Analysis

The 18 risk variables used in the survey questionnaire were grouped into four categories/factors: personnel, material, equipment and schedule. In order to study the inter-correlations between the risk variables, Cronbach's alpha test was employed. Cronbach's alpha increases with the increase in the inter-correlations among the survey items. It indirectly signifies the extent to which a set of items measure a single unidimensional latent construct (Cronbach, 1951). However, alpha can acquire higher values even when the set of items measure several unrelated latent constructs (Cortina, 1993), (Green et al., 1977). Therefore, alpha is mostly used when the items measure different substantive areas within a single construct (Louangrath, 2013), (Zinbarg et al., 2005). A large number of items in the test artificially inflates the value of alpha, and a sample with a narrow range can deflate it (Gliem and Gliem, 2003). The rule for measuring the data's internal consistency using Cronbach's alpha is shown in Table 4.3.

**Table 4.3:** Internal Consistency Table.

| Cronbach's alpha | Internal consistency |
|---|---|
| $\alpha \geq 0.9$ | Excellent |
| $0.9 \geq \alpha \geq 0.8$ | Good |
| $0.8 \geq \alpha \geq 0.7$ | Acceptable |
| $0.7 \geq \alpha \geq 0.6$ | Questionable |
| $0.6 \geq \alpha \geq 0.5$ | Poor |
| $0.5 \geq \alpha$ | Unacceptable |

The reliability analysis test was performed on the sample of 35 responses using the reliability analysis package in SPSS software. The obtained value of Cronbach's alpha was 0.733 as shown in Figure 4.3. The Cronbach's alpha value of 0.733 indicated that the survey questionnaire was reliable in its design and the survey variables were consistent.

| **Case Processing Summary** | | | |
|---|---|---|---|
| | | N | % |
| Cases | Valid | 35 | 76.1 |
| | Excluded[a] | 11 | 23.9 |
| | Total | 46 | 100 |

| **Reliability Statistics** | | |
|---|---|---|
| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | N of Items |
| **0.733** | **0.752** | **18** |

**Figure 4.3:** Reliability Analysis Results from SPSS Software.

## 4.6 Study of the Demographics

In terms of demographics, the respondents were categorized based on their years of work experience, educational qualification, and area of employment. Measuring the frequency of occurrence and distribution of data categories were effective methods of converting survey inputs into meaningful results. This study used bar charts and pie charts to represent the measurement of dispersion. Descriptive statistics results showed that 19% of the respondents had more than 20 years of relevant experience in manufacturing or production systems; 9% had between 15 and 20 years of experience; 25% had between 10 and 15 years of experience; 16% had between 5 and 10 years of experience; 22% had between 1 year and 3 years of experience while 9% had less than 1 year as shown in Table 4.4 and Figure 4.4.

**Table 4.4:** Respondents' Years of Experience.

| Item 1: How many years of work,experience do you have? | |
|---|---|
| Years of experience | Valid Percent (%) |
| Less than 1 year | 9 |
| 1-3 years | 22 |
| 5-10 years | 16 |
| 10-15 years | 25 |
| 15-20 years | 9 |
| 20 or more years | 19 |

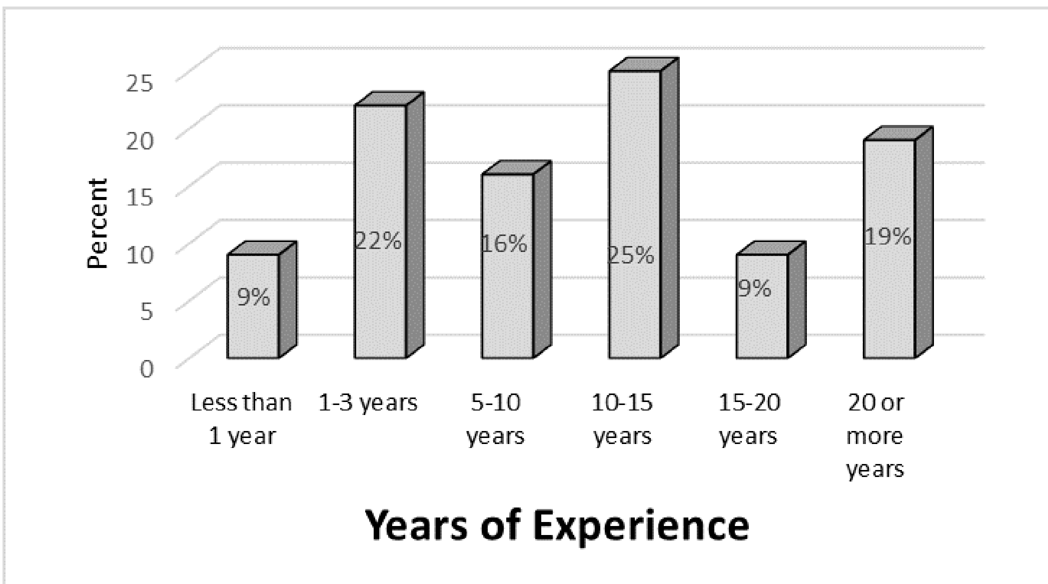


**Figure 4.4:** Bar Plot of Respondents' Years of Experience.

A period of 10 to 15 years of experience, in lean, formed the bulk of the responses at 25%. The distribution by highest level of education was 50% master's degree, 31% bachelor's degree, 16% doctorate degree, and 3% professional degree as shown in Table 4.5 and Figure 4.5.

**Table 4.5:** Respondents' Highest Level of Education.

| Item 2: What is the highest level, of education you have completed? | |
|---|---|
| Highest level of education | Valid Percent (%) |
| Masters degree | 50 |
| Bachelors degree | 31 |
| Doctorate degree | 16 |
| Professional degree | 3 |

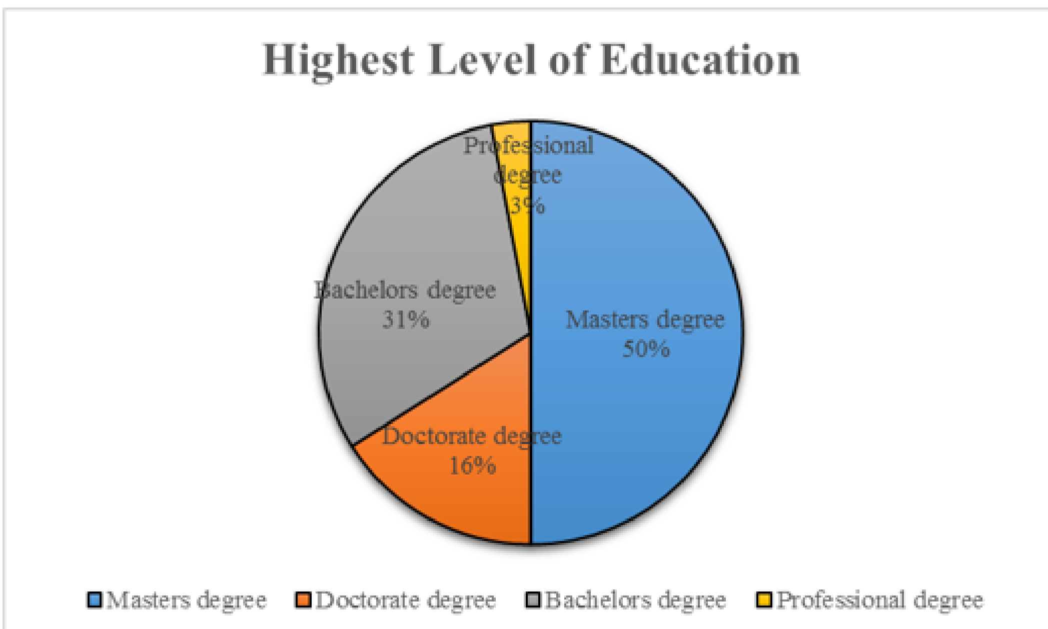


**Figure 4.5:** Pie Chart of Respondents' Level of Education.

The distribution by primary area of employment was 60% in manufacturing and other, 22% in education, 6% in information services, 6% in health care, 3% in transport and warehousing, and 3% in manufacturing-computers as shown in Table 4.6 and Figure 4.6. The major area of employment was manufacturing and other, and the respondents were mostly Master's degree holders. The demographics study of the survey population indicated that the respondents were highly qualified professionals with significant years of project experience in lean systems.

**Table 4.6:** Respondents' Primary Area of Employment.

| Item 3: Which of the following categories best describes your primary area of employment? | |
|---|---|
| Primary area of employment | Valid Percent (%) |
| Manufacturing and Other | 60 |
| Education | 22 |
| Information-services | 6 |
| Healthcare | 6 |
| Transport &Warehousing | 3 |
| Manufacturing-Computers | 3 |

## 4.7 Descriptive Statistics

This section illustrates the overall behavior and the basic features of the data set. This study included the measures of mean, standard deviation, median, measures of question spread, skewness, and kurtosis.

**Measures of the Question Spread:** The standard deviation, mean and median were calculated for every variable in the questionnaire to analyze its spread. A lesser standard deviation and a higher mean/median indicated a good response on the question and that the variable in question was more significant. A standard deviation of less than 1 and a mean/median value greater than 3 was the criteria for selecting the significant variables. Figures 4.7, 4.8 and 4.9 indicate the measures of the question

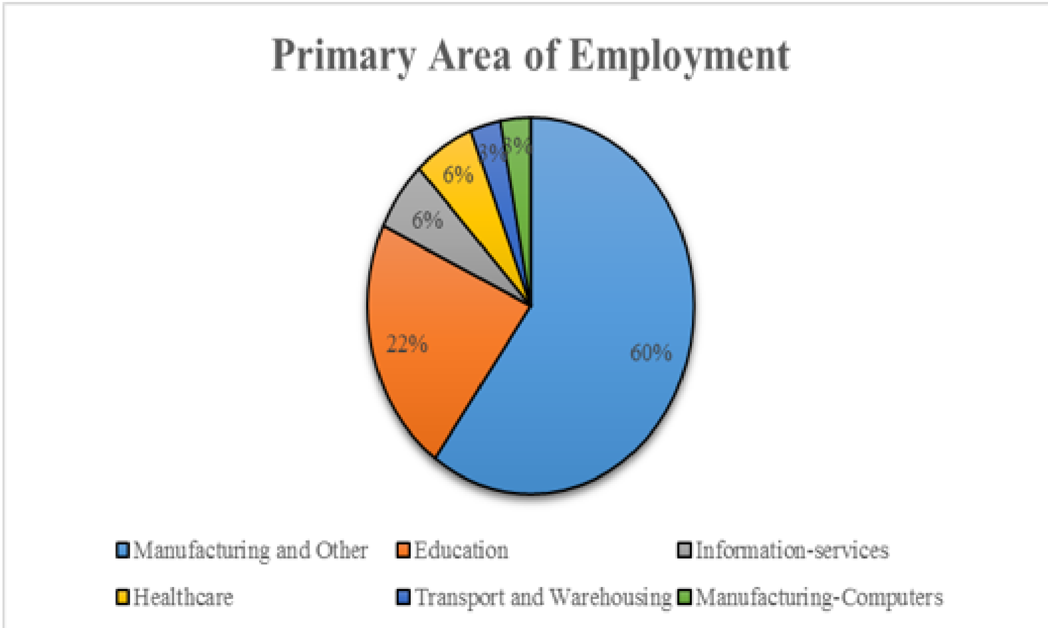


**Figure 4.6:** Pie Chart of Respondents' Primary Area of Employment.

spread. About one-third of the survey variables were significant as they had a lesser standard deviation and a higher mean/median.

| Variable | Name | Std deviation | Median | Mean | Decision |
|---|---|---|---|---|---|
| Q1_1 | Non-compliance with SOP in personnel | 1.252466702 | 4 | 3.62857 | Bad |
| Q1_2 | Lack of skills/capability in personnel | 1.166335932 | 4 | 4.14286 | Average |
| Q1_3 | Physical/mental stress in personnel | 1 | 4 | 3.77143 | Good |
| Q1_4 | Absenteeism in personnel | 1.165343165 | 4 | 3.54286 | Average |
| Q1_5 | Unapproved behavior in personnel | 1.034885334 | 3 | 2.45714 | Average |
| Q2_1 | Procurement of material | 1.040462267 | 4 | 4.14286 | Average |
| Q2_2 | Material misplacement | 1.027402334 | 4 | 4.11429 | Average |
| Q2_3 | Defective material | 1.139566194 | 4 | 4.2 | Average |
| Q2_4 | High mix of products | 1.189913888 | 3 | 3.05714 | Average |
| Q2_5 | Large batches of material | 1.063928778 | 4 | 3.85714 | Average |
| Q2_6 | Layout design | 1.054092553 | 4 | 4.11429 | Average |
| Q2_7 | Complex routing of material | 0.985621944 | 4 | 4.14286 | Good |
| Q3_1 | Planned maintenance in equipment | 1.182106824 | 3 | 2.71429 | Average |
| Q3_2 | Unplanned maintenance in equipment | 0.94607702 | 4 | 4.34286 | Good |
| Q3_3 | Malfunctioning equipment | 0.979732894 | 5 | 4.51429 | Good |
| Q4_1 | Non-adherence to schedule requirements | 0.965452622 | 4 | 4 | Good |
| Q4_2 | Extraordinary orders in schedule | 0.858868046 | 3 | 3.48571 | Good |
| Q4_3 | High mix of products in schedule | 1.16368667 | 3 | 3.17143 | Average |
| Standard deviation<1.00\|Mean/Median≥3 - Good | | | | | |
| 1.00<Standard deviation<1.25\|Mean/Median≥3 -Average | | | | | |
| Standard deviation>1.25\|Mean/Median<3 -Bad | | | | | |

**Figure 4.7:** Descriptive Statistics Table for the Variables from 1_1 to 4_3.

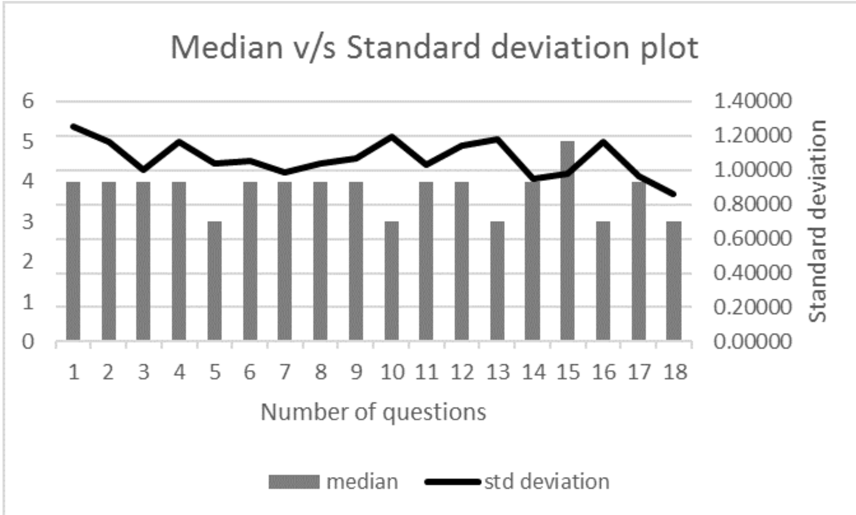


**Figure 4.8:** Plot of Median versus Standard Deviation for each Question.

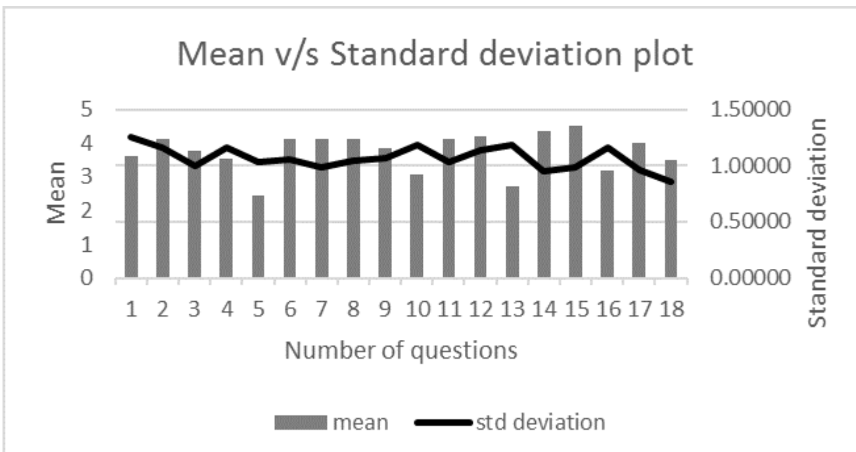


**Figure 4.9:** Plot of Mean versus Standard Deviation for each Question.

**Skewness and Kurtosis:** The peakedness or flatness of the distribution of the data was determined by studying its skewness and kurtosis measures. The normality of the survey data was assessed in terms of shape, skewness, and kurtosis. Most values of skewness and kurtosis generally fall within the recommended range of $\pm 1$. Skewness and kurtosis were used to flag the survey variables having a skewness/kurtosis value greater than $\pm 2$. Figure 4.10 shows the skewness and kurtosis for the variables from

1_1 to 4_3. The skewness and kurtosis plot for the survey variables indicated that the distribution of variables was symmetric with the absence of outliers.

| Variable | Name | Skewness | | Kurtosis | |
|---|---|---|---|---|---|
| | | Statistic | Std error | Statistic | Std error |
| Q1_1 | Non-compliance with SOP in personnel | -0.477 | 0.409 | -0.797 | 0.798 |
| Q1_2 | Lack of technical skills/capability in personnel | -0.908 | 0.398 | -0.154 | 0.778 |
| Q1_3 | Physical or mental stress in personnel | -0.259 | 0.398 | -0.235 | 0.778 |
| Q1_4 | Absenteeism in personnel | -0.288 | 0.398 | -1.067 | 0.778 |
| Q1_5 | Inappropriate behavior in personnel | -0.072 | 0.398 | -0.95 | 0.778 |
| Q2_1 | Improper procurement of material | -0.877 | 0.409 | 0.465 | 0.798 |
| Q2_2 | Material misplacement | -0.707 | 0.398 | 0.823 | 0.778 |
| Q2_3 | Defective material | -0.626 | 0.398 | -0.152 | 0.778 |
| Q2_4 | High mix of products | -0.534 | 0.398 | -0.165 | 0.778 |
| Q2_5 | Large batches of material | 0.292 | 0.398 | -1.012 | 0.778 |
| Q2_6 | Poor layout design for material | -0.213 | 0.398 | -1.372 | 0.778 |
| Q2_7 | Complex routing of material | -0.885 | 0.398 | -0.216 | 0.778 |
| Q3_1 | Planned maintenance in equipment | 0.476 | 0.398 | -0.373 | 0.778 |
| Q3_2 | Unplanned maintenance in equipment | -0.441 | 0.398 | -0.594 | 0.778 |
| Q3_3 | Malfunctioning equipment | -1.039 | 0.398 | 0.022 | 0.778 |
| Q4_1 | Non-adherence to schedule requirements | 0.096 | 0.398 | -0.867 | 0.778 |
| Q4_2 | Extraordinary orders in schedule | -0.486 | 0.398 | 0.472 | 0.778 |
| Q4_3 | High mix of products in schedule | 0.383 | 0.398 | -0.042 | 0.778 |

**Figure 4.10:** Skewness and Kurtosis Plot for the Variables from 1_1 to 4_3.

## 4.8 Validation of the Risks

Each question in the survey questionnaire was identified as a unique test variable. A total of 18 risk variables were tested for their relationship with flow effectiveness using a one-sample T-test (parametric test) at a level of significance $\alpha = 0.01$. The test median score for comparison (using a Likert scale rating) was 3. A one-sample Wilcoxon test (non-parametric test) at a level of significance $\alpha = 0.01$ was also conducted, while assuming that the distribution of the risk variables was not exactly normal. Both the T-test and Wilcoxon test indicated a similar result. This result helped in generalizing the significance of the relationship between the risk variables and flow effectiveness. The insignificant risk variables had a p value greater than 0.01. The results of the T-test and Wilcoxon test, along with their corresponding hypotheses' outcomes, are shown in Table 4.7. The T-test and the Wilcoxon test at $\alpha = 0.01$ level of significance indicated that the risk variables (e.g., product variety in material, planned maintenance in equipment, and product variety in schedule) are insignificant (i.e., they do not have a significant relationship with flow effectiveness). Figure 4.7 for standard deviation and mean/median also indicates that these variables have a higher standard deviation and a lesser median/mean, meaning that questions Q2_ 4, Q3_ 1, and Q4_3 are not good for capturing these variables.

**Multiple testing correction**: The present study had 18 hypothesis tests performed simultaneously at a level of significance $\alpha = 0.01$ on a single data set. The chance of obtaining false-positive results (type I errors) increases as multiple pair-wise tests are performed on a single set of data. The Bonferroni correction procedure is used to adjust the p-values, increasing the probability of identifying at least one significant result as many hypotheses are tested (Rice et al., 2008).

If a significance threshold of $\alpha$ is used and n separate tests are performed, then the Bonferroni adjustment considers a score to be significant only if the corresponding P-value is less than or equal to $\alpha$ /n (Noble, 2009). In this study, we use the correction factor $\alpha/\text{n} = 0.01/18$.

**Table 4.7:** Hypotheses Test Summary at $\alpha = 0.01$.

| Risk factors | Component | T-test at $\alpha = 0.01$ | One sample Wilcoxon signed rank test | $H_0$ | Hypothesis outcome |
|---|---|---|---|---|---|
| Non-compliance with SOP | Personnel | 0.002 | 0.000 | $H_{01}$ | Non-compliance with SOP has a significant relationship with flow effectiveness. |
| Lack of technical skills/capability | Personnel | 0.000 | 0.000 | $H_{02}$ | Lack of technical skills/capability in personnel has a significant relationship with flow effectiveness. |
| Physical or mental stress | Personnel | 0.000 | 0.000 | $H_{03}$ | Physical/mental stress in personnel has a significant relationship with flow effectiveness. |
| Absenteeism | Personnel | 0.002 | 0.003 | $H_{04}$ | Absenteeism in personnel has a significant relationship with flow effectiveness. |
| Inappropriate behavior | Personnel | 0.004 | 0.005 | $H_{05}$ | Inappropriate behavior in personnel has a significant relationship with flow effectiveness. |
| Improper procurement | Material | 0.000 | 0.000 | $H_{06}$ | Improper procurement of material has a significant relationship with flow effectiveness. |
| Material misplacement | Material | 0.000 | 0.000 | $H_{07}$ | Material misplacement has a significant relationship with flow effectiveness. |
| Defective material | Material | 0.000 | 0.000 | $H_{08}$ | Defective material has a significant relationship with flow effectiveness. |
| High mix of products | Material | 0.763 | 0.709 | $H_{09}$ | High mix of products doesn't have a significant relationship with flow effectiveness. |

**Table 4.7:** "Hypotheses Test Summary at $\alpha = 0.01$ Continued".

| Risk factors | Component | T-test at $\alpha = 0.01$ | One sample Wilcoxon signed rank test | $H_0$ | Hypothesis outcome |
|---|---|---|---|---|---|
| Large batches | Material | 0.000 | 0.000 | $H_{010}$ | Large batches have a significant relationship with flow effectiveness. |
| Poor layout design | Material | 0.000 | 0.000 | $H_{011}$ | Poor layout design has a significant relationship with flow effectiveness. |
| Complex routing | Material | 0.000 | 0.000 | $H_{012}$ | Complex routing has a significant relationship with flow effectiveness. |
| Planned maintenance | Equipment | 0.143 | 0.166 | $H_{013}$ | Planned maintenance in equipment doesn't have a significant relationship with flow effectiveness. |
| Unplanned maintenance | Equipment | 0.000 | 0.000 | $H_{014}$ | Unplanned maintenance in equipment has a significant relationship with flow effectiveness. |
| Malfunctioning equipment | Equipment | 0.000 | 0.000 | $H_{015}$ | Malfunctioning equipment has a significant relationship with flow effectiveness. |
| Non-adherence to schedule requirements | Schedule | 0.000 | 0.000 | $H_{016}$ | Non-adherence to schedule requirements has a significant relationship with flow effectiveness. |
| Extraordinary orders | Schedule | 0.000 | 0.000 | $H_{017}$ | Extraordinary orders has a significant relationship with flow effectiveness. |
| High mix of products | Schedule | 0.350 | 0.322 | $H_{018}$ | High mix of products in schedule doesn't have a significant relationship with flow effectiveness. |

Therefore, a variable is significant only if its corresponding P-value is less than 0.0005. Table 4.8 shows the hypothesis test results at $\alpha = 0.0005$. The T-test and the Wilcoxon test at $\alpha = 0.0005$ level of significance indicated that the risk variables (e.g., absenteeism in personnel, inappropriate behavior in personnel , product variety in material, planned maintenance in equipment and product variety in schedule) are insignificant (i.e., they do not have a significant relationship with flow effectiveness).

The structural networks were then developed for the risks in each of the primary resources (i.e., personnel, material, equipment, and schedule) in this study. Based on the survey data collected, weighted average scores were assigned to each connection in the network diagram. The strength of the connection was determined, and a strong connection was assigned with an average score rating greater than 3 on the Likert scale. In a similar way, a weak connection was assigned with an average score rating less than 3. These connections in the validated network diagram could also be verified using the one-sample t-test at a 99% confidence interval. Strong connections in the network diagram were represented using a thick line and weak connections using a thin line. Figures 4.11 ,4.12 , 4.13 and 4.14, below, present the validated structural networks for the risks in personnel, material, equipment, and schedule components respectively. The study identified the key risks for lean system sustainability in terms of personnel, material, equipment and schedule components. Furthermore, the focus of the study was on the resolution of the validated people-related risks as the people-related risks impacted the risks in other components such as material, equipment and schedule. The necessary skill sets required in personnel to resolve the people- related risks is discussed in the next section.

**Table 4.8:** Hypotheses Test Summary at $\alpha$= 0.0005.

| Risk factors | Component | T-test at $\alpha$= 0.01 | One sample Wilcoxon signed rank test | $H_0$ | Hypothesis outcome |
|---|---|---|---|---|---|
| Non-compliance with SOP | Personnel | 0.002 | 0.000 | $H_{01}$ | Non-compliance with SOP has a significant relationship with flow effectiveness. |
| Lack of technical skills/capability | Personnel | 0.000 | 0.000 | $H_{02}$ | Lack of technical skills/capability in personnel has a significant relationship with flow effectiveness. |
| Physical or mental stress | Personnel | 0.000 | 0.000 | $H_{03}$ | Physical/mental stress in personnel has a significant relationship with flow effectiveness. |
| Absenteeism | Personnel | 0.002 | 0.003 | $H_{04}$ | Absenteeism in personnel doesn't have a significant relationship with flow effectiveness. |
| Inappropriate behavior | Personnel | 0.004 | 0.005 | $H_{05}$ | Inappropriate behavior in personnel doesn't have a significant relationship with flow effectiveness. |
| Improper procurement | Material | 0.000 | 0.000 | $H_{06}$ | Improper procurement of material has a significant relationship with flow effectiveness. |
| Material misplacement | Material | 0.000 | 0.000 | $H_{07}$ | Material misplacement has a significant relationship with flow effectiveness. |
| Defective material | Material | 0.000 | 0.000 | $H_{08}$ | Defective material has a significant relationship with flow effectiveness. |

**Table 4.8:** "Hypotheses Test Summary at $\alpha$= 0.0005 Continued".

| Risk factors | Component | T-test at $\alpha$= 0.01 | One sample Wilcoxon signed rank test | $H_0$ | Hypothesis outcome |
|---|---|---|---|---|---|
| High mix of products | Material | 0.763 | 0.709 | $H_{09}$ | High mix of products doesn't have a significant relationship with flow effectiveness. |
| Large batches | Material | 0.000 | 0.000 | $H_{010}$ | Large batches have a significant relationship with flow effectiveness. |
| Poor layout design | Material | 0.000 | 0.000 | $H_{011}$ | Poor layout design has a significant relationship with flow effectiveness. |
| Complex routing | Material | 0.000 | 0.000 | $H_{012}$ | Complex routing has a significant relationship with flow effectiveness. |
| Planned maintenance | Equipment | 0.143 | 0.166 | $H_{013}$ | Planned maintenance in equipment doesn't have a significant relationship with flow effectiveness. |
| Unplanned maintenance | Equipment | 0.000 | 0.000 | $H_{014}$ | Unplanned maintenance in equipment has a significant relationship with flow effectiveness. |
| Malfunctioning equipment | Equipment | 0.000 | 0.000 | $H_{015}$ | Malfunctioning equipment has a significant relationship with flow effectiveness. |
| Non-adherence to schedule requirements | Schedule | 0.000 | 0.000 | $H_{016}$ | Non-adherence to schedule requirements has a significant relationship with flow effectiveness. |
| Extraordinary orders | Schedule | 0.000 | 0.000 | $H_{017}$ | Extraordinary orders has a significant relationship with flow effectiveness. |
| High mix of products | Schedule | 0.350 | 0.322 | $H_{018}$ | High mix of products in schedule doesn't have a significant relationship with flow effectiveness. |

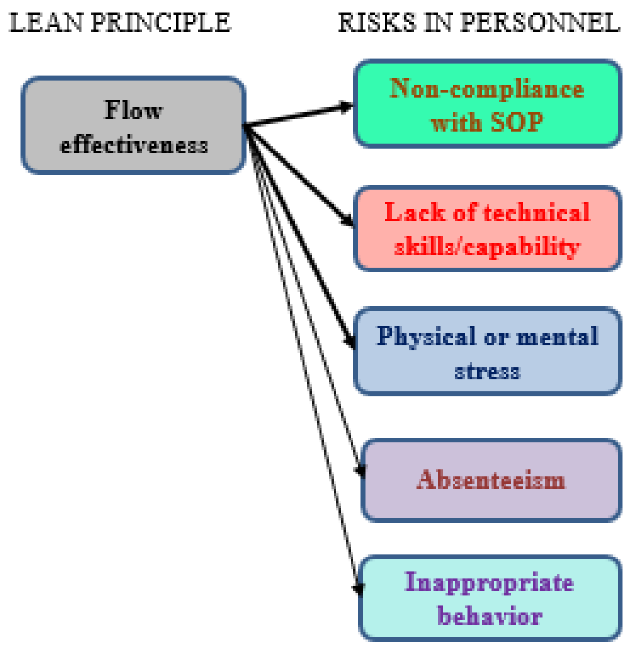


**Figure 4.11:** Validated Structural Network for the Risks in Personnel.

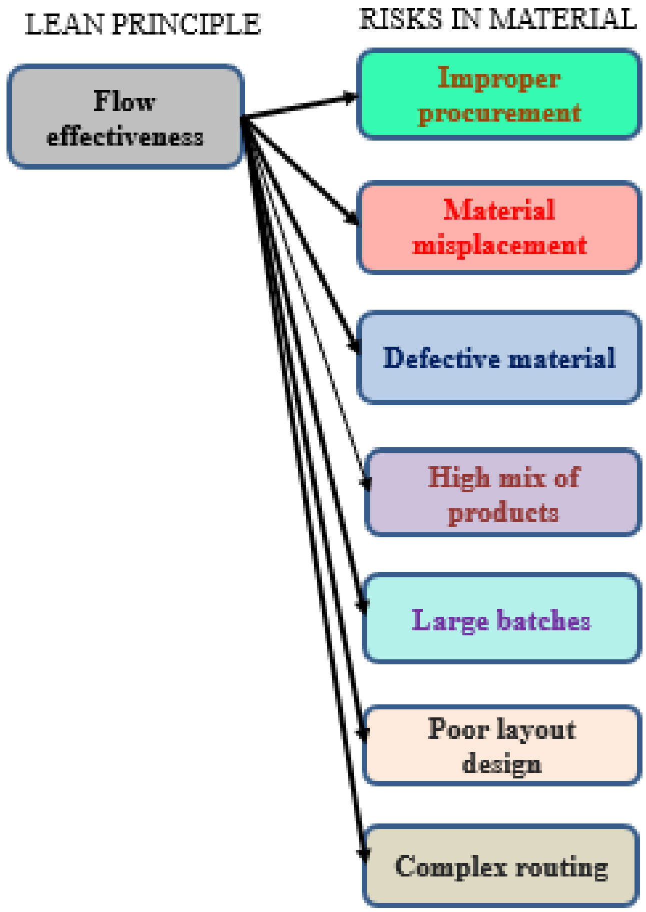


**Figure 4.12:** Validated Structural Network for the Risks in Material.

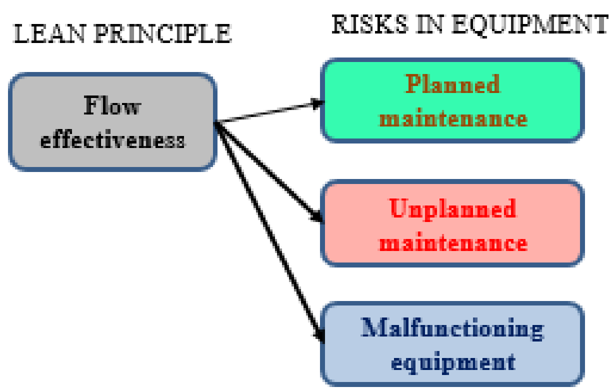


**Figure 4.13:** Validated Structural Network for the Risks in Equipment.

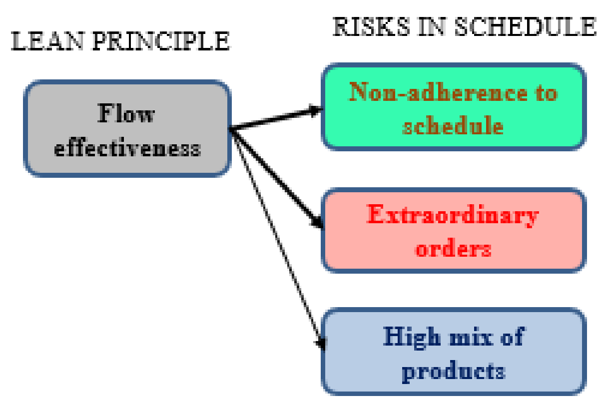


**Figure 4.14:** Validated Structural Network for the Risks in Schedule.

## 4.9 Mapping of Risks with Skills

A literature survey was performed to determine the skills required for shop floor personnel. The survey was carried out on various databases, such as Scopus, Google Scholar, and ISI Web of Knowledge. A total of 25 articles were used for the assessment, which focused on capturing skills associated with the most commonly used lean tools/techniques (e.g., cell layout, single-minute exchange of dies(SMED), total productive maintenance, scheduling). These skills were matched with the nine dimensions in Toyota's model of 'recruitment and selection process'. The aim of the survey was to determine, the most commonly used skills in shop floor personnel. The frequency of each skill was measured. The most repeated skills were Teamwork (16), Initiative (14), Communication (14), Attention to detail (11) and Flexibility (10), as shown in Figure 4.15. However, the frequency rate was categorized as high value instead of very high. The highest value was only 16 out of 25 studies, which included the mentioned skill sets as part of the study. Skills with a frequency of less than four were omitted from the study. The study reported the most common and most useful skills.

| Toyota Dimension | Factors (Skill Sets) | *Frequency in Lean literature |
|---|---|---|
| Team Orientation | Teamwork | **16(H)** |
| | Co-operation | 7(VL) |
| | Collaboration | 4(VL) |
| Initiative | Initiative | **14(H)** |
| | Sense of Belonging(Ownership) | 5(VL) |
| Oral Communication | Communication | **14(H)** |
| Problem Identification | Input | 3(VL) |
| Problem Solution | Problem-Solving | 9(VL) |
| Practical Learning | Quick Learner | 4(VL) |
| | Attention to Details | 11(L) |
| Work Tempo | Objective | 3(VL) |
| Adaptability | Flexibility | 10(L) |
| Mechanical Ability | Multi-Skilled | 7(VL) |

*Frequency scale: 1 to 7 = Very Low (VL); 8 to 13 = Low (L); 14 to 19 = High (H); 20 to 25 = Very High (VH)

**Figure 4.15:** Literature Survey Model.

The necessary skills, namely Teamwork, Initiative, Communication, Attention to Details and Flexibility, were then mapped with the previously identified and validated people-related risks namely Non-compliance with Standard Operating Procedures, Lack of technical skills/capability, Physical or mental stress, Absenteeism and Inappropriate behavior using the Analytic Hierarchy Process (AHP) technique.
AHP is an effective method for eliciting expert knowledge for analyzing complex decision problems under multiple criteria (Saaty, 1995). The goal of this study is to determine the skills required in personnel for resolution of people-related risks in a lean system (See Figure 4.16). The skills are evaluated as alternatives over different people-related risk criterion to determine important skills and the relative importance of all skills under consideration.

This study was carried out by surveying a specialized group of lean practitioners

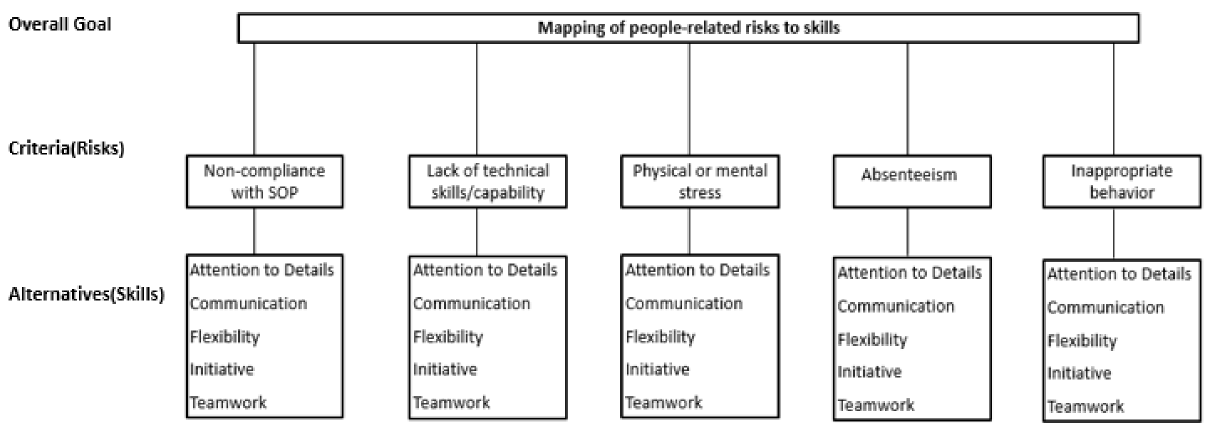


**Figure 4.16:** Mapping of Risks to Skills Decision.

in one of the manufacturing plants in Knoxville. The sample size used to carry out this study was eight responses. The appropriate sample size needed to run AHP in a survey based study can range from 5-9000 based on the target population interested in the criteria and the margin of error desired for carrying out the study (Barlett et al., 2001). The rating category used for this study was from 1-9, where 1 indicated the least level of importance and 9 indicated the highest level of importance based on the scale of relative importance (Saaty, 1995).(See Table 4.11.)

**Table 4.11:** Scale of Relative Importance (Source: Saaty,1980)

| Intensity of Importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Weak importance of one over another |
| 5 | Essential or strong importance |
| 7 | Demonstrated importance |
| 9 | Absolute importance |
| 2,4,6,8 | Intermediate values between the two adjacent judgments |
| Reciprocals of one above non-zero | If activity i has one of the above non-zero numbers assigned to it when compared to activity, then j has reciprocal value when compared to i |

The priority ranking for skill alternatives were computed and pairwise comparison matrices were generated using the Super Decisions AHP software. There were five pairwise comparison matrices in all, each one for the five alternatives with respect to all the five people-related risk criteria. The results of the pairwise comparison matrices are shown in the Table 4.12 to 4.16 below.

**Table 4.12:** Results of Pairwise Comparison Matrix for the Skill Alternatives with respect to the People-Related Risk Criteria; Non-Compliance with Standard Operating Procedures.

| Alternatives | Normalized | Idealized |
|---|---|---|
| Attention to details | 0.1202 | 0.4149 |
| Communication | 0.2896 | 1 |
| Flexibility | 0.2541 | 0.8774 |
| Initiative | 0.2157 | 0.7449 |
| Teamwork | 0.1202 | 0.4149 |

**Table 4.13:** Results of Pairwise Comparison Matrix for the Skill Alternatives with respect to the People-Related Risk Criteria; Lack of Technical Skills/Capability.

| Alternatives | Normalized | Idealized |
|---|---|---|
| Attention to details | 0.1867 | 0.5656 |
| Communication | 0.1867 | 0.5656 |
| Flexibility | 0.3301 | 1 |
| Initiative | 0.1867 | 0.5656 |
| Teamwork | 0.1096 | 0.3322 |

**Table 4.14:** Results of Pairwise Comparison Matrix for the Skill Alternatives with respect to the People-Related Risk Criteria; Physical or Mental Stress.

| Alternatives | Normalized | Idealized |
|---|---|---|
| Attention to details | 0.1867 | 0.5656 |
| Communication | 0.1867 | 0.5656 |
| Flexibility | 0.3301 | 1 |
| Initiative | 0.1867 | 0.5656 |
| Teamwork | 0.1096 | 0.3322 |

**Table 4.15:** Results of Pairwise Comparison Matrix for the Skill Alternatives with respect to the People-Related Risk Criteria; Absenteeism.

| Alternatives | Normalized | Idealized |
|---|---|---|
| Attention to details | 0.2857 | 1 |
| Communication | 0.1428 | 0.5 |
| Flexibility | 0.1428 | 0.5 |
| Initiative | 0.2857 | 1 |
| Teamwork | 0.1428 | 0.5 |

**Table 4.16:** Results of Pairwise Comparison Matrix for the Skill Alternatives with respect to the People-Related Risk Criteria; Inappropriate Behavior.

| Alternatives | Normalized | Idealized |
|---|---|---|
| Attention to details | 0.2715 | 1 |
| Communication | 0.1361 | 0.5011 |
| Flexibility | 0.1361 | 0.5011 |
| Initiative | 0.2387 | 0.8792 |
| Teamwork | 0.2174 | 0.8009 |

The pairwise comparison matrix for the risk criterion Non-compliance with Standard Operating Procedures indicates that Communication is the most important soft skill required in personnel for resolving the risk of Non-compliance with Standard Operating Procedures. On similar lines, the most important skill for a particular risk criterion is summarized in the Table 4.17 below.

**Table 4.17:** Comparing the Rating Result.

| Risk Criterion | Skill Alternatives | Idealized |
|---|---|---|
| Non-compliance with SOP | Communication | 0.2896 |
| Lack of technical skills/capability | Flexibility | 0.3301 |
| Physical or mental stress | Flexibility | 0.3301 |
| Absenteeism | Attention to details, Flexibility | 0.2857 |
| Inappropriate behavior | Attention to details | 0.2715 |

The overall synthesized priorities for all the skill alternatives are obtained as shown in Figure 4.17.

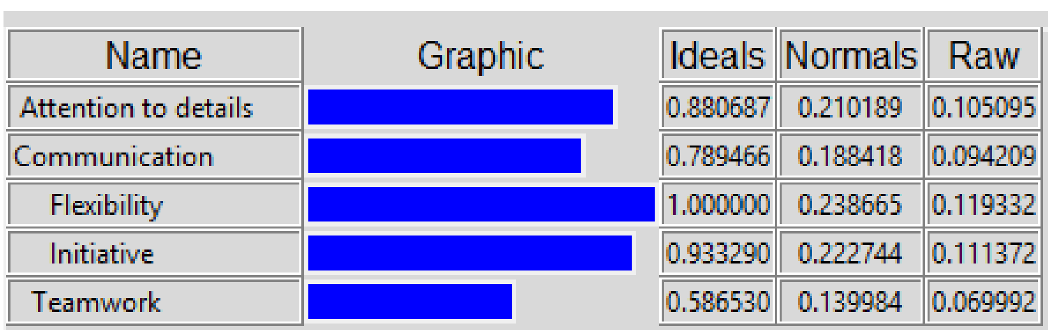


**Figure 4.17:** Output Graph for the Synthesized Priorities.

The most important skill is Flexibility. The skills in order of importance are as follows:

1. Flexibility

2. Initiative

3. Attention to Details
4. Communication
5. Teamwork

The alignment of all people-related risks, with their respective skills, ensures the successful resolution of these risks. This alignment helps an organization sustain its lean implementation efforts. As a result, the personnel working in the organization are empowered and engaged to participate in achieving continuous improvement.

# Chapter 5

# Conclusion & Future Work

This chapter summarizes the thesis, laying out the key contributions of the work and proposing the areas for future improvements.

## 5.1 Summary of Research

The main purpose of the thesis is to develop a conceptual model for enhancing the operation of a lean system by studying the risks for lean system sustainability and the necessary skills required in shop floor personnel to deal with these risks. The technical requirements of the lean system are analyzed using the functional classification of the Toyota Production System (TPS) into six subsystems; namely Operations Fundamentals, Enhancing Workplace Capability in Design, Standard Operations, Consistency, Flow and Production Scheduling and Motion. The precedence-based structures are developed for each subsystem. These structures propose the order of implementation of the lean activities/tools within each subsystem and help in understanding the step-wise evolution of the lean system.

The risks affecting the operation of the lean subsystems are identified and categorized into four critical components of reliability: Personnel, Material, Equipment and Schedule. The risk analysis in terms of Personnel, Material, Equipment and Schedule helps practitioners design and improve the reliability of the lean systems. This study examined the interaction between the lean principle of continuous flow and the risks affecting the flow by constructing and using a survey questionnaire. The eighteen risk factors obtained from risk analysis were validated by surveying lean experts from manufacturing industries. Thirteen risk factors were found to have a significant relationship with flow effectiveness in the lean system. This study focused on the key personnel-related risks: Non-compliance with Standard Operating Procedures, Lack of technical skills/capability, Physical or mental stress, Absenteeism and Inappropriate behavior.

The skills required to mitigate these risks were identified using a literature survey. The Toyota model of 'recruitment and selection process' was used as a reference for integrating the skills in personnel into the lean design. A Lean Personnel Alignment Model (LPAM) model was developed to align the skills in personnel with the requirements of the lean system. The necessary skills in shop floor personnel are Flexibility, Initiative, Attention to details, Communication and Teamwork. The alignment of these people skills, with the requirements of the lean system, ensures the sustained implementation of the lean system.

## 5.2 Key Contributions

The research leads to many contributions in the area of lean sustainability and personnel engagement. These contributions will result in the design of improved lean systems with higher productivity, improved quality , lesser costs and also lead to employee satisfaction and retention. Additionally, the researcher presents a Lean Personnel Alignment Model (LPAM) which aligns the personnel requirements with the lean system requirements. The key contributions are explained as follows:

1. Presented the classification of the Toyota Production System (TPS) into six subsystems which helps to understand the functional requirements of the lean system, order of implementation of lean activities/tools within each subsystem and also to identify all the risks for lean subsystem sustainability.

2. Determined the key risks for lean system sustainability and categorized them into Personnel, Material, Equipment and Schedule components respectively. This helps researchers design reliable lean systems.

3. Identified the important soft skills required in shop floor personnel to overcome the people-related risks in a manufacturing setup. This aids in the resolution of people-related risks with improved employee engagement.

4. Developed a Lean Personnel Alignment Model (LPAM) which aligns the soft skills in personnel with the requirements of the lean system. Companies can design skill-based assessments based on the LPAM to recruit employees with appropriate skills.

## 5.3 Further Research

The developed LPAM model can be further extended to incorporate the interactions between the risks affecting the lean subsystems. The risks impacting the Personnel, Material, Equipment and Schedule components can be studied in depth to analyze the impact of the personnel-related risks on the Material, Equipment and Schedule components respectively. The mapping of the personnel- related risks, with specific skill sets, can be validated practically by carrying out a case-study on a large sample in an organization. A well-designed skill-based assessment for shop floor workers would capture the skills required by them on a daily basis, indicate them about their strengths and also suggest areas of improvement.

These assessments would allow organizations to fine tune their training initiatives, increase productivity and narrow their performance gap by identifying the core skills required by workers to fulfill their work responsibilities. The skill-based assessments would have to be designed in a way to test both the technical and the soft skills in personnel but primarily focus on the job-specific skills.

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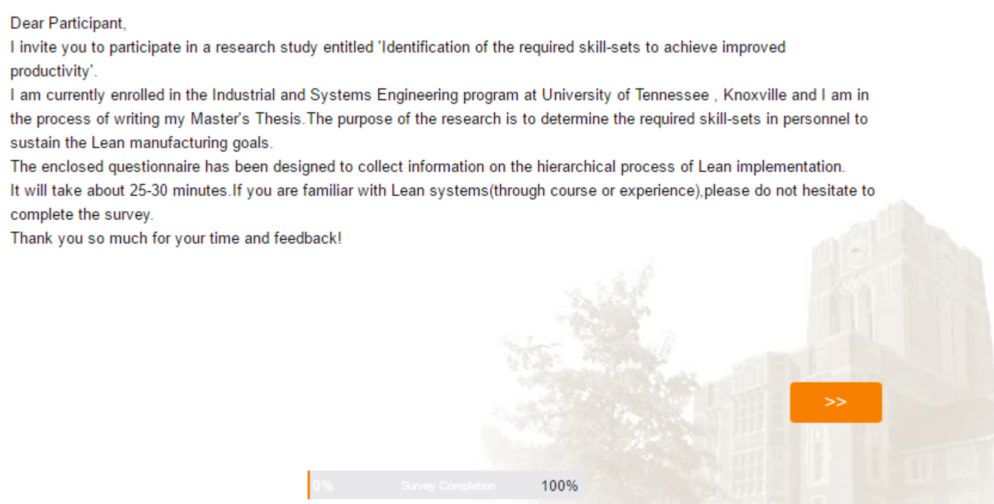
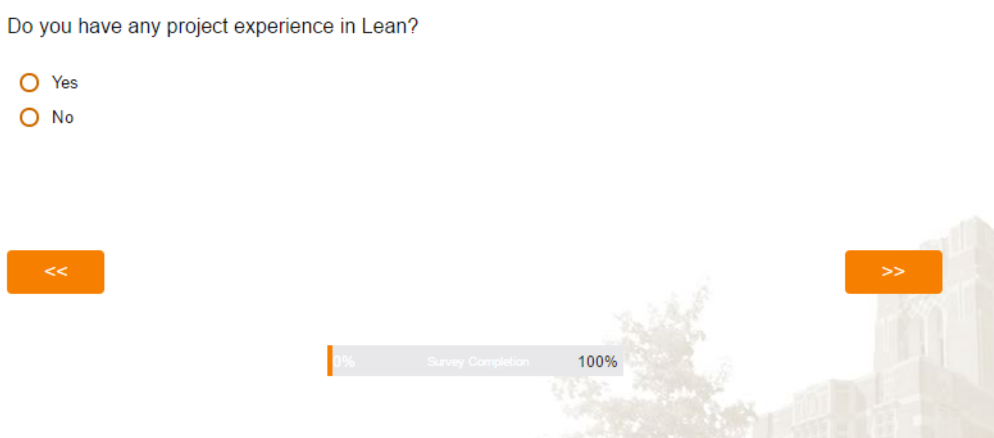
# Appendix

# Appendix A


Dear Participant,
I invite you to participate in a research study entitled 'Identification of the required skill-sets to achieve improved productivity'.
I am currently enrolled in the Industrial and Systems Engineering program at University of Tennessee , Knoxville and I am in the process of writing my Master's Thesis.The purpose of the research is to determine the required skill-sets in personnel to sustain the Lean manufacturing goals.
The enclosed questionnaire has been designed to collect information on the hierarchical process of Lean implementation.
It will take about 25-30 minutes.If you are familiar with Lean systems(through course or experience),please do not hesitate to complete the survey.
Thank you so much for your time and feedback!

>>

0% Survey Completion 100%


Do you have any project experience in Lean?

- Yes
- No

<< >>

0% Survey Completion 100%

1.To run a smooth production/manufacturing line, essential resources are categorized into Personnel, Material, Equipment and Schedule. On a scale of 1-5, please rate each of the following **personnel-related causes** that may disrupt the flow(smooth production).

| | 1-strongly disagree | 2-disagree | 3- somewhat agree | 4-agree | 5-strongly agree |
|---|---|---|---|---|---|
| Irresponsibility | | | | | |
| Lack of technical skills/capability | | | | | |
| Physical or mental stress | | | | | |
| Absenteeism | | | | | |
| Inappropriate behavior | | | | | |

Name a few more

2.To run a smooth production/manufacturing line, essential resources are categorized into Personnel, Material, Equipment and Schedule. On a scale of 1-5, please rate each of the following **material-related causes** that may disrupt the flow(smooth production).

| | 1-strongly disagree | 2-disagree | 3- somewhat agree | 4- agree | 5-strongly agree |
|---|---|---|---|---|---|
| Improper procurement | | | | | |
| Material misplacement | | | | | |
| Defective material | | | | | |
| High mix of products | | | | | |
| Large batches | | | | | |
| Poor layout design | | | | | |
| Complex routing | | | | | |

Name a few more

3.To run a smooth production/manufacturing line, essential resources are categorized into Personnel, Material, Equipment and Schedule. On a scale of 1-5, please rate each of the following **equipment-related causes** that may disrupt the flow(smooth production).

| | 1-strongly disagree | 2-disagree | 3- somewhat agree | 4- agree | 5-strongly agree |
|---|---|---|---|---|---|
| Planned maintenance/changeover | ○ | ○ | ○ | ○ | ○ |
| Unplanned maintenance(machine breakdown) | ○ | ○ | ○ | ○ | ○ |
| Malfunctioning machine/equipment(Off parameters) | ○ | ○ | ○ | ○ | ○ |

Name a few more

4.To run a smooth production/manufacturing line, essential resources are categorized into Personnel, Material, Equipment and Schedule. On a scale of 1-5, please rate each of the following **schedule-related causes** that may disrupt the flow (smooth production).

| | 1-strongly disagree | 2- disagree | 3- somewhat agree | 4-agree | 5-strongly agree |
|---|---|---|---|---|---|
| Non-adherence to schedule | ○ | ○ | ○ | ○ | ○ |
| Extraordinary orders | ○ | ○ | ○ | ○ | ○ |
| High mix of products | ○ | ○ | ○ | ○ | ○ |

Name a few more

5.What is your age?

- 25 or under
- 26-40
- 41-55
- 56 or older

6.What is the highest level of education you have completed?

- High school/equivalent
- Bachelor's degree
- Master's degree
- Professional degree
- Doctorate degree

Other

7.Which of the following categories best describes your primary area of employment(regardless of your actual position)?

- Communications/Media Entertainment
- Construction
- Education
- Energy
- Finance and Insurance
- Government and Public administration
- Health care and Social assistance
- Homemaker
- Hotel and Food services
- Information -services and data
- Information-Other
- Legal services
- Manufacturing-Computer and Electronics
- Manufacturing-Other
- Mining and quarrying
- Publishing
- Transport and Warehousing
- Wholesale trade and retail

Other

8.Which of the following best describes your role in industry?

- ☐ Upper management
- ☐ Middle management
- ☐ Junior management
- ☐ Administrative staff
- ☐ Support staff
- ☐ Trained professional
- ☐ Skilled laborer
- ☐ Consultant
- ☐ Temporary employee
- ☐ Researcher
- ☐ Self employed

Other

We thank you for your time spent taking this survey.
Your response has been recorded.

0% Survey Completion 100%

THE UNIVERSITY of TENNESSEE
KNOXVILLE
Office of Research & Engagement
INSTITUTIONAL REVIEW BOARD (IRB)

1534 White Ave.
Knoxville, TN 37996-1529
865-974-7697
fax 865-974-7400

December 07, 2016

Rupy S Sawhney,
Anju Bagre
UTK - Biological Sciences

**Re: UTK IRB-16-03214-XM**
**Study Title:** Identification of the required skill-sets in personnel for the implementation of a Lean system in a manufacturing setup.

Dear Rupy Sawhney and Anju Bagre:

The UTK Institutional Review Board (IRB) reviewed your application (version 1.1) for the above referenced project, and contacted you for more information regarding these data you collected before having IRB approval. The IRB has had the opportunity to review the email correspondence you submitted, as well as the attached recruitment email, consent, and survey documents you used. While the IRB would not have approved the recruitment and consent materials in the forms you used them, we have determined that your participants were not exposed to risks greater than those that meet the threshold for Exempt certification, and **you have approval for the use of your existing data under 45 CFR 46 Category 4.**

**Please note that this approval is for analysis of your existing data only.** If you wish to collect additional data, you must submit a new Form 1 Application to the IRB before you may begin any research activity.

Any alterations (revisions) in the protocol must be promptly submitted to and approved by the UTK Institutional Review Board prior to implementation of these revisions. You have individual responsibility for reporting to the Board in the event of unanticipated or serious adverse events and subject deaths.

In future, please be very careful to submit your application to the IRB before you begin recruiting participants, in order to avoid possible violations of human subject procedures.

Sincerely,

Colleen P. Gilrane

**Colleen P. Gilrane, Ph.D.**
Chair

# Vita

Anjushree Bangre was born in Bangalore, India. She received her Bachelor of Engineering degree in Industrial Engineering and Management in May 2014 from Bangalore Institute of Technology, India. Anjushree worked as a Graduate Research Assistant for Dr.Rupy Sawhney in the Industrial and Systems Engineering Department of the University of Tennessee, Knoxville from August 2014 to April 2017. Currently, she is employed as a Process Engineer EDP at Novelis in Greensboro, Georgia where she is responsible for process control and product quality. She will be graduating with a Master of Science degree in Industrial and Systems Engineering and a Minor degree in Statistics in May 2018.