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A Hybrid Approach to Analyzing the Interrelationships of Critical Success Factors of Lean Six Sigma (LSS) in Industry

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Abstract: Six Sigma and lean manufacturing have always been presented as a novel organizational change and an improvement approach, especially as a mechanism for cost reduction in industry. The objective of the present research is to analyze the interrelationships of critical success factors of Lean Six Sigma (LSS) in industry. For this purpose, based on the review of the extant literature, 34 items were identified as the most important and pertinent critical success factors of LSS in industry and grouped into seven main factors. A questionnaire was later distributed to some 20 professors and experts in the field in order to analyze the interrelationships of the final listed factors. Eventually, a hybrid Grey-DEMATEL approach proposed to analyze the interrelationships of the factors. The Grey system theory was first appliedto represent the experts opinions under uncertainty and later the interrelationships of the critical success factors were analyzed using the DEMATEL method. The results of the analysis represent four metrics, namely (R), (D), (R+D) and (R-D) which stand for the effectiveness, influence, importance and cause/effect, respectively.

Key words: Six Sigma, lean manufacturing, interrelationships, Grey system theory, DEMATEL method

INTRODUCTION

With the advent of globalisation and over the past decades, organisational quality initiatives have perfected and evolved dramatically (Habidin and Yusof, 2013). Lean and Six Sigma are among the most significant Continuous Improvement (CI) approaches which are thought to achieve operational and service excellence in organisations. These two methods are commonly considered as the best and the most state-of-the-art and are generally used by different industries globally. The disadvantage however, lies in utilising only one method alone which is quite slow (Salah *et al*., 2010). Lean methodology facilitates achieving organisational targeted performance as well as gaining advantages from the environment (Forrester *et al*., 2010; Habidin and Yusof, 2012). Furthermore, Six Sigma initiatives decrease the possibility of defects and help companies boost customer satisfaction along with financial profits (Nonthaleerak and Hendry, 2008; Habidin and Yusof, 2013). These two methodologies have been introduced as new organisational changes and improvements that can especially applied as cost reducing mechanisms (Achanga *et al*., 2006; Jeyaraman and Kee Teo, 2010). There have also been some efforts recently to promote Lean Six Sigma, commonly known as LSS (George, 2003; Brett and Queen, 2005; Caldwell *et al*., 2005; Jeyaraman and Kee Teo, 2010; Salah *et al*., 2010; Habidin and Yusof, 2013). Currently, LSS is believed to be the most influential business improvement method available (Spector, 2006). This integrated approach has help companies achieve a higher level of continuous improvement activity and better operational and quality cost savings. Today, more and more industries and companies are realising the strong synergy this integrated approach can produce (O'Rourke, 2005; Habidin and Yusof, 2012). LSS is the most current managerial exercise which helps create values via removing unnecessary wastes from the process of producing resulting in less defects in the produce (Kumar *et al*., 2006). The objective of LSS is to change an organisation from being merely a place to perform functionally oriented reactive operations to a company which is cross-functional process focused. According to Martin (2006), this results in focusing on customers, empowering employees and more flexibility. Furthermore, it will result in measurable business improvements for both the company and its customers. The benefits of LSS model, namely eliminating wastes, reducing defects, minimising process variation and increasing quality demonstrate that this model is one of the best business improvement initiatives to deal with current industrial challenges (Spector, 2006; Kumar *et al*., 2006). Therefore, LSS can be seen as a significant catalyst which continuously looks for better performance (Sharma, 2003; Basu and Wright, 2003; Arnheiter and Maleyeff, 2005; Spedding, 2010). Hayes

(2000) emphasises on the proper plan for successful implementation of corporate initiatives like Lean Manufacturing. Such plans can be improved via identifying critical success factors (CSFs) (Mann and Kehoe, 1995).

There have been some recent studies carried out regarding LSS in the context of industry (Kumar *et al*., 2006; Thomas *et al*., 2008; Thomas and Barton, 2011; Habidin and Yusof, 2012; Habidin *et al*., 2012; Habidin and Yusof, 2013). Yet, there is research gap related to the CSFs of LSS in industry. The identification of such critical factors and understanding their interrelationship under uncertainty can play a key role in the successful implementation of LSS. Hence, the present study focuses attention on the aforementioned topic and in so doing, it suggests applying a hybrid Grey-DEMANTEL approach which not only does assist the definition of the interrelationships between all CSFs but it also helps determine the relative importance of CSFs compared with the other relevant factors in each group.

Literature review

Lean manufacturing: Sakakibara *et al*. (1993) explains the notion of lean manufacturing in terms of a method of continuous production improvements in which the wastes of production process are removed. The main objective of applying any lean manufacturing plan in any production unit is to boost productivity, decrease lead times and costs and improve quality (Sriparavastu and Gupta, 1997). This methodology is believed to assist companies to achieve prompt delivery of goods with the desired quality and quantity to satisfy customers. The lean manufacturing method is unique in terms of providing a customer-oriented outlook on the product or service and their total value. It is generally applied to eliminate waste, variation and work imbalance. Here, wastes refer to unnecessary long cycle times or in other words delays between value-added activities. The notion of waste can further include rework or scrap as the result of variability. Therefore, there is an obvious connection between Six Sigma and Lean manufacturing. Removing any wastes that add extra costs to the product or service is a sole principle based on which the Lean Manufacturing initiative is implemented (Womack and Jones, 1996). The notion of waste has been elsewhere categorised into seven groups, commonly known as seven badly wastes, including over production, waiting, transportation, over processing, inventory, motion and defects (Womack and Jones, 1996). The continuous implementation of Lean Manufacturing and removing wastes, according to Li *et al*. (2005), can raise the pace of production process and lead to the improvement of the quality of the product or service, resulting in better customer satisfaction. Furthermore, Lean Manufacturing can ensure smooth production stream via increasing productivity to the level of quality goods, making use of production labour, reducing time delivery and production costs through nonstop improvement processes. This methodology is also considered as a multidimensional approach which encompasses diverse operation and management initiatives such as Quality Improvement/ TQM, Just In Time (JIT) flow, Total Productive Maintenance (TPM), advance manufacturing technology, workforce development, customer and employee involvement, statistical process control, supplier management and integrated system (Sakakibara *et al*., 1993; Flynn *et al*., 1995; Swink *et al*., 2005; Narasimhan *et al*., 2006; Shah and Ward, 2007). Four CSFs of Lean Manufacturing in SMEs have been identified by Achanga *et al*. (2006), namely leadership and management, finance, skills and expertise and culture of the continuous improvement.

Six Sigma: The Six Sigma approach is considered as a well-established method to improve process performance, achieve better quality standards and lower the amount of variability. This approach emphasises the existence of only two defects per billion opportunities. Yet, operating under such a low possibility of error may not necessarily be economical (Salah *et al*., 2010). This six-step method was first introduced by Motorola University design for manufacturing training program in 1988 and since then, it has evolved to become a sub-branch of Total Quality Management (TQM) (Tjahjono*et al*., 2010). Six Sigma can efficiently improve the production line and capability, minimise wastes like the need for inspection, eliminate unnecessary components and extra movements and reduce time for repairing (Oke, 2007). Ferrin *et al*. (2005) indicates reduced costs, less project time, improved results and better data integrity as some of the advantages of Six Sigma. There are some other benefits as well. Six Sigma can improve production cycles and process design and shorten product lead times through decreasing time cycle of the total production process. It can further be utilised to locate and remove the root causes of the problems and therefore help reduce the production process variability in order to prevent the occurrence of potential errors and defects (Tjahjono *et al*., 2010). Chan (2006) develops Six Sigma performance models for Chinese companies using CSFs of Six Sigma and later measuring the performance of Six Sigma implementation. The eight criteria to evaluate the implementation of Six Sigma in the companies were leadership, people management, process management,

management by fact, methodology and tool and application, continuous improvement, costumer focus and result. Schroeder *et al.* (2008) defines Six Sigma according to its organised and pertinent elements like leadership engagement and strategic project selection, parallel-meso metric, specialist improvement, metric performance to achieve strategic objectives, structured methods, reduced variation and better results in performance improvement. Further, Zu *et al.* (2008), using the identified factors of Six Sigma practices by Schroeder *et al.* (2008) has investigated the degree to which Six Sigma role Structured Improvement Procedures (SIPs) and Six Sigma metrics integrated with seven traditional quality management practices affect the quality management and business performance in 226 US manufacturing plants. The Six Sigma practices are understood as separate from traditional quality management practices. Furthermore, such practices can act as complements to the traditional quality management practices in improving performance. The results of the study indicate that Six Sigma elements contribute to a higher performance improvement.

Lean Six Sigma (LSS): Lean Six Sigma has been used and popularised by George Group since 1986. Now a days, it is widely accepted that lean manufacturing and Six Sigma have a complementary relationship and more companies are employing LSS initiatives, especially after its implementation results in leading corporations like GE and Toyota. This approach can be described as a method to remove wastes and variation in order to satisfy customers in terms of quality, delivery and cost. Therefore, it focuses attention on improving processes, satisfying customers and getting higher fiscal profits for the business (Salah *et al.*, 2010). Sheridan (2000) uses the term Lean Sigma to explain a system which integrates both Lean Manufacturing and Six Sigma. Some companies, according to Byrne *et al.* (2007), applying Six Sigma before Lean Manufacturing still call the approach Six Sigma, while others employ the term Six Sigma Lean. It is also referred to as LSS or Six Sigma Lean depending on which method is applied first. Honeywell calls it Six Sigma Plus (Kovach *et al.*, 2005). It is of high importance to apply Six Sigma and Lean Manufacturing simultaneously, not in parallel. This way, their synergy can be leveraged. Moreover, their parallel implementation is not always successful as they must still be applied separately to tackle the problems. Companies employing LSS in a parallel fashion may face problems like prioritising plans, allocating resources, selecting the right methodology and proving financial profits (Salah *et al.*, 2010). As is mentioned earlier, the integration of Lean manufacturing and Six Sigma can overcome the shortcomings of both methods since they perfectly complement ̀one another. This mixture can further assist companies to increase their chances for improvements (Bhuiyan *et al.*, 2006). Many companies try to use these methods stand alone and are unaware of all the advantages lie in what the other methodology can bring. Smith (2003) emphasises on the fact that the mixture of both methods results in achieving CI. LSS can ultimately help companies achieve zero defects beside prompt delivery at lower costs. One of the benefits of LSS repeatedly mentioned in the review of the related literature is better customer satisfaction (Teresko, 2008; Thomas *et al.*, 2009). Define-Measure-Analyse-Improve and Control (DMAIC) approach has been introduced as a roadmap by the majority of studies in this regard. It is also suggested that calling on lean tools is appropriate when carrying out the two kinds of practices in parallel (De Koning *et al.*, 2008; Proudlove *et al.*, 2008; Thomas *et al.*, 2009). Elsewhere in the related literature, some researchers identify the lack of a systemic method to combine the two approaches as the reason behind the implementation of Lean Manufacturing and Six Sigma in sequence (Shah *et al.*, 2008; NAslund, 2008). Yet, the combination of the two approaches in whatever fashion has brought undeniable benefits to companies, especially in terms of their performance (Tjahjono *et al.*, 2010).

MATERIALS AND METHODS

Identifying CSFs of LSS: CSFs are believed to be among the most significant criteria to achieve efficient quality management,organizational targets and objectives and OP (Habidin and Yusof, 2013). CSFs are commonly defined as necessary criteria which can assist companies to identify sections with the highest competitive leverages (Brotherton and Shaw, 1996). CSFs are therefore, not the main objectives but some practices and actions employed by the management to achieve organisational targets. Boynton and Zmud (1984) explain CSFs as Athose few things that must go well to ensure success. Chan (2006) emphasises that the successful implementation of Six Sigma needs the identification of CSFs. There is mounting research on CSFs for implementing Six Sigma and the studies include factors like organization infrastructure, management commitment, business strategy, cultural change, training and education, human resource management, customer focus, project management skill, project selection and priority, understanding tools and techniques, supplier management and DMAIC methodology (Habidin and Yusof, 2013).

Many general CSFs of Six Sigma and lean implementation have already been identified, some of

Table 1: The CSFs of LSS in industry

Factors	Sub-factors	References
Structured Improvement Procedure (SIP)	SIP_1: Planning process decision-making	Chan (2006), Zu *et al.* (2008), Habidin and Yusof (2013)
	SIP_2: Review project process	
	SIP_3: Product design procedures	
	SIP_4: Continuous project procedure	
	SIP_5: Improve management	
Leadership (LED)	LED_1: Personal leadership	Flynn *et al.* (1995), Boyer (1996), Cua *et al.* (2001), Chan (2006), Habidin and Yusof (2013)
	LED_2: Responsibility	
	LED_3: Quality is the top priority	
	LED_4: Motivating employee involvement	
	LED_5: Effective communication vision	
Focus in Metric (FIM)	FIM_1: Customer expectation on quality	Chan (2006), Zu *et al.* (2008), Habidin and Yusof (2013)
	FIM_2: Strategic goals towards improvement	
	FIM_3: Communication on goals	
	FIM_4: Measurement and specification on quality goals	
	FIM_5: Comprehensive process of goal setting	
Supplier Relationship (SR)	SR_1: Suppliers commitment	Shah and Ward (2003), Li *et al.* (2005), Habidin and Yusof (2013)
	SR_2: Suppliers location	
	SR_3: Suppliers reduction	
	SR_4: Communication on crucial issues	
Customer Focus (CF)	CF_1: Customer involvement and relationship	Shah and Ward (2003), Li *et al.* (2005), Chan (2006), Habidin and Yusof (2013)
	CF_2: Willingness of customers	
	CF_3: Customers comments	
	CF_4: Customer design requirement	
	CF_5: Customer demand	
Quality Information and Analysis (QIA)	QIA_1: Methods to reduce variance	Sakakibara *et al.* (1993), Flynn *et al.* (1995), Shah and Ward (2003), Chan (2006), Habidin and Yusof (2013)
	QIA_2: Process are under Statistical Process Control (SPC)	
	QIA_3: Information analysis before product lunch	
	QIA_4: Identification of cause of quality issues	
	QIA_5: Analysis of quality information	
Just in Time (JIT)	JIT_1: Presenting JIT to customers	Sakakibara *et al.* (1993), Koufteros *et al.* (1998), Habidin and Yusof (2013)
	JIT_2: Schedule design for JIT	
	JIT_3: Lower lot sizes	
	JIT_4: Lower setup times	
	JIT_5: Receiving a JIT basis from Vendor	

which were reviewed in the previous section. Having reviewed the related literature, the current study extracted 34 CSFs from the LSS CSFs represented by Habidin and Yusof (2013) which classified in seven main groups, namely: structured improvement procedure, leadership, focus in metric, supplier relationship, customer focus, quality information and analysis and just in time. Table 1 shows the final CSFS and their sub-factors.

LSS comprises diverse procedures which are affected by a number of internal/external factors. The CSFs identified in this research may not be the accurate criteria for every company, yet they were taken through a research process of expansive literature review and detailed interviews with local professionals involved in LSS methodology. These CSFs were validated by means of survey research and case studies. The CSFs cover a full range of key aspects of LSS methodology and provide a set of factors that assists to present a framework for evaluating and analyzing the CSFs of the LSS in industry.

Proposed hybrid approach to analyzing CSFs of LSS: In current study proposed a hybrid approach through integrating Grey system theory and DEMATEL technique to analyze interrelationships (cause and effect) of the CSFs of LSS in industry, under uncertainty.

Grey system theory: In grey systems, the word "grey" is applied when the information is partly known and partly unknown. In other words, being "grey" refers to having "incomplete information" (Vafadarnikjoo *et al*., 2015; Skeete AND Mobin, 2015). The grey theory introduced by Ju-Long (1982) from a grey set. Grey systems theory can handle many of the ambiguities generated from ambiguous human decisions (Asad *et al*., 2016b). Grey systems theory covers the data and series production for the real patterns modelling based on negligible information (Liu and Lin, 2006). Besides having been utilized in varied fields such as decision-making, system control, forecasting, computer graphics, etc. It also effectively solves the Multi-Criteria Decision Making

(MCDM) problems under uncertainty. The main advantage of grey systems theory is the capability to generate satisfactory outcomes through fairly small amount of data (Bai and Sarkis, 2013; Mobin *et al*., 2015). Recently, a grey systems theory has been successfully applied in varied research fields such as project risks management, business processes, insurance industry, outsourcing logistic activities, information technology selection, etc. (Govindan *et al*., 2016). The fundamental contents in grey systems theory are grey numbers, grey elements and grey relations (Vafadarnikjoo *et al*., 2015).

If X is a universal set and G a Grey set of universal set X, $\overline{\mu_G}(x)$ and $\underline{\mu_G}(x)$ /will be defined as the top and bottom limit of the G membership function as in Eq 1:

$$\underline{\mu_G}(x): X \rightarrow [0,1], \overline{\mu_G}(x): X \rightarrow [0,1] \quad (1)$$

The equation $\overline{\mu_G}(x) \geq \underline{\mu_G}(x)$ is completely understandable and changes into a fuzzy set in form of an equation of the grey set. This shows that the grey theory includes fuzzy and flexible cases when facing fuzzy problems. In the present study, the grey number $\otimes X_{ij}^p$ for P decision is considered to assess the effect of i criterion on j (Asad *et al*., 2016b):

$$\otimes.X_{ij}^p = \left[\underline{\otimes}X_{ij}^p, \overline{\otimes}X_{ij}^p\right] \quad (2)$$

The grey data turns into crisp number as following three steps:

Step 1: Normalization:

$$\Delta_{Min}^{Max} = Max_j \overline{\otimes}X_{ij}^p - Min_j \underline{\otimes}X_{ij}^p \quad (3)$$

$$\underline{\otimes}\tilde{X}_{ij}^p = \left(\underline{\otimes}X_{ij}^p - Min_j \underline{\otimes}X_{ij}^p\right)/\Delta_{Min}^{Max} \quad (4)$$

$$\overline{\otimes}\tilde{X}_{ij}^p = \left(\overline{\otimes}X_{ij}^p - Min_j \underline{\otimes}X_{ij}^p\right)/\Delta_{Min}^{Max} \quad (5)$$

Step 2: Calculate total normalized crisp number:

$$Y_{ij}^p = \frac{(\underline{\otimes}X_{ij}^p(1-\underline{\otimes}X_{ij}^p) + (\overline{\otimes}X_{ij}^p \times \overline{\otimes}X_{ij}^p)}{1-\underline{\otimes}X_{ij}^p + \overline{\otimes}X_{ij}^p} \quad (6)$$

Step 3: Calculate the crisp number:

$$Z_{ij}^p = Min_j \underline{\otimes}X_{ij}^p + Y_{ij}^p \Delta_{Min}^{Max} \quad (7)$$

Equation 8 is used to turn the opinions into a unified viewpoint:

$$Z_{ij}^p = \frac{1}{p}(Z_{ij}^1 + Z_{ij}^2 + ... + Z_{ij}^p) \quad (8)$$

DEMATEL method: Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is based on the assumptions of a system including a set of variables and mutual comparisons and the relationship amongst these variables calculated using mathematical models (Buyukozkan and Cifci, 2012). DEMATEL method developed between 1972 and 1976 by the Battelle Memorial Institute of Geneva (Vafadarnikjoo *et al*., 2015). The key advantage of DEMATEL method, compared with other multi-attribute decision-making methods (e.g., Analytical Hierarchical Process (AHP)) supposing independency of the factorsis that it attends to discover the interdependence amongst the system's elements through a causal diagram along with a structural modelling approach (Wu *et al*., 2010; Mobin *et al*., 2015). This method can structure and manage complex cause and effect relationships among the criteria through combination of matrices or graphs. Furthermore, DEMATEL aims to settle the complicated problems by figuring out the specific problems, the cluster of twisted problems and identifying practical solutions by a hierarchical structure (Hsu *et al*., 2013).

In the first step, based on the experts' opinions and the crucial criteria, a direct relation matrix was organized. The resulting T-matrix is an n×n matrix which demonstrates interactions criteria as T_{ij} points to the degree of effect of i criterion on j criterion, $T = [T_{ij}]_{n\times n}$ (Asad *et al*., 2016b).

Next step includes forming the normalized matrix of direct relation (S), $S = [_{sij}]_{n\times n}$, where $0 \leq S \leq 1$. The matrix S forms according to Eq. 9 and 10 as follows (Asad *et al*., 2016a):

$$K = \frac{1}{MAX_{1\leq i\leq n} \sum_{j=1}^{n} a_{ij}} \quad (9)$$

$$S = K \times T \quad (10)$$

Then, the total relation matrix (T) is made by Eq. 11, where I represent an nHn identity matrix:

$$M = S(I - S)^{-1} \quad (11)$$

The value of criteria "R" and "D" refers to the sum of rows and columns respectively, calculated by Eq. 12-14 as follows:

$$M = m_{ij}, (i, j = 1, 2..., n) \quad (12)$$

$$R = \left[\sum_{j=1}^{n} m_{ij}\right]_{n \times 1} \quad (13)$$

$$D = \left[\sum_{j=1}^{n} m_{ij}\right]_{1 \times n} \quad (14)$$

Finally, to analyze the cause and effect relationships of factors, the criterion (R) represents effectiveness of a factor on other factors, meaning the effectiveness of variables; the criterion (D) for each factor states the impact of other factors on it, meaning the influence of variables; the aInfluence horizontal axis vector (R+D) reflects how important the factor is and the Relation r vertical axis (R-D) categorizes the factors into a cause and effect group. If the value of (R-D) is positive, the factor will be associated to the cause group and if negative, it will belong to the effect group (Hung, 2011).

RESULTS AND DISCUSSION

In the present study, according to the related literature and research background, 34CSFs were identified and grouped into seven main factors. Then, to analyze the interrelationships of CSFs, a questionnaire was designed with one-by-one questions in which experts and practitioners were asked how each factor affected the other ones, using five-point linguistic variables (no effect, very low effect, low effect, high effect, very high effect). Finally, 20 completed questionnaires were collected to analyze the interrelationships among the CSFs via ahybrid Grey-DEMATEL approach. Table 1 shows the demographic statistics of respondents.

Next, having gathered all the completed questionnaires, the linguistic variables were converted to grey range of values (Table 2), then according to eq. 3-7, grey numbers were converted to crisp numbers and all points of view were turned into a single viewpoint by Eq. 8.

In the next step, the crisp numbers were normalized in DEMATEL using the Eq. 9 and 10 and total matrix of each of the main factors and their sub-factors were calculated using Eq. 11. In the end, the values of R, D, (R+D) and (R-D) were calculated. Table 3 shows the results.

Finally, the causal diagram for all main factors and their sub-factors were drawn through (D+R, D-R) dataset,

Table 2: Demographic statistics of respondents

Variables	Values
Gender	
Male	12
Female	8
Age	
Under 30	5
30-40	7
40-50	4
over 50	4
Education	
BA	2
MA	9
PhD	9

Table 3: Linguistic scales of factors' weight importance and their Grey values (Skeete and Mobin, 2015; Mobin *et al.*, 2015)

Linguistic variable	Grey values
No affect	[0,0]
Very low affect	[0,0.25]
Low affect	[0.25,0.5]
High affect	[0.5,0.75]
Very high affect	[0.75,1.0]

illustrated in Fig. 1 and 2. The diagram represents the ability to recognize remarkable factors as well as the realization of the factors that have more influence on the other factors in the system (Mobin *et al.*, 2015; Govindan *et al.*, 2016).

According to Table 4 and Fig. 1, the results for the seven main CSFs demonstrate that FIM (Focus in Metric) with respect to (R) criterion has the greatest influence on other main factors. Furthermore, regarding (D) criterion, ASIP (Structured Improvement Procedure) is most affected by other main factors. With respect to (R+D), the factor also has the most interaction with the other main factors, demonstrating its great importance in LSS. Moreover, with respect to (R-D) criterion, the main factors of AFIM, AQIA and AJIT are the causal factors (positive) and the main factors of ASIP, ALED, ASR and ACF are the effect factors (negative).

As is evident in Table 4 and Fig. 2, in the ASIP group, SIP_4 (Continuous project procedure) is the most influential factor with respect to (R) criterion. Regarding (D) criterion, SIP_5 (Improve management) is most affected by other factors. It also has the most interaction with the other factors in terms of (R+D) which demonstrates the great importance of this factor in this group. In addition, in terms of (R-D) criterion, SIP_2 and SIP_4 are causal factors (positive) in this group while SIP_1 $ASIP_3$ and SIP_5 are effect factors (negative).

In the LED group, LED_1 (Personal leadership) is the most influential factor with respect to (R)criterion. According to (D) criterion, LED_5 (Effective communication vision) is most affected by other factors. But altogether,

Table 4: Results of the interrelationshipanalysis of CFSs of LSS in industry

Factors	R	Rank	D	Rank	R+D	Rank	R-D	Cause or effect
SIP	4.133634535	3	4.76652462	1	8.900159155	1	-0.632890085	E
LED	3.801118468	4	4.654517631	2	8.455636098	2	-0.853399163	E
FIM	4.840012943	1	3.558606801	5	8.398619744	3	1.281406143	C
SR	3.629987149	5	4.236196347	3	7.866183496	5	-0.606209198	E
CF	3.310026728	7	4.057302598	4	7.367329325	6	-0.747275870	E
QIA	4.599583699	2	3.47253157	6	8.072115269	4	1.127052129	C
JIT	3.477951925	6	3.046635881	7	6.524587806	7	0.431316045	C
SIP_1	11.42701037	4	11.9140797	2	23.34109007	4	-0.487069328	E
SIP_2	12.29986273	2	11.57558659	4	23.87544932	2	0.724276143	C
SIP_3	10.96889731	5	11.76953307	3	22.73843038	5	-0.800635768	E
SIP_4	12.64735968	1	11.00334078	5	23.65070046	3	1.644018898	C
SIP_5	11.97889014	3	13.05948009	1	25.03837023	1	-1.080589946	E
LED_1	6.58182171	1	4.25009275	5	10.83191446	4	2.331728961	C
LED_2	5.948050645	2	7.096716015	2	13.04476666	1	-1.148665370	E
LED_3	5.938010472	3	5.280890966	3	11.21890144	3	0.657119506	C
LED_4	5.047806779	5	5.247569451	4	10.29537623	5	-0.199762672	E
LED_5	5.563924335	4	7.20434476	1	12.76826909	2	-1.640420425	E
FIM_1	5.077627244	3	5.76215551	1	10.83978275	1	-0.684528266	E
FIM_2	4.260080846	4	4.572735698	3	8.832816544	4	-0.312654852	E
FIM_3	5.414584482	2	4.156054875	5	9.570639357	3	1.258529608	C
FIM_4	5.554212898	1	4.518994542	4	10.07320744	2	1.035218356	C
FIM_5	3.670485487	5	4.967050332	2	8.637535819	5	-1.296564845	E
SR_1	6.619796448	2	8.785234882	1	15.40503133	1	-2.165438433	E
SR_2	6.396689683	3	5.541352227	3	11.93804191	3	0.855337456	C
SR_3	6.048623406	4	4.879089094	4	10.9277125	4	1.169534313	C
SR_4	7.369790357	1	7.229223692	2	14.59901405	2	0.140566665	C
CF_1	4.503649837	2	4.537452505	3	9.041102342	3	-0.033802668	E
CF_2	4.357116765	3	4.8166222 1	9.	1737389650	2	-0.459505434	E
CF_3	3.74797837	5	4.679586595	2	8.427564964	4	-0.931608225	E
CF_4	4.215527588	4	3.711193605	5	7.926721193	5	0.504333983	C
CF_5	5.218038232	1	4.297455888	4	9.515494119	1	0.920582344	C
QIA_1	3.498206179	5	2.450228332	5	5.948434511	5	1.047977848	C
QIA_2	4.293361173	3	3.250477655	4	7.543838828	4	1.042883518	C
QIA_3	4.145727123	4	6.230660001	1	10.37638712	2	-2.084932878	E
QIA_4	5.082354378	1	4.094241312	3	9.176595689	3	0.988113066	C
QIA_5	4.836898076	2	5.83093963	2	10.66783771	1	-0.994041553	E
JIT_1	8.814583317	4	8.533740945	4	17.34832426	5	0.280842372	C
JIT_2	9.622389461	2	10.47511699	1	20.09750645	1	-0.852727526	E
JIT_3	8.553440657	5	9.647361586	3	18.20080224	3	-1.093920929	E
JIT_4	10.03107898	1	7.692749559	5	17.72382854	4	2.338329423	C
JIT_5	9.391761979	3	10.06428532	2	19.4560473	2	-0.672523340	E

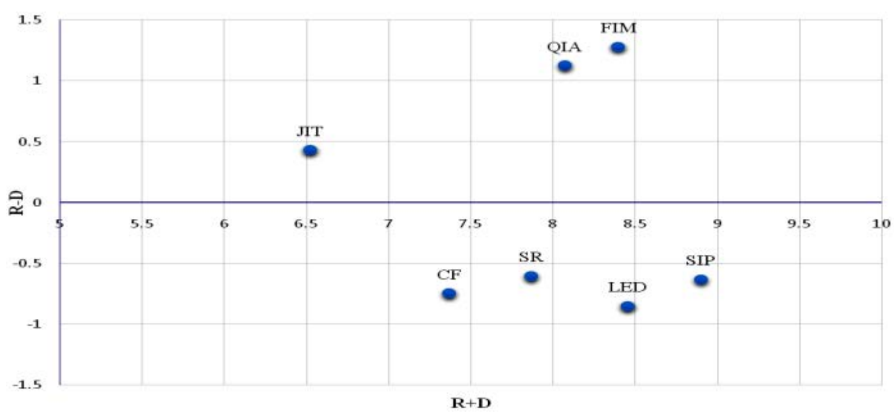

Fig. 1: Cause and effect diagram for the main CFSs of LSS in industry

regarding (R+D), the factor LED_2 (Responsibility) has the most interaction with the other factors, showing the pivotal role of this factor in the group. Also, with respect to (R-D) criterion, LED_1 and LED_3 are causal factors (positive) and LED_2, LED_4 and LED_5 are effect factors (negative). In the FIM group, FIM_4 (Measurement and specification on quality goals) is the most influential factor with respect to (R) criterion. Regarding (D) criterion,

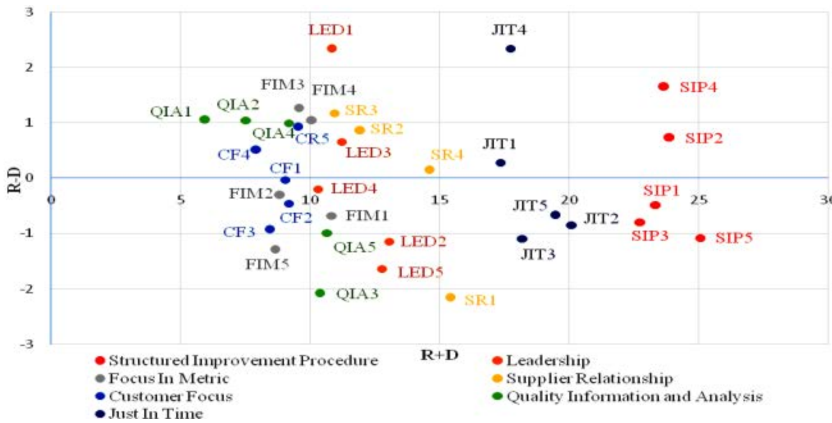

Fig. 2: Cause and effect diagram for all the CFSs groups' sub-factors of LSS in industry

FIM_1 (Customer expectation on quality) is most affected by other factors and also has the most interaction with the other factors in terms of (R+D), proving its great significance in this group. Furthermore, FIM_3 and FIM_4 are causal factors (positive) with respect to (R-D) criterion while FIM_1, FIM_2 and FIM_5 are effect factors (negative).

In the SR group, SR_4 (Communication on crucial issues) is the most influential factor in this group with respect to (R) criterion. In terms of (D) criterion, SR_1 (Suppliers commitment) is most affected by other factors; and has the most interaction with the other factors regarding (R+D) which underpins the great importance of this factor in the group. Also with respect to the (R-D) criterion, SR_2, SR_3 and SR_4 are causal factors (positive) in the group, yet SR_1 is categorized as effect factor (negative).

In the CF group, CF_5 (Customer demand) is the most influential factor with respect to (R) criterion. Regarding (R+D), this factor possesses the most interaction with the other factors, indicating its exclusive role in this group. With respect to (D) criterion, CF_2 (Willingness of customers) is most affected by other factors. Also, with respect to (R-D) criterion, CF_4 and CF_5 are causal factors (positive) while CF_1, CF_2 and CF_3 are effect factors (negative).

In the QIA group, QIA_4 (Identification of cause of quality issues) is the most influential factor in terms of (R) criterion. Moreover, QIA_3 (Information analysis before product lunch) is most affected by other factors with respect to (D) criterion. But altogether, regarding (R+D), QIA_5 (Analysis of quality information) has the most interaction with the other factors regarding (R+D) which demonstrates the great importance of this factor in the group. Regarding (R-D) criterion, QIA_1, QIA_2 and $AQIA_4$ are causal factors (positive) in this group. On the other hand, QIA_3 and QIA_5 can be considered as effect factors (negative).

In the JIT group, JIT_4 (Lower setup times) is the most influential factor with respect to (R) criterion. Regarding (D) criterion, JIT_2 (Schedule design for JIT) is most affected by other factors. It also has the most interaction with the other factors in terms of (R+D) which demonstrates the great importance of this factor in this group. In addition, in terms of (R-D) criterion, JIT_1 and JIT_4 are causal factors (positive) in this group while JIT_2, JIT_3 and JIT_5 are effect factors (negative).

CONCLUSION

The current studyproposed a hybrid approach, integrating Grey system theory and decision-making trial and evaluation laboratory (DEMATEL) technique to analyze the interrelationships of the CSFs of the LSS in industry, under uncertainty. One of the special features of applying Grey system theory in this study is considering the initial data as a range of uncertain numbers (Grey numbers) (Asad *et al.* 2016a, 2016b). In other words, the use of Grey system theory makes it possible to consider the uncertainty in the structure of decision-making system. Furthermore, the application of DEMATEL method assists the decision makers to recognize causal factors and sub-factors and helps figure out the relative cause-effect relationships between factors and sub-factors. Thus, the study provides another viewpoint to implement LSS in industry without the assumption of factors and sub-factors being mutually independent. Every actions taken on net causes (factor/sub-factor) will have direct/indirect impacts on the corresponding net receivers (factor/sub-factor). Therefore, the decision makers can give more credit and allocate more resources for cause factors and sub-factors to effectively implement LSS in industry.

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