Decision-making in manufacturing strategy using a maturity model

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Abstract

The study of manufacturing strategy is focused on two components: formulation process and content. While content has been widely discussed in the literature, formulation process has lagged behind. Therefore, this article presents the design and application of a Maturity Model to support Decision-Making (MMDM) in the MS formulation process. This model permits identification of a set of strategic projects to guide the long-term improvement of a manufacturing system. Using an action research approach, the model was validated in a Colombian manufacturing company, making both academic and practical contributions.

Keywords: Decision-making, manufacturing strategy, maturity model.

Introduction

Manufacturing strategy (MS) can be understood as a long-term strategic plan for manufacturing systems. This concept is concerned with what function manufacturing must fulfill in order to meet current and future challenges (Slack and Lewis, 2011). Typically, two MS components have been studied (Leong et al., 1990): process formulation and content. Process formulation establishes how to carry out the strategy (procedures), while content defines the objectives (competitive priorities) and which subsystems or manufacturing levers (products design, processes, facilities, etc.) must be modified so as to improve the manufacturing system.

The research of Dangayach and Deshmukh (2001), Boyer et al. (2005), and Chatha and Butt (2015) shows that scientific literature has focused on MS content, neglecting its formulation process. Our systematic literature review, based on 263 articles, confirms this trend, as only 6% of investigations have addressed this component. According to Jia and Bai (2011), the formulation process has been dominated by conceptual models, and more practical contributions are required.

The starting point for MS formulation is to identify the current maturity level of the manufacturing system. In other words, one must ascertain the performance level in terms of competitive priorities (cost, quality, deliveries, flexibility, etc.) and the current manufacturing lever capacities (products, processes, technologies, information systems, human resources, etc.). A maturity model would not only identify the current state of the system, but also project its long-term improvement to guide decision-making in manufacturing strategy.

According to Röglinger et al. (2012), maturity models establish a way for organizational capacities to evolve logically until arriving at ideal or mature states (maximum performance). However, our maturity model literature review (132 references) confirmed a research gap on this topic. Although maturity models have been developed to measure capacities in other organizational areas, contributions in the manufacturing field were not found. This gap may be filled by answering the following research question:

How can a maturity model be developed and applied to support decision-making in manufacturing strategy?

In order to tackle this research gap, the present paper proposes a Maturity Model to support Decision-Making (MMDM) in the MS formulation process. The model allows for establishment of manufacturing system maturity on five possible levels: preinfantile, infantile, industry average, adult, and world class. There are two stages followed for system improvement: in the first, the current maturity level is identified in three performance dimensions: competitive priorities, manufacturing levers, and manufacturing's strategic role. In the second, a preliminary set of improvement projects is established, and through a stochastic optimization process, the final set of projects is established to maximizes long-term manufacturing system performance.

Through use of an action-research approach, the model was validated in a manufacturing company in Colombia. According to the obtained results, in the first stage, the production system showed maturity at industry average level (68 points on a scale of 0-100). Once the stochastic optimization process was applied, the model identified the final set of strategic projects to position the production system at an adult level (82 points) in the long term.

The present investigation contributes to the field of study in two ways: firstly, the proposed maturity model is a useful tool to support decision-making in the MS formulation process. Secondly, since the proposed maturity model was validated in a real case with an action-research approach, it also contributes to reduce the gap between theory and practice, a goal widely discussed by different authors in the field of operations management (Koskela, 2017; O'Sullivan et al., 2011; Rynes et al., 2001; Shapiro et al., 2007).

The remainder of the paper is structured as follows: in the next section, the theoretical background is presented. Subsequently, the methodology employed to design and apply the maturity model is explained. Finally, the main conclusions and notes on the relevance of this contribution are addressed.

Theoretical background

The origins of Manufacturing Strategy (MS) stem from the seminal contributions of Wickham Skinner (Skinner, 1966; 1969), to which a set of later works were added to consolidate the theoretical bases of this field of study. The fundamental objective of MS is to orient decision-making, so as to achieve distinctive strengths in the production system (Miltenburg, 2005).

MS has traditionally been studied from two components (Leong et al., 1990): process formulation and content. Process formulation establishes how to develop strategy (procedures), while content defines the objectives (competitive priorities) and which manufacturing levers (products design, processes, facilities, etc.) must be modified in order to support company strategy.

Brown et al.'s (2007) research found that the highest performing plants (World Class Manufacturers) incorporate both content and process, while traditional plants do not. Hill (2000) argues that the discussion of process will yield poor results if the content is not of high quality.

However, the literature have mainly been focused on content, neglecting process (Boyer et al., 2005; Chatha and Butt, 2015; Dangayach and Deshmukh, 2001). In fact, the state of the art has been dominated by conceptual models, with little progress in concrete solutions to solve the problem of MS formulation. Thus, Jia and Bai (2011, p. 446) stated that: "*Most literature has proposed many prescriptive processes, and the manufacturing strategy domain has being dominated by conceptual models*".

Taking into account that companies must formulate an explicit MS, in terms of concrete strategic projects (Brown et al., 2007), alternatives are required to guide decision-making in such a way that each plant is able to establish its own improvement path, considering its particular situation in regards to its country, industry, and other contextual factors (Schroeder and Flynn, 2001). Because manufacturing could be described according to its evolution through different maturity stages (Hayes and Wheelwright, 1984; Rytter et al., 2007), the design of a maturity model to guide long-term manufacturing decisions constitutes a research topic for contributions to the field of study.

In a broad sense, a maturity model is used to "*…define a set of levels or stages, describing the development of the examined object in a simplified way. These stages should be sequential in nature and represent a hierarchical progression. Furthermore, they should be closely connected to organizational structures and activities*" (Wendler, 2012, p. 1319). According to Röglinger et al. (2012) maturity models represent theories about how an organization's capacities can evolve in stages, taking a logical path to reach an ideal or mature state, in which maximum performance is achieved.

In this study, a systematic literature review was carried out, following the principles of Bartels, (2013) and Kitchenham (2004). Although maturity models were identified in other fields such as industrial maintenance (Macchi and Fumagalli, 2013), product development (Farrukh et al., 2003), logistics (Battista and Schiraldi, 2013), collaboration (Campos et al., 2013), quality management (Morsal et al., 2009), and environmental concerns (Ormazábal and Sarriegi, 2013), few contributions regarding maturity models for manufacturing systems were found.

Hayes and Wheelwright (1984) proposed four stages in which a manufacturing system could be categorized, in accordance with its strategic role to support company competitive strategy: 1) internally neutral, 2) externally neutral, 3) internally supportive, and 4) externally supportive (world-class manufacturers). Nevertheless, Barnes and Rowbotham (2003) state that little empirical evidence has been reported for this perspective.

Rytter et al. (2007) analyzed the MS formulation process, proposing five maturity levels for manufacturing systems. However, said authors stated that: "*…part of the model (Steps 4 and 5 for manufacturing maturity; Step 5 for socio-political maturity) is speculative. Further, research is needed to test the validity of the model in a wider set of companies engaging in similar initiatives*" (Rytter et al., 2007, p. 1106).

Although Miltenburg (2009, 2008, 2005) proposed four qualitative capability levels for manufacturing systems: infantile, industry average, adult and world class, this author stated that, "*The strategy objects and the framework they comprise are not analyzed empirically. This work is left for future research. There are other areas where more* *research can be done. More detailed descriptions can be developed for each manufacturing strategy object. New objects can be developed*" (Miltenburg, 2008, pp. 321–322).

Methodology

In order to address the aforementioned gap, in the present investigation an action-research approach was used, aimed to design and apply a maturity model to support decision-making (MMDM) in the MS formulation process. Action research promotes the development of collaborative projects between researchers and practitioners (Avella and Alfaro, 2014). Given that the action research approach implies result validation in real companies, the methodology was developed and applied in a company from the manufacturing sector. Thus, the methodology employed was as follows: 1) conceptual design of the MMDM; 2) application of the MMDM; 3) result evaluation to validate the MS' contribution.

In the first step, a general model was constructed (see Figure 1). The MMDM has two phases: the current maturity level and continuous improvement. In Phase 1, an approach developed by Vivares et al. (2018) was used, as it provides five maturity levels (preinfantile, infantile, industry average, adult, and world-class manufacturing-WCM).

In order to establish the current state of the manufacturing system, the baseline was obtained through a maturity index (MI_k) [0,100], involving three performance dimensions (equation 1): competitive priorities (CP), manufacturing levers (ML) and manufacturing's strategic role (MR). CP represents the manufacturing system's performance level in terms of cost, quality, deliveries, flexibility, etc. ML refers to the manufacturing subsystems' maturity (human resources, process technology, facilities, etc.). MR is the role that the manufacturing system plays in the company's general strategy.

Equation (1):

$$MI_k = \frac{MI_{CP} + MI_{ML} + MI_{MR}}{3}$$

In the second phase, a projects portfolio $(PP)\{P_i, \quad i = 1, \dots, n\}$ should be identified and prioritized to support MS decision-making. Identifying the PP is a process based on three elements: the current maturity level of variables conforming the three performance dimensions (CP, ML, MR), company knowledge (theoretical and empirical), and the external signals influencing strategic decisions. It is expected that PP implementation will be reflected in a maturity increase (ΔMI), and therefore, in an improved maturity index $(MI_{k+1} = MI_k + \Delta MI)$. Many times, companies have financial constraints, and there is often uncertainty about the effect of each project on manufacturing performance, and so the MMDM provides a stochastic optimization model to prioritize PP (see equations 2-5).

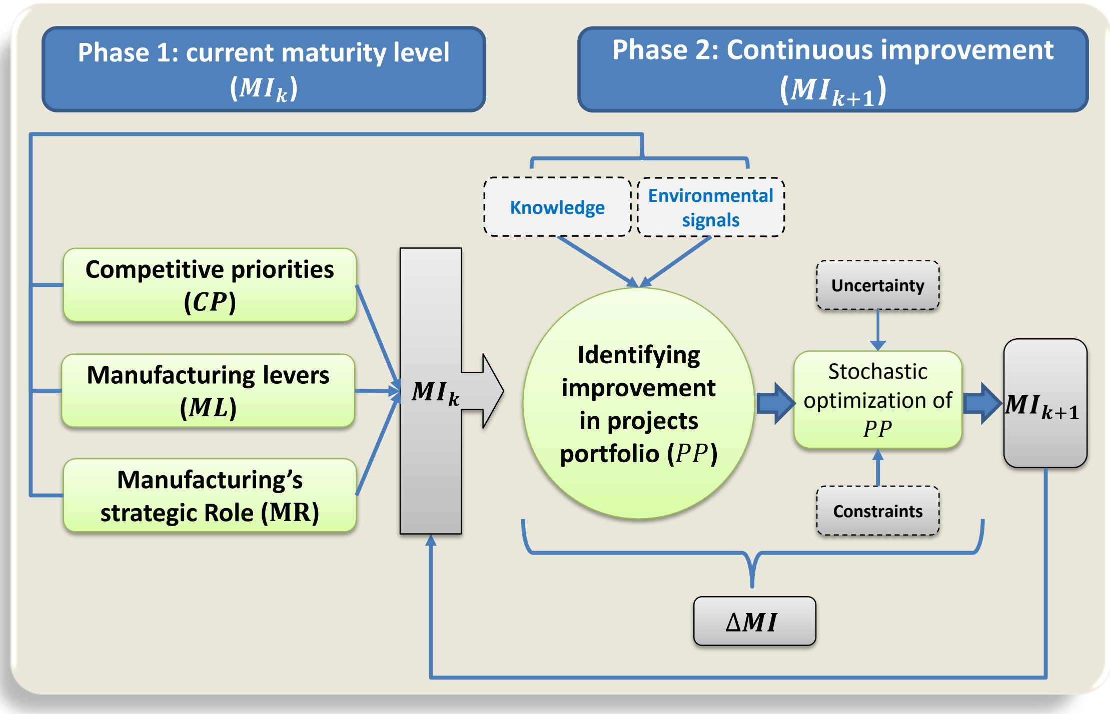

Figure 1- General overview of the MMDM

Decision variables: Project P_i $\begin{cases} 0\text{: project } i \text{ is not chosen} \\ 1\text{: otherwise} \end{cases}$

Objective function: Max MI_k(maturity index).

$$\Delta MI = \frac{1}{3}\left(\sum_{i=1}^{n} P_i \times w_{P_{iCP}} + \sum_{i=1}^{n} P_i \times w_{P_{iML}} + \sum_{i=1}^{n} P_i \times w_{P_{iMR}}\right)$$

Constraints:

Equation (2):

$\sum_{i=1}^{n} P_i \times c_i \leq K$ Budget availability.

Equation (3):

$P_{i=A} + P_{i=B} \leq 1$ $P_{i=A}$ and $P_{i=B}$ are two mutually exclusive projects.

Equation (4):

$P_{i=C} \geq P_{i=D}$ Project $P_{i=D}$ depends on $P_{i=C}$.

Equation (5):

$P_{i=E} = P_{i=F}$ Projects $P_{i=E}$ and $P_{i=F}$ are mutually inclusive, but there is not a dependence relationship in their execution.

Where:
n: number of improvement projects.
c_i: cost of project i.
K: budget threshold.
$w_{P_{iCP}}$: improvement generated by project P_i in CP.
$w_{P_{iML}}$: improvement generated by project P_i in ML.
$w_{P_{iMR}}$: improvement generated by project P_i in MR.

In *the second step* in the action research approach, the MMDM was applied in a manufacturing company from the Colombian metalworking sector. To this end, an immersion process was carried out during eight months by the research team. With the agreement of the company, the research team played the roles of observer, facilitator, change agent, and collaborator. This involved 42 people (top and middle-level managers) following the general procedure presented in Figure 2. This procedure contains a set of activities to advance Phase 1, and consequently, to deploy the set of prioritized strategic projects in the manufacturing system (Phase 2).

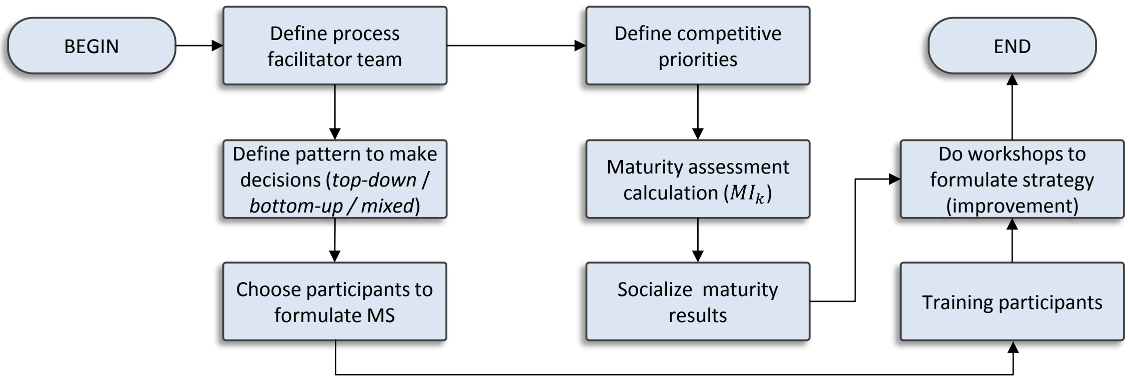

Figure 2- General procedure for MMDM application

In *the third step*, in order to validate the MDMM contribution, an assessment of the obtained results was carried out. Through an anonymous survey, participants evaluated 30 criteria aimed at assessing the applicability, comprehensibility, and usefulness of the MDMM, as well as the effectiveness of the results obtained in the company (1 = totally disagree, 5 = totally agree).

Results

After applying the MMDM, the current maturity index was $MI_k = 68$ (see Figure 3). This result places the manufacturing system at 'industry average' level (see Figure 3). Subsequently, as shown in Table 1, participants identified ten strategic projects for the manufacturing system. Table 1 shows the relations of dependency between the 10 projects and the minimum-maximum investment range (budget) assigned by the company for each one of them. Also, for each project, participants previously defined the potential impact of each of the variables conforming the three performance dimensions (CP, ML, MR).

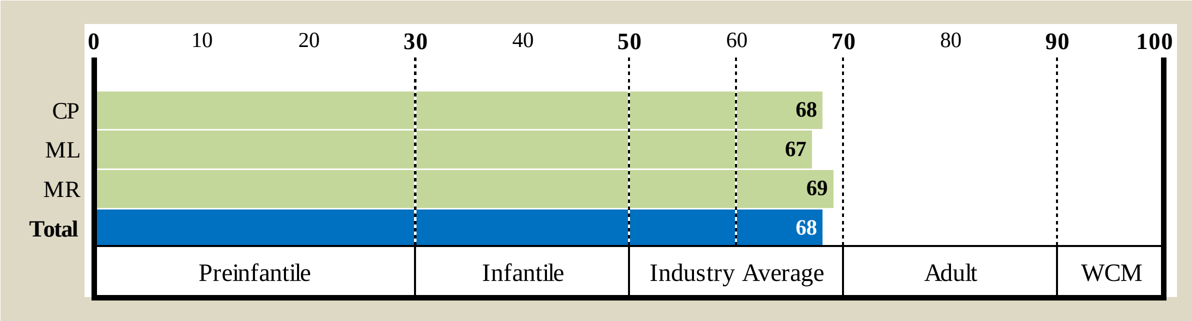

Figure 3- Current manufacturing system maturity

Table 1. Projects Portfolio (PP)

P_i	Project name	Relations between projects			Project cost ($COP)*	
		E[1]	D[2]	I[3]	Min.	Max.
P_1	TPM implementation		5,9,7, 8,		321	612
P_2	SMED implementation to reduce set up times		5,9,1,7		45	87
P_3	Strengthening of the production planning system		5		40.5	54
P_4	Strengthening of the institutional image		5		10	15
P_5	Strengthening of organizational culture			7	60	130
P_6	Improvement of environmental performance		5,9	10	25	40
P_7	Effective implementation of the “eight disciplines”			5	40.6	57.2
P_8	Strengthening of information and communication systems		5,7		33	52
P_9	Implementation of the 5S program		5	10	35	54
P_{10}	Strengthening of industrial safety		5,7	6,9	38	77
				Total	**648.1**	**1,178.2**

*Millions. [1]Exclusive projects (E). [2]Dependent projects (D). [3] Mutually inclusive projects (I).

These 10 projects required a minimum budget of COP$ 648.1 million, and a maximum of 1.1782 billion. Since the maximum availability of financial resources is COP$ 360 million, to obtain the set of final projects, the specific optimization model is as follows:

Decision variables: Project P_i $\begin{cases} 0\text{: project } i \text{ is not chosen} \\ 1\text{: otherwise} \end{cases}$

Objective function: Max ΔMI.

Equation system (6):

$$\sum_{p=1}^{n} P_i \times c_i \leq 360$$

$$P_9 \geq P_1 \qquad P_7 \geq P_2 \qquad P_5 \geq P_{10}$$
$$P_8 \geq P_1 \qquad P_5 \geq P_3 \qquad P_5 = P_{07}$$
$$P_9 \geq P_2 \qquad P_5 \geq P_4 \qquad P_6 = P_{10}$$
$$P_1 \geq P_2 \qquad P_5 \geq P_8 \qquad P_9 = P_{10}$$
$$P_i \geq 0 \qquad P_i \leq 1 \qquad P_i \in N$$

The histogram of maturity increases, obtained after 10,000 iterations, is shown in Figure 4. Table 2 shows the results of the stochastic optimization model. The model suggests eight solutions (combinations of strategic projects). However, based on the highest frequency, company managers selected Solution 1, which contains projects P_3, P_4, P_5, P_6, P_7, P_9 and P_{10}.

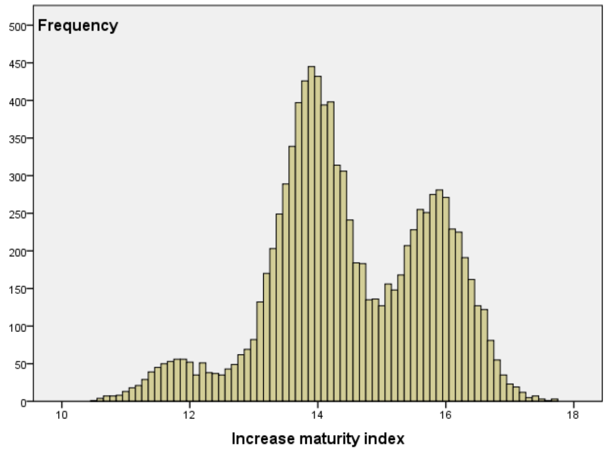

Figure 4-Histogram for ΔMI_k

Table 2- Results of stochastic optimization

Solution	**Decision variables (P_i)**										**Frequency**	Investment (millions of $COP)	Expected (MI_{k+1})
	P_{01}	P_{02}	P_{03}	P_{04}	P_{05}	P_{06}	P_{07}	P_{08}	P_{09}	P_{10}			
1	0	0	1	1	1	1	1	0	1	1	4,025	343,7	82
2	0	0	1	0	1	1	1	1	1	1	1,523	353,4	83
3	0	0	1	0	1	1	1	0	1	1	1,199	352,7	82
4	0	0	1	1	1	1	1	1	1	1	2,227	345,3	83
5	0	0	0	0	1	1	1	1	1	1	337	354,8	81
6	0	0	1	1	1	0	1	1	0	0	580	278,1	80
7	0	0	0	1	1	1	1	1	1	1	53	357,4	81
8	0	0	0	1	1	1	1	0	1	1	56	336,9	79

Figure 5 shows the expected manufacturing system maturity, based on the selected set of projects ($MI_{k+1} = 82$).

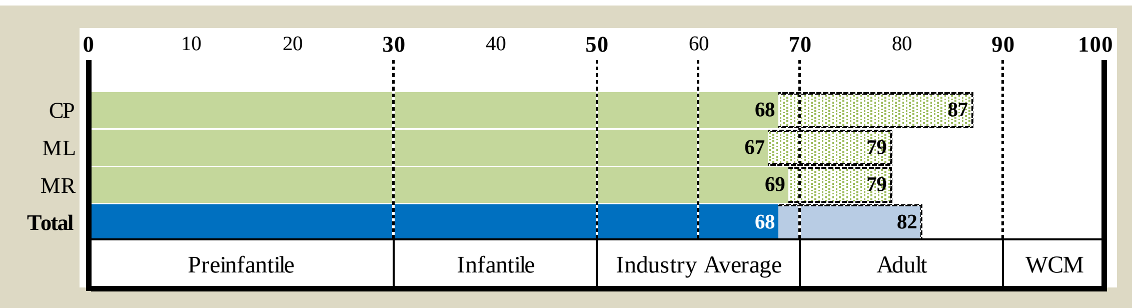

Figure 5- Expected maturity of the manufacturing system

Based on the 30 analyzed criteria, the MMDM assessment was carried out by company participants. As shown in Figure 6, suitable results were obtained.

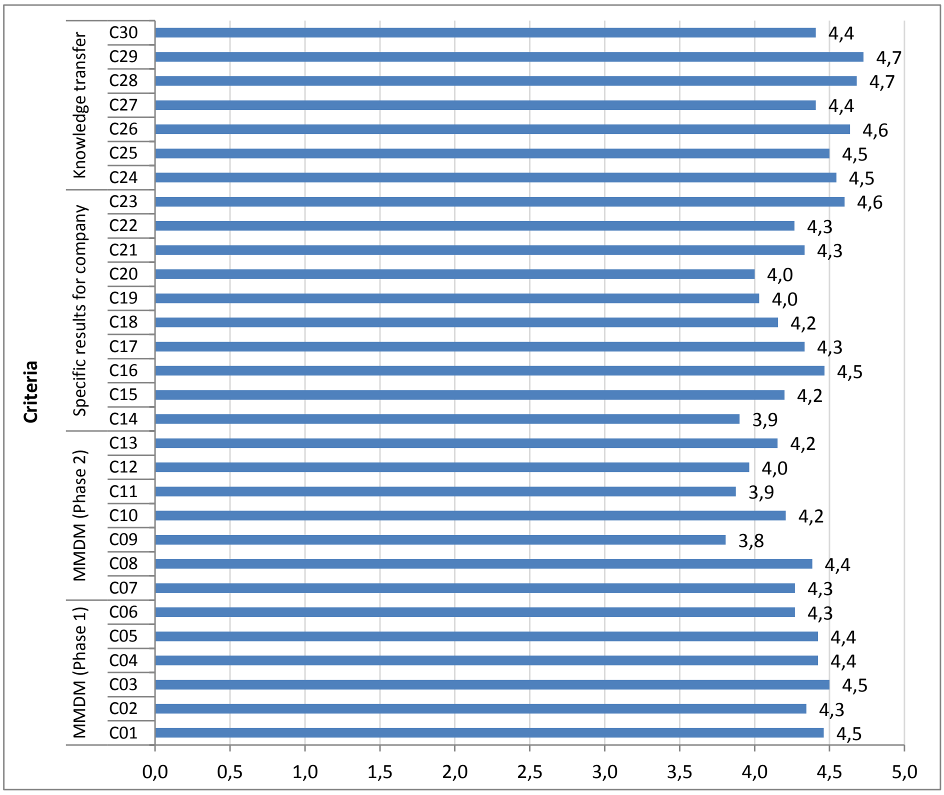

Figure 6- Participant's evaluation of the MMDM

Conclusions and relevance/contribution

The literature review reveals that, in the field of MS, there is lack of research in the formulation process. In order to address this gap, the proposed maturity model (MMDM) allows the company to project an improvement path, targeting three performance dimensions: competitive priorities, manufacturing levers, and manufacturing's strategic role. According to the obtained results, the model is a useful tool for choosing strategic manufacturing projects. As this investigation was conducted from an action research approach, both academic and practical contributions were made. In fact, according to participants, the MMDM is a useful tool to guide long-term decision-making in the selected company.

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