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LEAGILE MANUFACTURING IN A MEDIUM-SIZED AIR COMPRESSOR MANUFACTURING COMPANY

Summary

The research reported in this paper was carried out to provide a model for facilitating leagile manufacturing in the production of air compressors. Leagile manufacturing incorporates lean and agile manufacturing elements. This research begins by reviewing the literature and observing the manufacturing of air compressors. Using this knowledge, a model called LEAGICOM (LEAGIle implementation in the COMpressor manufacturing industry) was designed. LEAGICOM involves plant layout, the development of a human resource system and the conducting of training and educational programmes for effectively implementing the leagile manufacturing paradigm. The practicality of implementing the LEAGICOM model was explored by conducting a case study in a medium-sized air compressor manufacturing company. The experiences of conducting this case study revealed that the LEAGICOM model has the potential to enable air compressor manufacturing companies to gain competitive strength.

Key words: *lean manufacturing, agile manufacturing, leagile manufacturing, postponement, air compressors, plant layout, training and education.*

1. Introduction

During the past four decades, manufacturing engineering has witnessed abundant case studies and the reporting of research on lean and agile manufacturing paradigms [1, 2]. Lean manufacturing is required in companies manufacturing conventional products and offering traditional services. On the other hand, agile manufacturing is needed in organisations which aspire to produce innovative products quickly and offer fast, reliable and cutting-edge services [3-9]. This means that in contemporary companies, both lean and agile manufacturing principles are required [10-15]. This circumstance presumably triggered Naylor et al. [16] to introduce the concept "leagile manufacturing" [17]. As the term implies, leagile manufacturing encompasses lean and agile manufacturing principles [18-24]. Several researchers have contributed models to implement leagile manufacturing in different industries [25, 26]. Some of these include the pump manufacturing industry and the luxury products sector. However, such a kind of implementation model is yet to be developed for many industries, including the industry involved in manufacturing air compressors.

Air compressors find wide applications [27]. Some of the models of air compressors are highly innovative while others are hybrid and conventional in nature. In order to enable air

compressor manufacturing companies to produce these three categories of models of air compressors, the leagile manufacturing paradigm needs to be implemented. In order to carry out this task, research is required for the development of models for implementing leagile manufacturing in the air compressor manufacturing industry. Such research needs to acquire knowledge by capturing the theory and by exploring the practicality of leagile manufacturing by means of case studies. This research was conducted and is reported in the following sections of the paper.

2. Literature survey

Given the scope of the research reported in this paper, the literature was surveyed under two domains gathered from the ScienceDirect database and the databases of Emerald Insight, Elsevier, Taylor and Francis, Inderscience, Interscience and Springerlink. Under the first domain, eleven papers reporting exclusively research on leagile manufacturing were identified and the research presented in these papers is highlighted here. The review of research on leagile manufacturing is presented in Virmani et al. [17] and Bhamra et al. [26]. In other papers, the models, success factors and barriers associated with the implementation of the leagile manufacturing paradigm are presented [21,24] [29-35]. The research reported in these papers indicate that few researchers have contributed frameworks for implementing the leagile manufacturing paradigm in real time [28]. Under the second domain, seven papers reporting research on air compressors are reviewed. The review of these papers [37-43] shows that researchers have worked in different directions for improving the performance, reducing the failures and lowering energy consumption when operating air compressors. Following the literature survey under these two domains, the absence of any research on the practicality of implementing leagile manufacturing in the manufacturing of air compressors was identified as a research gap.

3. Theory of the leagile manufacturing paradigm

As appraised earlier, the leagile manufacturing paradigm was formally introduced in Naylor et al. [16] by incorporating certain principles of “lean manufacturing” and “agile manufacturing” [20, 29, 44]. The theory of leagile manufacturing incorporated with these concepts is depicted in Fig. 1.

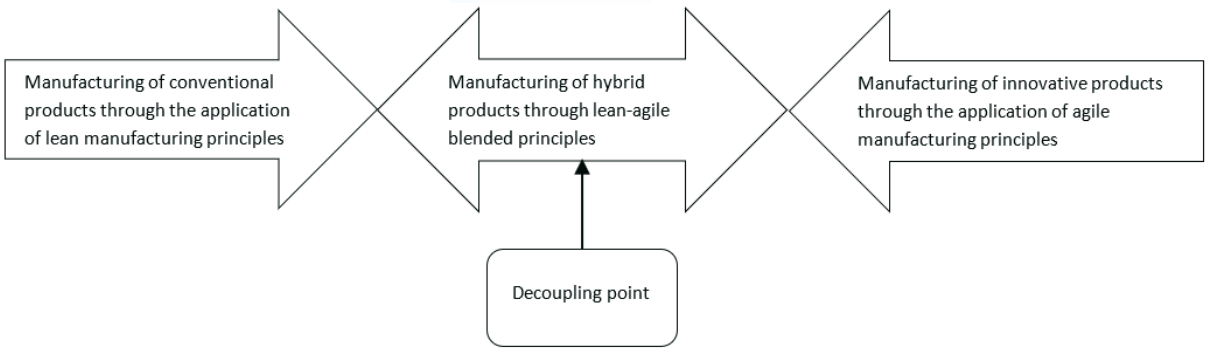


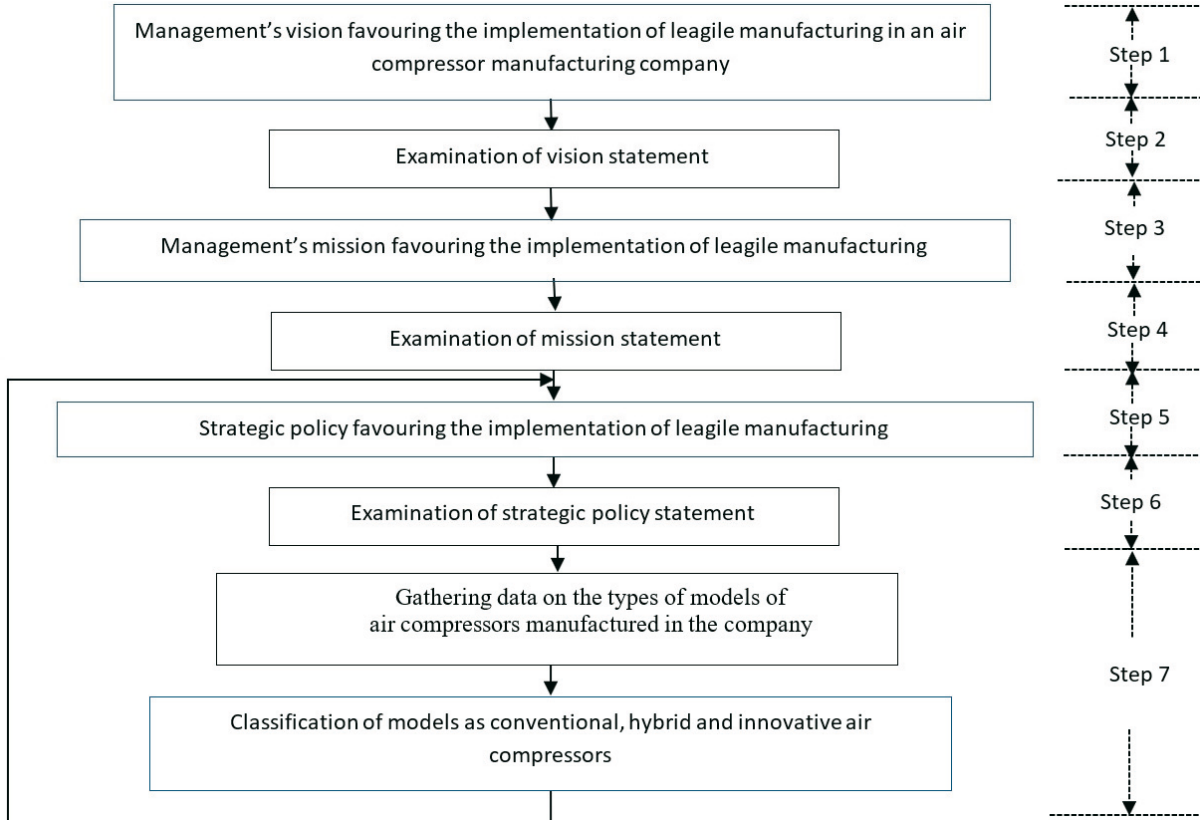
Fig. 1 Leagile manufacturing paradigm

As shown in Fig.1, three categories of products are produced by applying the leagile manufacturing paradigm. (Here, the term “products” includes services.) The first category of products is regarded as conventional products. This category is traditionally produced for a long time without any appreciable design changes. This type of product is produced in companies implementing the leagile manufacturing paradigm by applying lean manufacturing concepts. While producing conventional products, techniques like 5S, Kanban, Jidoka and value stream mapping (45) are implemented to eliminate waste. Another category of products resulting from the application of the leagile manufacturing paradigm is regarded as innovative products.

Innovative products are produced by applying the agile manufacturing concept [36, 46] in companies implementing the leagile manufacturing paradigm. While producing an innovative product, techniques like rapid prototyping, digital manufacturing and smart manufacturing are implemented to attain agility. The third type of product is regarded as a hybrid product which incorporates traditional and innovative design principles. While producing lean-agile hybrid products, up to the decoupling point, lean manufacturing concepts are applied. Beyond the decoupling point, agile manufacturing concepts are applied to react quickly to the dynamic demands of customers. In hybrid lean-agile production, the decoupling point separates the boundary of the conventional and innovative features of hybrid products. Thus, in total, the variations of customer demand can be met by supplying conventional, hybrid and innovative products in the market by applying leagile manufacturing in industries. This theory implies that leagile manufacturing helps companies gain high competitive strength [47].

4. Designing the model for leagile manufacturing in the air compressor manufacturing industry

Before designing the model, similar models presented in [24, 33,49] were studied. These models were found to be suitable for implementing leagile manufacturing in pump manufacturing companies and for new product development. However, they were not found suitable for implementing the leagile manufacturing paradigm in compressor manufacturing companies. As exploring the implementation of the leagile manufacturing paradigm in the compressor manufacturing industry was the primary goal of the research reported here, practical knowledge on manufacturing air compressors was gained by visiting the company mentioned in the case study section of this paper. Internet sites were also visited to gather knowledge about various models of air compressors. The theoretical and practical knowledge thus collected was used to design the model that would enable companies manufacturing air compressors to implement the leagile manufacturing paradigm. The model thus designed is shown in Fig. 2. This model is given the name LEAGICOM.



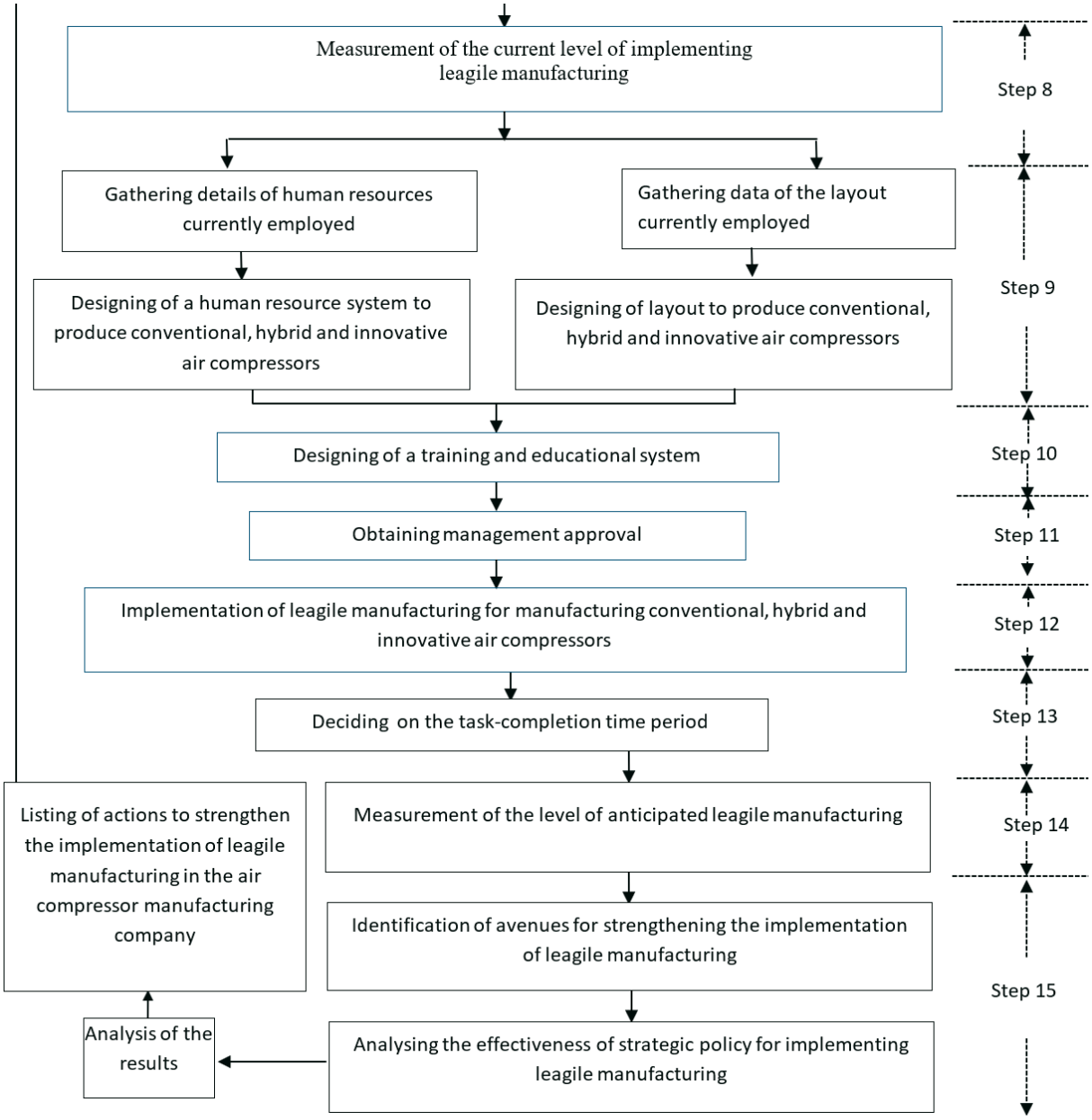


Fig. 2 LEAGICOM model

As shown in Fig. 2, the implementation of leagile manufacturing in an air compressor manufacturing company has to be carried out by following the 15 steps of this model. The details of the activities carried out under these 15 steps are briefly presented in the next section.

5. Case study in a medium-sized air compressor manufacturing company

After designing the LEAGICOM model, a medium-sized air compressor manufacturing company was approached to obtain permission to explore the practicality of this model. The name of this company is RMP Compressor (hereinafter: RMP). RMP is located in Coimbatore City, India. RMP started to operate in 1979 with 10 employees. When it began, only one type of air compressor, called the "bore well compressor", was produced. Today, 59 employees work at RMP. Besides the bore well compressor, another type called the reciprocating air compressor is produced. Currently, seven models of bore well compressors and nine models of reciprocating air compressors are manufactured at RMP. Permission to explore the practicality

of implementing LEAGICOM was granted by the general manager. The activities carried out to implement the 15 steps of LEAGICOM model are briefly described below.

5.1 Vision development

The general manager of RMP was appraised of the need to implement the LEAGICOM model. Subsequently, the vision for implementing the LEAGICOM model was created at RMP. Eventually, the following leagile vision statement was developed.

"The leagile vision of RMP is to produce several varieties and models of air compressors to meet the requirements of all customers economically while ensuring profitability."

5.2 Examination of the vision statement

The leagile vision statement was shown to the general manager of RMP. After examination, the general manager of RMP understood the meaning and approved the statement.

5.3 Mission development

The general manager was appraised of the need to develop an appropriate mission statement for implementing the LEAGICOM model and reap the benefits of doing so. The following leagile mission statement of RMP was therefore developed.

"The leagile mission of RMP is to transform current practices to new practices with appropriate infrastructure through education and learning to support the manufacturing of conventional, hybrid and innovative air compressors."

5.4 Examination of the leagile mission statement

The general manager of RMP examined the leagile mission statement and then approved and agreed to execute the activities specified in it.

5.5 Development of a strategic leagile manufacturing policy

During the past five decades, the scientific world has witnessed the development of several industrial strategies [48]. In line with this development, in order to implement a LEAGICOM model in an air compressor company, it was necessary to develop a strategic leagile manufacturing policy. Accordingly, by referring to the leagile vision and mission statements, the following strategic leagile manufacturing policy statement of RMP was developed:

"RMP's strategic leagile manufacturing policy is to enable the employees of today and tomorrow to learn new and improved technologies and approaches to produce conventional, hybrid and innovative air compressors by fine-tuning the organisational structure and plant layout to suit the leagile manufacturing paradigm and to acquire competitive strength."

5.6 Examination of the strategic leagile manufacturing policy

The general manager of RMP examined the strategic leagile manufacturing policy and foresaw the challenges of effecting the policy at RMP. He was appreciative of the competitive strength that could be acquired by RMP through the implementation of the LEAGICOM model while manufacturing air compressors.

5.7 Gathering data on the models of air compressors manufactured at RMP

The air compressors which have been manufactured at RMP during the past five years or more without being subject to any design changes and improvements were categorised as conventional air compressors. The air compressors which have been manufactured at RMP with certain additional features during the last five years were categorised as hybrid compressors.

The air compressors with innovative features produced over the past five years at RMP in accordance with the requirements of specific customers were identified as innovative air compressors. After carrying out this exercise, it was found that 37 conventional, 3 hybrid, and 7 innovative air compressors were manufactured at RMP.

5.8 Measurement of the level of implementing leagile manufacturing at RMP

In order to calculate the level of implementing leagile manufacturing in the compressor manufacturing company, a formula involving the manufacturing of conventional, hybrid and innovative compressors was designed while designing the LEAGICOM model. This model is presented below:

$$\left.\begin{array}{c}\text{Level of implementing}\\ \text{legile manufacturing}\\ \text{in the compressor}\\ \text{manufacturing company}\end{array}\right\} = \frac{\left(\begin{array}{c}\text{Number of}\\ \text{convetional}\\ \text{compressors}\\ \text{manufactured}\\ \text{in the company}\end{array}\right) \times 0.1 + \left(\begin{array}{c}\text{Number of}\\ \text{hybrid}\\ \text{compressors}\\ \text{manufactured}\\ \text{in the company}\end{array}\right) \times 0.5 + \left(\begin{array}{c}\text{Number of fully}\\ \text{innovative}\\ \text{compressors}\\ \text{manufactured}\\ \text{in the company}\end{array}\right) \times 0.4}{\text{Total number of air compressors manufactured}}$$

The above formula is named the leagile measurement model. As the implementation of the leagile manufacturing paradigm is required to be reflected largely though the production of hybrid and innovative air compressors, in this formula, the number of these models produced is given the importance of 0.4 and 0.5, respectively. As the practice of the leagile manufacturing model is also reflected through the production of conventional models of air compressors, albeit to a lesser extent, an importance value of 0.1 (that is, 10%) is incorporated in this formula. The current level of implementing leagile manufacturing at RMP was calculated using this leagile measurement formula. As mentioned in the previous section, the numbers of conventional, hybrid and innovative air compressors currently manufactured at RMP are 37, 3 and 7, respectively. These values were substituted in the leagile measurement formula to obtain the current level of implementing the leagile manufacturing paradigm at RMP. The details of this calculation are presented below:

$$\left.\begin{array}{c}\text{Level of implementing leagile}\\ \text{manufactuirng in the manufacturing}\\ \text{of air compressors at RMP}\end{array}\right\} = \frac{\left(\begin{array}{c}\text{Number of}\\ \text{conventional}\\ \text{air compressors}\\ \text{manfactured}\end{array}\right) \times 0.1 + \left(\begin{array}{c}\text{Number of}\\ \text{hybrid}\\ \text{air compressors}\\ \text{manufactured}\end{array}\right) \times 0.5 + \left(\begin{array}{c}\text{Number of}\\ \text{fully innovative}\\ \text{air compressors}\\ \text{manufactured}\end{array}\right) \times 0.4}{\text{Total number of air compressors manufactured in RMP}}$$

$$= \frac{(37 \times 0.1) + (3 \times 0.5) + (7 \times 0.4)}{47} = 0.17 = 17\%$$

As shown, the level of implementing leagile manufacturing in the manufacturing of air compressors currently at RMP is 17%. This low value indicates that RMP has to make further strides to effectively implement leagile manufacturing.

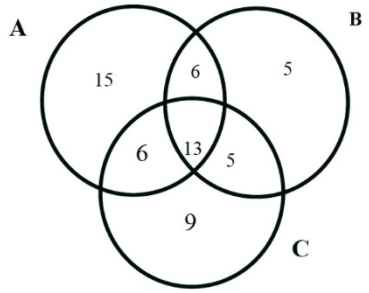
5.9 Design of the leagile manufacturing paradigm

Researchers [49, 22, 23, 24] who have built models for implementing leagile manufacturing have found that two developments need to be made. The first is a leagile human resource system. The second is a leagile manufacturing layout. The efforts made to design these two features at RMP are described in the following two sub-sections and are shown in Fig. 2.

5.9.1 Designing of a leagile human resource system

In order to design a leagile human resource system, the names of employees at RMP for producing air compressors were gathered. Further, by interviewing the general manger, the

capabilities of these employees were assessed and a leagile human resource system was designed. In order to identify the employees at RMP in this regard, seven rules were formulated. For instance, the first rule was to identify employees with fewer than 15 years of experience who are required to associate with the manufacturing of conventional air compressors. The statistics of employees identified to associate with the leagile human resource system with regard to the manufacturing of air compressors at RMP by following these seven rules are indicated in Figure 3.



Total number of employees who are associated with the manufacturing of air compressors at RMP=59.

A –Number of employees who are required to associate with the production of conventional air compressors at RMP

B - Number of employees who are required to associate with the production of hybrid air compressors at RMP

C - Number of employees who are required to associate with the production of innovative air compressors at RMP

Fig. 3 Statistics of employees to be associated with the leagile human resource system in the manufacturing of air compressors at RMP

A critical study of the statistics presented in Fig. 3 would indicate that the designed leagile human resource system will help RMP to implement the leagile manufacturing system gradually and without facing bottlenecks in the manufacturing of air compressors.

5.9.2 Design of the leagile manufacturing layout

After designing the leagile human resource system, the leagile manufacturing layout to apply the leagile manufacturing principles in the manufacturing of air compressors at RMP was designed. To begin with, the layout currently existing at RMP was captured by visiting the facilities and recording the details. The drawing of the current layout is shown in Fig. 4 which indicates that this existing layout is suitable for producing air compressors at RMP by applying the mass production paradigm. By keeping this existing layout as a reference and considering the principles of leagile manufacturing, a layout suitable for implementing leagile manufacturing was designed. This layout is shown in Fig. 5. As displayed, the development of three manufacturing cells to produce conventional, hybrid and innovative air compressors is proposed for implementing leagile manufacturing at RMP. Based on the three elements, these are named “lean compressor manufacturing cell”, “lean-agile-hybrid compressor manufacturing cell”, and “agile compressor manufacturing cell”. Since specialised knowledge and skills are required to assemble electrical motors and compressors, a common facility for carrying out this task is proposed in the leagile manufacturing layout at RMP.

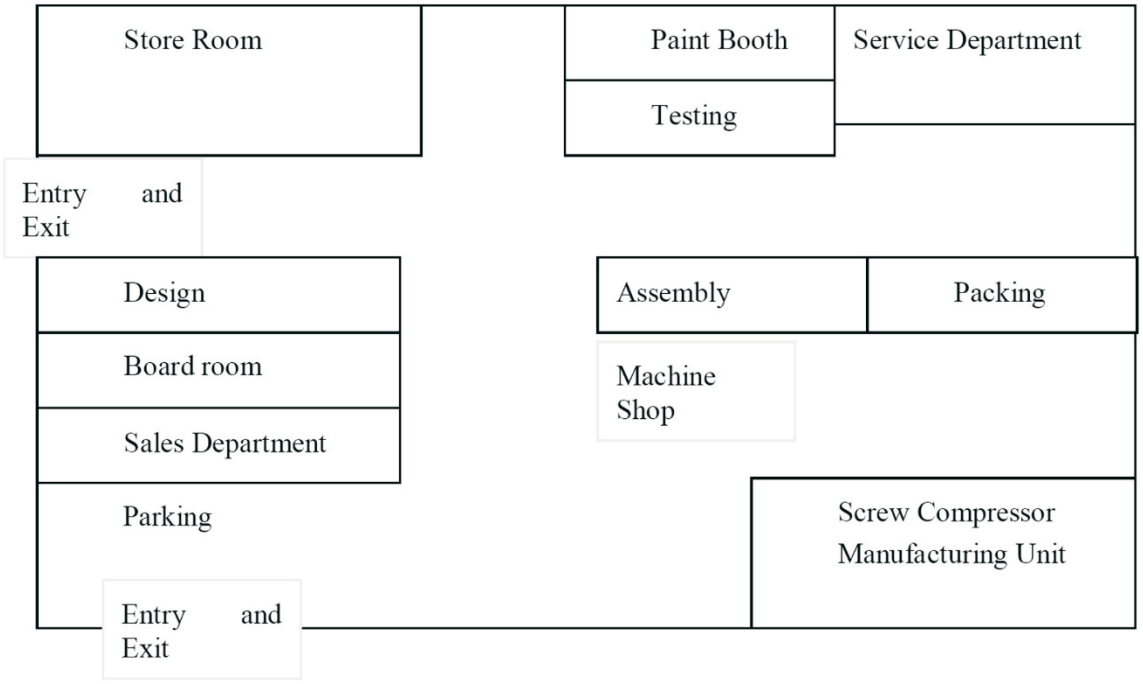


Fig. 4 The layout currently existing at RMP

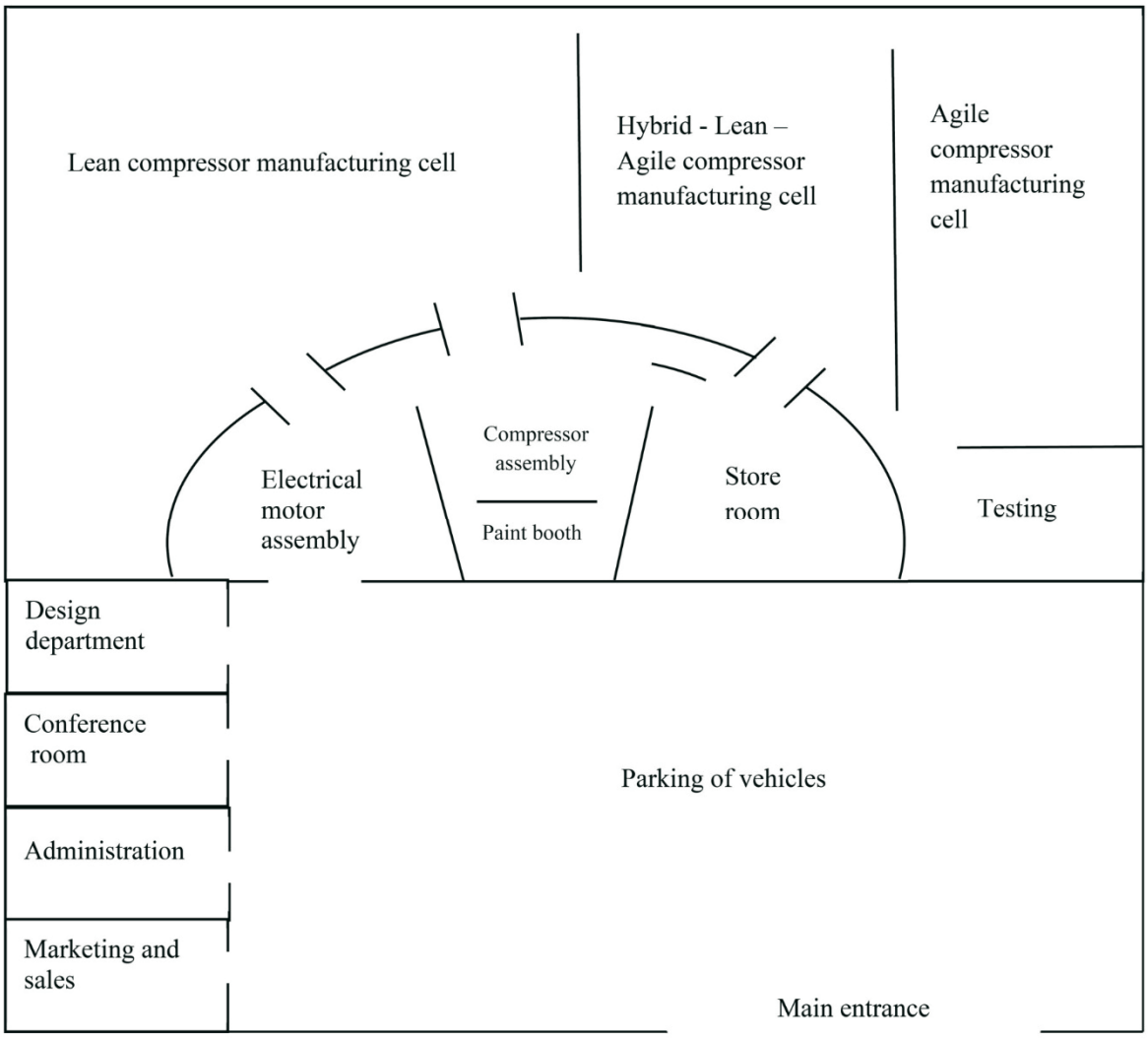


Fig. 5 Proposed leagile manufacturing layout at RMP

5.10 Designing of a leagile training and educational system

After designing the leagile manufacturing paradigm to enable RMP to produce conventional, hybrid and innovative air compressors, the training and educational system was designed. This activity was performed by identifying the training and educational requirements of every employee involved in the manufacturing of air compressors at RMP. A sample of such training and the educational requirements of four employees are presented in Table 1. The information shown in this table with regard to the training and educational requirements of an employee whose identity number is E1 at RMP is highlighted. He is the vice-president of the screw compressor division. As shown, this employee is required to acquire a high level of theoretical and practical knowledge on developing innovative air compressors. The training and educational requirements of this employee to achieve these outcomes are indicated in the table. In this way, while exploring the implementation of the LEAGICOM model at RMP, the training and educational requirements of all 59 employees associated with the manufacturing of conventional, hybrid and innovative compressors at RMP were prepared, and the respective expected outcomes were foreseen.

Table 1 A sample listing of training and educational requirements of four employees for implementing leagile manufacturing through LEAGICOM model at RMP

Employee number	Designation	Training requirements	Educational requirement	Category of air compressor to be associated with	Expected outcomes
E1	Vice President, Screw air compressor division	Demonstration of the construction and working of innovative air compressors	Lectures on the integration of new technologies with air compressors to develop new innovative air compressors	Innovative air compressors	High level knowledge of the theory and practice of manufacturing and developing innovative air compressors
E2	General Manager	Training on designing innovative methods of manufacturing innovative air compressors	Exposure programmes on design thinking to develop innovative air compressors	Innovative air compressors	Knowledge of designing and manufacturing innovative air compressors
E3	Production Manager	Observation of manufacturing and working of conventional air compressors	In-class education on the design and production of conventional air compressors	Conventional air compressors	Knowledge of the theoretical and practical aspects of manufacturing conventional air compressors
E4	Fitter	Fitting and assembling of innovative air compressors	Video programme on fitting and assembling of innovative air compressors	Innovative air compressors	Theoretical knowledge of fitting and assembling innovative air compressors. Skills on fitting and assembling innovative air compressors.

5.11 Obtaining management approval to implement leagile manufacturing at RMP

The design of the leagile human resource system and of the leagile manufacturing layout, and the proposal of “training and educational programmes” for implementing leagile

manufacturing at RMP were shown to the general manager. Further, the details of conventional, hybrid and innovative air compressors which need to be produced at RMP were appraised and the general manager was notified. The general manager approved the proposals and indicated that the same will be implemented in stages in due course at RMP.

5.12 Implementation of leagile manufacturing at RMP

The proposal for implementing the leagile manufacturing paradigm and the manufacturing of conventional, hybrid and innovative air compressors was not immediately put into practice at RMP. Hence, the feasibility of implementing this proposal at RMP was assessed by interviewing the general manager. The general manager stated that up to 70% of the proposal can be implemented 70% in the future at RMP.

5.13 Decision on the task-completion time

Following a discussion with the general manager of RMP to determine the task-completion time for implementing the leagile manufacturing paradigm at RMP, it was decided to allow six months to determine the effectiveness of implementing the leagile manufacturing paradigm through the application of one cycle of the LEAGICOM model.

5.14 Measurement of the level of implementing the leagile manufacturing paradigm at RMP

After completing the implementation of steps 1 to 13 of the LEAGICOM model, it is necessary to measure the level of implementation of leagile manufacturing at RMP. The implementation of the leagile manufacturing paradigm has not yet started there. Hence, the general manager was requested to estimate the number of conventional, hybrid and innovative air compressors that will be produced at RMP on implementing the proposal during the execution of steps 1 to 13 of the LEAGICOM model. The data thus obtained are shown in Table 2.

Table 2 Number of models of air compressors that will be manufactured following implementation of the LEAGICOM model at RMP

Type of air compressors	Number of models that will be manufactured in the anticipated implementation of the LEAGICOM Model at RMP
Conventional air compressors	37
Hybrid air compressors	8
Innovative air compressors	9

Subsequently, the anticipated level of implementation of leagile manufacturing through the LEAGICOM model and in manufacturing the three types of models of air compressor at RMP was calculated. This calculation is presented below.

$$\left.\begin{array}{l}\textit{Level of implementing leagile}\\ \textit{manufactuirng in the}\\ \textit{manufacturing}\\ \textit{of air compressors}\\ \textit{in the anticipated}\\ \textit{implementaiton of the}\\ \textit{LEAGICOM model at RMP}\end{array}\right\} = \frac{\left(\begin{array}{c}\textit{Number of}\\ \textit{conventional air}\\ \textit{compressors to be}\\ \textit{manfactured}\\ \textit{at RMP}\end{array}\right)\times 0.1 + \left(\begin{array}{c}\textit{Number of}\\ \textit{hybrid air}\\ \textit{compressors to be}\\ \textit{manufactured}\\ \textit{at RMP}\end{array}\right)\times 0.5 + \left(\begin{array}{c}\textit{Number of}\\ \textit{fully innovative air}\\ \textit{compressors to be}\\ \textit{manufactured}\\ \textit{at RMP}\end{array}\right)\times 0.4}{\begin{array}{c}\textit{Total number of air compressors to be manufactured in RMP}\\ \textit{in the anticipated implemtnation of the LEAGICOM model}\end{array}}$$

$$= \frac{(37\times 0.1)+(8\times 0.5)+(9\times 0.4)}{54} = 0.21 = 21\%$$

As shown, according to the assessment made by the general manager, the level of implementing the leagile manufacturing paradigm in the manufacturing of air compressors in the anticipated implementation of the LEAGICOM model at RMP is 21%.

5.15 Analysing the impact of implementing the previous steps of the LEAGICOM model in the attainment of the business goals of RMP

The anticipated performance of RMP was estimated and analysed in order to study the impact of attaining the strategic leagile manufacturing policy and the business goals through the implementation of the first cycle of the LEAGICOM model. It was anticipated that the business goals of RMP will be attained if the LEAGICOM model is implemented in the future.

The results of implementing the previous steps of the LEAGICOM model were critically examined. Based on the results of this examination, decisions were made on the actions to be taken to implement the second cycle of the LEAGICOM model for strengthening the capacity of RMP to implement leagile manufacturing and to gain competitive strength.

6. Conclusions

Modern companies are required to implement advanced paradigms to keep up with the competitive environment prevailing in the world. One among them is leagile manufacturing. The implementation of the leagile manufacturing paradigm helps the manufacturing company under review to produce three categories of products which are categorised as conventional, hybrid and innovative products [50]. The company implementing the leagile manufacturing paradigm builds its competitive strength by manufacturing these three categories of products to meet the needs of all its customers. A few models for implementing leagile manufacturing in organisations have been provided in the literature by a number of researchers [22-24, 33, 49]. These developments indicate that it is necessary to build exclusive models to implement leagile manufacturing in specific industries. In this context, the LEAGICOM model for implementing leagile manufacturing in the compressor manufacturing industry was developed in the research reported in this paper. The major capabilities of this model are to facilitate the measurement of the level of leagile manufacturing attained, to develop the leagile layout and the leagile human resource system, and to propose leagile training and educational programmes. The results of the exploration conducted at RMP indicate that LEAGICOM is a feasible model for implementing the leagile manufacturing paradigm in medium-sized compressor manufacturing companies.

A limitation of this research is that the practicality of the LEAGICOM model was explored only at RMP which is a medium-sized compressor manufacturing company. Therefore, the practicality of implementing the LEAGICOM model which was observed while carrying out the research reported in this paper may not hold good in all types of compressor manufacturing companies of various sizes. Hence, in future, case studies on implementing the LEAGICOM model in micro, small and large compressor manufacturing companies should be conducted. The generalised inference drawn by carrying out the research reported in this paper is that the LEAGICOM model has the capacity to enable compressor manufacturing companies to implement the leagile manufacturing paradigm and enhance their competitive strength.

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