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Implementing lean practices in manufacturing SMEs: testing ‘critical success factors’ using Necessary Condition Analysis

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Lean practices are known to increase operational performance. Previous research has identified critical success factors for implementing lean practices. This research aims to examine the extent to which success factors are critical for various degrees of lean practice implementation. Using multiple-respondent self-assessments from 33 Dutch manufacturing small and medium-sized enterprises (SMEs), we conducted a Necessary Condition Analysis. Our findings indicated that the criticality of success factors is progression dependent. In the initial stages of the lean journey, SMEs could improve their lean practices in a bottom-up manner through local factors such as a learning focus, improvement training and support congruence. When lean practices are more advanced, company-wide factors must be present: top management support, a shared improvement vision and a supplier link. Our findings question the universality of success factors such as strategic involvement and indicate the need for a more dynamic model of lean implementation.

Keywords: success factors; lean practices; operational performance; SMEs; manufacturing; Necessary Condition Analysis

1. Introduction

Manufacturing small and medium-sized enterprises (SMEs) are important for a nation’s economy: on average, SMEs contribute 42% to a country’s gross domestic product and provide work for 54% of its labour force (Ayyagari, Beck, and Demirguc-Kunt 2007). At the same time, large enterprises (LEs) find themselves at the top of entire networks of suppliers, most of which are SMEs. However, many SMEs struggle to survive (Levine and Renelt 1992; Beck, Demirguc-Kunt, and Levine 2005; Armstrong 2013). Competition has increased rapidly as new technologies (e.g. globally integrated information systems, flexible manufacturing and worldwide distribution) have enabled organisations to compete across the globe. At the same time, customers constantly demand excellent operational performance.

To survive in this competitive business environment, SMEs need to continuously increase their operational performance (Armstrong 2013). Operational performance is the accomplishment of an organisation’s primary activities, measured against pre-set standards like quality, delivery and costs (Slack, Chambers, and Johnston 2010). A widely acclaimed approach to increasing operational performance is that of lean practices, such as continuous flow of value-added activities and pull production through a limit on work-in-progress. Lean practices are a set of methods, procedures, techniques and tools aimed at continuously creating customer value and reducing product lead time (Shah and Ward 2007). Research shows that implementing lean practices helps large manufacturing enterprises increase their operational performance (Krafcik 1988; Ôno 1988; Womack, Jones, and Roos 1991).

However, manufacturing SMEs find it difficult to implement lean practices (White, Pearson, and Wilson 1999; Shah and Ward 2003; McGovern, Small, and Hicks 2017). One proposed reason is the absence of critical success factors (Hu et al. 2015). Saraph, George Benson, and Schroeder (1989, 811) define success factors as ‘areas of managerial planning and action that must be practised to achieve effective quality management in a business unit’. These are key organisational issues that managers need to address to be able to implement lean practices. Examples of success factors are ‘top management support’ and ‘a shared improvement vision’ (Sila and Ebrahimpour 2003). However, the term ‘success factor’ may be misleading, as the mere presence of a factor does not automatically lead to more success (Woodside 2013). Success factors are similar to Herzberg’s (1968) hygiene factors, which do not guarantee job satisfaction, but do need to be in place to prevent dissatisfaction. The same goes for success factors: they are necessary, but not a sufficient condition for success.

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The mere presence of top management support, for example, does not ensure the implementation of lean practices. Lean practices are implemented via improvement activities (Kim, Sting, and Loch 2014). But it is considered to be a necessary condition for success: if there is no top management support, it is very difficult to sustain the implementation of lean practices. So the general assumption for manufacturing SMEs is that success factors need to be present before lean practices can be implemented.

Previous research found that the importance of success factors depends on the stage of implementation of lean practices. Based on a cross-national survey amongst 432 respondents from two LEs, Netland (2016) found that the importance of success factors changed according to the stage of implementation of lean practices; some success factors are important in the initial stages, while others become important as organisations continue to implement lean practices. This is an important research topic because success factor criticality helps SMEs to focus their improvement efforts, enabling the implementation of lean practices and increasing operational performance. Netland (2016) linked success factors to the implementation of lean practices, but he did not deduce the criticality of these success factors (i.e. he did not identify which factors must be present for different stages of implementation of lean practices). After reviewing the literature on success factors, we found no studies that identify this criticality at different stages of implementation of lean practices. Therefore, the aim of this research is to identify the extent to which success factors are critical for different stages of implementation of lean practices in manufacturing SMEs.

The next section briefly highlights the key studies on success factors for the implementation of lean practices. The methodology section then justifies how this study investigated the criticality of success factors to implement lean practices; we specify the variables in our study and justify the multiple-respondent self-assessment as the method of gathering data and Necessary Condition Analysis (NCA) as the method of linking success factors to the implementation of lean practices. The results section indicates that success factors differ in criticality between cases with little implementation of lean and cases with more advanced lean practices. We then discuss these results and provide implications for manufacturing SME managers. The final section provides directions for future research.

2. Success factors for the implementation of lean practices

We reviewed the literature on success factors for the implementation of lean practices as well as for related concepts: Total Quality Management (TQM) and Just in Time production (JIT). TQM aims to meet customer requirements through continuous improvement, emphasising measurement and control (Ross 1999). JIT aims to reduce work in progress, variation and lead time (Monden 1981). Saraph, George Benson, and Schroeder (1989) were amongst the first to identify success factors for TQM and their study has been replicated several times (Motwani, Mahmoud, and Rice 1994; Badri, Davis, and Davis 1995; Quazi et al. 1998). Numerous other validation and replication studies have been conducted (for example Ahire, Golhar, and Waller 1996; Black and Porter 1996; Sohal and Terziovski 2000; Antony et al. 2002; Tari 2005; Karuppusami and Gandhinathan 2006). In a meta-analysis of 76 articles from different countries, Sila and Ebrahimpour (2003) identify 18 universally applicable success factors for the implementation of TQM. Only a few studies have extended their scope beyond TQM, towards other bundles of lean practices such as JIT and ‘supplier and customer integration’ (Kaye and Anderson 1999; Chong, White, and Prybutok 2001; García, Rivera, and Iniesta 2013; García et al. 2014; Marodin and Saurin 2015a). All of these studies were used to identify success factors for this study.

Stemming from success factors for manufacturing companies in general (Saraph, George Benson, and Schroeder 1989; Ahire, Golhar, and Waller 1996; Black and Porter 1996), Yusof and Aspinwall (1999) were amongst the first to suggest success factors specifically for SMEs. They found that most success factors for SMEs are similar to those for LEs; they only added ‘sufficient resources’ and ‘an informal culture’. Other SME-specific studies use data from specific countries (Achanga et al. 2006; Salaheldin 2009; Dorota Rymaszewska 2014) or industries (Dora et al. 2013; Dora, Kumar, and Gellynck 2016; Azyan, Ainul, and Pons 2017). They found that SMEs generally have more management involvement, but they lack resources and plan short-term. In a literature review of 16 articles from different countries and industries, Hu et al. (2015) identified 11 success factors specific to manufacturing SMEs. That literature review and other SME-specific studies have found a large overlap in the success factors for SMEs and LEs, so we used studies about LEs and SMEs to list success factors for this study. In our discussion, we emphasise success factors that are more relevant to SMEs.

To come to a comprehensive list of managerial aspects that need to be in place to be able to implement all lean practices, we compared all the success factors identified in the literature, merged some (e.g. process management and data and reporting (Saraph, George Benson, and Schroeder 1989) became a performance management system) and compiled them into a list of six groups and 12 success factors (see Table 1). These 12 success factors are very much in line with the 11 factors identified by Hu et al. (2015), though at the time of compilation (2013) we had added ‘leadership’
Table 1. Success factors necessary for implementing lean practices.

<table>
<thead>
<tr>
<th>Group</th>
<th>(i) Top management support</th>
<th>(ii) Shared improvement vision</th>
<th>(iii) Good communication</th>
<th>(iv) Leadership</th>
<th>(v) People focus</th>
<th>(vi) Learning focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Top management assume responsibility for and are positively involved in improvements to increase performance</td>
<td>A company-wide long-term direction, objectives and goals for improvement, aligned with the company’s vision and strategy, are developed, shared and followed</td>
<td>Ideas, information and knowledge are exchanged honestly, clearly and transparently, both orally and in writing, in all organisational directions</td>
<td>Team leaders facilitate, coordinate and balance improvements from shop-floor employees</td>
<td>Organisational systems help employees to do their work versus employees being bound to organisational systems</td>
<td>Both positive and negative experiences are shared and mistakes are considered opportunities for improvement rather than punished</td>
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<td>Article</td>
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<tr>
<td>Saraph, George Benson, and Schroeder (1989)</td>
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<td>Motwani, Mahmoud, and Rice (1994)</td>
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<td>Ahire, Golhar, and Waller (1996)</td>
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<td>Black and Porter (1996)</td>
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<td>Kaye and Anderson (1999)</td>
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<td>Yusof and Aspinwall (1999), (2000)</td>
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<td>Sohal and Terziovski (2000)</td>
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<td>Motwani (2001)</td>
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<td>Chong, White, and Prybutok (2001)</td>
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<td>Antony et al. (2002)</td>
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<td>Sila and Ebrahimpour (2003)</td>
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<td>Tari (2005)</td>
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<td>Kanuppusami and Gandhinathan (2006)</td>
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<td>Salaheldin (2009)</td>
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<td>Achanga et al. (2006)</td>
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<td>García et al. (2013), (2014)</td>
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<td>Dora et al. (2013), Dona, Kumar, and Gellyne (2016)</td>
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<td>Dorota Rymaszewska (2014)</td>
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<td>Marodin and Saurin (2015a)</td>
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<td>Azyan, Ainul, and Pons (2017)</td>
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(Continued)
### Table 1. (Continued).

<table>
<thead>
<tr>
<th>Group</th>
<th>Improvement structure</th>
<th>Integrated focus</th>
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<tbody>
<tr>
<td>Critical success factor</td>
<td>(vii) Sufficient resources</td>
<td>(viii) Improvement training</td>
</tr>
<tr>
<td>Description</td>
<td>Sufficient time and money are available for training and improvement activities</td>
<td>Managers and shop-floor employees get training in improvement concepts, tools, techniques and team building</td>
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<tr>
<td>Article</td>
<td>Sanaph, George Benson, and Schroeder (1989)</td>
<td>X</td>
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<td></td>
<td>Motwani, Mahmoud, and Rice (1994)</td>
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<td>Ahire, Golhar, and Waller (1996)</td>
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<td>Black and Porter (1996)</td>
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<td>Kaye and Anderson (1999)</td>
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<td>Chong, White, and Prybutok (2001)</td>
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<td>Antony et al. (2002)</td>
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<td>Sila and Ebrahimpour (2003)</td>
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<td>Tari (2005)</td>
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<td>Karuppusami and Gandhinathan (2006)</td>
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<td>Achanga et al. (2006)</td>
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<td>Dora et al. (2013), Dora, Kumar, and Gellynck (2016)</td>
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<td>Marodin and Saurin (2015a)</td>
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<tr>
<td></td>
<td>Azyan, Amul, and Pons (2017)</td>
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</table>
(Yusof and Aspinwall 1999, 2000; Salaheldin 2009; Dora et al. 2013; Dora, Kumar, and Gellynck 2016). We also split up ‘supply chain integration’ because we were interested in the importance of ‘a supplier link’ and ‘a customer link’ separately, and we left out ‘technical factors’ because they are only mentioned in relation to manufacturing resource planning (Chin and Rafuse 1993). To our knowledge, these 12 success factors cover the most important managerial areas from which we aim to identify factors that are critical for the implementation of lean practices.

Only a few studies have gone beyond identifying success factors for implementing lean practices. Motwani (2001) developed a TQM success factor implementation model, but his proposed sequence of success factors has not been empirically substantiated. Other studies identify sequences for success factors, based on their importance (Badri, Davis, and Davis 1995; Sohal and Terziovski 2000; Achanga et al. 2006) or their interrelationships (Kaye and Anderson 1999; Motwani 2001; García, Rivera, and Iniesta 2013; García et al. 2014; Marodin and Saurin 2015b). In those studies, ‘top management support’ and ‘shared improvement vision’ were consistently ranked as more important than ‘sufficient resources’ and ‘improvement culture’, indicating that a top-down approach might be more successful when implementing lean practices.

Netland (2016) found that the stage of lean implementation influences the importance of success factors, and that ‘leadership’ was ranked most important for both some implementation and for advanced implementation of lean practices. The same study also found that the importance of top management support increases with the extent of implementation of lean practices, and that the importance of improvement training, sufficient resources and support congruence decreases with advanced implementation of lean practices. This stage-dependent importance is in line with the process view on lean practice implementation as suggested by Shah and Ward (2007) and studied by Danese, Romano, and Boscari (2017). This paper will test the stage-dependent importance of the 12 success factors identified from the literature in a sample of manufacturing SMEs.

3. Research methodology

To test the extent to which success factors identified in the literature are critical for the implementation of lean practices, we conducted an NCA using self-assessment data.

3.1 Sample and data collection

The sample consisted of multiple-respondent self-assessments from 33 manufacturing SMEs recruited through the network of the Research Group Lean/World Class Performance at HAN University of Applied Sciences. Manufacturing was defined using the classification of economic activities in the European Community (commonly referred to as NACE) as ‘Level 1, Group C: Manufacturers’ (EC 2010). SMEs were defined as companies that employ 10–250 employees (EC 2005). We gathered data between 2013 and 2016 using multiple-respondent self-assessments.

To overcome respondent bias (Bowman and Ambrosini 1997), we asked multiple respondents per case to participate. To ensure that participants were suitable to fill in the self-assessment, they were selected based on their own understanding of the questions as well as their familiarity with the concepts surveyed. The production manager was always involved, but was complemented by the owner/director, general manager, managers of marketing, sales, R&D, engineering and/or logistics, production leaders and/or team leaders, resulting in a cross-level and cross-functional self-assessment. The number of respondents per case was linked to the number of employees at the company and varied from two to 13, with an average of six respondents per case.

3.2 Measures

The 12 success factors identified from the literature are: (i) top management support, (ii) shared improvement vision, (iii) good communication, (iv) leadership, (v) people focus, (vi) learning focus, (vii) sufficient resources, (viii) improvement training, (ix) performance measurement system, (x) supplier link, (xi) customer link and (xii) support congruence (see Table 1). Each factor was measured with a single item: e.g. ‘To what extent is top management support present for the implementation of lean practices in this organisation?’. To overcome idiosyncratic variation and increase construct validity for multiple respondents, we explained all the items beforehand, both orally and in writing. We also gave the results back to the respondents and discussed them with them afterwards. This enabled us to check whether the results were representing the constructs we intended to measure for that case. When using single questions to measure an item, nine-point Likert scales leave sufficient room for discrimination and are suitable for preventing measurement error (Finstad 2010). The Likert scale ranged from (1) ‘no presence’ to (9) ‘full presence’ of the success factor.
To measure the implementation of lean practices, we used a widely accepted questionnaire developed by Shah and Ward (2007) (e.g. Vinodh and Balaji 2011; Hofer, Eroglu, and Hofer 2012; Marodin and Saurin 2013). The questionnaire consists of 41 questions covering ten lean practices: (i) involved employees, (ii) productive maintenance, (iii) controlled processes, (iv) pull, (v) flow, (vi) low set-up, (vii) supplier feedback, (viii) JIT delivery, (ix) developing suppliers and (x) involved customers. Using Shah and Ward’s questionnaire, we used multiple questions to measure all lean practices. And, like Shah and Ward, we used a five-point Likert scale where: (1) ‘no implementation’, (2) ‘some implementation’, (3) ‘moderate implementation’, (4) ‘extensive implementation’ and (5) ‘full implementation’. With multiple questions per item, five points are sufficient to overcome measurement error (Finstad 2010).

Operational performance was measured using seven frequently used indicators: (i) cost, (ii) quality, (iii) delivery speed, (iv) delivery dependability, (v) delivery flexibility, (vi) product flexibility and (vii) volume flexibility (c.f. Vickery, Droge, and Markland 1993; Sakakibara et al. 1997; McKone, Schroeder, and Cua 2001; Pont, Furlan, and Vinelli 2008; Slack, Chambers, and Johnston 2010). These seven formative indicators of operational performance were each measured with single questions: e.g. ‘How is this organisation’s performance on cost, compared to that of its competitors?’. They were explained and checked in the same way as the success factors, and again a nine-point Likert scale was used, ranging from (1) ‘very bad performance’ to (9) ‘very good performance’.

3.3 Data analysis

Since we found a positive relationship between lean practices and operational performance in the introduction, we first validated whether this relationship also applied to our set of SMEs. Given the relatively small sample size, we answered this question by conducting a between-case comparison (Dul and Hak 2012). For each pair of cases, the average values of lean practices and operational performance were compared according to the following rule: if case A’s operational performance (OP-A) was higher than or equal to case B’s operational performance (OP-B) and case A’s lean practice implementation (LP-A) was higher than or equal to case B’s lean practice implementation (LP-B), the outcome was 1. Likewise, if case A’s operational performance (OP-A) was lower than case B’s operational performance (OP-B) and case A’s lean practice implementation (LP-A) was lower than case B’s lean practice implementation (LP-B), the outcome was 1. In other words, the outcome was 1 if the pairwise comparison met the expected pattern that a higher value on lean practices was linked to a higher value on operational performance. If this was not true, then the outcome was coded as 0. Applying this rule to each pairwise comparison \( \frac{1}{2} - \frac{1}{2} = \frac{13}{2} - \frac{13}{2} = 528 \) pairwise comparisons in total) produces an overall score between 0% (none of the pairwise comparisons met this condition) and 100% (all the pairwise
comparisons met this condition) indicating the strength of the relationship between the implementation of lean practices and operational performance in manufacturing SMEs. An outcome of 50% would indicate there was no relationship.

To identify the extent to which success factors were critical at different stages of implementation of lean practices in manufacturing SMEs, we conducted an NCA (Dul 2016). In contrast to the more regular regression analyses that study variables in a probabilistic relationship to each other, NCA allows us to study variables that are necessary but no guarantee for a certain outcome (e.g. success factors are necessary but no guarantee for the implementation of lean practices).

Using a regression analysis of the upper-left observations of an x–y plot, the NCA identifies a ceiling line. This line serves as a border between the ‘empty space’ and the ‘full space’ of the data-set (Goertz, Hak, and Dul 2012), and indicates the degree to which lean practices (y-axis) could be implemented without the presence of success factors (x-axis). See, for example, Figure 1: the solid line is the ceiling line for the regression equation \( y = f(x) \), where \( x \) is ‘top management support’ and \( y \) is ‘the implementation of lean practices’. This ceiling line indicates the minimum presence of a given success factor to be able to implement a certain degree of lean practices. Using the regression equations of the ceiling lines of all success factors, we identified a minimum extent of each success factor’s presence for every stage of implementation of lean practices. This method of analysis follows other examples of NCA application such as Valk et al. (2016), who determined the criticality of contracts and trusts for supplier relations, and Sousa and da Silveira (2017), who found necessary degrees of services in the process of servitisation.

4. Results

This section first shows that more implementation of lean practices was indeed also linked to a higher operational performance in SMEs. We then report the extent to which the success factors were found to be critical for the implementation of lean practices in SMEs.

4.1 The effect of lean practices on operational performance in manufacturing SMEs

To analyse whether implementation of lean practices was also linked to higher operational performance in our set of manufacturing SMEs, we conducted a between-case comparison (Dul and Hak 2012). Our findings confirm the improvement effect found in earlier studies of LEs: in most pairwise comparisons, SMEs with higher scores for implementation of lean practices also had higher operational performance. The between-case comparison score for this study – i.e. the percentage of 528 pairwise comparisons that met the expected pattern that a higher value on lean practices was linked to a higher value on operational performance – was 70.08%.

This relationship is not stronger because the observations, especially those of the lean practices, were close to each other. Between-case comparison is very sensitive to the absolute distance between observations (Dul and Hak 2012). A margin of plus or minus 5% for the ‘bigger than or equal to’ or the ‘smaller than’ was applied. This means that the comparison was disregarded when the observations were within a 5% range of each other. Using this margin resulted in 413 pairwise comparisons and a positive finding of 75.30%.

Another reason for the relationship being weaker is that organisations often choose to excel at specific operational measures. For example, if price or quality are most important for certain customers, companies that serve such customers might agree to perform less on other performance measures, resulting in a lower average operational performance compared to other cases. Both arguments strengthen our finding that there is a relationship between the implementation of lean practices and increased operational performance in our set of manufacturing SMEs.

4.2 Critical success factors for the implementation of lean practices

To identify the extent to which success factors were critical at different stages of implementation of lean practices, we first used x–y plots for each success factor (x-axis) in relationship to each lean practice (y-axis). If visual inspection indicated an ‘empty space’ in the upper-left corner of the x–y plot (e.g. Figure 2), there was no implementation of lean practices without the presence of that specific success factor, which suggests that that success factor would have been necessary for the implementation of lean practices. The x–y plots of the 12 success factors and lean practices are presented in Figures 1 through 6. Visual inspection of all figures indeed showed an empty space in the upper-left corner of each figure. These empty spaces indicated that all 12 success factors were necessary for implementing lean practices.

Visual inspection of the x–y plots suggest that all the success factors are necessary, but their criticality was not quantitatively specified. To further analyse the findings for criticality, we first drew a ceiling line to indicate the degree to which lean practices (y-axis) were implemented without the presence of success factors (x-axis). The ceiling line could
either envelop the upper-left observations with a piecewise-linear convex line (a ceiling envelopment line, CE-FDH hereafter referred to as CE line), or it could be a regression trend line through the upper-left observations of the data-set (ceiling regression line, CR-FDH hereafter referred to as CR line) (Dul 2016). Dul (2016) recommends using a CE line for a discrete data-set and a CR line for a continuous data-set. The data in this study were gathered using a discrete scale, then averaged from multiple respondents, and analysed using a continuous scale. Therefore, both CE and CR lines were drawn. Using the software ‘R 3.3.1’ with the package ‘NCA 2.0’, ceiling lines were automatically drawn for the CE and CR. Both lines are shown in Figures 1 through 6; the CE lines are represented by broken lines and the CR lines are represented by solid lines.
To determine the validity of the ceiling lines, two parameters are calculated: the accuracy and the effect size. The accuracy of success factor criticality depends on the number of observations above these ceiling lines. Dul (2016, 28) defines accuracy as ‘the number of observations that are on or below the ceiling line, divided by the total number of observations, multiplied by 100%’. Because there can be observations above the ceiling line, the empty space is henceforth referred to as the ‘ceiling zone’. If there are many observations above the ceiling line and in the ceiling zone, the success factors will not always be critical for implementing lean practices. So, the more observations found above the ceiling line, the less accurate the indication of success factor criticality for implementing lean practices.

The success factor accuracies are further provided by the NCA software, shown in Table 2. As the CE is a piecewise-linear line through the upper-left observations, the ceiling zone left of the CE line was completely empty. This results in an accuracy of 100% (i.e. the CE line was valid for all cases). The ceiling zone above the CR line, however, did contain cases, hence its accuracy was not 100%. This lower accuracy might have resulted from the limited number of cases and/or larger ceiling zones. Fewer cases increase the ratio of outliers compared to all cases, and with an equal distribution of cases, a larger ceiling zone leaves more room for outliers. Table 2 generally shows a lower accuracy for
higher ceiling zones. Given the limited number of cases in this study, the resulting CR line was considered valid for finding success factor criticality and thus could be used in the bottleneck table later in this section.

The size of the ceiling zone is also important, because almost every scatterplot contains a ceiling zone, no matter how small, in its upper-left corner. The larger the size of the ceiling zone, the more effect the success factor has on the implementation of lean practices. It was therefore important to calculate the effect size of the success factors (i.e. how large their enabling effect was on the implementation of lean practices).

Dul (2016) defines the effect size \( d \) as the size of the ceiling zone \( C \) divided by the scope of all observations \( S \), or \( d = C/S \). For example, the ceiling zone of (i) top management support divided by its scope gives the effect size \( 1.049/4.220 = 0.249 \). The effect size can range from 0 to 1. To establish the importance of the effect size, Dul (2016) proposes a general benchmark of \( 0 < d < 0.1 \) as a small effect, \( 0.1 < d < 0.3 \) as a moderate effect, \( 0.3 < d < 0.5 \) as a large effect and \( 0.5 < d \) as a very large effect possible for CE only. The larger the effect size of the success factor, the more sensitive the implementation of lean practices is to the absence of the success factor. The results are given again in Table 2. A large effect was found for a shared improvement vision, good communication, sufficient resources,

Figure 5. NCA plots of improvement structure: (a) sufficient resources, (b) improvement training and (c) performance management system for lean practices.
improvement training and a supplier link; a small effect was found for a customer link; and a moderate effect was found for all the other success factors.

To test the extent to which success factors were critical, we created a bottleneck table (Dul 2016). The presence of the success factors was compared with the implementation of lean practices, using the regression equation \( y = f(x) \) from the CR line. For every level of \( y \) (implementation of lean practices), this equation gave a level of \( x \) that the success factor appeared critical. The success factor(s) that require(s) the highest presence for a certain degree of implementation of lean practices can be seen as the most critical. If the required aspect is not yet in place, this success factor might have been the bottleneck for the implementation of lean practices. If this success factor was met, the next most critical success factor might have been the next bottleneck for the implementation, and so on, until all success factors were met.

Table 3 presents the bottleneck table for all 12 success factors. The lean practices and success factors are shown as a percentage of the range of the lowest and highest observed values. The first column gives the percentage of implementation of lean practices. Because the bottleneck table only covers the data spectrum we observed, the NCA software translates the lowest observed outcome, 2.24 on the 5-point Likert scale, to ‘0’ for the first row, and it translates the

![Figure 6. NCA plots of integrated focus: (a) supplier link, (b) customer link and (c) support congruence for lean practices.](image-url)
highest observed outcome, 3.28 on the 5-point Likert scale, to ‘100’ for the last row. The former are cases with initial implementation of lean practices, and the latter are cases with more advanced implementation of lean practices. The other 12 columns give the extent to which the 12 success factors were present. Again, the percentage of the range of the conditions is given. The lowest observed condition was 1.4 and represents no presence on the 9-point Likert scale and the highest condition was 8.5 and represents full presence on the 9-point Likert scale. Therefore, ‘NN’ stands for not necessary and ‘100’ stands for full presence of the success factor. Since our data do not cover the entire Likert scale of lean practices (1–5) or success factors (1–9), NN in the very first row means that we do not have data to show what percentage is required to start with lean. NN and the numbers in the remainder of this bottleneck table indicate the success factor criticality for various stages of implementation of lean practices.

Using the bottleneck table, we identified the required sequence of critical success factors for the implementation of lean practices. The first row of percentages in Table 3 (outcome 10%) suggests that in our set of manufacturing SMEs, only some presence of a learning focus (3.8%), improvement training (3.1%) and support congruence (4%) (corresponding to 1–2 on the 9-point Likert scale) are critical to starting to implement lean practices. The next set of success factors for implementing lean practices (outcome 20%) are good communication (2.1%), sufficient resources (6.2%) and a performance management system (5.2%). These results show that manufacturing SMEs that started to implement lean practices also had some sort of measurements to guide the process, they had a few people who were open to improvements and discussed them, and they had a basic improvement structure (some training, time and money to make improvements).

Looking at the other end of the spectrum, the last three rows (outcome 80–100%) showed percentages for all success factors, meaning that all success factors were at least partially present (21.2%–61.3% corresponding to 3–6 on the 9-point Likert scale) at manufacturing SMEs with more advanced implementation of lean practices (3 on the 5-point Likert scale). The extent per success factor is again given by a percentage. The factors that require the greatest presence are a shared improvement vision (85.9%), leadership (86.9%) and a supplier link (83.2%) (corresponding to 8 on the 9-point Likert scale); these percentages indicate that these success factors are very present in more advanced implementations of lean practices. This means that in our set of manufacturing SMEs, more advanced lean practitioners gradually focused more on developing a shared and overall improvement vision and they needed managers to coordinate the different improvement projects.
Table 3. Bottleneck table of the 12 critical success factors for implementing lean practices.

<table>
<thead>
<tr>
<th>Lean Practices/CSF</th>
<th>(i) Top management support</th>
<th>(ii) Shared improvement vision</th>
<th>(iii) Good communication</th>
<th>(iv) Leadership</th>
<th>(v) People focus</th>
<th>(vi) Learning focus</th>
<th>(vii) Sufficient resources</th>
<th>(viii) Improvement training</th>
<th>(ix) Performance management system</th>
<th>(x) Supplier link</th>
<th>(xi) Customer link</th>
<th>(xii) Support congruence</th>
</tr>
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<tr>
<td>0</td>
<td>NN</td>
<td>NN</td>
<td>NN</td>
<td>NN</td>
<td>NN</td>
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<td>NN</td>
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<td>NN</td>
<td>NN</td>
<td>NN</td>
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<td>NN</td>
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<td>NN</td>
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<tr>
<td>50</td>
<td>9.9</td>
<td>24.1</td>
<td>26.5</td>
<td>NN</td>
<td>4</td>
<td>26.7</td>
<td>25.6</td>
<td>33.9</td>
<td>22.2</td>
<td>23.7</td>
<td>NN</td>
<td>30.3</td>
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<tr>
<td>60</td>
<td>22.2</td>
<td>36.4</td>
<td>34.6</td>
<td>11.6</td>
<td>15.2</td>
<td>32.4</td>
<td>32.1</td>
<td>41.6</td>
<td>27.9</td>
<td>36.4</td>
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</tr>
<tr>
<td>70</td>
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<td>48.8</td>
<td>42.7</td>
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<td>38.1</td>
<td>38.6</td>
<td>49.4</td>
<td>33.5</td>
<td>48.1</td>
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<td>61.2</td>
<td>50.8</td>
<td>49.2</td>
<td>37.6</td>
<td>43.9</td>
<td>45.1</td>
<td>57.1</td>
<td>39.2</td>
<td>59.8</td>
<td>21.3</td>
<td>50</td>
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<tr>
<td>90</td>
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<td>73.6</td>
<td>58.9</td>
<td>68.1</td>
<td>48.8</td>
<td>49.6</td>
<td>51.5</td>
<td>64.8</td>
<td>44.8</td>
<td>71.5</td>
<td>44.1</td>
<td>56.6</td>
</tr>
<tr>
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<td>72.5</td>
<td>50.5</td>
<td>83.2</td>
<td>66.9</td>
<td>63.1</td>
</tr>
</tbody>
</table>
The factors that require the least presence for more advanced implementation are a performance management system (50.5%), a learning focus (55.3%) and sufficient resources (58%) (corresponding to 5–6 on the 9-point Likert scale). These results indicate that the success factor criticality changes with various extents of implementation of lean practices. This bottleneck table suggests that the only success factors critical for some implementation of lean practices are good communication, a learning focus, an improvement structure (sufficient resources, improvement training and a performance measurement system) and support congruence, and that the most critical factors for more advanced lean practitioners are a shared improvement vision, leadership and a supplier link.

4.3 High-variety/low-volume cases are most efficient
Special cases can provide new insights into success factors for lean practices. Cases of particular interest were found on the CE line, because these cases were the most efficient performers: their implementation of lean practices was the highest, while their success factor presence was the lowest. By listing these cases for all success factors, we found that cases 4, 10, 21, 29 and 32 were on the CE line for eight or more of the 12 success factors. We consider these five cases to be the most efficient performers. Case 10, however, was in the bottom 25% of lean practice implementers (bottom left), while the other four cases were amongst the top 25% of lean practice implementers (upper right). The latter four cases were thus highly efficient as top performers in implementing lean. These four top cases had varying numbers of employees (38–250) and were from different industries (electronics and manufactured goods), but all of them were high-variety/low-volume producers.

Looking at the implementation of lean practices, the top cases had higher implementation of the pull driven flow of value-added activities (3.3–3.9) than the other 29 cases (average of 2.7). Controlled processes and productive maintenance, and supplier and customer integration were only slightly better (2.5–2.9/2.3 and 2.9–3.3/2.8, respectively). Employee involvement was not better than in the other cases. This extent of implementation of lean practices enabled the top-performing medium-sized cases to excel at product flexibility (7.1–8.0/6.8) and the top-performing small-sized cases to excel at volume flexibility (7.8–8.5/6.5). In sum, these results indicate that high-variety/low volume manufacturers more easily reach the full potential of implementing lean practices, compared to low-variety/high volume manufacturers and jobbers, enabling them to perform in a highly flexible way while meeting their customer requirements.

5. Discussion
The aim of this study was to identify which success factors were critical at different stages of lean practices implementation. We analysed a data-set from manufacturing SMEs using a novel method: NCA.

5.1 Focus on shop-floor activities when starting with lean
Our results indicate that the following factors are critical for companies with little implementation of lean practices: communication, a learning focus, an improvement structure (sufficient resources, improvement training and a performance management system) and support congruence. It is logical that good communication is important for initiating lean practices, because improvements always require communication with colleagues, team leaders, upstream and downstream processes and so forth. This finding is in line with Achanga et al. (2006) and Dora, Kumar, and Gellynck (2016), who found that some degree of communication is desirable when implementing any kind of improvement. A learning focus also seemed crucial from the start, which seems plausible: improvements require experimenting, so employees need to be allowed to make mistakes and learn from them. This is in line with Yusof and Aspinwall (1999, 2000) and Dora, Kumar, and Gellynck (2016), who found that a ‘blame game’ in companies leads to low levels of trust and hence counters employee initiative.

An improvement structure also needs to be present from the start. Sufficient resources and improvement training are needed to think of, experiment with and implement improvements, and a performance management system is needed to monitor whether these implementations actually lead to improvements. According to Yusof and Aspinwall (1999, 2000) and Dora, Kumar, and Gellynck (2016), a lack of resources can act as an excuse not to improve, and the measurement of results, progress and performance is critical for implementing lean practices. Zhou (2016) found that the lack of time and budgets was high for companies with initial implementation of lean practices and Hu et al. (2015) found that training was important to diffusing lean implementation. The criticality of support congruence in the initial stages of implementing lean is also plausible because employees act, or refrain from acting, based on the rewards they receive, both intrinsically and extrinsically. If these rewards are not in line with required improvements, there is no drive to improve (Achanga et al. 2006; Dora, Kumar, and Gellynck 2016).
All these success factors are linked to shop-floor activities, so they seem mostly linked to local improvements. This is in line with Bessant, Caffyn, and Gallagher (2001) and Dora, Kumar, and Gellynck (2016), who found that all the manufacturing SMEs they studied adopted a gradual approach to the implementation of lean practices. This gradual approach may be suitable to SMEs in particular because they lack the resources to launch a company-wide implementation programme (Dora, Kumar, and Gellynck 2016). In sum, we can conclude that good communication, a learning focus, an improvement structure and support congruence are critical for the initial stages of lean practice implementation on a local level.

5.2 Strategic involvement for advanced lean practitioners
We also conclude that different success factors are critical for manufacturing SMEs that are more advanced lean practitioners. Only those organisations that achieved more advanced implementation of the lean practices showed an extensive presence of top management support, a shared improvement vision, leadership and a supplier link. This contrasts with the received wisdom that strategic involvement is most important from the start (Badri, Davis, and Davis 1995; Kaye and Anderson 1999; Sohal and Terziovski 2000; Motwani 2001; Achanga et al. 2006; García, Rivera, and Iniesta 2013; García et al. 2014; Hu et al. 2015; Netland 2016). In hindsight, further development of these factors seems more relevant for continued company-wide improvements. Such a company-wide approach is only possible if top management supports these initiatives (Saraph, George Benson, and Schroeder 1989; Motwani, Mahmoud, and Rice 1994). This is especially true for SMEs where managers are already more actively involved in day-to-day operations and operators rather than consultants or staff are needed to make improvements, shifting efforts from the board room to the shop floor (Dora, Kumar, and Gellynck 2016). Furthermore, a shared improvement vision may only become critical when a company-wide approach is being attempted; it ensures that improvement projects in different departments are in line with each other, not causing any sub-optimisation. According to Salaheldin (2009), Achanga et al. (2006), and Dora, Kumar, and Gellynck (2016), a shared improvement vision is needed to guarantee the long-term effectiveness of the improvements. Finally, leadership was only found to be a critical success factor when coordinating different improvement projects, even within the same departments. This is in line with Saraph, George Benson, and Schroeder (1989), Yusof and Aspinwall (1999, 2000), and Achanga et al. (2006), who found that leadership enables the integration of different improvements, which helps to succinctly implement lean practices. Therefore, we conclude that, in contrast to previous literature, a more extensive presence of top management support, a shared improvement vision and leadership are only critical for continued company-wide implementation of lean practices in manufacturing SMEs.

5.3 Downstream improvements precede upstream improvements
The bottleneck table shows that dependencies on external processes were only stronger for those manufacturers that had improved internal processes, starting with the success factor ‘a supplier link’. Sakakibara, Flynn, and Schroeder (1993) and Danese, Romano, and Bortolotti (2012) found no direct link between external JIT and performance, and argue that external JIT might be necessary for internal JIT rather than directly linked to performance. Saraph, George Benson, and Schroeder (1989), Motwani, Mahmoud, and Rice (1994), Yusof and Aspinwall (1999, 2000), Hu et al. (2015) and Zhou (2016) found that suppliers came in at a later stage, after many of the internal improvements had been accomplished. This order of improving the supply chain was replicated in our findings. First, there was alignment within the organisation (support congruence). Next, improvements were achieved together with suppliers (a supplier link). Finally, when processes were reliable and in line with suppliers, improvements also extended to customers (a customer link). Such a customer link means that organisations not only take customer value as the starting point – which, according to Womack and Jones (2003), is the first principle of lean – but also cooperate with customers in their improvement activities. Cooperation with customers will probably only be achieved if both internal and upstream processes are in good order. Therefore, we conclude that in manufacturing SMEs, organisations should only continue to improve upstream processes when the internal processes are in good order; only thereafter cooperation with customers becomes a critical success factor for improving the entire supply chain.

5.4 Lean in high-variety/low-volume organisations
The analyses further show that the most efficient top-performing cases are all high-variety/low-volume producers. Compared to the other cases, these companies had the highest implementation of JIT practices (a pull driven flow of value-added activities) and the highest performance of product flexibility and volume flexibility. JIT practices are seen as the core of lean (Shah and Ward 2003). This might indicate that lean practices come fully into play in organisations that
produce small bulk or custom-made products. An explanation for this finding is that JIT practices are counterproductive in conditions of extremely low demand variability (King 2009; Powell, Alfnes, and Semini 2010) and extremely high demand variability (Bortolotti, Danese, and Romano 2011, 2013).

5.5 Theoretical contributions

Previous research identified many success factors presumed necessary for implementing lean practices. This study suggests that, in manufacturing SMEs, there might be a sequence in which success factors become critical for success: not all success factors are critical for organisations that are in the initial stages of implementing lean practices, and some success factors appear to only be critical for organisations that have already become advanced lean practitioners.

This insight into the temporal nature of success factors contributes to the existing literature in two ways. First, our findings provide a more nuanced understanding of the criticality of success factors, suggesting that rather than being static in nature, success factor criticality changes during an organisation’s lean journey. Further confirmation in longitudinal studies and in a larger sample notwithstanding, these findings can help to advance the body of knowledge on how to stage and tailor improvement activities to an organisation’s maturity in terms of lean practices. Second, the study also makes a methodological contribution in showing that some relationships are better analysed using a necessary perspective rather than a probabilistic perspective and that the NCA method can be applied to open up novel perspectives on improving management practices. While the majority of statistical methods work based on correlations, NCA allows us to investigate criticality, which helps to deepen our understanding of management practices and performance outcomes.

5.6 Practical implications

These new insights into success factor criticality can help manufacturing SME managers in two ways. First, it can help them focus on those specific managerial areas that enable either starting or advancing the implementation of lean practices. If an organisation has only implemented lean practices to a limited degree, they should focus on shop-floor-related success factors, such as communication, a learning focus, an improvement structure and support congruence. If an organisation is more advanced in lean terms, managers should focus on company-wide success factors, such as top management support, a shared improvement vision and a supplier link. Second, understanding which success factors are critical for various stages of implementation of lean practices helps managers to re-allocate their resources to sustain resource efficiency. If certain bottleneck factors have been implemented, the remaining resources can be dedicated to other success factors for which the threshold has not yet been met. This combination of focus on critical success factors and sustaining resource efficiency helps SME managers to more effectively deploy their efforts and increase the possibility that lean practices are implemented in their organisation.

5.7 Recommendations for future research

Although the underlying question of this study on the criticality of success factors for the implementation of lean practices is generic in nature, the nature and size of our sample also limit its generalisability. Our data were drawn from a small set of Dutch manufacturing SMEs and the findings may or may not extend to other sectors or locations. Future research could replicate the approach presented here and study success factors in different countries and/or use samples suitable for generalising success factor criticality. Furthermore, sectors other than manufacturing might require different success factors or different levels of criticality in relation to implementing lean practices. To enable further abstraction, future research could therefore focus on success factors and data-sets in other branches such as maintenance or services. Such replication studies would validate the findings presented here.

In addition to replication studies, the NCA method offers other exciting opportunities for future research. For example, it is known that lean practices are implemented via continuous improvement routines, like a shared belief in improvement and employee initiative to improve (Koufteros, Vonderembse, and Doll 1998; Bessant, Caffyn, and Gallagher 2001; Bortolotti, Boscari, and Danese 2015). Future research could use the NCA view of necessity thinking to discover which improvement routines are critical for different stages of the implementation of lean practices. Furthermore, future research could use the NCA approach to determine whether different success factors are necessary for different combinations of lean practices, and whether different lean practices in turn increase operational performance. Further insights into sequencing of improvement routines and different combinations of lean practices could help manufacturing SMEs to further increase their operational performance and competitive advantage. Finally, we used cross-sectional data to propose a sequential model of maturity, which should be confirmed in a longitudinal study to exclude other confounding factors such as the nature of their business (low volume – high variability).
Disclosure statement
No potential conflict of interest was reported by the authors.

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