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Systems Evaluation Methodology to Attend the Digital Projects Requirements for Industry 4.0

Luiz RAMOS[a,1], Eduardo LOURES[a], Fernando DESCHAMPS[a], Edson GIESEL[b] and Everson SAVARIS[b]
[a] *Pontifical Catholic University of Parana (PUC-PR), Brazil*
[b] *Renault of Brazil*

Abstract. Large corporations work with legacy systems to standardize the execution of activities, support, data formatting and communication between different sites around the world. However, some companies in certain countries have been unable to integrate these systems due to a number of factors involving cultural aspects, local legislation and infrastructure. With the arrival of the Fourth Industrial Revolution, also known as Industry 4.0, there is a need to deploy digital projects that have a dependency relationship with legacy systems in acquiring and managing information making it more accessible to the user. In addition, this integration needs to be synchronized with other countries so as not to lead to uneven maturity among organizations, leading to difficulties in adopting I4.0 in different plants around the world. The objective of this article is to elaborate an evaluation methodology between legacy and local systems, using multi-criteria decision-making methods (MCDM/A), in order to verify if both attend the specifications of the organization's digital transformation projects. As a way to evaluate the proposed model was used the case of an automotive company located in Brazil for more than 20 years that has one of its units in South America (Colombia) with local systems that are bringing numerous difficulties of implementation of projects geared to I4.0. With the support of the MCDM/A methods, it was noticed that some local systems would be able to attend the scope of the projects since it would allow a flexibilization to customize certain points of integration.

Keywords. Industry 4.0, Digital Project, Legacy Systems, Local Systems and MDCM/A Methods.

Introduction

With the advances of science and technology the manufacturing industry has undergone constant modifications to attend the needs of the market worldwide [1]. This is due to the demand of different types of customers who have requested higher quality products produced in a short term and affordable prices to all levels of society [2]. In this way, companies have observed the need to increase their competitiveness by transforming their productive process to become them more adaptive, digital, integrated and with a more solid conceptual foundation [3]. Thus, the term Advanced Manufacturing or Industry 4.0 has been constantly mentioned in brazilian industries as a way to achieve this goal.

[1] Corresponding Author, Mail: luiz.pierin@pucpr.edu.br.

To make processes more flexible and productive, it is necessary to realize certain customizations to the systems that are currently in operation in organizations, usually called legacy systems or standard. Typically, such systems (software) have been operating with a standalone architecture for approximately 50 years [4]. Legacy systems are already existing enterprise systems that are challenged to upgrade or integrate with new functions demanded of I4.0, as well as with local systems present on different sites of the organization [5]. The existence of local systems in corporations is due to unique characteristics of each internal process that are not mapped by the standard systems and attend specific needs. The I4.0 era has called for the adoption of agile decision-making methods based on consistent data from manufacturing systems, allowing process reconfiguration to be rapidly changed in an automated way. Current legacy systems do not have these characteristics. They have a low autonomy in disruptive events where the response time needs to be immediate [6]. In addition, there is a marked difficulty in integrating them with local systems. Local applications are designed to attend a timely need that does not follow the company's global standard. This is due to several factors such as usability, costs and infrastructure.

Therefore, the objective of this article is to develop a methodology that allows the evaluation of local and legacy systems for the implementation of projects related to Industry 4.0. Some projects require information from legacy/local software to make its operationalization feasible. With a model that provides more assertive decision making through closer analysis, it is possible to judge whether or not the project can be adopted in a determined organization. In order to contextualize the research, section 1 highlights the concepts of Industry 4.0, Enterprise Information Systems (EIS) and Multicriteria Decision Making/Analysis (MCMD/A). Section 2 presents the methodology used in the research. In section 3 the results obtained are discussed. Finally, section 4 mentions the final conclusions.

1. Background

1.1. Industry 4.0

The term Industry 4.0 (I4.0) was mentioned for the first time at the Hannover fair in 2011. It is a denomination for the integration of several technological concepts that will impact the organizational management of the company and in society. Communication between devices is one of the most critical issues in I4.0 due to the different interfaces and communication protocols that exist among them. New technologies are emerging to facilitate communication between various types of software and hardware such as Internet of Things (IoT) [7], Machine-to-Machine [8] and Cyber-Physical Systems (CPS) [9].

Under point of view of manufacturing, recent research emphasizes the idea that the frequent control of the production process, traditionally carried out by PLCs and numerical computers, will be integrated with the CPS and IoT devices to attend the specifications predefined by the organization [10]. In one of these research, [11] claims that IoT will modify the way of manufacturing systems operate, especially when it involves the adaptation of the Representational State Transfer (REST) architecture. In this way, there will be a decentralization of the legacy systems currently used to allow flexibility in the production of the factory floor through the use of I4.0 technologies.

1.2. Enterprise Information Systems

Enterprise Information Systems (EISs) began with the introduction of computers in industries in the early 1960s where it was intended to automate manual activities on paper [5]. The EIS can be defined as systems for business management that includes modules of the company's organizational structure from planning, manufacturing, sales, marketing, logistics, accounting, human resources, services and maintenance [14]. The entire process is done through computers, software, people, processes and data. EISs are typically divided into six particular types: Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Manufacturing Execution Systems (MES), Customer Relationship Management (CRM), Product Lifecycle Management (PLM), and Business Intelligence (BI).

This paper will focus on projects with systems focused on supply chain (SCM) and production process management (MES). Most of the digital transformation projects, adopted in manufacturing companies, have a growing demand in these sectors due to their high maintenance costs. Therefore, the leadership of large organizations has called for the implementation of initiatives in these areas in order to better integrate the entire value chain.

1.3. MCDM/A Method – Promethee

Promethee (Preference Ranking Organization Method for Enrichment Evaluations) is a decision-making method developed by Brans et al. in the early 1980s [12]. It is a MCDM/A classification method adapted to problems where a finite number of alternatives should be ranked according to the criteria. The models developed in Promethee require two types of information: (i) Information about the relative relevance (weights) of the considered criteria and; (ii) Information related to the preference function used to optimize the comparison between criteria and alternatives [13]. There are six preference functions in Promethee that allow to adjust the parameters to find the best answer: Usual, U-Shape, V-Shape, Level, V-Shape with Indifference and Gaussian.

In this paper the Promethee method, due its characteristic of the evaluation space involved, will be used to rank and determine which systems attend the most criteria defined based on the functional requirements obtained about I4.0 projects.

2. Methodology

The research consists of 8 steps, as shown in Figure 1. The first step is to choose which projects have the highest priority following the criteria defined by the company. Typically, the criteria that define this are the time and budget that certain sectors of the organization have to dispense with the proposed demand. The second step is the definition of the processes that need to be analyzed based on the predefined projects. The third step is the definition of the local systems that are used in Colombia. The fourth step refers to the survey of which legacy systems are used to operationalize the processes involved in the projects. The fifth step brings a simple comparison, using the weighted average, to determine which system is most relevant to another. The sixth stage encompasses the use of multicriteria decision-making methods. In this article the focus will be given to the analysis using the Promethee method. The seventh and eighth steps consist in the decision of the project managers with their stakeholders to determine which of them will be prioritized taking into account the data obtained in the analysis and other criteria with equal relevance.

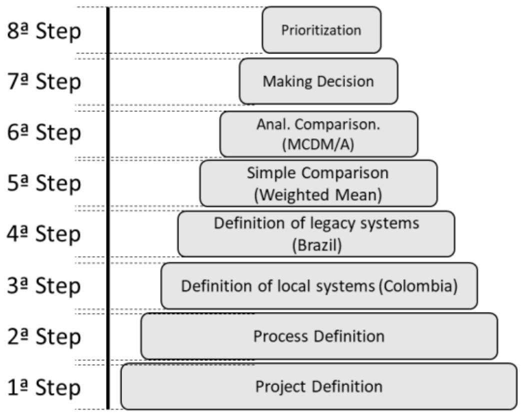

Figure 1. Process flow of this research.

The exigency for the implementation of systems and tools containing the concepts of Industry 4.0 is growing. Many companies have built their own methodology to try to correlate the interface between systems and technologies that have more autonomous characteristics. The study realized at the french multinational points to the procedure shown in Figure 2. It was developed based on studies from consultancies and also from the experience of the professionals who have worked for years in the support and implementation of systems in different sectors of the organization. In this way, two types of digital projects were defined: (1) Those that have integration with legacy systems; and (2) Those that have their own characteristics that can be adopted in any sector of the company without the necessity of interaction with legacy or local systems already present. The representation of the area where "Digital Project" (Figure 2) is described represents the stages of executing of a project following the procedures adopted by the organization. The "Flow Implementation" arrow, located next to the triangle (Figure 2), indicates the direction in which the procedural flow should be directed. Both projects require the infrastructure layer to make it possible to deploy to the enterprise. In the case of projects involving legacy systems, there are situations where they do not apply due to the several characteristics of the plant. One of the factories that was pointed out this fact is located in Colombia. Originally the plant belonged to a Japanese multinational and all its architecture was imported with some supply chain and manufacturing information systems. To attend the company's structure and operational demands, not all legacy systems were adopted. Thus, a space has been left for possible inefficiencies in the exchange of critical information with the headquarters located in France and with other factories in South America. The evaluation proposed in the research can therefore support the understanding of which are the main gaps that the company has in relation to the manipulation of their local systems. In the infrastructure there is a need to integrate legacy/local systems with the existing architecture. When new projects are involved without reliance on information from the standard systems, it is a new concept that demands elements to guarantee the technical interoperability between infrastructure and devices to be homologated in the organization, as described in Figure 2.

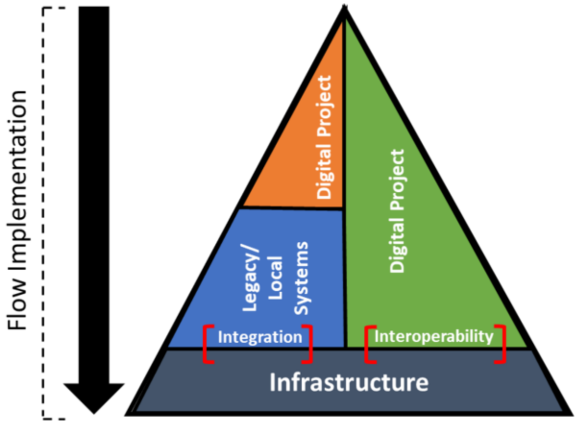

Figure 2. Industry 4.0 projects implementation methodology.

Table 1 presents the list of the main demands that have arisen in the case study company that need to be integrated with existing manufacturing and logistics systems. Four projects stand out, depending on information from legacy systems to assist users in specific tasks. The first is for traceability of parts. The second, third and fourth relate production line demands so the process has its improved performance. All of these projects rely on information from legacy systems for their functionality to be attended (as highlighted in the Demanded Systems column of Table 1).

Table 1. Recurrent digital transformation projects.

Project Name	Functionalities	Demanded Systems
Project #01	Enable traceability of parts in the stamping area through of an RFID tag in the rack	Legacy inventory management system information (LS#01).
Project #02	Allow the operator to answer workstation calls from the factory floor using mobile devices	Information coming from the maintenance alert message system (LS#02), product failure management (LS#03) and product quality assessment (LS#04).
Project #03	Allow the service technician view alert messages (by SMS) of equipment from the factory floor using a mobile phone	Information coming from the maintenance alert message system (LS#02).
Project #04	Allow the head of the production line work unit check different information from manufacturing systems through a mobile platform	Information from maintenance alert messaging systems (LS#02), manufacturing execution systems (LS#05), product failure management (LS#03) and documentation management and process sequencing (LS#06).

To compose the evaluation, eight criteria were adopted that allow a more effective comparison between the different systems to be evaluated. They were obtained based on the experience of the professionals who pointed out a greater relevance in these aspects for a more assertive decision making. Table 2 presents the defined elements, their description and also the weight of each one. The criterion "External Accessibility and Integration with Systems" received the highest value due to the increasing demand for integration between the systems of different company sites. Another relevant point is the "Infrastructure Demands" that directly impacts the viability of the project due to the implementation costs overcome the possible gains that will be obtained.

Table 2. Criteria used for the systems evaluation.

Criteria Name	Description	Weight
Support	Assistance to solve specific problems of the system	10
Infrastructure Demands	Infrastructure that guarantees the correct execution of the system in different layers of the organization	20
Possibility of Replace	Flexibility to introduce new features with superior quality to existing	10
Autonomy for System/Process Evolution	Need for possible intervention to ensure that the process does not stop suddenly	15
Capacity/Speed of Processing	Velocity in exchange of information and commands given by the user	5
Usability of End User	User-friendly interaction with the system	10
Trainings	Costs related to user training that will handle the systems	5
External Accessibility and Integration with Systems	Integration of the systems in different sites allowing a more adequate control of the production indicators of the plant	25

3. Results

The data presented refer to the study for Project#01, described in Table 1, which has the inventory management system LS#01. Table 3 presents the data related to the supply chain domain, whose process was the reception of materials where the main functionalities of the local systems (LO#01) and legacy (LS#01) were collected, as well as the most relevant outputs.

Table 3. Characteristics of the systems.

Systems	Functionalities	Outputs
LO#01	Record container to be received	Container recorded.
	Package registration	Registered packaging.
	Inspect package	Checklist for supplier responsible for inspection.
	Print new label with location	Printed label and packaging in buffer.
	Record physical location of the packaging	Packaging in the indicated location.
LS#01	Receive and check the package physically	Reception and record executed.
	Print the identification form	Printed and distributed form.
	Print the labels	Printed and delivered labels.
	Validate the load	Validated load.
	Correct the amounts, if it is necessary	Amounts corrected.

Systems	Functionalities	Outputs
	Update inventory on another legacy system	System updated.
	Perform material traceability	Traceability performed.

Based on the data presented in Table 3, it can be seen that the functionalities between the local and legacy systems are similar. This demonstrates that, a priori, Project#01 has no implementation barriers, from the point of view of system characteristics, since it is being designed for legacy system adoption (LS#01). Table 4 highlights the evaluation made, considering the criteria mentioned in Table 2, where the local and legacy systems are compared through a 5-point scale. The description of this qualitative scale is composed by: (1) Very Low; (2) Low; (3) Average; (4) High and (5) Very High. In this way, it is possible to ponder more criteria are more significant in relation to each system being evaluated. The analysis was carried out by specialists and with the main stakeholders of the project.

Table 4. Evaluation of the systems.

Criteria Name	Local System (LO#01)	Legacy System (LS#01)
Support	5	5
Infrastructure Demands	5	3
Possibility of Replace	5	5
Autonomy for System/Process Evolution	5	2
Capacity/Speed of Processing	5	5
Usability of End User	4	5
Trainings	5	1
External Accessibility and Integration with Systems	2	5

The weighted average obtained in LO#01 and LS#01 was 4.15 and 3.95, respectively, indicating that the local system is able to attend the demands required in the project. However, only these numerical data make the evaluation fragile because the values are relatively closer and the individual performance of each alternative in its different criteria that allow a better seek for the best system is not available. Therefore, to support the evaluation requirements, the Promethee method was used, characterizing an evaluation matrix that considers the defined criteria, under weights (from Table 2) and alternatives (legacy/local systems). Thus, Table 5 shows the values Φ obtained after the application of the method using Visual Promethee software V1.4.0.0, with a 10-point scale in the performance of the alternatives to each criterion, increasing the discrimination of supported comparison by the method.

Table 5. Systems evaluation using the Promethee method.

Criteria Name	Local System (LO#01)	Legacy System (LS#01)
Support	0,6	0,6
Infrastructure Demands	0,6	-0,6
Possibility of Replace	0,2	0,2

Criteria Name	Local System (LO#01)	Legacy System (LS#01)
Autonomy for System/Process Evolution	0,6	-0,4
Capacity/Speed of Processing	0,4	0,4
Usability of End User	0,2	0,2
Trainings	1	-0,6
External Accessibility and Integration with Systems	-1	0,6

Based on the results, it was obtained the values of Φ for LO#01 and LS#01 equal to 0,13 e 0,06, respectively. The interval of Φ values is inserted among 1 and -1. In other words, if it is closer to the positive value, the alternative (system) has more adherence to the analyzed criteria. The opposite also applies, when the alternative is closer to -1, it tends to suffer more influence of the criteria. Figures 3 and 4 present the graphs that show which criteria prevail most in relation to the alternatives.

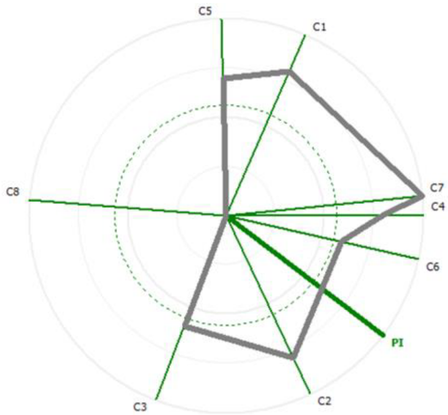

Figure 3. Local System (LO#01) Decision Axis Chart.

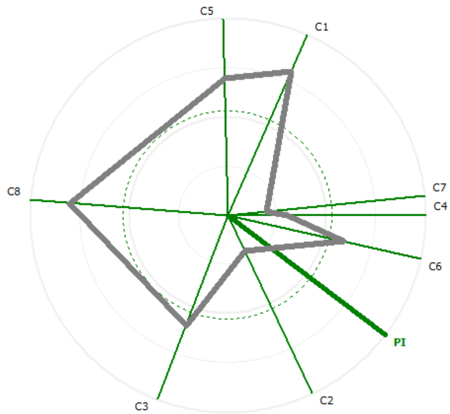

Figure 4. Legacy System (LS#01) Decision Axis Chart.

The criteria are represented by "Cn" following the same sequence as in column 1 of Table 5. LO#01 holds a larger area where the most relevant criteria are inserted in relation to LS#01. It is also possible to observe that the dotted circumference, at the center of the image, is larger for the local than for the legacy systems. This means that this alternative attends a higher number of criteria with higher weights. In this way, it is diagnosed, in light of the mathematical basis Promethee, that the local system (LO#01) has the most expressive elements for the implementation of Project#01.

With these results, it was possible to start planning for the ideation phase of the project more assertively. The costs in relation to changes from local to legacy systems are very high. It was the initial idea of the organization that, with a more accurate assessment, was able to realize that a measure would have a direct impact on ROI (Return of Investment). This would prevent the Colombian plant from advancing along the same strategic planning proposed by the global matrix, since the local management would not approve the projects that were being adopted in the Brazil plant. In addition, the mathematical demonstration, presented by the MCDM/A methods, corroborates that the decision making becomes more solid and allows the advances of the projects related to Industry 4.0 to be maintained according to the initial planning for the region of South America.

4. Conclusion

Through the proposed evaluation methodology, it was possible to provide a more detailed analysis base that assists in the decision-making spheres that guide the planning of activities throughout the life cycle of projects aimed at Industry 4.0. In addition, it is possible to identify possible barriers that impede the expansion of the Digital Age in organizations because most existing systems have been developed on closed platforms with little flexibility. A methodological evaluation including MCDM/A methods assists in assessing the viability of the application as well as in the knowledge on the maturity level of the company for the introduction of Digital Transformation. In this research the Promethee method was used, very appropriate to the evaluation space (modeling and analysis), but other methods could be adopted as long as they attended the same requirements and purpose of ordering alternatives.

The research did not include other aspects considered fundamental in the implementation of I4.0 projects, such as a better detailing of the costs for implementing new systems or even maintaining of them. Another essential topic considered is the possibility of adapting the project that is intended to be adopted in other sites with different systems and infrastructure. It is understood that an analysis including only systems can give a cursory view of the company's real needs. In such cases, a better evaluation of all elements of the project conception is required.

This article presented the applied methodology for a project with only one dependence relation of legacy and local systems. There are cases, mentioned throughout the paper, where is necessary to interact with two or more systems to obtain the information requested to attend the project requirements. There are also projects that do not depend on standard systems that can be simplified. However, a more granular and accurate diagnostic analysis methodology is demanded for these assessment dimensions, since technical elements involving infrastructure and interoperability must be mapped.

The company decided to adopt the MCDM/A methods to make preliminary analyzes, not only for local systems and legacy, which is a very specific case, but for other project requirements that demand the basic concepts of Industry 4.0. These requirements highlight the choice of the best technology to be applied and also the measurement of the technical infrastructure barriers that exist in the organization. This fact reaffirms the importance of the methods to support decision making in the planning phase of projects related to Digital Age. Thus, the company has the opportunity to realize the steps that compose the Fourth Industrial Revolution in a more agile way with considerable impact in the business areas, as defined by the members of the strategic direction of the corporation on a global scale.

Acknowledgement

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