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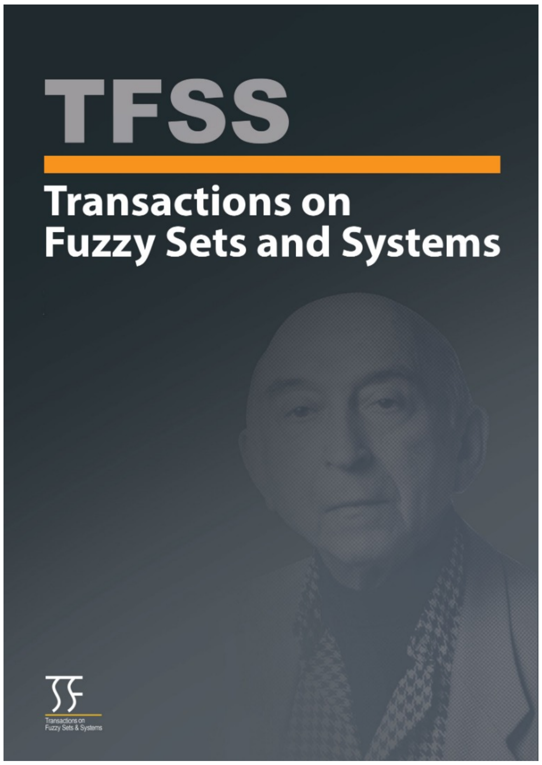

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Author(s):

Mazdak Khodadadi-Karimvand, Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran. E-mail: mazdak.kh@gmail.com
Hadi Shirouyehzad, Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran. E-mail: hadi.shirouyehzad@gmail.com
Farhad Hosseinzadeh Lotfi, Department of Mathematics, Science and Research Branch, Islamic Azad University, Tehran, Iran. E-mail: hosseinzadeh_lotfi@yahoo.com

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Proposing a Conceptual Model of Critical Success Factors in Lean Production Using Interpretive Structural Modeling and Fuzzy MICMAC Analysis

Mazdak Khodadadi-Karimvand, **Hadi Shirouyehzad***, **Farhad Hosseinzadeh Lotfi**

Abstract. Since companies are inclined to implement lean production, researchers have proposed a number of fundamental success factors to facilitate the implementation of this production approach. This study analyzes the critical success factors (CSFs) in lean production extracted from 14 review studies. The interpretive structural modeling approach is utilized to analyze the impact of these critical success factors on one another. The aim is to enhance insights into lean production and facilitate informed decision-making. In this article, a seven-tiered model is presented. According to the conceptual model of success factors in lean production, leadership is positioned at the base of the model and serves as the origin for other factors. It should be regarded as the foremost critical success factor in lean production. When establishing lean production systems, organizations and senior managers should focus on higher levels and critical success factors that underlie the model. Subsequently, nonfuzzy and fuzzy driving and dependence power analyses were conducted that the fuzzy matrix cross-reference multiplication applied to a classification (MICMAC) analysis provides deeper insights into the analysis of driving and dependence power. The fuzzy matrix cross-reference multiplication applied to a classification analysis helped identify some key factors that are highly effective for successfully implementing lean manufacturing.

AMS Subject Classification 2020: 03B52, 03E72, 68T27
Keywords and Phrases: Critical success factors, Lean production, Interpretive structural modeling, Fuzzy MICMAC analysis.

1 Introduction

Lean thinking received considerable attention in the 1990s [36]. The notion was introduced to assist manufacturers in improving the performance of their manufacturing system by eliminating unnecessary activities [35]. Lean thinking helps organizations to identify types of waste, such as overproduction in mass production systems. When these wastes are reduced, and the production flow is streamlined, fewer resources would be required to perform operations. Consequently, waste reduction can result in improved performance, primarily characterized by lower costs, shorter lead times, and more stable quality. Additionally, it can lead to lesser work in progress, lower inventory levels, and higher product diversity. Subsequently, implementing lean concepts can lead to greater customer satisfaction and increased market competitiveness [10].

In recent years, there has been a renewed emphasis on lean production [22, 16]. The global economic recession has compelled companies operating in today's open global economy to raise productivity and lower

***Corresponding Author:** Hadi Shirouyehzad, Email: hadi.shirouyehzad@gmail.com, ORCID: 0000-0002-8339-1013
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costs. Accordingly, lean production has gained popularity as a strategy to enhance the competitiveness of industrial companies [14, 36].

Despite their best efforts, most companies are unable to successfully implement lean manufacturing programs [20, 22, 29]. Researchers and consultants have proposed a set of critical success factors (CSFs) to assist businesses in implementing lean manufacturing and avoiding costly failures. CSFs refer to factors that must go well to ensure the success of a manager or organization. These factors are directly associated with specific areas of management or the company that require consistent attention to achieve optimal performance [8].

There are several lists of CSFs for lean production implementation as well as improvement models, including total quality management, just-in-time production, Six Sigma, and total productive maintenance. On the whole, there is a strong theoretical consensus among studies as to what the CSFs are.

Interpretive structural modeling (ISM) is a useful approach for analyzing subjects that involve interrelated qualitative variables of varying importance [7]. ISM aids in identifying the internal relationships between variables and is an appropriate technique for analyzing the effect of one variable on others [5]. Additionally, ISM can rank and sort out system components, which greatly aids managers in implementing the intended model [15].

This study categorizes and evaluates 24 CFSs in the context of lean production. These CFSs are extracted by Netland from a review of 14 articles in this field and cited in "Critical Success Factors for Implementing Lean Production: The Effect of Contingencies" [23]. Here, in the current paper, they are partitioned into levels using the ISM method and categorized into four groups based on fuzzy driving and dependence power analyses.

2 Literature Review

CSFs are characteristics, conditions, or variables with a significant impact on the success of an organization in specific domains [18] if used and managed properly. Rungasamy, Antony, and Ghosh [27] argue that organizations can gain a competitive advantage by identifying and achieving favorable outcomes in CSFs. If an organization's objectives conflict with the CSFs in a particular domain, it may experience significant failure in that domain. Conversely, an organization's upper hand in one or more CSFs compared to competitors presents an exceptional opportunity for it to attain a competitive advantage.

Quality leaders such as Deming (1986), Crosby (1979), and Joran (1988), as well as advocates of lean manufacturing, such as Laker (2004) and Womack and Jones [35], have compiled comprehensive lists of CSFs (cited in Netland [23]).

The identification and proposal of CSFs for lean production, total quality management, just-in-time production, Six Sigma, and total productive maintenance, along with other methods, have consistently been the focus of scholarly articles and research in the field of operations management. Numerous explanations have been provided. Several researchers, including Achanga, Shehab, Roy, and Nelder [2], Cotte, Farber, Merchant, Paranikas, and Sirkin [11], Losonci, Demeter, and Jenei [19], and Vinodh and Joy [33], have produced lists of CSFs for lean manufacturing.

Many academic sources have synthesized a wealth of scientific literature on CSF for improvement programs. The articles concur that "Corporate management commitment", "Education", and "Employee involvement and support" are three of the key success factors. Refer, for example, to Sila and Ebrahimpour's review of 76 articles on total quality management [30], Nitin et al.'s review of success factors among 10 companies winning the National Quality Award [24], Brady and Allen's review of 201 published articles on Six Sigma [9], and Marodin and Saurin's review of 102 published studies on lean production [22]. The findings suggest that managers should play an active role in leading and supporting the implementation of lean production. This is important to ensure that all employees have a clear understanding of lean production and know how to effectively implement it. Organizations should educate employees and support them in implementing the designated changes. Scientific sources emphasize aligning improvement programs with business strategy, creating long-term plans, managing cultural changes, and involving supply chain partners as key factors.

Netland [23] extracted 22 CSFs from 14 structured review articles on total quality management, Six Sigma, total productive maintenance, just-in-time production, and lean production in his research work titled "Critical Success Factors for Implementing Lean Production: The Effect of Contingencies". These CSFs are summarized in Table 1.

Table 1: Critical success factors for implementing lean production programs [23]

Critical Success Factors					
1	Lead actively	9	Commit corporate management	17	Focus on areas and prioritize activities
2	Participate personally	10	Integrate lean in every day business	18	Invest time and money
3	Educate employees	11	Develop a vision and roadmap	19	Benchmark others
4	Educate managers	12	Use rewards and recognition	20	Emphasize team concept
5	Communicate, inform, and discuss	13	Monitor and audit implementation	21	Use external experts
6	Set and follow-up targets	14	Standardize and manage discipline	22	Hold regular implementation meetings
7	Involve and support employees	15	Find and share best practices	23	Emphasize safety and job attractiveness
8	Dedicate human resources	16	Stepwise approach	24	Use lean tools and methods

3 Methodology

The ISM is a systems design method initially proposed in 1973 by Warfield, a systems scientist at George Mason University in the United States. This approach was initially introduced and subsequently developed to facilitate the design of economic and social systems [34].

The ISM approach is an efficient methodology for addressing issues associated with interacting qualitative variables with varying degrees of importance [7]. It is a useful technique for analyzing the relationships between variables and assessing the influence of one variable on others [5]. ISM enables managers to prioritize and assess the importance of system elements, thereby facilitating the effective implementation of the model [15]. In order to apply the ISM technique and determine the internal relationships and priorities of system elements, the subsequent steps should be followed [17].

A- Identifying the variables to be used in the model

B- Developing the structural self-interaction matrix (SSIM) of the variables

C- Developing the reachability matrix

D- Checking the matrix for transitivity

E- Partitioning of the reachability matrix into different levels

F- Drawing the ISM

G- Analyzing the driving and dependence power using the MICMAC[2] diagram

[2]Matrix Cross-reference Multiplication Applied to a Classification (MICMAC)

4 The ISM of CSFs in Lean Production

4.1 Identifying the Variables to Be Used in the Model

The initial step in the ISM involves identifying variables relevant to the topic in question [3]. Here, the desired variables are the CSFs in lean production.

4.2 Developing the SSIM of the Variables

After identifying the variables, they need to be placed in the SSIM. The matrix in question has dimensions corresponding to the variables specified in its first row and column [26]. In order to determine the type of binary interaction between the variables, a questionnaire was developed, and experts were consulted. Ultimately, experts decided on the type of interaction. The experts in this study were selected from a pool of industry managers, professionals, and university professors.

4.3 Developing the Reachability Matrix

The reachability matrix is obtained by transforming the symbols of the SSIM relations into 0 and 1 [12].

Table 2: Aggregate initial binary reachability matrix

		Use lean tools and methods	Emphasize safety and job attractiveness	Hold regular implementation meetings	Use external experts	Emphasize team concept	Benchmark others	Invest time and money	Focus on areas and prioritize activities	Stepwise approach	Find and share best practices	Standardize and manage discipline	Monitor and audit implementation	Use rewards and recognition	Develop vision and roadmap	Integrate lean in everyday business	Commit corporate management	Dedicate human resources	Involve and support employees	Set and follow-up targets	Communicate. inform and discuss	Educate managers	Educate employees	Participate personally	Lead actively
#	**Critical Success Factors**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	Lead actively	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
2	Participate personally	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**
3	Educate employees	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**
4	Educate managers	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
5	Communicate. inform and discuss	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
6	Set and follow-up targets	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**0**
7	Involve and support employees	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**0**
8	Dedicate human resources	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
9	Commit corporate management	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**
10	Integrate lean in everyday business	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**
11	Develop vision and roadmap	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**
12	Use rewards and recognition	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**1**
13	Monitor and audit implementation	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**
14	Standardize and manage discipline	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
15	Find and share best practices	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**
16	Stepwise approach	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
17	Focus on areas and prioritize activities	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18	Invest time and money	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
19	Benchmark others	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**
20	Emphasize team concept	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
21	Use external experts	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**
22	Hold regular implementation meetings	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
23	Emphasize safety and job attractiveness	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**
24	Use lean tools and methods	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

4.4 Checking the Matrix for Transitivity

Once the initial reachability matrix is generated, its internal consistency must be established. For instance, if variable 1 leads to variable 2 and variable 2 leads to variable 3, variable 1 should also lead to variable 3. If the reachability matrix does not meet the condition, it should be revised by replacing the missing relationships. Multiple techniques exist for assessing the transitivity of a matrix. This article employs mathematical principles to establish consistency in the reachability matrix. Specifically, the reachability matrix is raised to the power of K+1, where K is a positive integer greater than or equal to 1. Notably, the exponentiation operation must adhere to the rules of Boolean algebra [12].

Table 3: Final (binary) reachability matrix (after transitivity check)

		Use lean tools and methods	Emphasize safety and job attractiveness	Hold regular implementation meetings	Use external experts	Emphasize team concept	Benchmark others	Invest time and money	Focus on areas and prioritize activities	Stepwise approach	Find and share best practices	Standardize and manage discipline	Monitor and audit implementation	Use rewards and recognition	Develop vision and roadmap	Integrate lean in everyday business	Commit corporate management	Dedicate human resources	Involve and support employees	Set and follow-up targets	Communicate. inform and discuss	Educate managers	Educate employees	Participate personally	Lead actively	**Driving Power**
#	**Critical Success Factors**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
1	Lead actively	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	24
2	Participate personally	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	12
3	Educate employees	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	11
4	Educate managers	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	21
5	Communicate. inform and discuss	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	17
6	Set and follow-up targets	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	16
7	Involve and support employees	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	10
8	Dedicate human resources	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	6
9	Commit corporate management	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	17
10	Integrate lean in everyday business	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	9
11	Develop vision and roadmap	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	17
12	Use rewards and recognition	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**1**	14
13	Monitor and audit implementation	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	17
14	Standardize and manage discipline	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	6
15	Find and share best practices	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	14
16	Stepwise approach	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	6
17	Focus on areas and prioritize activities	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	3
18	Invest time and money	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	9
19	Benchmark others	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	16
20	Emphasize team concept	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	6
21	Use external experts	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	14
22	Hold regular implementation meetings	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	5
23	Emphasize safety and job attractiveness	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	13
24	Use lean tools and methods	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	21
Dependence Power		18	18	13	8	18	12	6	14	12	15	17	8	8	18	19	10	9	15	8	12	10	13	12	11	

4.5 Partitioning of the Reachability Matrix into Different Levels

In order to rank the variables, each variable's reachability set and antecedent set must be specified [30]. The reachability set for each variable includes the variables that can be reached through the variable of interest, and the antecedent set includes the variables through which the variable of interest can be reached. The level of each variable is determined after these sets and the shared elements are specified [3].

Table 4: Level partitioning

Levels	CSFs Row No.
1	10
2	15,18,19,24
3	13,14,16,17,21,22
4	7,12,20,23
5	2,3,4,8
6	5,6,9,115
7	1

4.6 Drawing the ISM

After determining the relationships and the level of the variables, they are translated into a model [5]. For this purpose, we first arrange the variables according to their level. In this research, the variables are placed in 7 levels, as illustrated in Figure 1.

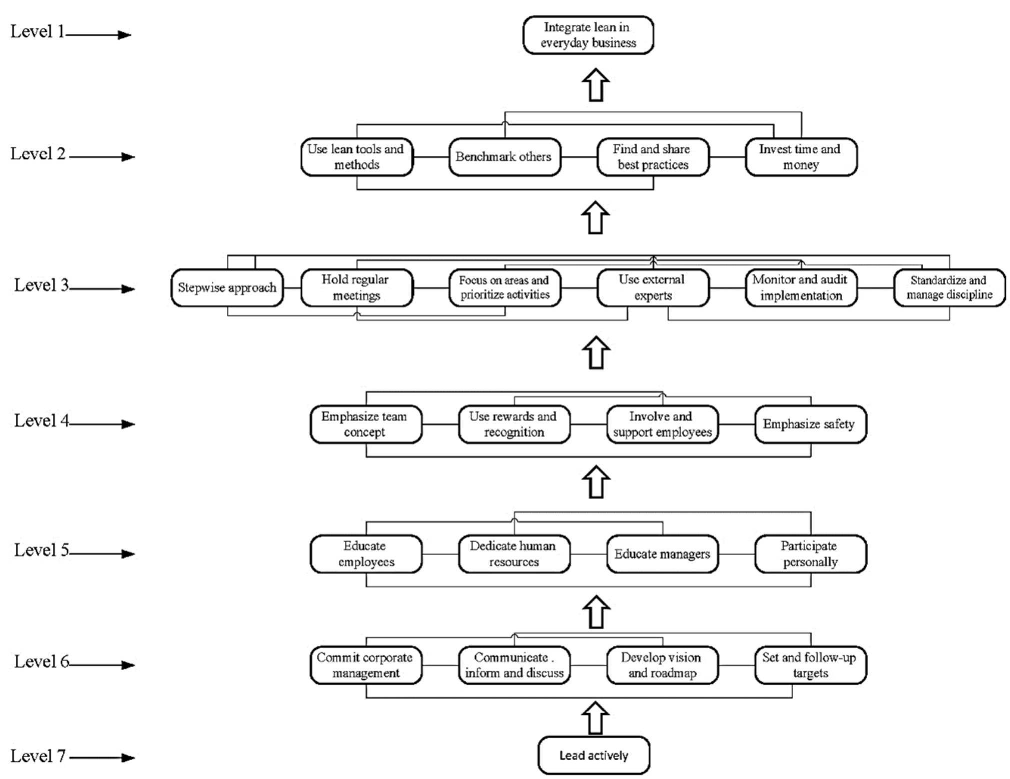

Figure 1: Interpretive structural model

4.7 Analyzing the Driving and Dependence Power Using the MICMAC Diagram

The MICMAC matrix is employed to analyze the reciprocal influence between variables and their categorization [6]. This analysis categorizes variables into four groups based on their driving and dependence power. The first category includes autonomous variables with weak driving and power dependence. These variables exhibit limited and weak connections to the system. No variables fell in this category in the current research, suggesting a substantial connection between variables in the developed model. Dependent variables are the second category, with weak driving but a strong dependence. These variables primarily consist of specific results that are the product of certain factors. Rarely can these variables serve as the basis for other variables. The third category, known as linkage, includes variables with strong driving and dependence. The variables are non-static, as changes to them can affect the whole system. The fourth category consists of variables with strong driving but weak dependence. This group serves as the fundamental basis of the model and should be given primary emphasis when initiating the system [5]. Figure 3 depicts the positions of each CSF.

Next, with the assistance of experts, these binary numbers from Table 3 are replaced with appropriate fuzzy values using Table 5, and a fuzzy direct reachability matrix (FDRM) is developed following Table 6. In fuzzy ISM, experts are free to consider the degree of relatedness when deciding whether to include or exclude an element as related or unrelated to another. In this study, experts could consider even the weakest degree of relation (0.1) as a relationship. In this FDRM, the sum of values between rows and columns indicates the driving and dependence power of each of the variables, respectively. The results are then used for fuzzy MICMAC analysis, as depicted in Figure 4 [13, 1, 31].

The selection of the fuzzy membership function for the seven linguistic variables is attributed to rank as follows.

The set of values related to the linguistic variable $= \{N, NL, L, M, H, VH, F\} = T(x)$ Variation range of the reference set $= [0, 1] = U$

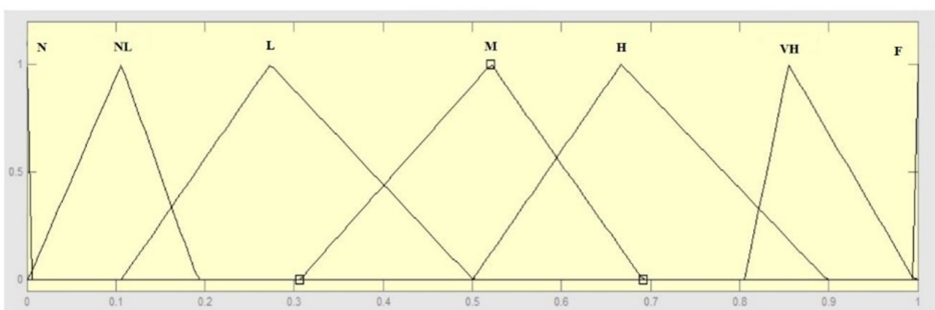

Figure 2: Membership function of linguistic variables (adopted from [4, 28])

The values presented in Table 3 are developed in the form of an FDRM using the values of Table 5, the results of which are reported in Table 6. Finally, the FDRM provides the possibility of MICMAC fuzzy analysis [1, 32].

Table 5: Scheme for the degree of perceived dominance factor (Adopted from [4, 28])

Value on the Scale	Fuzzy Triangular Numbers	Grade	Dominance of Interaction
0	(0,1,0)	N	No
0.1	(0,0.1,0.2)	NL	Very Low
0.3	(0.1,0.3,0.5)	L	Low
0.5	(0.3,0.5,0.7)	M	Medium
0.7	(0.5,0.7,0.9)	H	High
0.9	(0.8,0.9,1)	VH	Very high
1	(1,1,1)	F	Full

Table 6: Uzzy direct reachability matrix with driving and dependence power

		Use lean tools and methods	Emphasize safety and job attractivenes s	Hold regular implementation meetings	Use external experts	Emphasize team concept	Benchmark others	Invest time and money	Focus on areas and prioritize activities	Stepwise approach	Find and share best practices	Standardize and manage discipline	Monitor and audit implementation	Use rewards and recognition	Develop vision and roadmap	Integrate lean in everyday business	Commit corporate management	Dedicate human resources	Involve and support employees	Set and follow-up targets	Communicate. inform and discuss	Educate managers	Educate employees	Participate personally	Lead actively	**Driving Power**
#	**Critical Success Factors**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
1	Lead actively	**1**	**1**	**0.7**	**0.9**	**0.9**	**1**	**1**	**0.9**	**0.9**	**0.7**	**0.5**	**0.5**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9**	**0.9**	**0.7**	**1**	21.5
2	Participate personally	**0.9**	**1**	**0.9**	**0**	**1**	**0.3**	**0**	**0**	**0.5**	**0.7**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.7**	**0**	**1**	**1**	**1**	9.9
3	Educate employees	**1**	**1**	**0.7**	**0**	**0.9**	**0**	**0**	**0**	**1**	**0.9**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.9**	**0**	**1**	**0.3**	**0.3**	8.9
4	Educate managers	**0.9**	**1**	**1**	**0**	**1**	**0.7**	**0**	**1**	**1**	**1**	**1**	**0.7**	**0**	**0.9**	**0.7**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9**	**0.5**	19.3
5	Communicate. inform and discuss	**0.5**	**0.9**	**0.9**	**0.3**	**0.1**	**0.7**	**0.7**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0.5**	**0.1**	**0**	**0**	**0.9**	**0.7**	**1**	**0.3**	**0.3**	**0.9**	**1**	10.3
6	Set and follow-up targets	**1**	**0**	**0**	**0**	**1**	**0.9**	**0.5**	**1**	**1**	**0.9**	**1**	**0**	**0**	**1**	**0.9**	**1**	**1**	**0.5**	**1**	**0**	**1**	**1**	**0**	**0**	14.7
7	Involve and support employees	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0.7**	**0**	**0**	**0.3**	**0.1**	**0.1**	**0**	**0.3**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	6.5
8	Dedicate human resources	**0.7**	**0**	**0**	**0**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0.7**	**0**	**0**	**0.3**	**0.3**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	3.9
9	Commit corporate management	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	17
10	Integrate lean in everyday business	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.9**	**1**	**0.7**	**0**	**1**	**0**	**0**	**0.7**	**0.7**	**1**	**1**	8
11	Develop vision and roadmap	**0.7**	**0.5**	**0**	**0**	**0**	**0.1**	**1**	**0.5**	**0**	**0**	**0.5**	**0.3**	**0.9**	**1**	**0.9**	**0.5**	**0**	**0.3**	**0**	**0.7**	**1**	**1**	**1**	**1**	11.9
12	Use rewards and recognition	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0.7**	**0.3**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0.9**	12.9
13	Monitor and audit implementation	**1**	**1**	**0.7**	**0**	**0**	**0**	**0**	**0.3**	**0**	**0**	**0.5**	**1**	**0.7**	**0.9**	**0.9**	**0.7**	**0.3**	**0.1**	**0.9**	**0.9**	**1**	**1**	**1**	**0**	12.9
14	Standardize and manage discipline	**0.7**	**0.9**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0.5**	**0.7**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	4.7
15	Find and share best practices	**1**	**0.5**	**0**	**1**	**1**	**1**	**0**	**0.1**	**0**	**1**	**1**	**0**	**1**	**1**	**0.9**	**0**	**0**	**0.9**	**0**	**0.7**	**0**	**0**	**0**	**1**	12.1
16	Stepwise approach	**0**	**0**	**0.7**	**0**	**0.5**	**0**	**0**	**0.7**	**1**	**0**	**1**	**0**	**0**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	4.8
17	Focus on areas and prioritize activities	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	2.9
18	Invest time and money	**0.3**	**0.1**	**0.1**	**0.3**	**0.1**	**0.5**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	3.5
19	Benchmark others	**0.9**	**0.9**	**0.5**	**1**	**0.7**	**1**	**0.1**	**0.3**	**0.9**	**1**	**1**	**0**	**0**	**0.9**	**1**	**0**	**1**	**0.9**	**0.9**	**0**	**0**	**0**	**0**	**0**	13
20	Emphasize team concept	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0.1**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0.9**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	4.5
21	Use external experts	**1**	**0.3**	**0**	**1**	**0**	**1**	**0**	**0.7**	**0**	**1**	**1**	**0**	**0**	**0.9**	**0.9**	**0**	**0**	**0.3**	**1**	**1**	**1**	**1**	**0**	**0**	12.1
22	Hold regular implementation meetings	**0**	**0**	**1**	**0**	**0.9**	**0**	**0**	**0.9**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	4.3
23	Emphasize safety and job attractiveness	**0.7**	**1**	**0**	**0**	**0.7**	**0**	**0**	**0**	**0.5**	**0.5**	**1**	**1**	**1**	**0.7**	**0.3**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	10.4
24	Use lean tools and methods	**1**	**0.9**	**0**	**1**	**0.9**	**1**	**0**	**0.9**	**0**	**0.7**	**0.9**	**1**	**1**	**0.5**	**1**	**0.5**	**0.9**	**0.9**	**1**	**0.9**	**1**	**1**	**0.7**	**1**	18.7
	Dependence Power	15	15	10	6.5	15	9.2	4.3	10	9.9	12	15	6.5	6.9	14	13	7.6	7.5	12	7.5	11	8.9	12	11	9.7	

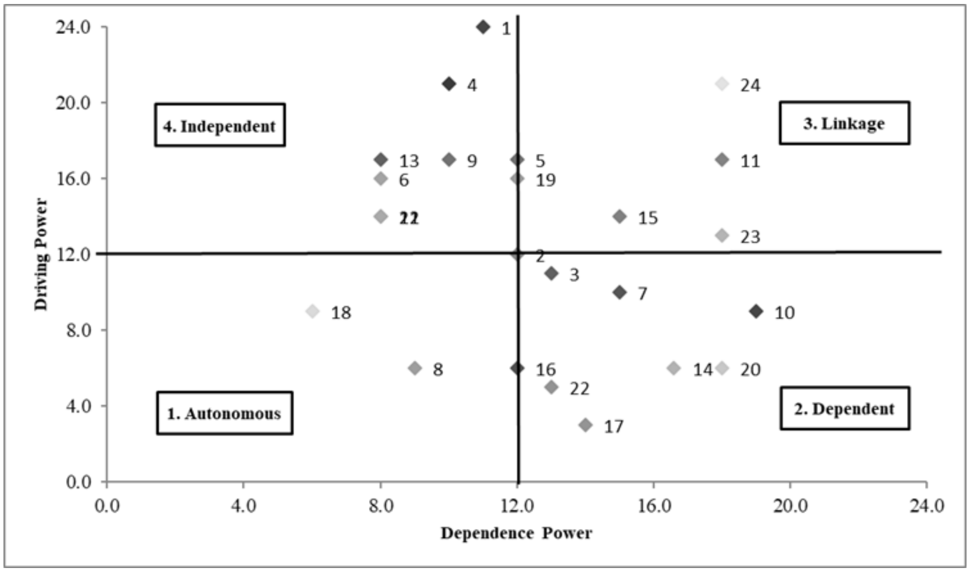

Figure 3: MICMAC analysis

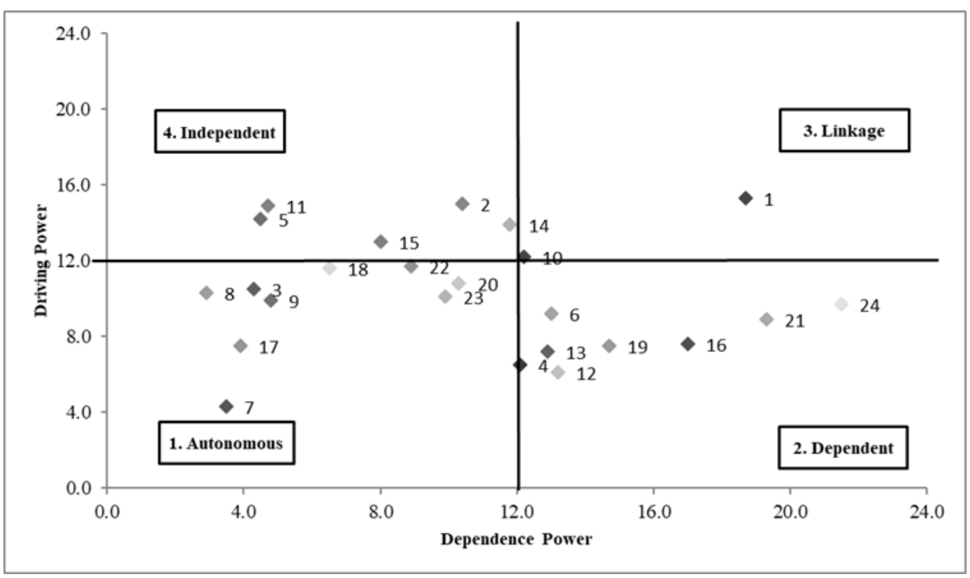

Figure 4: Fuzzy MICMAC analysis

In Table 7, the position of each CSF in fuzzy and nonfuzzy MICMAC analyses is specified.

Table 7: Driving and dependence power of critical success factors

Group	Critical Success Factors		
	Nonfuzzy		Fuzzy
1. Autonomous	18,8	2*16	3,7,8,9,17,18,20,22,23
2. Dependent	3,7,10,14,16,17,20,22		4,6,12,13,16,19,21,24
3. Linkage	11,15,23,24	2*5,19	1,10
4. Independent	1,4,6,9,13,22		2,5,11,14,15

5 Conclusion

As organizations are interested in implementing lean production systems, it would be of particular importance to identify CSFs to facilitate their implementation and provide a conceptual model in this area. ISM provides a proper framework and order for such systems. Thereby, decision-makers are given a clear picture of how various factors influence the system as a whole and how to best proceed to reach their objective. The current research utilized ISM to identify the type of relationship between factors and determine the levels of CSFs. Then, seven levels were assigned to the factors based on a summary of expert opinions and an ISM analysis. The conceptual model of CSFs in lean production indicates that leadership is the foundational element of the model and serves as the driver for other factors. Consequently, leadership is deemed the foremost CSF in lean production. When establishing lean production systems in organizations, senior managers should focus on higher levels and the CSFs underlying the model.

Based on the findings from Figures 3 and 4, as well as Table 7, it can be inferred that the fuzzy MICMAC analysis offers superior insights into the analysis of driving and dependence power. This eliminates the issue posed by the presence of border CSFs in the nonfuzzy MICMAC analysis. The fuzzy MICMAC analysis helped identify several key factors that are highly effective in achieving success in implementing lean production. These factors include "participate personally", "communicate, inform, discuss", "develop vision and roadmap", "standardize and manage discipline", and "find and share best practices". These factors exhibit high driving and weak dependence power. The CSFs of leadership and lean business are linkage factors, which exhibit a significant correlation with the factors at the preceding levels of the model and a moderate driving on other factors.

The key factors of "educate managers", "set and follow-up targets", "use rewards and recognition", "monitor and audit implementation", "stepwise approach, "benchmark others", "use external experts", and "use lean tools and methods" are also dependent on the factors of the previous levels in the model. Other factors with low driving and dependence power include "educate employees", "involve and support employees", "dedicate human resources", "commit corporate management", "focus on areas and prioritizing activities", "invest time and money", "emphasize team concept", "hold regular implementation meetings", and "emphasize safety and job attractiveness" in the autonomous category.

In future studies, fuzzy-based conceptual models can be developed by FDRM or fuzzy ISM that builds on a questionnaire with linguistic variables and completely fuzzy calculations. Alternatively, ISM can be considered to develop models of quantitative approaches. In the current study, ISM was used as a tool whose performance is based on the judgment of experts for the development of the model.

Conflict of Interest: "The authors declare no conflict of interest."

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Mazdak Khodadadi-Karimvand
Department of Industrial Engineering
Najafabad Branch, Islamic Azad University
Najafabad, Iran
E-mail: mazdak.kh@gmail.com

Hadi Shirouyehzad
Department of Industrial Engineering
Najafabad Branch, Islamic Azad University
Najafabad, Iran
E-mail: hadi.shirouyehzad@gmail.com

Farhad Hosseinzadeh Lotfi
Department of Mathematics
Science and Research Branch, Islamic Azad University
Tehran, Iran
E-mail: hosseinzadeh_lotfi@yahoo.com