The impact of lean methods and tools on the operational performance of manufacturing organisations

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Abstract
Evidence suggests that lean methods and tools have helped manufacturing organisations to improve their operations and processes. However, the real effect of these methods and tools on contemporary measures of operational performance, i.e., cost, speed, dependability, quality and flexibility is still unclear. This paper investigates the impact of five essential lean methods, i.e., JIT, autonomation, kaizen, TPM, and VSM on these measures. A linear regression analysis modelled the correlation and impact of these lean practices on the operational performance of 140 manufacturing organisations around the world. In addition, structural equation modelling (SEM) was used to cross verify the findings of the regression and correlation analyses. The results indicate that JIT and automation have the strongest significance on operational performance while kaizen, TPM, and VSM seem to have a lesser, or even negative, effect on it. This paper provides further evidence regarding the effects that lean practices have on the performance of organisations and thus the research offers companies, and their managers, a better understanding of the relationship between the lean strategy and the performance of their operations.

Keywords: autonomation, JIT, kaizen, lean methods, measures of operational performance, SEM, TPM, VSM.

1. Introduction

With the contemporary market being more and more competitive worldwide, manufacturing organisations are under immense pressure to pursue operational excellence and improve their performance in order to reduce their costs and provide products of higher quality in shorter lead times. Lean manufacturing principles and techniques have been widely used by manufacturing organisations to achieve these and gain a competitive advantage over their rivals (Garza-Reyes *et al.*, 2012). Lean manufacturing is a management approach to manufacturing that strives to make organisations more competitive in the market by increasing efficiency and decreasing costs through the elimination of non-value added steps and inefficiencies in the process (Sohal and Egglestone, 1994; Garza-Reyes *et al.*, 2012).

Various methods and tools that aim to improve the operational performance of organisations are comprised under the lean strategy's umbrella (Bhasin, 2012). In particular, Rocha-Lona *et al.* (2013) consider Just-in-Time (JIT), total productive maintenance (TPM), autonomation, value stream mapping (VSM), and kaizen/continuous improvement (CI) as the most essential methods of the lean approach. JIT is a method which states that an organisation should produce the right item at the right time (Womack and Jones, 2003); this helps in reducing inventories, space utilisation and possible wastes. The most commonly associated tools of JIT are one piece flow, pull system, takt time, cell manufacturing, levelled production, kanban, visual control, multifunctional employees, and JIT purchasing (Rocha-Lona *et al.* 2013; Kumar, 2010; McLachlin, 1997). In the case of TPM, it is a lean manufacturing method that contributes to the optimisation of predictive, preventive and corrective maintenance activities in order to achieve the maximum level of efficiency and profit from production equipment (Brah and Chong, 2004). To achieve this, TPM relies on tools such as overall equipment effectiveness (OEE), single minute exchange of die (SMED), 5S, autonomous maintenance, quality maintenance, initial control before starting production, and a safety and hygiene environment (Rocha-Lona *et al.*, 2013; Brah and Chong, 2004). Autonomation, also known as jidoka, is a lean method that targets the reduction of quality defects with the use of tools that include mistake proofing devises (i.e. poka-yokes), visual control systems (i.e. andons) and a full working system (Shingo, 1986). In the case of VSM, it is a lean manufacturing method that visually identifies and measures waste resulting from the inefficiencies, unreliability and/or incapability of information, time, money, space, people, machines, material and tools during the transformation process of a product (Pavnaskar *et al.*, 2003). Rocha-Lona *et al.* (2013) considers the current and future value stream maps and flow diagrams as the most commonly used tools employed during a VSM analysis. Finally, kaizen, or CI, is one of the most important processes in a lean organisation. The focus of kaizen is on the elimination of waste through the continuous and incremental improvement of processes. Once embedded as part of an organisation's culture, kaizen acts as a platform for the sustainment of lean initiatives (Imai, 2012). Rocha-Lona *et al.* (2013), Bhuiyan and Baghel (2005) and Lyu (1996) suggest 5S, brainstorming, continuous flow, kanbans, data check sheet, five whys, run charts, Pareto chart, VSM, Gantt chart, mistake proofing and process maps as those tools that most commonly contribute to the kaizen strategy. Table 1 presents a summary of the most essential methods of lean manufacturing and the tools comprised under their umbrella.

Insert Table 1 in here

Several decades have passed since the initial conception of lean manufacturing. Since then, evidence has suggested it as an effective approach to improve the performance of organisations (Forrester *et al.*, 2010). For this reason, a broad portfolio of academic research (see Section 2) has been dedicated to investigate the impact of its methods and tools on various measures of performance. However, due the nature of the research conducted, the overall effect of lean methods and tools on operational performance may still be considered unclear. For example, the research discussed in Section 2 and summarised in Table 2 has been mainly focused on very specific lean methods and tools; that is, it has not included all the essential components (i.e. JIT, TPM, autonomation, VSM and kaizen/CI) strongly associated to the lean approach nowadays. Similarly, the measures of performance selected to investigate the effects of lean practices vary considerably from some researches to others. Thus, to complement these studies and support the body of knowledge on the effects that lean manufacturing has on the performance of organisations, this paper investigates the impact of the main methods and tools of lean manufacturing on what Ahmad and Schroeder (2003), Slack *et al.* (2013) and Hill (1989) consider the most important contemporary measures of operational performance, i.e., cost, speed, dependability, quality, and flexibility.

2. Lean manufacturing and its impact on performance

When measuring the impact of lean practices, different authors have tried to connect and reflect the combined effect of these practices into one indicator (Bayou and Korvin, 2008), now popularly known as "leanness". In this context, Bayou and de Korvin (2008) developed a model that measures the level of leanness using lean attributes such as JIT, quality control, and kaizen. Bayou and de Korvin (2008) used this model to compare the level of leanness of General Motors and Ford using Honda as a benchmark company. From the financial statements of these companies, they concluded that Ford was 17 percent leaner than General Motors. Soriano-Meier and Forrester (2002) developed a model with nine variables to measure the degree of leanness of manufacturing organisations. The model has been used to measure the degree of leanness of the UK ceramic sector (Soriano-Meier and Forrester, 2002) and the agricultural machining sector of Brazil (Forrester *et al.*, 2010). Anvari *et al.* (2013) examined the impact of specific influences on the leanness of a manufacturing system. They found that the most crucial components to leanness are defects, cost, lead time, and value. Moreover, in their study Anvari *et al.* (2013) developed a method to evaluate the impact of specific lean attributes on leanness. Wan and Chen (2008) proposed a measure to evaluate the overall leanness level of an organisation having a self-contained benchmark. In their model, Wan and Chen (2008) considered cost, value, and time in order to evaluate leanness. Finally, Vinodh and Vimal (2012) developed a model that measures the level of leanness based on thirty criteria and by using a fuzzy logic approach.

However, although the level of leanness is related to the performance of an organisation, various authors have investigated the impact of lean manufacturing practices not based on an overall and combined indicator but on certain individual measures. Table 2 presents a summary of this research. In reference to Table 2, Rahman *et al.* (2010) developed a model in order to measure the impact that the implementation of lean practices has on the operational performance of Thai manufacturing organisations. They found that all the three constructs studied (i.e. JIT, waste minimisation and flow management) have a significant impact on their operational performance. However, JIT has a higher importance for large companies compared to SMEs, whereas waste minimisation affects more SMEs compared to large organisations. Shah and Ward (2007) developed a method to measure lean production and provided a framework which identified its most important dimensions (see Table 2). In a different study, Shah and Ward (2003) examined the effect on operational performance of the lean practices and contextual factors presented in Table 2. Shah and Ward (2003) found that JIT, Total Quality Management (TQM), TPM, and Human Resource Management (HRM) are positively related to operational performance. However, these only represented 23 percent of the effect related to the overall operational performance. Moreover, they identified that there is no effect of unionisation on operational performance. In terms of the size and age of the plant, it was found that it is not always advantageous that large size will lead to higher operational performance and that in many cases, large size has a negative impact on the operational performance when the effects of JIT, TQM, TPM, and HRM are taken into consideration. Bhasin (2012) adopted a Balanced Scorecard to measure the financial and operational efficiency levels of an organisation during the implementation of lean. His study found that large organisations that implemented lean manufacturing achieved higher improvements in their performance compared to SMEs. Cua *et al.* (2006) suggested that there are important variations in manufacturing performance, which are related to the level of adoption of the lean techniques, practices, and other coherent factors they studied and categorised (see Table 2). In summary, Cua *et al.* (2006) found that JIT, TPM, and TQM positively and significantly affect quality, cost, flexibility, and delivery.

Insert Table 2 in here

In another study, Taj and Morosan (2011) examined the impact that lean operations have on the performance of Chinese manufacturing companies. Specifically, they studied the effect that the lean operation practices presented in Table 2 had on the operational performance measures of flow, quality and flexibility. They found that supply chains, human resources, and design of production systems have remarkable positive effects on the flexibility and flow measures while quality is only related to the design of the production system. The relationship between some JIT activities and performance was studied by Lawrence and Hottenstein (1995) (see Table 2). In contrast to the findings of Sakakibara *et al.* (1997), Lawrence and Hottenstein (1995) concluded that JIT is related to superior performance. Thun *et al.* (2010) found that the higher the degree of implementation of lean manufacturing practices, the better the performance is. Bortolotti *et al.* (2013) studied the effect that demand variability and product customisation have on JIT practices and how this further impacts operational performance; they used the practices and measures shown in Table 2. Demand variability and product customisation are two characteristics that are related to manufacturing repetitiveness and the degree of repetitiveness can negatively affect the effect of JIT on performance. Bortolotti *et al.* (2013) found that JIT has a positive effect on operational performance, which is not affected from the level of product customisation and that demand variability has a significant impact on organisational performance, in terms of responsiveness and efficiency. Searcy (2009) developed a lean performance score and measured lean performance taking into account the five elements presented in Table 2. Searcy (2009) considered the measurement of the lean transformation as a key element for its success.

Furthermore, Fullerton and Wempe (2009) developed a model where they show the connection of non-financial measures to lean practices and the combined effect that these have on the financial performance of an organisation. Fullerton and Wempe (2009) found that non-financial manufacturing performance measures mediate the relation between the financial performance and lean manufacturing practices. They also found that the lean practices they tested (see Table 2) had varied and direct effects on profitability. Hallgren and Olhager (2009) studied lean and agile manufacturing and evaluated them according to the impact that they have on specific indicators that measure the operational performance of an organisation (see Table 2). They found that the most significant differences between the lean and agile manufacturing concepts were that lean affects at a large scale cost performance while agile manufacturing has a significant impact on volume and product mix flexibility, which lean does not. Behrouzi and Wong (2011) developed a measurement model using fuzzy membership values, and the lean practices and measures shown in Table 2. Behrouzi and Wong (2011) suggested that based on the value of a performance's score; managers could obtain an overview of the effectiveness of the manufacturing strategies. Rivera and Chen (2007) proposed the use of cost-time profile, which is a tool that evaluates the cumulative cost in the production of a product as time passes, in order to evaluate the impact that lean tools have on the cost-time investment of a product. In this way, they highlighted the economic impact that the reduction of waiting time, durations of activities, reduction of material, and JIT materials have as a result of the application of lean manufacturing tools. Dora *et al.* (2013) examined the application of lean manufacturing and its impact on operational performance measures, shown in Table 2, in some SMEs of the food processing industry. Dora *et al.* (2013) found that productivity and quality showed the highest improvement due to the implementation of lean. In addition, the analysis revealed significant differences, in the improvement of the operational measures studied, among the countries where lean was implemented.

Hofer *et al.* (2012) investigated the impact that lean production has on the financial performance of an organisation and the mediating role of inventory leanness on proving the economic benefits associated with the deployment of a lean strategy. Moreover, they examined the effect of internal and external lean practices on performance and whether the effect is greater if they are implemented concurrently. For this purpose they classified lean practices as internal and external, as presented in Table 2. Hofer *et al.* (2012) found that inventory plays a significant role in the relationship between financial performance and lean production. Furthermore, they found that external lean practices do not have a significant direct effect on financial performance, but that external lean practices affect the inventory leanness. Karim and Arif-Uz-Zaman (2013) developed a method which evaluates the performance of lean manufacturing using continuous performance measurement. They found that the method they proposed contributed to the selection of the most appropriate lean tools and the identification of relevant performance indicators. Moreover, they concluded that the continuous performance measurement matrices are effective methods for the continuous evaluation of lean manufacturing performance. Finally, Sakakibara *et al.* (1997) investigated the effect of JIT and its infrastructure on operational performance and the competitive advantage. They used in their survey the six JIT practices and measures of performance shown in Table 2. Sakakibara *et al.* (1997) found that the effect of JIT practices on the operational performance of an organisation was not significant. However, the results showed the significant connection between infrastructure and JIT practices, and the combined approach of JIT management and infrastructure practice and impact that this connection have on operational performance. Furthermore, they found that infrastructure could explain the level of operational performance and that competitive advantage was strongly related to the operational performance.

Unlike these studies, the research presented in this paper investigates the effect of JIT, TPM, autonomation, VSM and kaizen/CI, which are considered cornerstones of the lean strategy on the most important measures of operational performance, i.e., cost, speed, dependability, quality and flexibility. Thus, this study aims at not only complementing the previous research in this area but also expanding its reach and scope.

3. Research methodology

To evaluate the effect of lean manufacturing on operational performance, the relationship between the measures studied (i.e. dependent variable - Y_i) was established as an accumulation of a number of explanatory independent variables (i.e. lean methods - X_n), where each of them had its own role and effect on the dependent variable. Such relationship is represented by the following regression model and the variables presented in Table 3.

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_4 i + \beta_5 X_{5i} + e_i \qquad (1)$$

Insert Table 3 in here

The data collection for the regression model was carried out through a survey questionnaire designed by using the SNAP computer software (Saunders *et al.*, 2009). The questionnaire consisted of two main sections. Section 1 comprised a set of general questions related to the organisation's size, location and industrial sector where the respondent company competed as well as the respondent's position. In the case of section 2, it was focused on investigating whether the participating companies had experienced, based on the perception of the respondent, some degree of improvement in relation to the measures of operational performance studied after the implementation of the lean methods considered within this investigation. Initially, the respondents were asked which of the tools (see Table 1), for every one of the five lean methods studied, their organisations had implemented. For example, if a company had implemented four out of the nine tools that comprised JIT, then the extent of implementation of JIT (X_1) was considered to be .444. This helped to measure the extent of implementation for every lean method (X_n). Subsequently, the respondents were asked to estimate the percentage of improvement achieved for every operational indicator (i.e. cost, speed, dependability, quality and flexibility - Y_i). This was measured by using a Likert scale from 0 percent to 100 percent, with increments of 5 percent (i.e. 0, 5, 10, 15, etc.) for every one of the measures studied. See Figure 1 for an example of some of the key questions included in the questionnaire survey. Six different regressions, one for every dependable variable Y_i (i.e. quality-Y_1 or speed-Y_2 or dependability-Y_3 or flexibility-Y_4 or cost-Y_5) plus one for overall operational performance (Y_0) were run as indicated in Table 3. In order to reduce the degree of subjectivity of the study, the survey targeted respondents that included quality directors/managers, lean six sigma black belts, or executives that had knowledge on the subject. This type of respondents was considered to have a deeper and more accurate understanding of the company's performance before and after the implementation of lean. In addition, the respondents were initially briefed about the Likert scale, and some other aspects of the questionnaire that included the definition of the lean concepts, methods and tools included, in order to obtain more uniform and less subjective answers. The questionnaires were anonymous in order to protect the respondent's own personal privacy, integrity and interests. This strategy helped to avoid/minimise any possible biased answer as suggested by Robson (2002) and Saunders *et al.* (2009). In terms of the time that it had taken the surveyed organisations to reach and/or sustain the improvements achieved, this was not considered within this study due to the complexity of adding an extra variable (i.e. time) to the analysis. The inclusion of this "extra-variable" can be considered as part of the agenda for further research proposed from this work. Before being distributed, the questionnaire was validated through a small pilot study (Robson, 2002) that consisted in distributing the questionnaire to four experts. The objective of this was to eliminate irrelevant and ambiguous questions, receive feedback on the questionnaire's logic, add extra relevant questions if necessary, and check its language and presentation.

Insert Figure 1 in here

The questionnaires were randomly distributed via e-mail to 710 organisations that were perceived, after reviewing their official websites, annual reports and press releases, as having implemented lean. The companies were identified from data bases such as Amadeus, Marketline and LinkedIn. When contacted, the respondents were initially asked whether their organisations had embarked in the implementation of lean and whether they considered it as the main operations improvement strategy employed by their companies. If the answer was "no" to any of these two questions, then the organisation was not considered suitable for the study. On the other hand, if the answer was "yes" to both of these questions, then the questionnaire was administrated to the respondent. Out of the 710 questionnaires that were sent, 141 answers were received, but 1 was eliminated for being incomplete. Thus, the sample available for analysis was 140 responses, which corresponded to a response rate of 20 percent. Although the response rate did not reach the range of between 30 to 35 percent perceived by Cohen *et al.* (2007) and Watt *et al.* (2002) as acceptable, based on comparable sample sizes used on similar researches (i.e. Thun *et al.*, 2010; Rahman *et al.*, 2010; Bhasin, 2012), this response rate was still considered acceptable to carry out a reliable analysis and drawn conclusions to complement the studies discussed in Section 2.

The computation of the linear regression and correlation analyses was carried out using the advanced statistical software EViews and SPSS. In the case of the structural equation modelling (SEM) analysis, it was conducted using the AMOS software. The regressions and correlation analyses were performed to understand the impact of lean methods on operational performance. To understand the causality, explore the interrelationship among the variables, and verify the findings of the regressions, structural equation modelling (SEM) analysis was also used as a methodological tool. Path analysis is a special case of structural equation modelling (SEM), which is one of the emerging methodologies in operations management (Kumar *et al.*, 2008; Shah and Goldstein, 2006). The multi-iterated modelling approach of SEM allows a detailed understanding of particular variables in terms of key influencing factors (Kumar *et al.* 2011). It is used to find the causal relationship among the variables. It allows examination of a set of relationships between one or more independent variables and one or more dependent variables, and estimates the relative importance of the alternative paths of influence (Kline, 1998; Kumar et al., 2008). In practice, it is a straightforward extension of multiple regressions, aimed at providing estimates of the magnitude of hypothesised causal connections between sets of variables. In this research Path Analysis is used to depict the inter-relationships between the variables and, most importantly, to show the impact of lean methods on operational performance. Path Analysis therefore will explore the causality among the measured constructs. Moreover, it will provide justification for the earlier findings of the correlation and regression analysis methods.

4. Results

The first section of the survey provided a profile's overview of the responding organisations and individual respondents. In this case, 78 percent of the respondents worked for large organisations, 13 percent for medium size, and 9 percent for small companies. 46 percent of the respondent organisations were located in Europe, 33 percent in North America, 11 percent in Asia, 6 percent in Africa, and 3 and 1 percent in South America and Australia respectively. The respondent organisations competed in various manufacturing sectors that included machinery, primary metals, chemical, wood products, transportation equipment, furniture and related products, among others. In terms of the individual respondents, 48 percent were executives that had knowledge on the subject, 33 percent quality directors/managers and 19 lean six sigma green belts. The study results showed that all of the 140 organisations surveyed had implemented all of the lean methods (i.e. JIT, TPM, Automation, VSM and Kaizen) studied, although the extent of implementation was different for all of them as not all of the companies had implemented all of the lean tools (see Table 1).

To analyse the survey data, a correlation analysis was firstly performed (Table 4). This showed that most of the lean methods were correlated with the operational performance measures studied, except VSM, which did not show any significant correlation. Some of the correlations between few variables are high indicating that multicollinearity may be an issue however, referring to literature such as Sheeran and Orbell (1999) and Grewal et al. (2004) multicollinearity only causes problem when it is extremely high (over 80%). Since correlations reported in the paper for five lean methods do not exceed more than 0.6, indicating that multicollinearity is not a problem for the current data. These papers also report that multicollinearity can be an issue if correlation is between 0.6 and 0.8, R^2 values are low, and sample size is small. Therefore R^2 values for the highly correlated variables (JIT and TPM; JIT and AUTO) were calculated. To further verify, we estimated the R^2 for JIT, TPM, and AUTO and the R^2 value was found to be 0.6. These findings suggest that in our case though correlations are high they do not pose any significant issue. To further explore the findings, a regression analysis was also conducted; a summary of the regressions outcome is presented in Figure 2. Table 5 illustrates the results of the regression analysis and the impact of the lean methods studied on the five performance measures as well as overall operational performance. The ratio of the factor loadings or coefficients with their standard errors (i.e. "Std Error" column) is expressed by their *t*-values. The variables with a *t*-value greater than 2 can be considered statistically significant if their *p* values (i.e. corresponding value in the "Prob." column) are equal or less than 0.05, whereas if their *t*-values are greater than 2.576 then they are statistically significant if their $p \leq 0.01$ (Koufteros, 1999). For this study, variables with $p \leq 0.1$, which means a level of confidence of 90 percent, were considered statistically significant. The SEM analysis was performed using AMOS 19.0 and total number of iterations used was 10. Table 6 shows the normal (NFI), relative (RFI), incremental (IFI) and comparative (CFI) fitness indices as well as the root mean square error of approximation (RMSEA) and chi-square for the "best fit" SEM models tested to investigate the lean methods and their impact on the performance measures studied.

Insert Table 4 in here

Insert Figure 2 in here

Insert Table 5 in here

Insert Table 6 in here

For *Quality*, both correlations and regression analysis show (see Figure 2 and Table 4) that JIT has the highest impact on the performance of this measure while autonomation and kaizen, as expected, seem to also contribute to its improvement at 90 percent level of confidence. VSM appear to have a negative impact on the quality measure. The correlation analysis indicates that TPM affects quality, though the regression findings do not support this notion. To further verify this, SEM analysis was performed (Figure 3) and the analysis supported the findings of regressions as no links between TPM and quality was evident. The outcome of the SEM analysis also supported the other findings of the regression. For *Speed*, the correlation analysis showed that except for VSM, all other lean methods were correlated to this performance measure. Similar to quality, the results of the regression analysis found that JIT has the strongest significance on this measure, followed by autonomation and kaizen. Once more, VSM had a negative effect on speed while the effect of TPM was not found significant. Thereafter, SEM analysis was performed (Figure 4) and the outcome cross verified the findings of the regressions as it showed that TPM was not linked to speed whereas VSM negatively affected it.

When focusing on *Dependability*, the correlations showed that similar to speed, dependability was also correlated to all the lean methods except VSM. The regression analyses revealed that JIT has the strongest effect on this performance parameter. Although with a lesser effect, autonomation also has some inference on dependability while kaizen, TPM, and VSM do not affect the dependability measure as the coefficients were not significant. To verify this, SEM analysis (Figure 5) was run and the outcome verified the findings of the regressions. Interestingly, SEM also showed that kaizen do impact dependability but to a lesser extent than JIT and autonomation. SEM also shows that VSM negatively affects dependability similar to speed. In relation to *Flexibility*, the correlation analysis results were similar to speed and dependability. The regression results show that out of all the five measures of performance considered in the analysis, dependability is the most positively affected by JIT, see Figure 2. It also shows that TPM, automation, and kaizen do not affect flexibility while VSM has a negative effect on it. Best fit SEM model (Figure 6) verified the negative effect of VSM but it also showed that TPM is the second important method after JIT to affect flexibility, which contradicted the findings of regressions but supported the findings of correlations. SEM also found that kaizen does affect flexibility though to a lesser extent.

Finally, correlations for *Cost* showed that except for VSM and kaizen, other lean methods were significantly correlated. Further regressions show that JIT has the greatest impact on the reduction of *cost,* followed by autonomation. SEM (Figure 7) verified the outcome of the regressions and also showed that in this case too, TPM was not linked to cost and VSM shares a negative relationship with cost. Figure 2 also presents the results from the linear regression which examine the impact that the lean methods have on the overall operational performance. This was calculated as the average of the five performance measures that were examined in the previous regressions. It is evident that apart from TPM, all the other methods have a statistically significant impact on the overall operational performance. Table 4 illustrates the results of the regression analyses and the impact of the lean methods studied on the five measures considered and overall operational performance.

Insert Figure 3 in here

Insert Figure 4 in here

Insert Figure 5 in here

Insert Figure 6 in here

Insert Figure 7 in here

5. Discussion of results

Quality measure

Lean manufacturing emphasises the reduction of quality defects through autonomation. The main objective of autonomation is to detect any abnormalities, prevent quality defects and thus improve quality (Liker and Meier, 2006; Shingo, 1981). This may suggest autonomation as the strongest contributor to the quality measure. However, the results of this study contradict this “natural perception” and although it found that automation has a significant effect on quality, JIT has the strongest effect on this measure. This corroborates the results of a previous study by Cua *et al*. (2006), which found that JIT has a significant and positive effect on quality. JIT's main objective is to reduce inventory through the application of one piece flow, pull system, takt time, cell manufacturing, levelled production, kanban, visual control, multifunctional employees, and JIT purchasing. The improvement of quality through the reduction of inventory can be explained as a mean of exposing problems (Flynn *et al.* 1995), which forces organisations to tackle and eliminate such problems from their root cause.

The results of this study revealed that TPM does not have an impact on quality. However, Cua *et al*. (2006) found that TPM is related to quality at a significant level, but not as strong as JIT. TPM aims to reduce machine changeovers and breakdowns. Nakajima (1988) suggests that these actions will contribute to the reduction of quality defects as machines will run at an optimum level. A possible explanation about the lack of impact of TPM on quality found in this study is an ineffective implementation of TPM. Bashin and Burcher (2006) stated that only 10 percent or less organisations manage to implement TPM successfully. Similarly to this study, Ghosh (2013) found that TPM has a negative impact on productivity and manufacturing lead time. This may indicate that in order for TPM to positively affect quality, a more strategic level to the approach must be taken, as opposed to the traditional operational approach where only people from the shop-floor is involved in its application and management. According to this study, kaizen contributes to the improvement of quality at a moderate level compared to JIT and autonomation. It is known that kaizen contributes to the support and sustainment of lean improvement initiatives (Imai, 2012; Rocha-Lona *et al.*, 2013). Thus it is expected to have some positive impact on quality, which is confirmed by this study's results.

The coefficient value of VSM in the regression appears to be negative and statistically significant for all the measures studied (including quality), which was also verified by the SEM analysis. In other words, the results of this study indicate that the application of VSM has negative effects not only on quality but also on speed, flexibility, cost, and the overall performance of an organisation. Various studies have highlighted the positive effects of VSM in different operational areas (Seth and Gupta, 2005; Abdulmalek and Rajgopal, 2007; Sahoo *et al.*, 2008; Singh and Sharma, 2009; Chen *et al.*, 2010). Our study, however, contradicts their findings. VSM is typically the initial step in the implementation of lean manufacturing (Rivera and Chen, 2007). Thus, if a VSM analysis is incorrectly performed and therefore not accurate, then the information obtained regarding the processes and their waste may lead to the wrong selection of priorities and implementation of lean methods and tools, which would obviously undermine the management and sustainment of the whole lean strategy. In the case of the companies studied, this may be a reason as to why their VSM approach had a negative effect on most of the measures of performance considered in this study. Furthermore, VSM can be considered a method applied at a more specific operational level than JIT, autonomation and kaizen. For example, VSM is a technical tool that examines the physical system, processes and interconnections but does not involve the socio-technical (i.e. teamwork for motivation, coordination and problem solving) aspect of the system and its long term benefits. This may make the benefits of VSM more difficult to appreciate and recognise by top management. Based on our practical experience, the authors are convinced of the value and effectiveness of the VSM method. However, since the results of the study contradict this experience and the results of other researches, a suggestion to performed further studies in relation to this aspect is recommended as part of a future research agenda.

Speed measure

It is evident that the impact of JIT on speed is higher compared to the rest of the lean manufacturing methods studied, see Figures 1 and 3. Furthermore, its impact is greater on speed compared to the impact that it has on quality. This is expected as the parameters that measure speed are normally related to lead time, cycle time and on time delivery, which are reduced when JIT is effectively implemented. Many studies support the positive and significant impact of JIT on lead and cycle time reduction and on time delivery (Womack *et al.*, 1990; Womack and Jones, 2003; Ward and Zhou, 2006; Cua *et al.*, 2006). Autonomation, as it occurs from the results of the regression analysis, has a significant positive impact on speed. The prevention of the defects and the reduction of the percentage of scrap and rework that is achieved in a large scale by the implementation of autonomation tools contribute to the increase in speed and specifically, to the reduction of order lead time. Kaizen affects in a positive way the performance measure of speed, but its impact is lower compared to the impact of JIT and autonomation. This may be considered logical, as the main purpose of kaizen is to support and sustain the improvement in performance that is achieved as a result of the implementation of other lean manufacturing practices (Liker, 2004). In reference to TPM and VSM, the results of the regression analysis on the measures studied are the same as for the quality measure, with the possible reasons for this being the same.

Dependability measure

In the case of dependability, it was found that JIT is the lean manufacturing method that has the strongest effect. There are two main parameters that represent the measure of dependability. These are on time delivery and level of inventory. Cua *et al.* (2006) found a significant impact of JIT on the measure of on time delivery. Daugherty and Spencer (1990) argue that one of the characteristics of JIT that helps organisations to improve dependability is it emphasises on the close proximity of suppliers. The delivery of products on time, and speed of delivery (i.e. speed measure), is also affected by quality defects that occur during the production as they require to be reworked before they are delivered to the customer. Thus, rework consumes valuable time and delays further the delivery of the finished goods. As a result, since autonomation contributes to the reduction of quality defects, it also positively affects the delivery time due to the products that need rework are less and thus can be delivered to the customer faster. On the other hand, according to the results of the regression analysis, VSM, TPM and kaizen do not affect dependability. In this context, their p values exceeded 0.1, see Figure 2, which means that they are not statistically significant. Due to their own nature, the effective implementation of TPM and kaizen may be assumed to help reducing machine breakdowns, quality defects, improve efficiency, etc. and thus to help improving the dependability measure. However, although these approaches may in theory aid an organisation to achieve these improvements, their effective implementation, management and sustainment will also play a critical role. This may have acted as a barrier for the studied organisations to experience the theoretical benefits of these approaches.

Flexibility measure

Flexibility has been used by various authors as a performance measure for lean implementation. Cua *et al.* (2006) found a significant effect of the JIT and TPM methods on flexibility. As it can be seen from the regression results, JIT has a significant impact on flexibility. This is due to the lower the inventory, the faster an organisation can change its direction towards the manufacture of different products and adapt to new market trends. On the other hand, kaizen and autonomation were not statistically significant, which means that they have no impact on flexibility, though SEM analysis showed that it does affect flexibility but its impact is minimal. As it has been previously mentioned, kaizen is based on incremental improvements (Imai, 2012) and mainly acts as the sustainment base for the lean initiative. For this reason, its effects on the improvement of different measures, including flexibility, may not be easily perceived by organisations in the short term or as very significant. In the case of autonomation, although it may be argued that the reduction of defects will keep the level of inventories low due to less products will need to be reworked, the regression analysis shows that this is still not significant, at least for the companies involved in this study. Once more, the regression analysis has showed no statistical significance of the effect of TPM on the flexibility measure. According to Kodali and Chandra (2001), companies that successfully implement TPM can expect a 70 percent reduction in lost production, 60 percent reduction in maintenance cost per unit, 50 percent reduction in breakdowns, and between 50 and 90 percent reduction in setup time. It is obvious that the successful and/or full implementation of TPM was not achieved by the companies participating in this study, which once more, may explain the lack of impact of TPM on the flexibility measure.

Cost measure
The regression and SEM analyses showed that the impact of JIT on cost is strongly significant, see Figures 1 and 6. Specifically, the reduction of inventory that is achieved with the implementation of JIT significantly contributes to the reduction of cost. Moreover, Fullerton and Wempe (2009) found that the implementations of tools like cellular manufacturing, which is one of the JIT tools, improve the profitability of the company. Furthermore, Cua *et al*. (2006) found that JIT has the strongest impact on cost efficiency compared to other approaches and methods like TQM or TPM. Although, it would be expected to be universally accepted the fact that JIT, or other lean methods and tools, have a significant contribution to the increase of profitability of a manufacturing organisation, some authors have contradicted this point (Huson and Nanda, 1995; Mohrman *et al.*, 1995; Lau, 2002). Despite these, it is well accepted in the academic literature that lean methods and tools have a positive effect on the success and performance of organisations (Eriksson and Hansson, 2003; Nahm *et al.*, 2003; Kinney and Wempe, 2002; Fullerton and Wempe, 2009).

In the case of autonomation, it has a stronger effect on the cost measure than TPM, kaizen and VSM. This is due to the prevention and reduction of quality defects, which add a significant cost due to rework, inspection, after sales service, warranty claims, etc. In addition, it also contributes to the increase of sales due to good product's reputation and imagine of the company. The regression and SEM analyses results in relation to TPM and cost showed that similarly as with all the other measures, TPM does not affect it. It has been discussed previously that the possible reason as to why TPM in this study seems not to have any effect on any performance measure studied is the lack of its effective and/or full implementation. The *t*-value of TPM is shown as negative in the results of the regression analysis. This may be due to the fact that if TPM is not implemented effectively it will fail to achieve the expected results, and it will also incur on extra cost for the organisation.

6. Conclusions, limitation and further research

This paper fills a research gap by investigating the relationship and impact that some of the most essential and commonly implemented lean methods (i.e. JIT, TPM, autonomation, VSM and kaizen) have on important contemporary measures of operational performance (i.e. cost, speed, dependability, quality and flexibility). The study employs a three pronged verification approach by using correlations, regressions, and structural equation modelling (SEM) method to justify the findings. The results of this study indicate that out of the five lean methods studied, JIT contributes to the highest impact on improvement in all five individual measures and the overall performance of organisations. The relationship between JIT and significant improvements in organisational performance has been well documented in the academic literature (Cua *et al.*, 2001; Lawrence and Hottenstein, 1995; Fullerton and McWatters, 2001; Bortolotti *et al.*, 2013). This study corroborates and supports the importance and impact of the JIT method on performance highlighted in the academic literature. In the case of autonomation, this study indicates that it also plays a significant role on the performance of companies. In this context, the prevention and elimination of quality defects has a positive impact, particularly, on the quality, speed, dependability and cost performance of organisations. Similarly as with JIT, the results of this study corroborate the vast amount of literature (Deming, 1986; Dale, 2003; Slack *et al.*, 2013; Hill, 1989) that highlights the benefits that the improvement of quality has on the performance of organisations. On the other hand, kaizen was found to have a modest contribution towards the overall performance of a company and the quality and speed measures. As previously discussed, this may be explained due to the strategic objective of kaizen, which is more related to the sustainment of the lean strategy and its methods and tools rather than to be directed toward the improvement of specific operational aspects (Liker, 2004), such as is the case for JIT and autonomation.

Surprising results were obtained in relation to the no impact of TPM and negative effect of VSM on the performance of organisations. As previously discussed, the academic literature widely exposes the positive effects of TPM (Nakajima, 1988; Kodali and Chandra, 2001) and VSM (Seth and Gupta, 2005; Abdulmalek and Rajgopal, 2007; Sahoo *et al.*, 2008; Singh and Sharma, 2009; Chen *et al.*, 2010). Thus, the outcomes of this study contradict such results. A possible explanation for this may be that the organisations studied have not been able to obtain such benefits due to implementation, management and/or sustainment problems with these lean methods. In addition, due to the purely operational scope of these lean methods, top management may have less opportunity to observe and thus recognise the benefits of these tools in the performance of their organisations.

Managerial and theoretical implications

The study presented in this paper offers organisations, and their managers, a better understanding of the relationship and impact that some of the most essential lean methods have on the performance of their operations. Thus, managers will be able to take better and more effective decisions about the implementation of lean methods. Even the largest and most profitable organisations will face some type of resource constraint that may stop them from implementing all lean methods and tools simultaneously. Thus, this study can also guide organisations to prioritise the implementation of lean methods according to the performance measures they consider more strategically important to improve. In terms of its theoretical value, this study complements the previous research performed in this area by considering the analysis of the effects of all the most essential lean methods on the most currently important measures of operational performance. None of the previous research had considered all the same lean methods and measures of performance investigated in this study.

Research limitations and further research

In terms of the study limitations, various constraints were encountered with factors that are important to highlight in order for similar future studies to take them into consideration. The survey questionnaire software had access restrictions from a number of organisations' internet browsers. It is unknown how many organisations were affected by this problem, but it can be assumed that corporate restrictions within a number of organisations, particularly large organisations that impose stricter access to external websites, were a barrier to increase the questionnaire's response rate. Due to the problems encountered with internet restrictions, it may prove beneficial to send out a number of questionnaires by post in future studies. Alternatively, carrying out interviews would increase response rates; these methods however are constrained by resources such as time and capital. Although the response rate obtained and used for the analysis is comparable to other similar studies, it can also be considered limited. Therefore, similar studies conducted by using a higher response rate are considered part of the agenda for further research proposed by this paper.

To further develop this area, research should be carried out with a focus on not only the manufacturing industry, as it was the case for this research, but also on other industries where the lean strategy can also be beneficial. Furthermore, considering the importance that many governments, industries and society in general are paying to the "green" and sustainable area, the impact of lean methods and tools can also be explored in relation to these two aspects. Future empirical studies can also follow a mixed method approach involving quantitative and qualitative data sets that could be tested through rigorous statistical methods, including the conduction of a non-response bias test (Armstrong and Overton, 1977) in order to ensure a higher confidence in the data collected. A higher response rate and a mixed quantitative-qualitative approach with strong statistical analysis method may allow the generalisation of the findings in similar studies. Finally, an analysis of results and drawn of conclusions from a more specific level's view point (i.e. considering industrial sector, company size, length of time of the lean initiative) could also be carried out.

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Table 1. Lean manufacturing essential methods and tools

JIT	**TPM**	**Autonomation**	**VSM**	**Kaizen/CI**
Tools: • One piece flow • Pull system • Takt time • Cell manufacturing • Levelled production • Kanban • Visual control Multifunctional employees • JIT purchasing	*Tools:* • Overall equipment effectiveness (OEE) • Single minute exchange of die (SMED) • 5S • Autonomous maintenance • Planned maintenance • Quality maintenance • Initial control before the starting of the production • Safety and hygiene environment	*Tools:* • Mistake proofing / Poka-yoke • Visual control system / Andon • Full Work system	*Tools:* • Current state map • Future state map • Flow diagrams	*Tools:* • 5S • Brainstorming • Continuous Flow • Kanban • Datacheck sheet • Five whys • Pareto chart • Run chart • Gantt chart • VSM • Process map • Mistake proofing

Table 2. Research summary in the area of lean impact on organisational performance

Authors	**Lean and Associated Practices/Tools**		**Impact on (Measure)**
Rahman *et al.* (2010)	• Reduction of inventory • Preventive maintenance • Cycle time reduction • Use of new process technology • Use of quick changeover techniques • Reducing set-up time	JIT	1. Quick delivery compared to the main competitor 2. Unit cost of the product compared to competitors 3. Overall productivity 4. Overall customer satisfaction
	• Eliminate waste • Use of error proofing techniques (Poka-yoke) • Using pull-based production system (Kanban) • Remove bottlenecks	Waste Minimisation	
	• Reduce production lot size • Focus on single supplier • Continuous/one piece flow	Flow Management	
Shah and Ward (2007; 2003)	• JIT • Total Quality Management (TQM) • Total Productive Maintenance (TPM) • Human Resource Management • Contextual factors: plant age, plant size, unionisation		1. Five year changes in cycle time 2. Scrap and rework costs 3. Productivity of labour 4. Customer lead time 5. First pass yield 6. Unit manufacturing costs

Bhasin (2012)	• Lean manufacturing (as overall approach)		1. Balanced Scorecard (financial and operational efficiency)
Cua *et al.* (2006)	• Cross-functional product design • Process management • Supplier quality management • Customer involvement	TQM basic techniques	1. Quality 2. Flexibility 3. Cost 4. Delivery
	• Setup time reduction • Pull system production • JIT delivery by suppliers • Daily schedule adherence	JIT basic techniques	
	• Autonomous and planned maintenance • Technology emphasis • Proprietary equipment development	TPM basic techniques	
	• Committed leadership • Cross-functional training • Employee involvement • Information and	Human and strategic oriented common	

Table 2. Research summary in the area of lean impact on organisational performance (cont.)

Authors	**Lean and Associated Practices/Tools**		**Impact on (Measure)**
Taj and Morosan (2011)	• Human resources • Supply chains • Design of production systems		1. Flow 2. Quality 3. Flexibility
Lawrence and Hottenstein (1995)	• Reduction of setup times • Reduction of production lot sizes • Reduction of inventories • Simplification of materials flow and handling • Prevention of defective products	JIT practices	1. Quality 2. Customer service 3. Lead time 4. Productivity
Thun *et al.* (2010)	• Lean manufacturing (as overall approach)		1. On time delivery 2. Inventory turnover 3. Flexibility to change volume 4. Product conformance 5. Cycle time 6. Cost
Bortolotti *et al.* (2013)	• Pull production systems • Lot size reduction • Cellular layout • Setup time reduction • Daily scheduled adherence • JIT delivery by suppliers	JIT practices	1. Inventory turnover 2. Cycle time 3. Unit cost 4. On time delivery 5. Product volume 6. Product mix flexibility 7. Fast delivery
Searcy (2009)	• Lean manufacturing (as overall approach)		1. Quality 2. Capacity 3. Productivity 4. Inventory 5. Cost

Fullerton and Wempe (2009)	• Shop floor employee involvement in the problem solving process • Cellular manufacturing • Setup time reduction • Quality improvement	1. Financial measures
Hallgren and Olhager (2009)	• Lean manufacturing (as overall approach) • Agile manufacturing (as overall approach)	1. Cost 2. Volume flexibility 3. Quality 4. Delivery speed 5. Product mix flexibility 6. Delivery dependability
Behrouzi and Wong (2011)	• JIT • Waste elimination	1. Quality 2. Cost 3. Time 4. JIT delivery
Rivera and Chen (2007)	• Waiting time • Activities duration • Reduction of material • JIT materials	1. Cost-time investment of a product
Dora *et al.* (2013)	• Lean manufacturing (as overall approach)	1. Productivity improvement 2. Inventory reduction 3. Cycle time or lead time reduction 5. On time delivery

Table 2. Research summary in the area of lean impact on organisational performance (cont.)

Authors	**Lean and Associated Practices/Tools**		**Impact on (Measure)**
Hofer *et al.* (2012)	• Pull • Flow • Set-up • SPC • Employee involvement • TPM	Internal lean practices	1. Financial performance 2. Mediating role of inventory leanness in the relationship between final performance and lean production
	• Supplier feedback • Supplier JIT • Supplier development • Customer involvement	External lean practices	
Karim and Arif-Uz-Zaman (2013)	• Lean manufacturing (as overall approach)		1. Effectiveness 2. Defect rate 3. Efficiency 4. Productivity 5. Value added time ratio
Sakakibara *et al.* (1997)	• Setup time reduction • Maintenance • Kanban • Equipment layout • JIT supplier relationships • Scheduling flexibility	JIT practices	1. Inventory turnover 2. Lead time 3. On time delivery 4. Cycle time 5. Quality 6. Flexibility 7. Unit cost 8. Plant's management opinion for the performance of the plant compared to global competition.
	• Quality management • Manufacturing strategy • Product design • Workforce management • Organisational characteristics	Infrastructure practices	

Table 3. Linear regression model variables

Independent Variable	Lean Method	Dependent Variable		Measure of Operational Performance
X_1	Just-in-Time	Y_i	Y_1	Quality for $i = [1,140]$
X_2	Total Productive Maintenance		Y_2	Speed for $i = [1,140]$
X_3	Autonomation		Y_3	Dependability for $i = [1,140]$
X_4	Value Stream Mapping		Y_4	Flexibility for $i = [1,140]$
X_5	Kaizen/Continuous improvement		Y_5	Cost for $i = [1,140]$
			Y_0	Operational Performance (Average of $Y_1 + Y_2 + Y_3 + Y_4 + Y_5$)
e_i : Error and main assumptions $E_{ei} = 0$ and $Var(e_i) = \sigma^2$				

Table 4. Correlations

	JIT	TPM	AUTO	VSM	KAIZEN	QUALITY	SPEED	DEPEND	FLEX	COST
JIT	1									
TPM	**.572****	1								
AUTO	**.599****	**.517****	1							
VSM	**.414****	**.303****	**.325****	1						
KAIZEN	**.215***	.126	.048	**.224****	1					
QUALITY	**.395****	**.300****	**.312****	.086	**.210***	1				
SPEED	**.411****	**.307****	**.304****	.153	**.186***	**.732****	1			
DEPEND	**.417****	**.324****	**.373****	.107	**.178***	**.671****	**.766****	1		
FLEX	**.445****	**.364****	**.322****	.066	**.172***	**.740****	**.754****	**.721****	1	
COST	**.438****	**.261****	**.350****	.107	.127	**.709****	**.750****	**.744****	**.748****	1

** Correlation is significant at the 0.01 level (2-tailed).
*   Correlation is significant at the 0.05 level (2-tailed).

Table 5. Illustration of regression results

	Quality	Speed	Dependability	Flexibility	Cost	Overall
JIT	+++	+++	+++	+++	+++	+++
TPM	0	0	0	0	0	0
Autonomation	++	++	++	0	++	++
VSM	-	-	0	-	-	-
Kaizen	+	+	0	0	0	+

+++: highest effect; ++: significant effect; +: small effect; - : negative effect; 0: no effect

Table 6. Fitness indices for best fit path models

CONSTRUCTS/FITNESS INDICES	NFI	RFI	IFI	CFI	RMSEA	Chi-Square/df
QUALITY	0.997	0.930	1.002	1.000	0.000	0.6
SPEED	0.997	0.945	1.003	1.000	0.000	0.5
DEPENDABILITY	0.997	0.927	1.002	1.000	0.000	0.7
FLEXIBILITY	0.997	0.943	1.002	1.000	0.000	0.5
COST	0.999	0.989	1.005	1.000	0.000	0.1

5 Which of the following lean manufacturing tools that are related with the Just-in-time philosophy have been implemented in the company?

☐	*One piece flow*
☐	*Pull system*
☐	*Takt time*
☐	*Leveled production*
☐	*Cellular manufacturing*
☐	*Visual Control*
☐	*Kanban/Pull production*
☐	*Multifunctional Employees*
☐	*Just in time Purchasing*

10. Please estimate the percentage of the improvement achieved in the following operational performance indicators because of the implementation of Lean Manufacturing

	00%	*10%*	*15%*	*20%*	*25%*	*30%*	*35%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*100%*
Quality (e.g. defects per unit, customer complaints, scrap level, warranty claims, mean time between failures, customer satisfaction)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Speed (e.g. customer query, order lead time, frequency of delivery, actual versus theoritical throughput time, cycle time)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Dependability (e.g. percentage of orders delivered late, average lateness of orders, proportion of products in stock, mean deviation from promised arrival, schedule adherence)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Flexibility (e.g. time needed to develop new products, range of products, machine change over time, average capacity/maximum capacity, time to change schedules)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Cost (e.g. variable against budget, utilisation of resources, labour productivity, efficiency, cost per operation hour)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Figure 1. Example of questions included in the questionnaire

Dependent Variable: QUALITY
Method: Least Squares
Sample: 1 140
Included observations: 140

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.234815	0.082887	2.832955	0.0053
JIT	0.241289	0.107981	2.234558	0.0271
TPM	0.064164	0.112579	0.569948	0.5697
AUTONOMATION	0.183432	0.103765	1.767755	0.0794
VSM	-0.160012	0.087347	-1.831904	0.0692
KAIZEN	0.070437	0.033808	2.083468	0.0391

R-squared	0.207493	Mean dependent var	0.454286
F-statistic	7.016728		
Prob(F-statistic)	0.000007		

Dependent Variable: SPEED
Method: Least Squares
Sample: 1 140
Included observations: 140

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.313065	0.084301	3.713640	0.0003
JIT	0.306871	0.109823	2.794227	0.0060
TPM	0.022309	0.114500	0.194834	0.8458
AUTONOMATION	0.176818	0.105536	1.675432	0.0962
VSM	-0.188648	0.088838	-2.123513	0.0355
KAIZEN	0.057567	0.034385	1.674198	0.0964

R-squared	0.212831	Mean dependent var	0.508929
F-statistic	7.246068		
Prob(F-statistic)	0.000005		

Dependent Variable: DEPENDABILITY
Method: Least Squares
Sample: 1 140
Included observations: 140

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.192860	0.087062	2.215200	0.0284
JIT	0.282269	0.113420	2.488712	0.0140
TPM	0.090275	0.118250	0.763430	0.4465
AUTONOMATION	0.196547	0.108992	1.803315	0.0736
VSM	-0.148997	0.091747	-1.624001	0.1067
KAIZEN	0.052183	0.035511	1.469514	0.1440

R-squared	0.222807	Mean dependent var	0.456071
F-statistic	7.683078		
Prob(F-statistic)	0.000002		

Dependent Variable: FLEXIBILITY
Method: Least Squares
Sample: 1 140
Included observations: 140

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.170978	0.082366	2.075817	0.0398
JIT	0.389683	0.107302	3.631631	0.0004
TPM	0.130601	0.111872	1.167414	0.2451
AUTONOMATION	0.082616	0.103114	0.801214	0.4244
VSM	-0.174778	0.086799	-2.013607	0.0461
KAIZEN	0.046916	0.033595	1.396509	0.1649

R-squared	0.263197	Mean dependent var	0.436786
F-statistic	9.573336		
Prob(F-statistic)	0.000000		

Dependent Variable: COST
Method: Least Squares
Sample: 1 140
Included observations: 140

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.249313	0.082210	3.032647	0.0029
JIT	0.339633	0.107098	3.171227	0.0019
TPM	-0.022794	0.111659	-0.204138	0.8386
AUTONOMATION	0.237743	0.102917	2.310037	0.0224
VSM	-0.173907	0.086633	-2.007384	0.0467
KAIZEN	0.028448	0.033531	0.848406	0.3977

R-squared	0.247282	Mean dependent var	0.460000
F-statistic	8.804303		
Prob(F-statistic)	0.000000		

Dependent Variable: OVERALL PERFORMANCE (AVERAGE)
Method: Least Squares
Sample: 1 140
Included observations: 140

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.232206	0.071237	3.259650	0.0014
JIT	0.311949	0.092803	3.361409	0.0010
TPM	0.056911	0.096755	0.588197	0.5574
AUTONOMATION	0.175431	0.089180	1.967154	0.0512
VSM	-0.169268	0.075070	-2.254812	0.0258
KAIZEN	0.051110	0.029056	1.759046	0.0809

R-squared	0.289336	Mean dependent var	0.463214
F-statistic	10.91119		
Prob(F-statistic)	0.000000		

Figure 2. Summary of the linear regression results

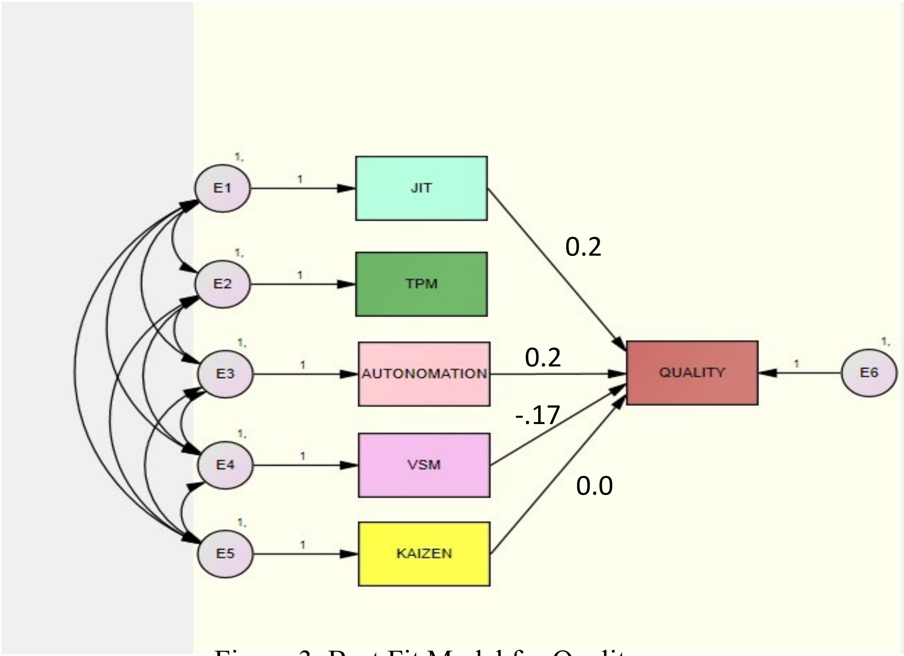

Figure 3. Best Fit Model for Quality

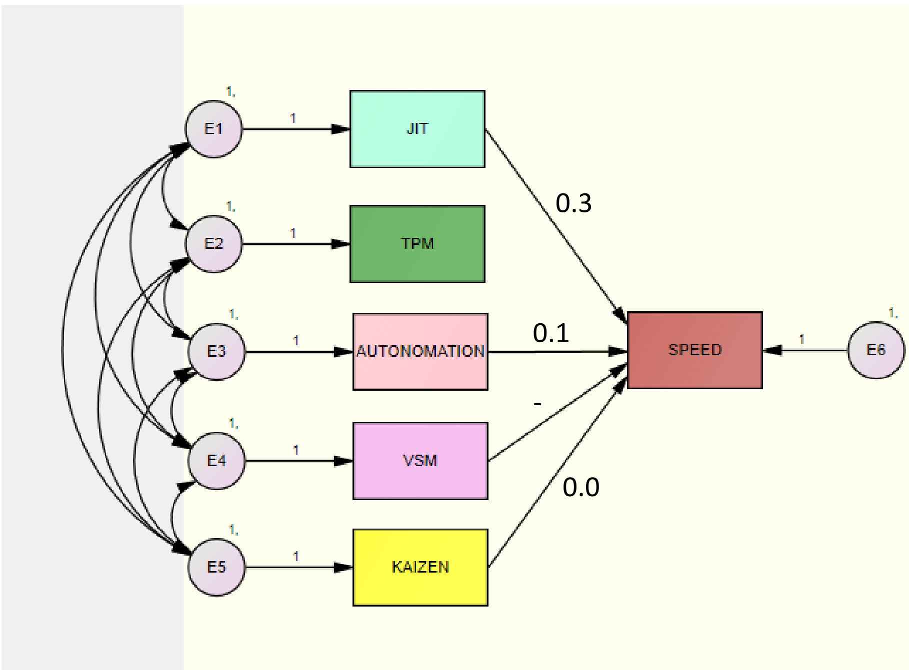

Figure 4. Best Fit Model for Speed

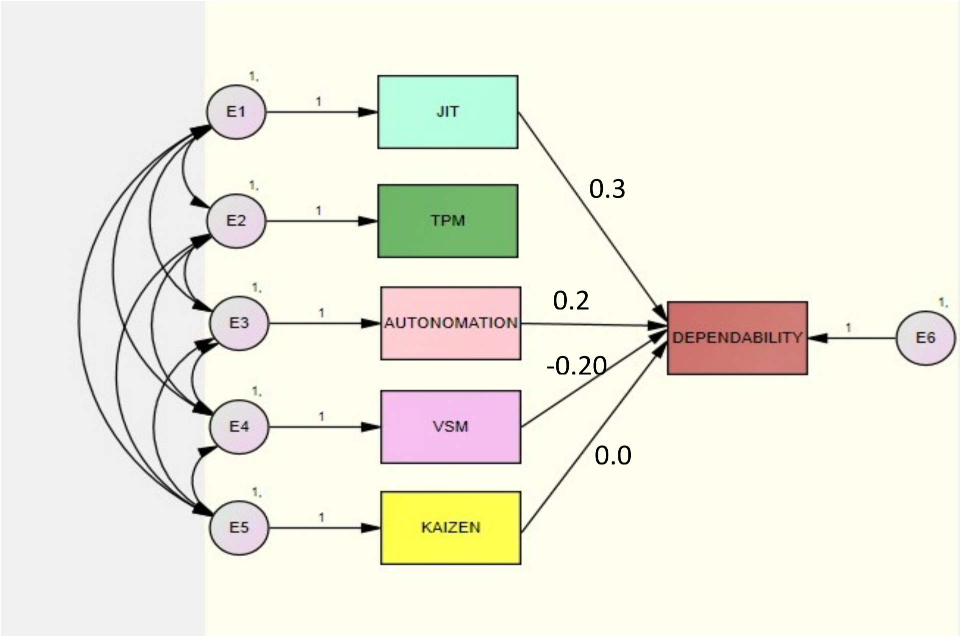

Figure 5. Best Fit Model for Dependability

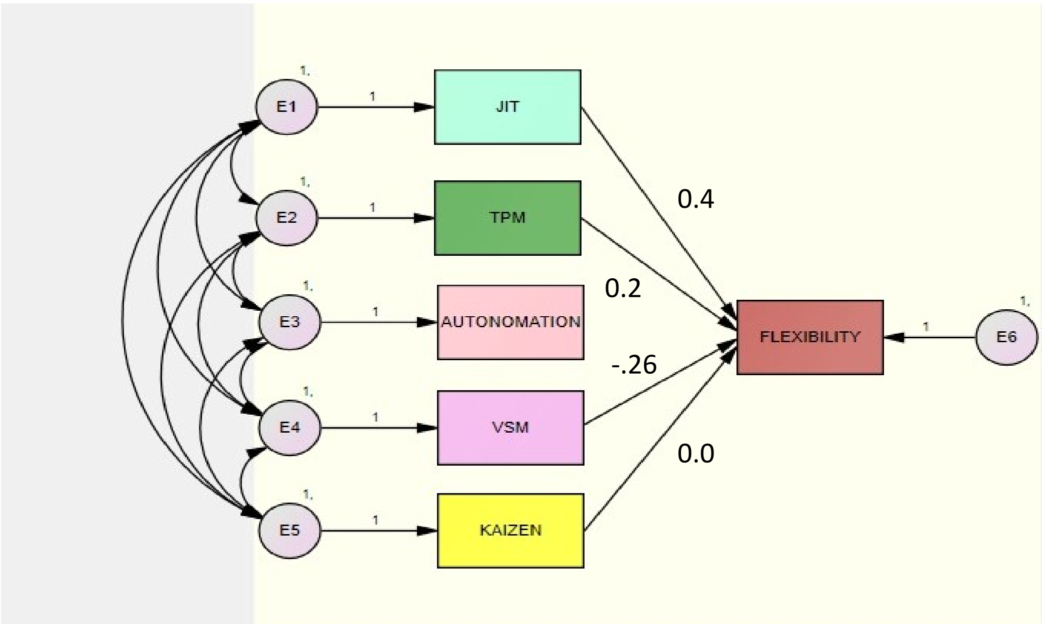

Figure 6. Best Fit Model for Flexibility

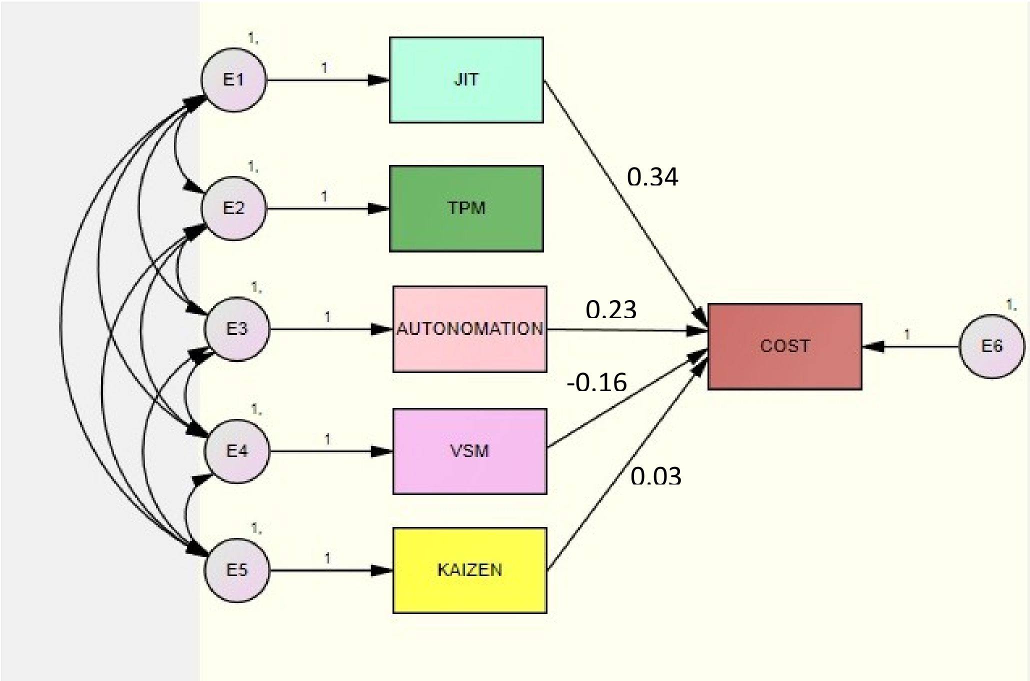

Figure 7. Best Fit Model for Cost