INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN TECHNOLOGY AND SCIENCE

ISSN: 2321-1156 www.ijirts.org Volume 10 Issue 1, January 2022

Analysis of Productivity, Quality and Flexibility of an Advanced Manufacturing System

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ABSTRACT:- *In the past, productivity was the main factor for evaluating manufacturing systems, which does not depict the system's overall performance. Frequent change in the design and need for continuously improving product quality requires a high degree of automation and flexibility of the manufacturing system. For such systems, productivity, quality and flexibility are critical measures of total manufacturing performance for justifying capital-intensive project investment. This work aims to define and quantify productivity, quality, and flexibility and evaluate their combined effect on the overall manufacturing performance index. A mathematical model for performance index has been developed using multiple regression analysis. A relationship among productivity, quality and flexibility has been investigated, and a method has been proposed to decide whether decision-makers should opt automated production system or not.*

INTRODUCTION

The economic theory for Productivity measurement to the work of Jan Tinbergen (1942) and independently to Robert Solow (1957) prepare productivity measures in a production area and associate them with the analysis of economic growth. The world has changed a lot after the end of the cold war in early 1990. For example, the promotion of free trade, the advancement in information technology and the use of Euro-money have made it easier than ever to trade across the border. The business is now competing with some enterprises around the world.

Manufacturing organisations are experiencing a common phenomenon of frequent change, uncertainty and unpredictability in the business environments. In the past, production systems were either high production with less flexibility or less production with high flexibility. This led to the involvement of enormous capital in switching over from one system to the other. There was no specific method to evaluate the technology economically before deciding on adopting the new system. Earlier only productivity was the main factor for system evaluation, which in actual practice does not depict the system's complete picture or overall performance. The complete evaluation of economic viability can not be done based on only one measurement variable such as productivity, profit or rate of return because it doesn't help identify the specific area for management's attention. It may even be irrelevant in some organisations. The project's economic feasibility has been evaluated by accounting for the economic scale's productivity, quality, and flexibility. The industry has two management aspects: marketing, where new products are required because of changing user needs. The generation of the new market increases product variety due to market segmentation, fluctuation in demand and short product life cycle. The second is a production where product line and specification vary, part configurations are made up, and precision and speed of production equipment are different due to technological changes. Market demands and rapid technological development have created a demand for a more flexible production system and more complex products with greater precision. There is intense pressure towards the use of more automated equipment. At the same time need for flexibility towards the change in products. These changes have to be made in a short period. Thus flexibility has become a critical success factor in today's dynamic and competitive manufacturing environment. But there may be a conflict of aims between flexibility and productivity. Strategically, the production system is so flexible that neither the product nor the renewal of the process to be hindered by "sunk" costs in production. For proper evaluation of any production system relative to these parameters, precise productivity, quality and flexibility are required. Performance measurement for a system is one of the essential engineering and management tools for Justifying the investment in integrated manufacturing and production system continuous improvement of the existing system and providing an insight into where the change is needed.

PRODUCTIVITY

Productivity is defined as the value of goods manufactured divided by input. Productivity may be in terms of labour, material, process overhead. These productivities are termed partial productivity. Initially, industries were using either labour or material productivity for performance measures which was a severe misunderstanding. Therefore, a company-wide decision measure of total productivity is essential, combining labour, material, overhead, and productivity.

QUALITY

Quality is defined as the degree of excellence in manufacturing a product. With the world economy tending to be more global, the manufacturing industry faces tremendous competition in producing products at lower cost, with shorter lead times, a quicker market response, better quality and service, and more environmentally friendly. Quality is a crucial factor for the success of Japanese industries. The key for manufacturers to survive is quality, which means that manufacturing enterprises must meet customers' requirements. Globalisation forces companies to consider strategies of quality improvement initiatives. Voluminous work is available on quality control, but very few are on quality measures, mainly economic terms to establish a relationship, quality and productivity should be expressed in terms of rupees.

FLEXIBILITY

With the emergence of new microprocessor technologies, the concept of flexibility in manufacturing has become a key consideration in the design, operation and management of manufacturing systems. A substantial amount of literature dealing with manufacturing flexibility has been accumulated over the last thirty years. The central part of the literature is devoted to defining various types of flexibilities and identifying systems that exhibit one or more of these. More than 50 different terms for various types of flexibilities can be found in the manufacturing literature. Usually, several terms refer to the same flexibility type.

LITERATURE REVIEW

The manufacturing industries are using different techniques to improve performance. Some of the techniques require huge investment. In such circumstances, decision-makers are not willing to take a financial risk for adopting high technologies for improved performance unless they have sufficient economic justifications. Therefore critical evaluation of manufacturing performance is essential.

PRODUCTIVITY

Sink, DS; De Vries, S.; Swaim, J. Tuttle, T. (1984), identified three generic productivity measurement techniques. These techniques are the Multi-Factor Productivity Measurement Model (also called the total factor Productivity Model), the multi-criteria performance Measurement Technique, and a structured Participative approach to developing Productivity and Performance Measurement, evaluation, and control and improvement systems. In 1989, Sink, DS suggested that the quality of work-life can significantly influence operational and labour productivity. He also suggested that quality of work-life can be the measure of performance of any manufacturing organisation and established the correlation between productivity and quality of work life. In their research, S.C. Rastogi and R.P. Mohanty (1994) present four strategies for total Productivity optimisation of a manufacturing company. These strategies are developed to attain overall growth, cost reduction, upgrading technical efficiency and management effectiveness. The strategies are modelled mathematically by using a nonlinear mathematical programming approach. Don oh Choi, Ji Soo Kim (2005) proposed a model which can be employed for a partial factor Productivity measurement and evaluation. The partial factor Productivity measure is obtained by dividing one input factor into the weighted sum for each output factor. Mohan P. Rao (2006) introduces a performance measurement system using a multifactor Productivity measurement model in a real-world setting. The model uses operational level accounting data such as quantities and prices of inputs and outputs of a revenue-generating organisation.

QUALITY

In their research work, Yoram, Reich and Eyal levy (2004) have developed a simple, intuitive method for managing Product development for obtaining the best quality Product under dynamic resource constraints. The model can respond to changes in the environment, including changes in the company workforce, introducing new technologies, and reducing budget. V.H.Y.Lo et al. (2007) in their study have stressed the importance of supplier quality management (SQM) in the improvement of an organisation's quality performance. D. Ojha, BR Sarker and P. Biswas (2007) have developed a total cost equation and evaluated the optimal ordering quantities for an imperfect production system with quality assurance and rework. M.M. Fuentes et al. (2007) aim to determine the possibility of differences in quality management implementation across competitive environments. In their study, G. Prabhaharan, R. Ramesh and P. Asokan (2007) optimised the assembly tolerances for quality and minimised the manufacturing cost.

FLEXIBILITY

Manbir S. Sodhi and Bhaba R. Sarker (2003) have considered the problems of configuring flexible flowlines and attempted to minimise the line size. Palani Rajan et al. (2003) provided an alternative understanding of product flexibility from a design perspective. They have developed a method to evaluate the flexibility of product design and derived a set of guidelines to guide product architecture to a desired state of flexibility. KK. Yang, S. Webster and R. Ruben (2003) have analysed and compared the performance

ISSN: 2321-1156 www.ijirts.org Volume 10 Issue 1, January 2022

of a job shop operating on a fixed 8-hour day schedule with a job shop that had some flexibility to vary an employee's workday by compensating hours over an 8 hour day with an equivalent amount of time off. The impact of shop and worker flexibility has been investigated by A.J. Ruiz-Torres and F. Mahmoodi (2007). The results suggest that the implementation of only worker flexibility results in most improvements concerning the average percentage of job tardy in most cases.

METHODOLOGY

MEASUREMENT OF PRODUCTIVITY

Productivity measures manufacturing performance, indicating a firm's efficiency in converting inputs to total outputs. The output is calculated as the summation of all units produced times their market price. In this work, three different partial productivity measures have been considered, viz.

Labour Productivity

Labour productivity measures labour performance required to produce total output. Labour productivity for a given period has been defined as

$$Labour\ \mathrm{Pr}oductivity = \frac{Total\ Output}{Labour\ \mathrm{cost}}$$

$$P_L = \frac{OP}{C_L}$$

Labour cost includes the direct as well as the indirect labour cost.

Material Productivity

Material productivity measures the efficiency of raw material use. Material productivity for a given period has been defined as

$$Material\,\mathrm{Pr}oductivity = \frac{Total\,Output}{Material\,Cost}$$

$$P_m = \frac{OP}{C_m}$$

Material cost includes costs of both direct and indirect material.

Overhead Productivity

Overhead productivity is the efficiency of all resources except labour and material. This group of inputs includes machines, tools, floor space costs. Machine cost includes energy, maintenance, repair, insurance and property tax. As automation increases, overhead cost increases due to the high initial investment required for the advanced machine. Overhead productivity for a given period has been defined as

$$Overhead\,\mathrm{Pr}oductivity = \frac{Total\,Output}{Overhead\,\mathrm{cost}}$$

$$P_{OH} = \frac{OP}{C_{OH}}$$

Productivity Index

The productivity index is formed by integrating the partial productivity measures and measuring the total manufacturing efficiency. The productivity index for a given period has been defined as

$$\mathrm{Pr}oductivity\,Index = \frac{Total\,Output}{Labour\,Cost + Material\,Cost + Overhead\,Cost}$$

$$PI = \frac{OP}{C_L + C_M + C_{OH}}$$

QUALITY

Quality management is too important to be handed over to just one quality control department. Quality has to be incorporated at every function that the product interacts with them. In today's parlance, quality means 'total customer satisfaction, and this cannot come about unless the organisation's culture, values, processes, employees, and business associates are all aligned to this quality objective. It has to be a 'Total Quality Management' effort. It is influenced by the design quality:-The degree to which the product's specifications satisfy the customer's requirements. process quality:-The degree to which the product, which is made available, to the customer, conforms to specification."

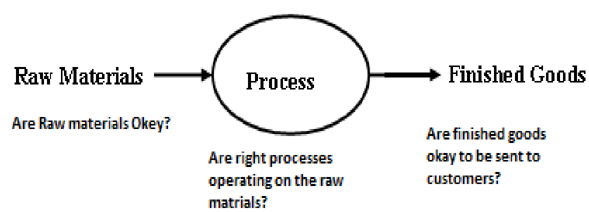

Figure 1: Three aspects of assuring quality

RESULT

From the equations obtained after multiple regression analysis, it is clear that the productivity index has a positive regression coefficient. It means that per unit increase or decrease in productivity index accordingly increases or decreases the integrated manufacturing performance index by 0.04915 in case of manual 0.070369 in case of automatic line. Although the overhead productivity of automatic lines is comparatively less than that of manual lines, overall productivity is more significant in the case of automatic than manual lines. The quality index has a negative regression coefficient in both cases. But in the case of automatic line, it is numerically less. This shows that failure cost and prevention cost is less in the automatic system than manual system. Being conventional machines and comparatively less-skilled workers,

ISSN: 2321-1156 www.ijirts.org Volume 10 Issue 1, January 2022

failure of the product is more and hence more frequent inspection is required, and thus extra cost is occurring to the production cost of the items. In the automatic line, precise and technologically upgraded types of equipment are installed, and hence less inspection or automated inspection is carried out. The probability of failure of the product is considerably reduced, improving the quality index of the line. The result shows that the flexibility index positively impacts the integrated manufacturing performance index. Unit increase or decrease in flexibility index increases or decreases the integrated manufacturing performance index by 0.6094 and 0.5457 in the case of manual and automated lines, respectively. In the case under study, an automated line's product and demand flexibility are higher than a manual one, but equipment contains less flexibility other than that. The flexibility index is calculated based on set-up cost, inventory cost of finished product and raw materials and idle cost of equipment. In the case under study, the automated line is not being fully used, and its depreciation cost is also higher than the manual line, hence the higher idle cost. That is why the coefficient of flexibility index of the automated line is lower than the manual line.

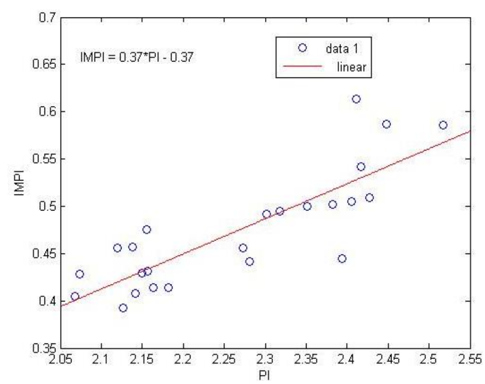

Figure 2: IMPI vs PI for Manual Line

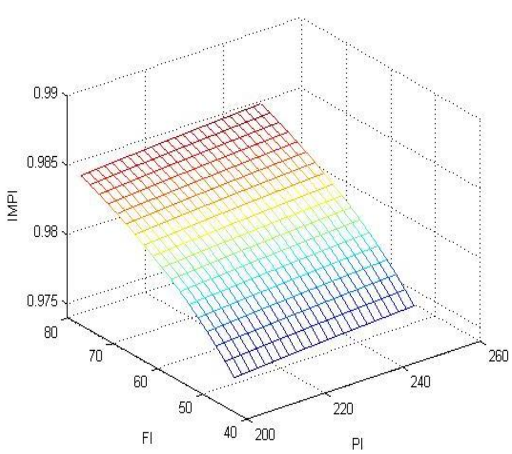

Figure 3: Relation among IMPI, FI, and PI when QI is fixed for Manual Line

CONCLUSION

The study indicates that adopting an automated manufacturing system improves the overall manufacturing performance compared with a conventional manual manufacturing system. However, just because an automated system performs better than others does not mean we abandon the conventional manual system. Adopting an automated system requires a significant initial investment in a long-term environment. The Economics of the project should be considered over the project's life cycle. The performance indexes developed here can be helpful in strategic planning since they evaluate past or current manufacturing performance and predict the effect of capital investment on future performance.

SCOPE FOR FURTHER WORK

The present study is concerned to quantify and combining three critical performance measures, i.e. productivity, quality and flexibility, to obtain IMPI. The evaluation of IMPI for a conventional and automated production system is done. The following recommendations are made for some possible extensions of the present study. In the present study, we have considered only labour productivity, material productivity and overhead productivity. Capital productivity should also be considered for calculating total productivity because it measures the efficiency of capital invested in equipment and building. This measure is helpful in capital intensive projects.

Similarly, one can form energy productivity when energy cost is a large part of the total cost. For calculation of process quality index, we have considered labour and equipment cost in approximate involved in inspection process on an average basis. A more precise result can be obtained by using a control chart. In this case, the cost of sampling, improving assignable cause, and improving process capability in each cycle are also calculated. In calculating failure cost, we have considered the material and processing cost. For better result cost of scraping a defective part, accepting a defective part should be considered. We have considered only the finished product's inventory cost and WIP for demand flexibility. For better results, cost of service and risk per unit raw material of part, backorder cost of unit raw material, backorder cost of the unit finished product should also be considered.

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