A roadmap for lean production tools implementation

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Abstract: The purpose of this study is to identify the tools for implementing lean production. Also, providing a suitable roadmap for the implementation of lean production tools is another purpose of this research. This study examined the priority of using various lean tools with the focus on achieving lean production goals in Supplying Automotive Parts Company (SAPCO). At first, various tools of lean production were extracted using library research. They were reviewed and prioritised by analytic network process (ANP). In the next step, the interactions of the effectiveness and susceptibility of lean tools has been extracted through decision-making trial and evaluation laboratory (DEMATEL) method. By analysing the obtained results, a suitable roadmap for the implementation of lean manufacturing tools [including personnel (continuous improvement, performance management, organising), Kaizen, value stream map, 5S, standard work, productive maintenance, pull system, Jidoka, single minute exchange of die, Heijunka and continuous flow] has been presented.

Keywords: lean production; analytic network process; ANP; DEMATEL; supplier enhancement.

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1 Introduction

Competitive market had been tempting manufacturers to yearn for mass production for centuries including two previous decades. However, this method has been totally replaced by lean production. Global competition, uncertain demand environment and higher consumer expectations are among the many drivers for businesses to implement productive improvement tools such as lean (Goshime et al., 2019). It considers plentiful revised objectives including quality, innovation and variety in addition to time and cost reduction as the result of recent enhancement in manufactures attitudes and consequently their technical knowledge (Womack et al., 2007). Lean approaches should comply with organisational strategies, like all functional strategies (Salah, 2017; Lauver et al., 2020).

Supply chain management (SCM) has become of great competitive interest in global business. It includes continuous monitoring of products flow from the first step (providing raw material) to the last one (delivering it to the final customer). SCM coordinates and integrates products, information and material flow from supplier to the final user. In other words, all activities related to raw material are included in SCM. It moves along a process from supplier to manufacturer, wholesaler, retailer and finally consumer (McGreevy, 2003). Lean production overlaps SCM. Apparently, a good supplier performance tends to simplify lean production. Moreover, application of lean concepts in supply chain represents remarkable chances to stand on higher levels than other competitors. Lean production can be described as the SCM at an operational level or transaction-based SCM, focusing on information and material flows particularly in the automotive industry (Vanichchinchai, 2019). Lean production is a system for optimising manufacturing processes and procedures by decreasing inefficient wastes. Implementation of lean production involves fundamental changes in the management systems of companies, across organisational and department levels (Tortorella et al., 2017).

Accordingly, facilitating SCM with lean production can bring about such stunning results which are definitely to organisations and consequently their customers benefit. Competitive advantage is given when customer satisfaction is reached. As the result, the facilitated company with lean production and enhanced SCM gains higher levels of market share (Lebosse et al., 2017).

Despite the enormous potential of lean strategy, many studies on lean implementation have failed and it has brought unexpected results to organisations.

Unfortunately, the results were far stranger than researchers' expectations in some practical scopes. They focused on a new system to reduce cost and time and improve quality, to remove waste and win competitive advantage, but what came out was the appearance of a variety of different inevitable issues.

Evidently, lean production was not the main reason behind the emerged problem. Then, lean productions implementation and its performing methods were playing primary roles. Therefore, finding out appropriate tools can be of great importance while implementing and running lean production systems in supply chain scope which is poorly mentioned in previous studies. The contribution of this study is to identify the most deserved lean tools in implementation phase of lean production and offering a proper roadmap and save time and cost as the result. Furthermore, the main criteria (success factors) of each tool were identified. Their main criteria are prioritised using analytic network process (ANP) and interactions rates using decision-making and decision-making trial and evaluation laboratory (DEMATEL) techniques. Finally, a roadmap is offered to establish lean tools in supplier companies serving Iran Khodro, the largest auto company in Iran.

2 Literature review

This section presents the origin of conducted studies on lean topics including lean production, lean management, lean tools and finally, the proposed criteria to investigate lean tools.

2.1 Lean production and its correspondence to supply chain

Increasing consumer expectations, high quality goods and services are pushing companies to accept lean method as their methodology for process improvement and management philosophy (Narottam et al., 2020). Lean approach was first introduced by Toyota in Japan. Being influenced by great demand to motor vehicles in 1930, the company changed its area of expertise and stepped toward automotive industry. In 1950, two chief executive officers of Toyota observed Ford Motor Company and its mass production system convinced them to implement similar procedures in Toyota. Soon after performing mass production, Ohno concluded that this system fails in meeting the desired results.

Japan industry was suffering from small domestic markets, fixed and inflexible workforce, dearth of investment and many interested foreign competitors at the same time. Consequently, a remarkable study was performed in Massachusetts Institute of Technology (MIT) in cooperation with some concerned organisations. For five years, they explored all procedures and processes in Toyota production system which had made it different from the so-called mass production system. Eventually, they came to an agreement about ‘lean production’ as a key enabler in Toyota system (McGreevy, 2003). However, the term ‘lean production’ is more recent, first suggested by Krafcik. Lean manufacturing thus evolved at Japan in the automotive sector after the Second World War (AlManei et al., 2017). Lean approaches should comply with organisational strategies, like all functional strategies (Lauver et al., 2020).

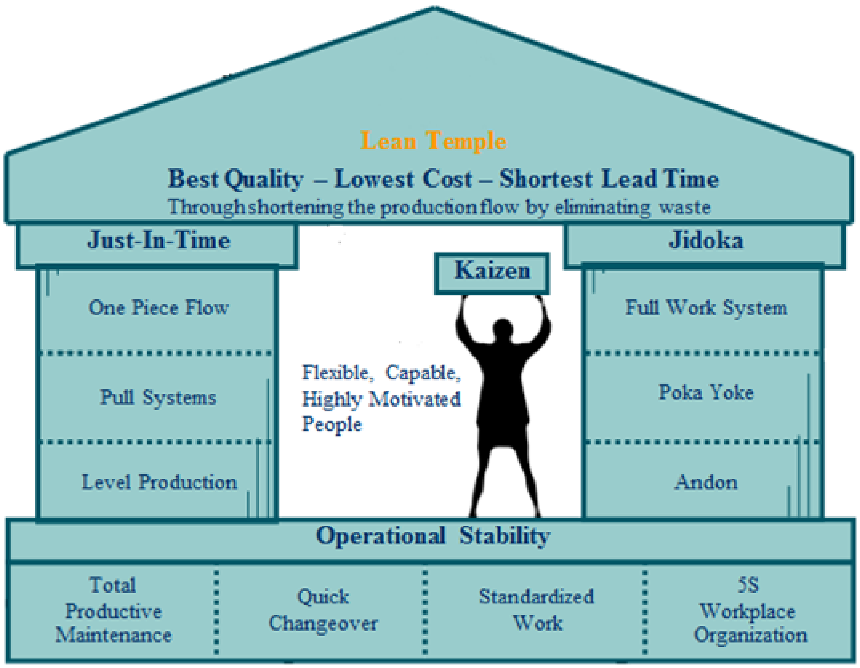
Lean production literature is prolific and it is a forum focused on increasing productivity and reducing the cost of processes (Kumar et al., 2018; Tortorella and Fogliatto, 2017). It has also been the subject of increased academic interest within recent years. For example, Payatodora states that in a supply chain with stable demand fluctuation the more increase in leanness, the more reduction in overcapacity and inventory level is appeared (they are not mutually exclusive). This proves that lean thinking is a key enabler to adapt supply chains capacity to customer need as well as removing fat or waste from business and trade (Adam et al., 2014).

2.2 Lean management

Lean management is focused mainly on waste disposal and promotes the value creation process for all stakeholders (Régis et al., 2019). It is a complicated context which is formed in relation to disparate conceptual and physical aspects. In point of fact, it can be explained as a different insight into organisation, i.e., a specific interpretation of ongoing activities within organisation. This system is really inclusive and includes a wide variety of practical methodologies.

Lean fundamentals and tools are considered to be a part of this system (Dennis, 2016). Construction and elements of a lean production are illustrated in Figure 1.

Figure 1 Lean home (see online version for colours)



Source: Bayoua and de Korvin (2008)

2.3 Lean production tools

Lean tools proved to be critical factors in implementing lean production system. Accordingly, Shah and Ward (2003) studied literatures published on lean tools during 1977 to 1999. The study was then implemented by Bayoua and de Korvin (2008) to introduce rate of lean tools envelopment. They highlighted a few tools as major lean tools capable of fulfilling lean goals (Shah and Ward, 2003).

McGreevy (2003) performed a collaborative study on self-assessment check list for lean organisations that introduced an optimised level for each feature. In this work, structure of self-assessment was mainly focused on leadership, life cycle and deep-seated capability.

Abdulmalek and Rajgopal (2005) considered practical approaches in their studies. But there was still a weak point which was to ignore effectiveness of lean tools in waste reduction (Abdulmalek and Rajgopal, 2005). In other words, there have been plenty of researches exploring implementation and conformation of lean tools but they never highlight importance of tools in eliminating wastes as well as the ways they affect waste reduction (Soriano-Meier and Forrester, 2002).

Table 1 Major lean tools explored in literature

Lean production tools	*Extreme envelopment*	*Mid envelopment*	*Limit envelopment*
Just in time/continuous flow	*		
Kanban	*		
Quick changeover techniques	*		
Lot size reductions	*		
Continuous improvement plans	*		
Multi task work force	*		
Total productive maintenance (TPM)	*		
Self-directed work teams	*		
Cell manufacturing system		*	
Focusing on plant		*	
Reducing work cycle		*	
Process capability measurements		*	
Technology/equipment for new process			*
Safety improvement plans			*
Bottleneck removal (production smoothing)			*
Quality management plans			*
Process reengineering			*
Competitive benchmarking			*
Optimizing maintenance			*
Planning and timing of strategies			*

Source: Abdullah (2003)

Major lean tools explored in literature are shown in Table 1. In Table 1, the term ‘extreme envelopment’ indicates that a large number of research have had their focuses on this mean. This is while mid envelopment and limit envelopment has been ranked as the second and third tools on which research have been focused (Abdullah, 2003).

It is worth mentioning that lean tools have been far regarded as assorted techniques in various researches, which might take different names. From one side, this complexity refers to their origination. They were derived from the Japanese style production (Toyota); thus, being translated to English, might mislead the readers. For instance, using ‘self-direct production’ instead of ‘Heijunka’ and ‘continuous improvement’ instead of ‘Kaizen’.

Lean production tools were also illustrated in Table 2 regarding their frequencies of being mentioned in various studies. For instance, Soriano-Meier and Forrester (2002) applied Kaizen, pull system, flexible work system, JIT and poka-yoke in its study.

Table 2 Implemented tools in literature

Research background / *Lean production tools*	Jidoka	Kaizen	Standard work	5S	Total productive maintenance (TPM)	Heijunka	Value stream mapping (VSM)	Pull system	Continuous flow	Single minute exchange of dies (SMED)	Flexible work systems	Just in time (JIT)	Cellular manufacturing	Poka-yoke	Visual management	Kanban	Personnel (continuous improvement culture, performance management, organising)
Soriano-Meier and Forrester (2002)		X						X			X	X		X			
Abdullah (2003)		X	X	X	X	X			X	X							
Abdulmalek and Rajgopal (2005)	X			X	X		X	X		X							
Rivera and Chen (2007)	X		X	X	X	X	X			X	X	X			X		X
Saurin and Ferreira (2008)			X								X		X				X
Alvarez et al. (2009)							X									X	
Gupta and Kundra (2012)		X		X	X	X	X			X				X		X	
Rajenthirakumar and Shankar (2011)				X		X	X			X							
Haque and Chakraborty (2012)			X	X	X		X	X	X		X	X	X	X	X	X	X
Rajenthirakumar et al. (2013)							X										
Anvari et al. (2014)	X	X	X	X	X			X	X		X	X	X	X	X		X
Ståhl et al. (2015)			X	X			X										
Tyagi et al. (2015)							X										
Arunagiri and Gnanavelbabu (2014)		X		X			X										
Chiarini (2014)				X	X		X			X			X				
Adam et al. (2014)		X			X		X	X	X	X							
Dresch et al. (2019)		X	X	X						X				X	X		
Kumar et al. (2018)		X					X										
Patel et al. (2019)		X		X	X		X										
Régis et al. (2019)		X	X	X			X								X		
Leksic et al. (2020)		X		X	X	X				X				X		X	

Despite the fact that plenty of lean tools have been introduced, some criteria were still needed to extract the superior ones. Accordingly, this work evaluated related criteria in the literature as well.

2.4 Main criteria to investigate lean production tools

Various surveys have also been conducted by lean practitioners and researchers to assess lean tools. Even though those indicated advantages of each tool, the main objectives for implementing lean tools fall into four categories: waste reduction and quality improvement, cost reduction and shorter lead time. Thus, they can be recommended as major criteria for the assessment of lean tools (Rivera et al., 2007).

In the context of lean production researches, Lockamy (1995) provided a different insight in world class companies. He evaluated companies based on leanness percentage applied on their process. Performance evaluation and its strong linkage to manufacturing systems, marketing, warehouse, logistic, maintenance, after sale services have been far known as critical tools to increase quality as well as reducing cost and lead time (Lockamy, 1995).

Later, Mahapatra and Mohanty (2007) performed a survey on discrete and process manufacturing systems in India and classified lean tools in two categories. According to this study, total productive maintenance, transformation time and self-directing have gained top three priorities among process manufacturing systems (Mahapatra and Mohanty, 2007).

Undoubtedly, the automotive industry is one of the most important industries in the world as well as in Iran. Due to various reasons such as high production, global competition and complexity, this industry has always been the birthplace of many models of management and industry. It has often been the inspiration for other industries. One of the characteristics of Iran's automotive industry during the revitalisation period is the creation of a supply chain and its management by internal automakers (Fathia and Ahmadian, 2016). Many technologies and tools are used to improve supply chain solutions. Among these, lean supply chain is of great importance (Mensaha and Merkuryeva, 2014).

Lean production and other production methods are also tied to the automotive industry, and to describe lean production methods, it is necessary to examine the tools used and provide an appropriate roadmap. Thus, the present study identifies the success factors of each tool and provides an appropriate model for the use of lean manufacturing implementation tools in the supply chain of the automotive parts industry.

Regarding literature review, despite the clear motivation toward lean production, studies in this strand of research are highly structured on the effectiveness of lean application and implementation. There is no practically accepted roadmap to implement lean production and employ relevant tools. This work fulfils the blanks by identifying lean production tools and defines various indicators to measure their efficiency. Then, importance of each tool is deducted according to the extent to which it affects outcomes of applying lean production, using pairwise comparisons. The next step explains importance of each outcome as diagnosed by experts who are pioneer in automotive industry and education sector. They make decisions and expert judgements considering cost, quality and lead time as three main objectives of lean production.

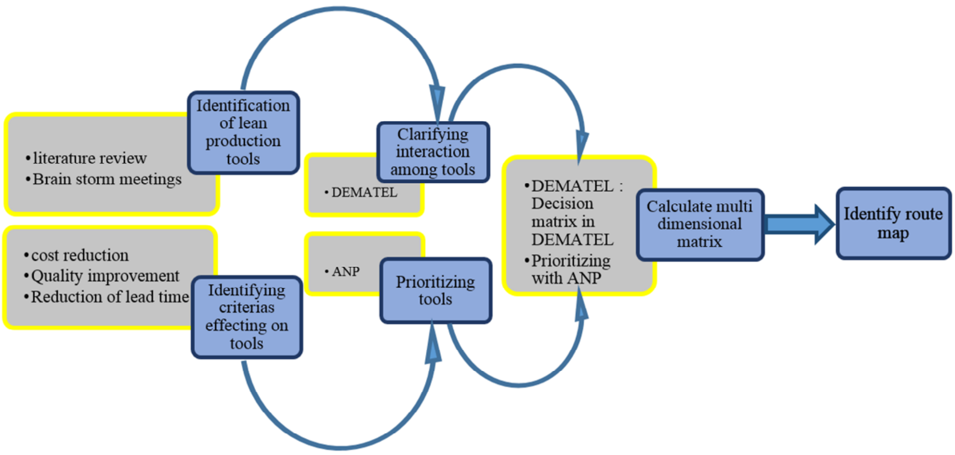
3 Methodology

In terms of the objective, this research is applied. Therefore, it uses theories, principles and techniques proven in development research. Also, ANP and DEMATEL methods are used to identify and prioritise lean production tools. Finally, it provides a roadmap for implementing lean production. However, this study is descriptive and survey based on the method of data collection and analysis.

In the first step, the tools of lean production were first collected from the theoretical foundations of the subject. Brainstorming was the right path to get to this destination and the results were summarised in Table 2. In the second step, effective criteria on lean productions success was identified in supply chain scope. Cost reduction, lead time reduction and quality improvement came out to be three main criteria as the result of experts brainstorming. Next, considering comments of a group made up of six logistics experts in Supplying Automotive Parts Company (SAPCO) and four university experts. DEMATEL technique was successfully applied to study interaction (effectiveness and susceptibility) among tools. The priority of lean tools is determined by the indicators of cost reduction, quality increase and reduction of lead time by ANP technique.

In the next step, a multidimensional matrix was formed, and led us to obtain a roadmap. Figure 2 illustrates the mentioned steps in order to clarify them (Karim and Arif-Uz-Zaman, 2013).

Figure 2 Research framework (see online version for colours)

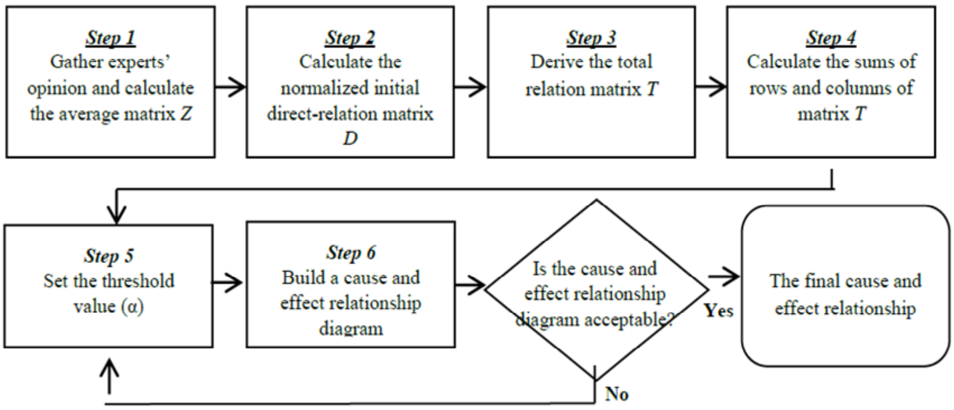


3.1 DEMATEL technique

DEMATEL is a multi-criteria decision-making technique based on graph theory that enables users to plan and solve problems. Moreover, DEMATEL can be used to verify cause-effect relations among criteria and construct interrelations between criteria, so as to build a cause-effect map (Aghaie and Fazli, 2012).

Ultimate outcome of DEMETEL is a map that indicates work construction and interdependencies among criteria (Hsu et al., 2013). DEMATEL steps are summarised in Figure 3.

Figure 3 DEMATEL steps



Fourth step is allocated to weighting lean tools based on extracted criteria in Step 2, determining the best tools and prioritising them using ANP.

3.2 ANP

ANP is a more general form of the analytic hierarchy process (AHP) used in multi-criteria decision analysis. AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while the ANP structures it as a network. Both of them then use a system of pairwise comparisons to measure the weights of the components of the structure, and finally to rank the alternatives in the decision. ANP includes the following steps: model construction and problem structuring, pairwise comparison matrices and priority vectors, Super matrix formation and finally selection of the best alternatives.

3.3 Statistical population

Statistical population refers to all items and events that have been studied. Generally, researchers perform their studies on an originally complete group of samples called statistical population. They tend to study variable features in the population.

Thus, experts are among sophisticated managers in SAPCO who are capable of identifying and comparing lean tools. Also, master engineers in logistics, evaluation and upgrading supplier's departments are considered as the statistical population. Since each individual expert had his/her own professional opinion, it focused on any individual ideas. Therefore, there is no particular sampling technique applied in this study.

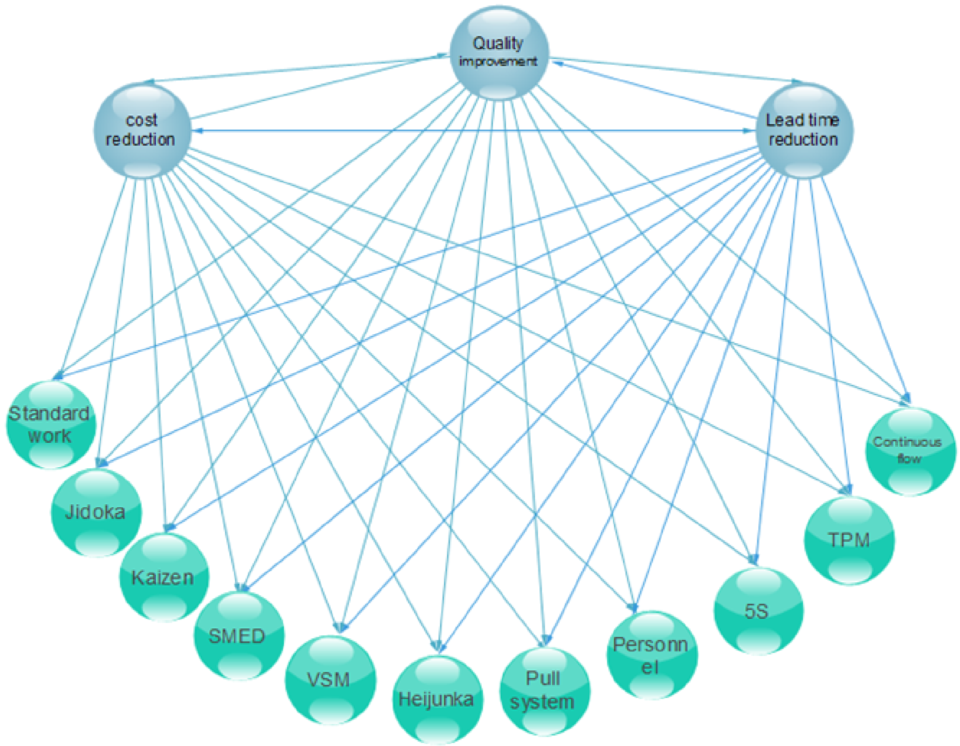
4 Data analysis and results

In this section, the mentioned methods were performed and the obtained results were discussed.

4.1 Design of ANP

Considering the present research objectives, tools and criteria, a model was proposed using Super Decisions Software (Kumar et al., 2018). According to the proposed model, Figure 4 has been mapped to indicate ANP.

Figure 4 ANP (relations between criteria and tools) (see online version for colours)

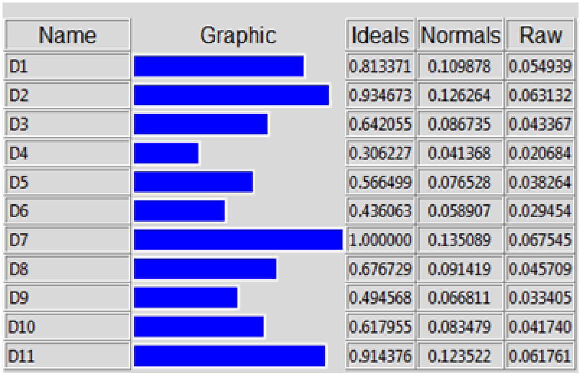


As it is shown in Figure 4, all criteria are linked to tools and other criteria as well. Questionnaires are also designed with the same criteria. Since, more than one expert is involved in the study, it is used geometric mean to prioritise experts' judgement. It is a well-known method to combine comparison tables. Geometric mean helps applying experts' judgements individually as well as considering groups' judgements about pairwise comparison. Therefore, it is the most appropriate mathematical technique to comprise all judgements in an analytic network as it preserves pairwise comparison matrix as an invertible matrix.

4.2 Criteria-based prioritisation

Lean tools were subjected to pairwise comparisons based on introduced criteria. Furthermore, it was implemented decisions made by pioneer experts in the specific industry and education field. Then, all values were calculated using geometric mean. The values were then fed into Super Decisions Software where those were processed. Results are presented in Figure 5.

Figure 5 Final outputs of super decisions (see online version for colours)



Name	Graphic	Ideals	Normals	Raw
D1		0.813371	0.109878	0.054939
D2		0.934673	0.126264	0.063132
D3		0.642055	0.086735	0.043367
D4		0.306227	0.041368	0.020684
D5		0.566499	0.076528	0.038264
D6		0.436063	0.058907	0.029454
D7		1.000000	0.135089	0.067545
D8		0.676729	0.091419	0.045709
D9		0.494568	0.066811	0.033405
D10		0.617955	0.083479	0.041740
D11		0.914376	0.123522	0.061761

Final outputs of Super Decisions, indicating priorities of criteria based on total objectives (Figure 5).

With Super Decision's outputs obtained, priority matrix was built of normalised columns. Table 3 illustrates lean tools priorities.

Table 3 Priorities of tools using ANP

Grade	*Lean production tools*	*Normal*
1	Personnel	0.123522
2	Kaizen	0.126264
3	VSM	0.135089
4	Standard work	0.086735
5	5S	0.041368
6	Jidoka	01.9878
7	TPM	0.076528
8	SMED	0.083479
9	Pull system	0.091419
10	Heijunka	0.058907
11	Continuous flow	0.066811

4.3 Detecting patterns of interactions between variables using DEMATEL

DEMATEL is able to recognise the casual relationships by dividing important issues into cause and effect groups as well as making it possible to draw the casual relationships of subcriteria and systems in the course of casual diagram. It is able to demonstrate communication network. This method has advantages in analysing the relation between components of a system with respect to its type (direct/indirect) and severity. It helps experts in providing a proper judgement about effects (direction and severity) between criteria. It is worth noting that, the matrix obtained from DEMATEL technique (internal interactions) demonstrated cause-effects relations as well as interactions between variables.

Table 4 Effectiveness and susceptibility in cells

Matrix relations	*Jidoka*	*Kaizen*	*Standard work*	*5S*	*TPM*	*Heijunka*	*VSM*	*Pull system*	*Continuous flow*	*SMED*	*Personnel*
Jidoka		Ok	Nok	Ok	Nok	Nok	Nok	Nok	Nok	Nok	Ok
Kaizen	Nok		Nok	Ok	Nok	Nok	Nok	Nok	Nok	Nok	Ok
Standard work	Nok	Nok		Ok	Nok	Nok	Nok	Nok	Nok	Nok	Ok
5S	Nok	Nok	Nok		Nok	Nok	Nok	Nok	Nok	Nok	Ok
TPM	Nok	Nok	Nok	Nok		Nok	Nok	Nok	Nok	Nok	Ok
Heijunka	Nok	Nok	Ok	Ok	Ok		Ok	Ok	Nok	Nok	Ok
VSM	Nok	Nok	Nok	Ok	Nok	Nok		Nok	Nok	Nok	Ok
Pull system	Ok	Nok	Ok	Ok	Ok	Ok	Ok		Ok	Ok	Ok
Continuous flow	Nok	Nok	Ok	Ok	Ok	Ok	Ok	Ok		Nok	Ok
SMED	Nok	Nok	Nok	Nok	Nok	Nok	Nok	Nok	Nok		Ok
Personnel	Nok	Nok	Nok	Nok	Nok	Nok	Nok	Nok	Nok	Nok	

Table 5 Analysis of DEMATEL technique

Analysis	*Jidoka*	*Kaizen*	*Standard work*	*5S*	*TPM*	*Heijunka*	*VSM*	*Pull system*	*Continuous flow*	*SMED*	*Personnel*
j	3.05107995	3.00014554	3.14269645	2.95870312	2.92042368	3.45956104	2.98833487	3.90738723	3.69753845	2.83155977	2.94914008
R	2.69675999	3.69316816	3.27404625	3.48096868	3.04056556	2.80648487	3.16493778	3.12172121	2.90976413	2.68453442	4.03361913
R+j	5.74783995	6.6933137	6.4167427	6.4396718	5.96098924	6.26604591	6.26604591	7.02910844	6.60730258	5.51609419	6.6827592
R–j	–0.35431996	0.69302262	0.13134979	0.52226556	0.12014188	–0.65307616	–0.65307616	–0.78566602	–0.78777432	–0.14702535	1.08447905

4.4 Drawing network relationship map

To determine the network relationship map (NRM), a threshold value was calculated. By this method, partial relations were ignored and a network of reliable relations was drawn. Only those relations in matrix T which were greater than the threshold value would be present in NRM. To calculate the threshold value of a relation, it was necessary to calculate average values of the matrix T. After determining the threshold value, all elements of matrix T with their values smaller than the threshold were identified as a susceptible tool. In this study, the threshold value was 0.28848. The threshold value represents arithmetic mean of all values existing in the decision matrix. Thus, the model of significant relations took the following form:

In Table 4, effective and significant cells are indicated by Oks, while susceptible cells are shown by Nok.

4.5 Developing a roadmap to implement lean tools

In order to draw the roadmap, all results obtained from DEMATEL and ANP were compiled and analysed as follows.

In Table 5, the sum along each row (R) indicates effectiveness of the corresponding criterion on the rest of criteria. Accordingly, project-related items were observed to have gained maximum effectiveness, followed by environment-related and organisation-related items (which have been found to impose minimum effectiveness).

The sum along column (J) indicates the degree of effectiveness of the corresponding item on other items of the system. Hence, environment-related were found to be of maximum susceptibility, while organisation-related items were of minimum susceptibility.

Horizontal axis (R + J) shows the degree of interactions among criteria in the system. In other words, the greater the value of (R + J), the further the corresponding criterion interacts to other criteria within the system.

Figure 6 Prioritising the use of lean tools by DEMATEL technique (see online version for colours)

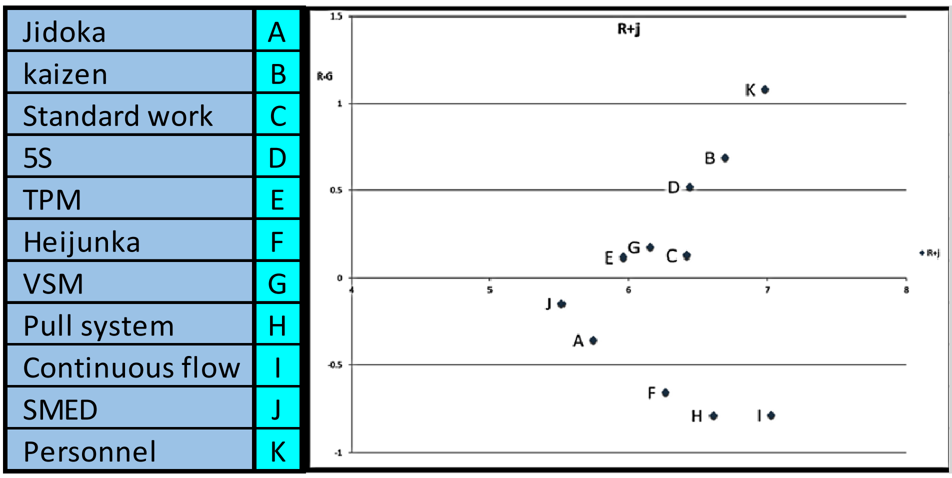


Table 6 Analysis of combined ANP and DEMATEL

Analysis	*Jidoka*	*Kaizen*	*Standard work*	*5S*	*TPM*	*Heijunka*	*VSM*	*Pull system*	*Continuous flow*	*SMED*	*Personnel*
j	3.05108	3.0001455	3.1426965	2.9587031	2.9204237	3.459561	2.9883349	3.9073872	3.6975384	2.8315598	2.9491401
R	2.69676	3.6931682	3.2740462	3.4809687	3.0405656	2.8064849	3.1649378	3.1217212	2.9097641	2.6845344	4.0336191
R+j	5.7478399	6.6933137	6.4167427	6.4396718	5.9609892	6.2660459	6.1532727	7.0291084	6.6073026	5.5160942	6.9827592
R–j	–0.35432	0.6930226	0.1313498	0.5222656	0.1201419	–0.653076	0.1766029	–0.785666	–0.787774	–0.147025	1.0844791
Ranking from effectiveness to susceptibility	4	10	7	9	6	3	8	2	1	5	11
Ranking from effectiveness to susceptibility (normalised)	0.0606061	0.1515152	0.1060606	0.1363636	0.0909091	0.0454545	0.1212121	0.030303	0.0151515	0.0757576	0.1666667
Ranking of ANP	0.109878	0.126264	0.086735	0.041368	0.076528		0.135089	0.091419	0.066811	0.083479	0.123522

Vertical axis (R – J) indicates effectiveness of each criterion. In general, if R – J is positive, the corresponding variable is considered as a cause, with negative R – J values indicating that the corresponding variable is an effect.

Degree of effectiveness of each tool was analysed on the basis of the results reported in Table 5, and then Figure 6 displayed priorities of tools as determined based on their effectiveness (in an ascending order from top to bottom).

In order to draw a roadmap and prioritise lean production tools, the following steps were taken and the results of ANP and DEMATEL were investigated in Table 6:

1 Prioritising tools using ANP.

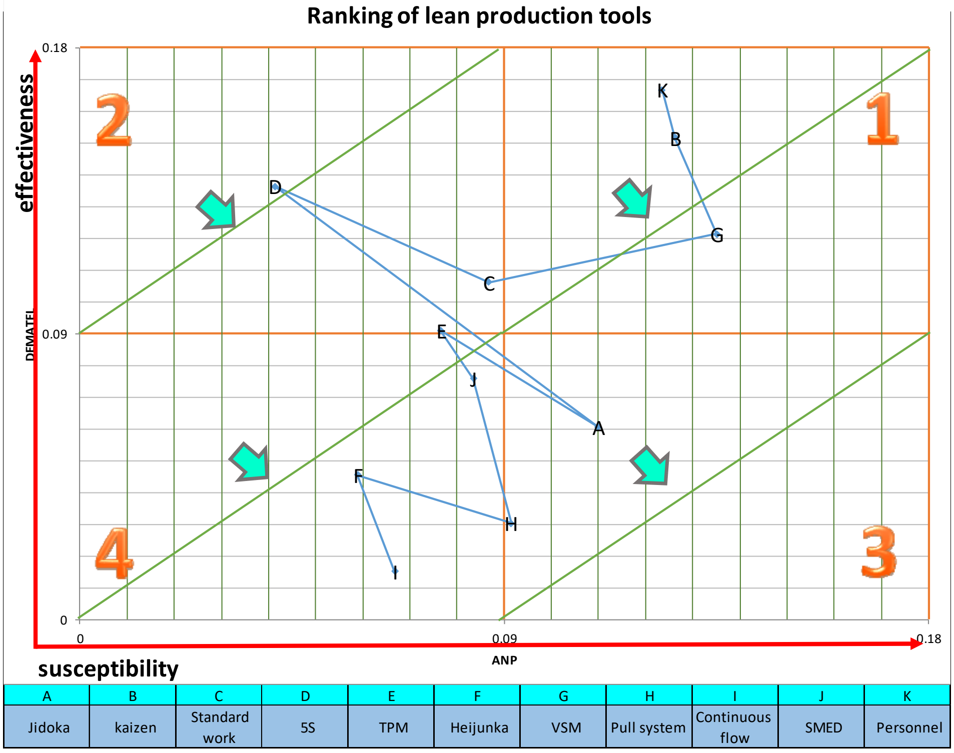
2 Evaluating effectiveness degrees of tools using DEMATEL.

3 Prioritising tools from effectiveness to susceptibility.

Prioritisation of tools is done using ANP and DEMATEL is used to evaluation of effectiveness degree, and overall rank is determined using average of ANP and DEMATEL. Then, a graph is drawn which simplified analysis of the results.

Ranking lean production tools in Table 6 help to extract a roadmap which is illustrated in Figure 7.

Figure 7 Roadmap (see online version for colours)



In agreement with Figure 7 and taking effectiveness as a major preference, it start to outline tools from cell 1 which shows the maximum rank in effectiveness and the highest priority using ANP. In this way, cells 2, 3 and 4 are processed (direction of arrows on Figure 7 depicts priorities of tools).

Table 7 ANP, DEMATEL and total grade of lean production tools

Grade	*Lean production tools*	*Grade (ANP)*	*Grade (DEMATEL)*	*Total grade*
1	Personnel	0.123522	0.166666667	0.145094333
2	Kaizen	0.126264	0.151515152	0.138889576
3	VSM	0.135089	0.121212121	0.128150561
4	Standard work	0.086735	0.106060606	0.096397803
5	5S	0.041368	0.136363636	0.088865818
6	Jidoka	0.109878	0.060606061	0.08524203
7	TPM	0.076528	0.090909091	0.083718545
8	SMED	0.083479	0.075757576	0.079618288
9	Pull system	0.091419	0.03030303	0.060861015
10	Heijunka	0.058907	0.045454545	0.052180773
11	Continuous flow	0.66811	0.015151515	0.040981258
Average		0.090909091	0.090909091	0.090909091

According to cell 1, tools are of following priorities:

1 personnel

2 Kaizen

3 value stream map.

Reported by cell 2, priorities of tools are as follows:

1 5S

2 standard work

3 total productive maintenance.

According to cell 3, however, tools are prioritised as follows:

1 Jidoka

2 pull system.

And according to cell 4, the following series of priorities were obtained for the tools:

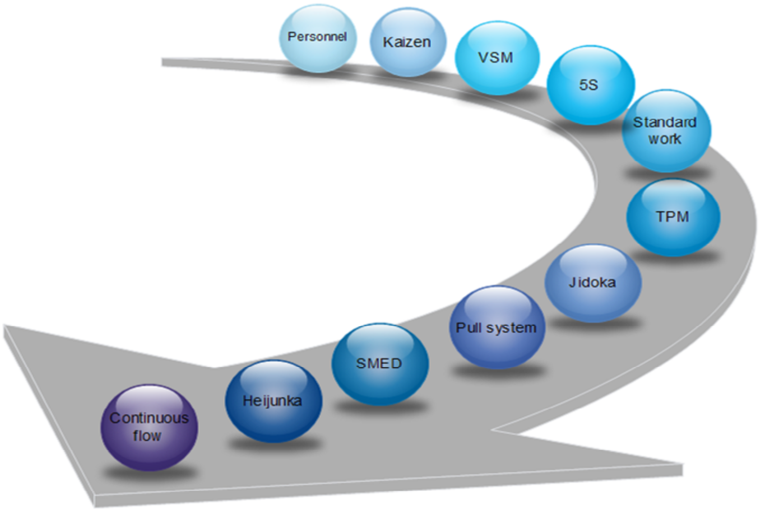
1 single minute exchange of die

2 Heijunka

3 continuous flow.

To clarify and summarise the obtained results Figure 8 depicts a general outline of the roadmap.

Figure 8 The roadmap for implementing lean tools in the Iranian automotive industry (see online version for colours)



5 Conclusions

Winning competitive advantage has been of utmost priority for caring companies for centuries. This strong desire was formed in mass production frame at first but soon was totally replaced by lean production to meet quality, innovation and variety requirements. Evidently, mass production was not able to quench skilled and knowledgeable manufactures and experts thirst anymore. Being facilitated by lean production, organisations could identify potential capacities and provide their customers with value-added activities through SCM.

Despite the proven capabilities of lean production, it sometimes failed to succeed in some practical context. Not only, the expected requirements were not met, but also many inevitable problems arose. This issue tempted researchers to scrutinise lean production systems and search for lean tools to implement this system in supply chain scope properly. Accordingly, this paper contributes to lean production systems literature in identifying the most deserved lean tools in implementation phase of lean production.

Personnel (continuous improvement, organising, performance management), Kaizen, value stream map, 5S, standard work, productive maintenance, Jidoka, pull system, single minute exchange of die, Heijunka and continuous flow can be mentioned as effective tools obtained by experts brainstorming. Then, effective criteria on lean tools were defined as cost reduction, lead time reduction and quality improvement. Afterwards, considering comments of a group made up of six logistics experts in SAPCO and four university experts. DEMATEL technique was successfully applied to study effectiveness and susceptibility among tools. Then, lean tools were weighted based on extracted criteria, the best tools were prioritised using ANP technique, a multidimensional matrix was formed, and a roadmap that well presents precedence of tools ensured predicted results to be accomplished to establish lean tools in supplier companies serving SAPCO.

As existing results show, personnel and continuous improvement are driving factors in lean production and positively affect other criteria. In addition, strengthening culture of continuous improvement, Kaizen and performance management can provide a smooth path to accomplish other tools. It is further emphasised in this study to implement Kaizen immediately after personnel (continuous improvement culture, organising and performance management) to provide continuous improvement culture.

Standard work, productive maintenance and 5S are fundamental factors to perform a reliable lean system, they also secure reliable outcomes while preventing the system from rolling back.

The results of this research are in line with the research of Leksic et al. (2020). Stepwise multiple regression model revealed that TPM, Poka-Yoke, Kaizen, 5S, kanban, six big losses, Heijunka, takt time, andon, OEE, SMED, and KPIs are best waste management techniques. Also, research of Kumar et al. (2018) showed that the lean-Kaizen using VSM tool is an effective and reliable improvement technique which helps to tackle all types of inefficiencies in all sorts of organisations.

6 Implication

In the proposed roadmap, these tools are preferred over pull system and Jidoka. It suggests that, before applying pull system and continuous flow, an organisation needs to provide proper circumstance for pull system, continuous flow and flexibility using reduced preparation time.

It is worth reminding that domestic products are supplied under a system called kanban system in SAPCO. Thus, increasing the capability of suppliers in supplier's pull system prevents inventory accumulation in supplier companies. Then, they are able to deliver orders with minimum cost and time and enjoy flexibility in terms of shorter lead time. The latest generation of parts which are applied in automotive industry tend to have short life cycles. Hence, application of lean infrastructures in supplier companies further empowers automotive manufacturers to manage manufacturing processes within product's life cycle and even in design phase.

Officials and managers are advised to first be aware of the goals and philosophy of lean production. They are familiar with the functions of each activity and lean tools and their contribution to achieving the goals and objectives of the organisation so that they can adopt a clear and explicit orientation. Companies should take advantage of lean manufacturing tools and balance tools, infrastructure and technology to effectively utilise their benefits and enable the company to grow.

Despite the contribution of this paper, model constraints can be minimised in terms of number and other combinational multi-criteria decision-making techniques can be applied for data analysis. Furthermore, to identify effective tools on lean production, Delphi can be a gorgeous technique. Another path for future research can be applying more tools in order to come up with a more detailed roadmap. Also, it is recommended that future research will use new multiple-criteria decision-making (MCDM) tools such as SWARA and COPRAS. This research was limited to the automotive industry in Iran. Therefore, using a wider statistical population, for example, comparing the automotive industry in Iran with a developed country could have more generalisable results.

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