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IMPLEMENTATION MODEL AND PHASED DEPLOYMENT OF INDUSTRY 4.0 TECHNOLOGIES IN INDUSTRIAL COMPANIES

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Abstract

Strategic and economic issues lead industrial companies to adopt several information systems and industrial management tools, in order to improve their performance and strive for operational excellence. Most of the information systems used, such as: ERP (Enterprise resource planning), MES (Manufacturing execution system), CMMS (Computerized maintenance management systems) and AIDC (Automatic Identification and Data Collection) do not communicate between them can constitute a source of brake for the company. We present in this article an implementation model of the Industry 4.0 approach, and its mode of deployment. The study focuses on a multi-dimension approach to increase the rate of implementation efficiency. This implementation model is based on establishing a strategic vision of value, identifying the value chain, determining the challenges of implementing an MRP2 (Management Resources Planning 2) and Lean Manufacturing approach, choosing the scope and technologies, risk analysis, choice of pilot site, analysis of results and deployment. Frameworks have been developed to guide change management.

Keywords: Industry 4.0, Lean Manufacturing, Industrial Companies.

1. INTRODUCTION

The use of different information systems in the industry can be a factor of performance as it can be a brake on performance [1,2], in several cases of company, several systems coexist, we can find production management systems (CAPM), ERP (Enterprise resource planning), MES (Manufacturing Execution system), CMMS (Computerized maintenance management systems) and AIDC (Automatic Identification and Data Collection), these systems in most cases do not communicate between them, which generates redundant operations without added value, so a rational and consistent use of all of these systems can help improve communication between its systems, reduce non-value added operations and contribute to a real-time exchange of information that can help in immediate decision-making [3].

Nowadays we are witnessing a growth in international competitiveness to bring more competitive and available products to the market, a variability in customer demand and the resurgence of customer dissatisfaction complaints, which generates significant lead time for companies [4], the main motivations of the Lean Manufacturing approach is to be able to synchronize production with customer demand by eliminating losses due to waiting times, transport times, stocks, inappropriate processes, overproduction and to non-quality [5,6,7].

The Seybold Report
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However, in addition to the multiplication of information systems, several management principles cohabit in the same company, the case for example of Lean Manufacturing, Lean service, KANBAN, JAT, MRP2..., these management principles influence the way with which information systems are configured, a back and forth is made between information systems and management systems to find compromises in configuration and mode of operation [8, 9],

In the literature, various studies [9-16], have developed approaches to deploying information systems and Lean manufacturing tools, showing their level of efficiency in relation to objectives defined by the companies.

The traditional approach to the implementation of information systems such as ERP, CMMS, MES, automatic data acquisition and identification systems (AIDC), whose companies rely on an installation in a local server, this way of implementing information systems has found its limits, with regard to the integration of new services such as remote monitoring or real-time data exchange between all information systems, these limits are also evident in the compatibility of software with infrastructures. Currently the trend is cloud computing oriented with its public cloud, private cloud or hybrid cloud variants [9], SAAS (software as a service) is gaining more and more momentum, the study by Chin-Sheng Chena, Wen -Yau Liangb and Hui-Yu Hsu [7] shed light on a service selection model offered by cloud computing for better efficiency according to the objectives sought by companies and proposes a Cloud ERP platform and describes a method composition of web services for ERP providers and enterprise users.

An implementation process called "time frame for the Lean Leap" was initiated by Womack and Jones [4], it consists of identifying a change agent and training him in the principles of Lean Manufacturing to share them with the rest of the staff of organization before establishing the VSM (Value Stream Mapping). When the Lean function and the Lean promotion strategy are created, the organization installs the activities to support the Lean process and encourage the Lean spirit (Lean thinking) [17-23].

In this article, we present an industry 4.0 integration model, taking into consideration the requirements of the Lean Manufacturing principle and the MRP2 organization, which is the most widespread concept in the design of ERPs.

This model is based on 10 axes:

I. Establishing a strategic vision of value

II. Identification of the value chain

III. Challenges of setting up an MRP2 approach

IV. Lean Manufacturing challenges

V. Choice of scope

VI. Choice of technologies

VII. Risk analysis

VIII. Choice of pilot site

ISSN 1533-9211
DOI 10.17605/OSF.IO/4NMP3

IX. Results analysis

X. Deployment

Principle of implementation of Industry 4.0 technologies

In the first part of this article, it was a question of making a reading of the articles having approached the steps of implementation of ERP, Lean Manufacturing, EMS and AIDC based on RFID, these steps [8- 12], have proven their effectiveness and are adapted to the context and objectives chosen for their implementation, however, a global approach to implementing the Industry 4.0 principle in line with a Lean Manufacturing approach and an MRP2 approach is essential in order to adopt a these principles in a rational and effective way while reducing the risk of failure.

The proposed approach is based on 10 axes of figure 1 that the steering committee and the project teams must develop, frameworks are developed to guide the expected objectives of each axis.

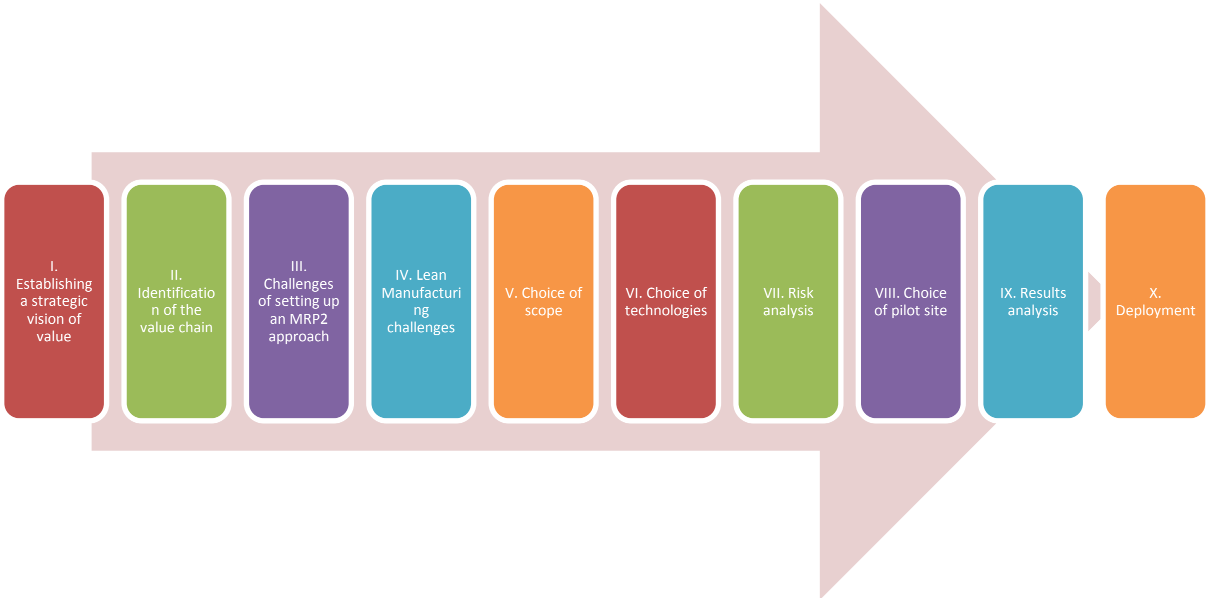

Figure 1: the 10 axes of the Industry 4.0 implementation process combined with Lean Manufacturing and MRP 2

I. Establishing a Strategic Vision of Value

Before starting any major change that could break with practices rooted in the way the company operates, it is important that top management with its steering committee define a strategic vision of value, this vision is based on a strategic analysis of the political, economic, social, technological, environmental and legal (PESTEL) context, this analysis must identify the key factors of success and the strategic axes of innovation in the value chain. Based on a PESTEL analysis, matrix 1 helps to guide the decision to define a strategic orientation for maintaining production according to the level of maturity of the finished products in their life cycles: growth,

ISSN 1533-9211
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maturity or decline, the decision may initially relate to product reengineering, process reengineering, or discontinuing or maintaining the product.

finished product PFi	Growth	Maturity	Decline	Strategic Direction
Political Context	√			Product reengineering Process reengineering Product discontinuation: product maintaining: √
Economic context		√		Product reengineering Process reengineering: √ Product discontinuation: product maintaining:
Social context			√	Product reengineering: √ Process reengineering: √ Product discontinuation: product maintaining:
Technological context	√			Product reengineering Process reengineering Product discontinuation: product maintaining: √
Legal context		√		Product reengineering Process reengineering Product discontinuation: product maintaining: √
Environmental context			√	Product reengineering Process reengineering Product discontinuation: √ product maintaining:

Matrix 1: PESTEL Analysis of the Finished Product

II. Identification of the Value Chain

The basic principle of the identification of the value chain is based on the monitoring of the material flow and the flow of information in the production of a good.

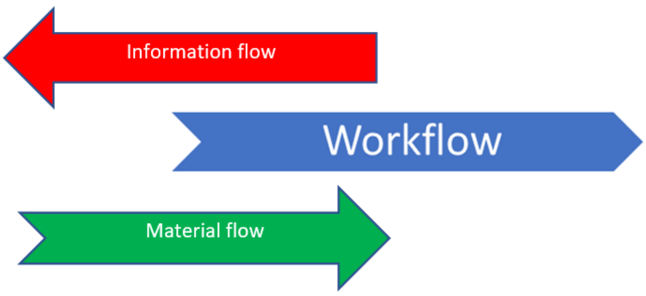


Figure 2: Value chain

ISSN 1533-9211
DOI 10.17605/OSF.IO/4NMP3

Several value chains can be identified according to the products manufactured by the company, in this case it is necessary to target the most relevant value chains to implement an industry 4.0 approach coupled with Lean Manufacturing and ERP.

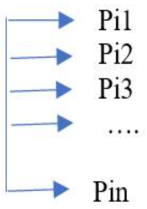
The choice of the target value chain can then be made with the method of Principal Component Analysis (PCA) [11], in a value chain that includes several versatile production equipment, this method makes it possible to group similar products into terms of mutual use of this equipment, this method is based on the calculation of the correlation coefficients between the series of values of two variables in order to determine if they are dependent on each other.

The choice of the target value chain can also be made according to the products whose production added value (AV) is significant, the production cost of a finished product P being C (P) = $\sum$ of consumption (P) + VA (P).

By dissecting the finished product FPi, the latter can be made up of subsets (Pix), for which the cost C (Pix) = $\sum$of consumption (Pix) + AV (Pix).

Bill of materials of FPi:

Finished product FPi



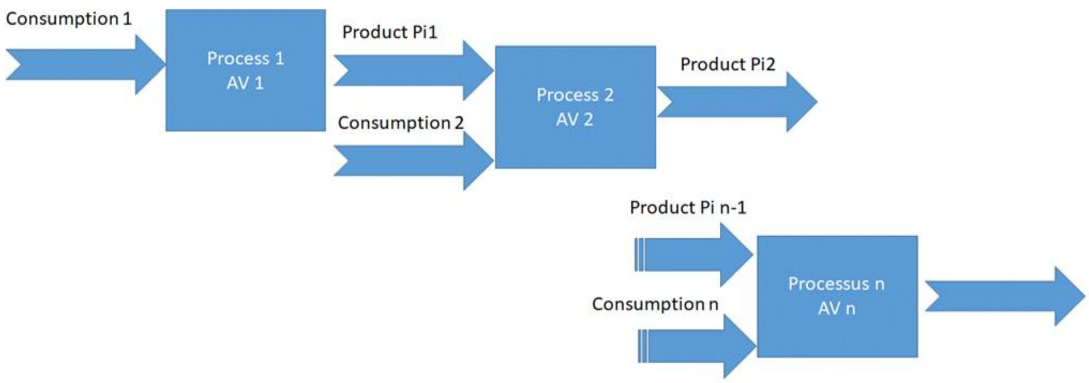


Figure 3: Finished Product Manufacturing Process FPi

The AV of the finished product FPi will thus be: AV (FPi) = $\sum$AVi, AVi being the AV at the level of process i, figure 3.

The Pareto's rule can be used to identify finished products that represent 80% of all AV in the value chain.

ISSN 1533-9211

DOI 10.17605/OSF.IO/4NMP3

In several ERPs, the calculation of the AV is done according to the ABC method (Activity Based Costing) based on the creation of work centers and calculated according to the formula:

AV= (Section rate in currency per hour/ production cadence in number of product per hour) + (Setting rate in currency per hour x Setting time in hour) / production batch size, where the section rate is calculated as:

The Section Rate= (total costs of the Work Center) / Productive Hours in Work Center

Material flow and information flow

The choice of target value chains through the choice of target finished products will allow us to identify the flows of material and the flows of information throughout the value chain figure 4.

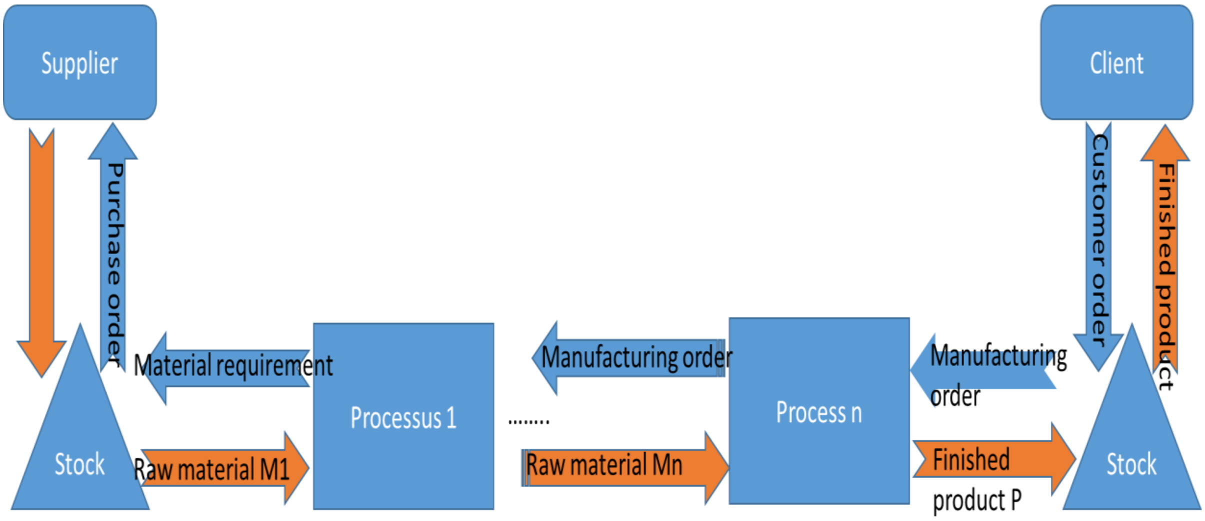


Figure 4: Material Flow and Information Flow

III. Challenges of Setting up an MRP2 Approach

The implementation of an MRP2 approach (Management of production resources 2) aims to control the flow of information in the value chain of the finished product, its entry point is the customer needs which are then translated in production order, which generate a calculation of raw material needs, a planning of purchases, a planning of production and a planning of capacities.

The information flow can be constructed using the SIPOC (Supplier Input Process Output Client) matrix in Matrix 2.

ISSN 1533-9211

DOI 10.17605/OSF.IO/4NMP3

	Information flow / material flow	Supplier / Supplier process	Input	Process	Output	Client/ client process
Material flow	Raw material M1	Supplier	Raw Material M1	Stock		
Information flow	Material purchase order M1	Stock	Material purchase order M1	Supplier	Delivery note Raw material M1	Stock
Material flow	Raw material M1	Stock	Raw material M1	Process PS1	Subset P1	Process PS2
Information flow	Work Order P1	Process PS2	Work Order P1	Process PS1	Production report P1	Process PS2
Material flow	Raw material M2 / Subset P1	Process PS1	Raw material M2 / Subset P1	Process PS2	Subset P2	Process PS3
Information flow	Work Order P2	Process PS3	Work Order P2	Process PS2	Production report P2	Process PS3
....	....	....	....	....	....	....
....	....	....	....	....	....	....
Material flow	Raw material Mn/ Subset Pn-1	Process PSn-1		Process PSn	Finished Product P	Stock
Information flow	Work Order Pn	Stock	Work Order Pn	Process PSn	Production report P	Stock
Material flow	Finished Product P	Process PSn	Finished Product P	Stock	Delivery Finished product P	Client
Information flow	Customer order	Client	Customer order	Stock	Delivery note Finished product P	Client

Matrix 2: SIPOC Matrix Combined Material Flow/ Information Flow

In order to set up an MRP2 approach, it is necessary to choose the relevant information to be put in place that can make the processes run smoothly and efficiently, matrix 3 will guide the choice of this information.

	Finished product FP 1	Finished product FP 2	Finished product FP 3	...	Finished product FP n	Subset P11	Subset P12	....	Subset Pin
BOM management	x	x	x	x	x	x	x	x	x
Production line management	x	x	x	x	x	x	x	x	x
Work center management	x	x	x	x	x	x	x	x	x
Customer management	x	x	x	x	x	x	x	x	x
Management of suppliers	x	x	x	x	x	x	x	x	x
Sales forecast management	x	x	x	x	x	x	x	x	x
Management of customer orders	x	x	x	x	x	x	x	x	x
Management of supplier orders	x	x	x	x	x	x	x	x	x
Inventory management	x	x	x	x	x	x	x	x	x
Management of outstanding stocks	x	x	x	x	x	x	x	x	x
Calculation of need	x	x	x	x	x	x	x	x	x
Production order management	x	x	x	x	x	x	x	x	x
Production cost management	x	x	x	x	x	x	x	x	x
Management of production reports	x	x	x	x	x	x	x	x	x
Management of supplier deliveries	x	x	x	x	x	x	x	x	x
Management of customer deliveries	x	x	x	x	x	x	x	x	x

Matrix 3: Choice of Relevant Information for Implementation of an MRP2 Approach

ISSN 1533-9211
DOI 10.17605/OSF.IO/4NMP3

IV. Lean Manufacturing Challenges

Through the value chain identified for each FPi finished product, it is essential to follow the finished product from the stock of the raw material to the delivery to the customer, the principle is to identify the value-added times (VAT) and non-value-added times (NVAT), value-added operations are operations for the transformation of raw materials or semi-finished products and non-value-added operations are those that correspond to the 7 mudas in the Lean Manufacturing approach namely: waiting, Shifting, transport, stock, inappropriate process, non-quality and overproduction.

The principle consists in measuring the production time (Lead Time) of the finished product FPi, the times of value-added operations and non-value-added operations based on the matrix in Figure 5.

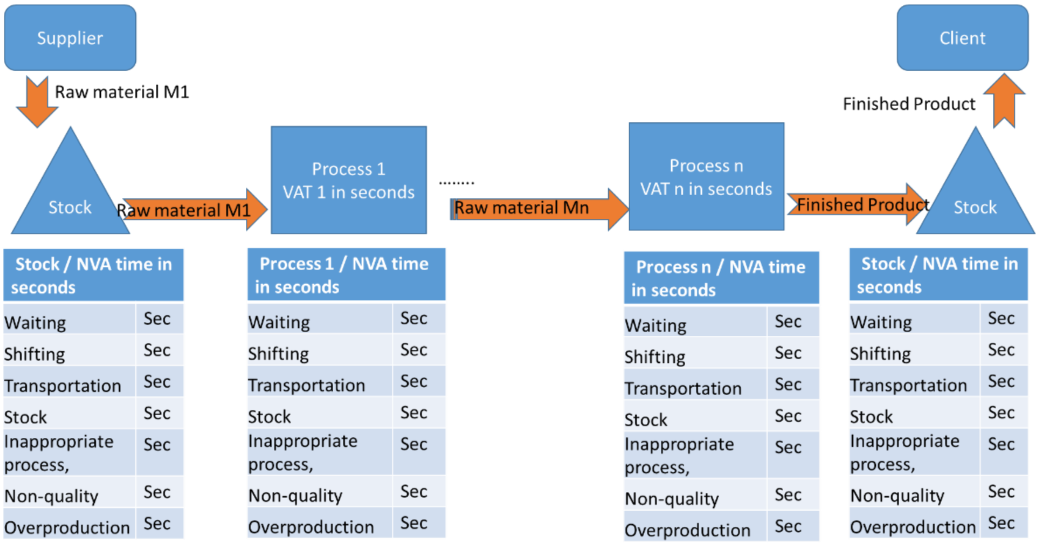


Figure 5: Matrix of NVA Times and VA Times

V. Choice of Scope

The calculation of non-value added time NVAT will make it possible to set objectives for reducing the 7 wastes of the Lean Manufacturing principle, certain actions can be based on the KAIZEN approach which does not require a lot of investment, on the other hand other innovation actions will require investments and in this case a profitability study of the contribution of Industry 4.0 technologies is essential.

VI. Choice of Technologies

For each process, matrix 4 can be used to make an initial targeting of the technologies to be implemented with an evaluation of the cost of the investment and its profitability.

The Seybold Report
ISSN 1533-9211
DOI 10.17605/OSF.IO/4NMP3

	Stock / Process Psi						
	Waiting	Shifting	Transportation	Stock	Inappropriate process,	Non-quality	Overproduction
ERP (Entreprise ressource Planning)							
MES (Manufacturing Execution Systems)							
Artificiel Intelligence (AI)							
Identification Radiofrequency (RFID)							
Communication machine to machine (M2M)							
Simulation							
Big data analytics							
Total waste second							
Prediction of total wastage saved second							
Investment							
Profitability							

Matrix 4: Choice of Industry 4.0 technologies

The calculation of profitability can be done based on a full year of activity, the estimated savings generated by the implementation of a technology are valued at standard costs as follows:

Total savings (by process or work center) = (Section rate before Industry 4.0 integration – Section rate after Industry 4.0 integration) x Total number of productive hours for the year.

Profitability will then be calculated as follows:

Number of years of profitability = Total savings (by process or work center) / Total investment (by process or work center).

The company will then define the break-even point according to its medium and long-term strategic objectives to approve the investment or disapprove it.

VII. Risk Assessment

Pre-implementation risk assessment is very important to conduct, in order to identify risks that may affect the efficiency and rationalization of new investments.

Several types of risks can be identified according to the chosen context, the strategic analysis of the context can be based on the PESTEL method which consists in carrying out an assessment of the Political, Economic, Social, Technological, Environmental and Legal environment.

The issues may be quality and customer satisfaction, information security in terms of confidentiality, integrity and availability of information in the production cyber-physical systems, continuity of activity, safety and health at work or environmental protection.

The Seybold Report
ISSN 1533-9211
DOI 10.17605/OSF.IO/4NMP3

For all of these issues, it is important to draw inspiration from the ISO 9001 standards for the quality management system, the ISO 27001 standard for the information security management system, the ISO 22301 standard for the business continuity management system, the ISO 45001 standard for the occupational health and safety management system and the ISO 14001 standard for the environmental management system, Matrix 5.

	ERP (Entreprise ressource Planning)	MES (Manufacturing Execution Systems)	Artificiel Intelligence (AI)	Identification Radiofrequency (RFID)	Communication machine to machine (M2M)	Simulation	Big data analytics
	Risk criticality= occurrence x severity						
Risk category							
Operational risks							
Product quality risks							
Risks related to customer satisfaction							
…..							
Information security risks							
Confidentiality							
Integrity							
Availablity							
…..							
Business continuity risks							
Risks of technological obsenescence							
Supplier continuity risks							
….							
Occupational safety and health risks							
Risks related to occupational diseases Risks related to legal and regulatory …							
Environmental risks							
Pollution risks Risks related to legal and regulatory							

Matrix 5: Risk assessment

VIII. Choice of Pilot Site

The preliminary studies concerning the identification of the value chain, the determination of the challenges of the implementation of an MRP2 approach and Lean Manufacturing, the choice of the scope and technologies as well as the risk analysis make it possible to provide some assurance for the successful implementation of the Lean Manufacturing approach supported by Industry 4.0 technologies. However, it is necessary to work on a small scale on a pilot site in

The Seybold Report
ISSN 1533-9211
DOI 10.17605/OSF.IO/4NMP3

order to capitalize on the experience and avoid mistakes that can be disastrous for the company. In the choice of the pilot site, it should be representative and contain processes identical to those which are targeted by the change, it is also of great importance to establish procedures for managing changes and rollback. Which are essential tools for the deployment of these new principles. The choice of the pilot site must be one of the prerogatives of the steering committee.

Matrix 6 will guide the pilot team to the choice of the pilot site with a scoring grid, the site or the process with the highest score can be chosen as the pilot site.

Resources present / can be implemented	Score
Implemented	3
Can be implemented without investment	2
Can be implemented with investment	1
Not suitable	0

Resources present / can be implemented	Site 1 / process 1	Site 2/ process 2	Site 3 / process 3	Site n / process n
Automatic machines	3	0		
Semi-automatic machines	3	0		
Automatic assembly	2	0		
Semi-automatic assembly	2	0		
Manual assembly	3	1		
MRP2	3	3		
Lean Manufacturing	2	3		
MES	3	1		
RFID	1	1		
Communication M2M	1	0		
Total Score	23	9		

Matrix 6: Choice of pilot site

IX. Results Analysis

The analysis of the results of the partial implementation of Industry 4.0 at the pilot site level must shed light on post-implementation performance for a significant period, the analysis must also highlight the actions to be implemented in order to improve the implementation and change process, the actions may concern the mode of governance of the project, relations with service providers, mastery of technologies, training to be carried out for the project team and the review of risk mapping. The analysis must also cover the new process cycle times, the new lead time, the reduction of non-value added times, the new production costs and the return on investment. The deployment can thus be decided when the threshold of the desired objective is reached.

ISSN 1533-9211

DOI 10.17605/OSF.IO/4NMP3

X. Deployment

Like all projects, the deployment of the industry 4.0 concept must be based on appropriate governance ensured by a steering committee which appoints the project teams according to their commitments and their technical and managerial skills.

The project can be carried out by following the following steps:

Phase 0: constitutes the preliminary phase which consists of an opportunity analysis which is sanctioned by a GO/NO GO decision,

Phase 1: constitutes the first phase of the implementation characterized by the constitution of the project teams, the planning of the project and the fixing of the objectives, in this phase a selection of the modules is operated, the configuration and the installation of these basic modules ERP, MES, M2M communication and RFID.

Phase 2: relates to the integration of the value chain from the supplier to the customer.

Phase 3: is the final phase of ERP, MES, M2M communication and RFID, characterized by the strengthening of financial and accounting modules, the integration of other modules such as HR modules, maintenance, research and development.

CONCLUSION

Strategic and economic issues lead companies on an international scale to adopt different approaches to operational management, in order to progress in their efforts to improve competitiveness and performance and achieve a certain level of operational excellence. We have developed an implementation model for Industry 4.0 technologies based on the requirements of the Lean Manufacturing principle and the MRP2 organization in 10 synchronized steps.

The integrated implementation of the industry 4.0 concept with the principles of Lean Manufacturing is a fairly complex mission requiring an appropriate approach to opportunity study, risk analysis, value chain analysis, choice of technologies and choice of the pilot site that can reflect a faithful image of the production processes, this approach proposes an implementation that takes into account the current challenges of the industry, namely the challenges of competitiveness, system interoperability, information security issues and business continuity issues.

The study [2, 3] demonstrates that Industry 4.0 technologies support the Lean Manufacturing approach by feeding it with real-time data, however, an inconsistent approach to implementing Industry 4.0 technologies can lead to heavy investments without significant results. It is therefore important to establish appropriate governance of the implementation project by adopting the different stages while adapting it to the specific challenges of the industry sector in question.

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