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Measuring Machinery Capacity Utilization and Its Impact on Manufacturing Performance and Environment

Shahidul,M., S. T. Syed Shazali, Abdullah Y., C. H. Ting, A. H. Hishamuddin, M. S. M Azrin, and A. F. K. Adzlan

Abstract

Underutilized of machinery capacity appears as non-value added hidden factor in production process which contributes to reduce production performance. In that context, this research aims to estimate capacity utilization (CU) of production machinery by using short run production function for evaluating its impact on production efficiency and environmental quality. Short run production function is developed based on engineering concepts of capacity measurement. Developed model has tested in a manufacturing industry which reveals machinery was operated by 70% CU and 73% efficiency. Additionally, degree of CU appears positively associated with production efficiency and negatively associated with industrial wastage. Despite a few limitations, the CU model appears a useful tool for optimizing production performance and environmental quality. However, this study concludes that underutilize CU contributes to increases industrial wastage which negatively associates with environmental quality. Further study is essential for measuring the effect of machinery breakdown and working environment on capacity utilization.

***Keywords*:** capacity utilization, production performance, environment sustainability, production efficiency

Introduction

The aim of this paper is to estimate capacity utilization of production machinery of manufacturing industry for evaluating its impact on production efficiency and environmental quality. While past literature has concentrated on developing and using capacity utilization measurement model on macro-level manufacturing sector by looking at inputs-outputs in long term production perspective; and information produced by using long run CU is not useful for industry level managers for evaluating production performance. On the other hand, this paper concentrates on the framework to analyze CU of single manufacturing industry for capturing and picturing production behavior by looking at engineering concepts of short term production function and findings are useful for factory level managers. The theoretical framework chosen to analyze the proposed issues is based on the content, context, process (CCP) design (Pettigrew, 1985) of production system. This is an important piece of research because it addresses an industrial production issue which previously did not get attention though a few decades research related to CU have moved from the conceptual domain to the empirical level without considering micro-level manufacturing industries. However, there is a lack of a standardized approach to empirically analyze CU in a single industry for short term production function. As this empirical study performed with a structure of machinery for a single industry in short term production function, it will fill this gap, though it is tough to draw common conclusions and develop hypothesis without a benchmark. This paper proceeds as follows: Section 2 presents literature review. The research methodology is described in Section 3. Section 4 dedicated to data analysis. Section 5 states about conclusion and remarks.

Industrial capacity is a measure of outputs that can be produced in a fixed period of time with given production resources. On the other hand, CU measures how much potential of a plant is being used at a given point of the production cycle. However, CU is used to explain some important factor of manufacturing such as productivity, profit, assessing growth, future investment and employment generation [1]. The most used definition of the "capacity utilization" is the ratio of the actual output to potential output. Potential output, indeed, can be defined in engineering and economic perspective. The “engineering" concept deals with physical units as outputs and say that capacity utilization is (weighted) average of the ratio between actual outputs of a firm to maximum output in a unit time [2]. The economic definition, CU is a ratio of actual output and economic capacity output [3][4][5].

Production performance is strongly associated with utilization of inputs for maximizing outputs; in this perspective machine factor inputs are more concerned. Underutilized capacity is a capacity gap appears as non-value added inputs and ultimately turns as the lower physical efficiency of the production process. Indeed, degree of CU of production resources depends on a few potential factors such as labour skills and availability of machineries. It is evident that the overall effectiveness of equipment (OEE) is deeply linked with CU [6] as stated by David et al. [7] and Krisztina et al. [8]. They found a strong relationship between production performance and CU; this finding is supported by James [9] and Samuel [10].

2 Literature Review

This section summarizes findings of the literature review on research related to capacity utilization of manufacturing industries and its impact on production performance and environment. The authors identify a significant number of academic papers on conceptual and empirical covering CU for economic and environmental sustainability. Among the papers, more than half are conceptual and other half is empirical. Published papers on CU indicate that less than half of the papers published before the year 2000 and after that period research on CU has moved significantly from conceptual state to empirical level. Literature review on CU reveals that official estimates of CU is not released by many counties; however, some countries disseminate its CU estimate of manufacturing sectors. In the USA, Federal Reserve Bank conducts survey of plant capacity utilization and provides statistics for the U.S manufacturing industries. In the United Kingdom (UK), picture on CU is captured through a survey by the Bank of England's regional agencies and other stakeholders [11]. In Turkey, both the central bank and the Turkish statistical Institute compile and disseminate information on CU on the manufacturing sectors [12].

CU presents most useful economic indicators such as output gap, installed capacity used, potential outputs, actual outputs, effect of degree of machinery maintenance, market inflation, GDP growth and government monetary policy. CU also speaks about product demand conditions, machinery maintenance capability, operator skills and supply chain efficiency of industries. Indeed, labour problems, transport bottlenecks, failure in power supply also responsible for underutilization of industrial capacity [13], [14]. Degree of CU is a manufacturing performance indicator; and CU growth rate is positively associated manufacturing productivity. Practically, productivity growth is measured and adjusted with CU for maintaining sustainable industrial growth. Productivity growth is also realized by reducing non-value added inputs and maximizing output [15]. It is because underutilized capacity creates capacity gap and capacity gap acts as non-value added input which contributed to reduce productivity.

Maintenance of production machineries is an indispensable function in a manufacturing plant for utilizing its capacity and optimizing production performance. A well-conceived TPM implementation not only improves machinery efficiency and effectiveness but also brings appreciable improvements in plant CU. Resulting effect of maintenance and CU is more productive in terms of both partial and total productivity measures [16]. However, maintenance creates a sense of joint responsibility of production supervisors, operators and maintenance workers, not only to keep the machine running smoothly, but also to optimize overall performance [17]. Indeed, machinery maintenance is based on basic three interrelated parameters such as maximizing equipment effectiveness, autonomous maintenance by operators, and group activities relating to production systems [18].

Industrial practice shows that lack in machinery maintenance and working skills of machine operators create malfunctioning of machinery which contributes to increase industrial waste such as rejection of products, increases exhaust gases of machineries with unburned fuel. Shahidul and Sadrul [19] were working with water treatment plant in Bangladesh and they found that lack of maintenance and environment hazard are positively associated. Similar finding has reported by Vusumzi an industrial professional [20]. They added, poor maintenance of wastewater and sewage treatment plants have great negative impact on both environment and human health. A report published in the Mercury [21] claimed that large amounts of sewage effluents were being discharged into Durban harbour and killed large population of fish and destabilizing aquatic ecosystem.

However, the common consensus of academic and industrial professions is that maintenance indeed contributes to increase plant machinery CU and reduce negative impact on the environment. Literature review of relevant issue reveals that CU of production machinery is highly dependent on degree of machinery maintenance; and CU is also positively associated with environmental sustainability as it contributes to reduce wastage. Studies at CU in global manufacturing context conclude that CU and its effect on production performance and environment has not received high attention but it is an important issue for manufacturing and environmental sustainability. In developing country's perspective, this issue is more important. Based on this background, this study suggests that research on CU estimate and its effect on production performance and environment is essential for sustainability.

2.1 **Problem Statement**

Almost all studies relating to CU estimates reported in literature focused on macroeconomic structure; and have built based on long term production and cost functions for providing information to a government administrative level for making investment policy. The reports preparing on CU is not useful at factory level for evaluating performance and making operating policy. Hence, the basic question is how to use reports on CU for developing an operating strategic plan at the industry. This implies the need for a model to be useful to estimate CU at the individual plant level. To address this issue, the obvious question is: What empirical model could generate information about the impact of CU on production efficiency and environmental? This study aims to develop a model and test to answer this question.

2.2 **Research Objectives**

The broad objective of this research is to investigate whether CU of production machinery has any effect on production efficiency and environmental sustainability. For achieving the research goal, this study will look at the following specific objectives:

1. To evaluate impact of CU on efficiency of machinery.
2. To investigate the impact of CU on wastage and environmental sustainability.

3 **Research Methodology**

The research approach used in this study for measuring capacity utilization of single manufacturing industries is developed from the concept used by Atri Mukherjee [22], James [1] and Hemanta Saikia [13]; though all these studies were focused on measuring macroeconomic perspective. Research for measuring impact of CU on production efficiency and the environment:

- Develop explanatory variables.
- Develop models for estimating production efficiency and wastage
- Develop strategy for data collection
- Case selection for testing model
- Data analysis and model validation

The steps adapted for information generated relating to CU and its effect on efficiency of production machinery and environment are model development, data sheet design, data collection from industry, analysis by using software and report writing. The components of research namely explanatory, potential output, mathematical modelling and case description are described below.

3.1 **Explanatory Variables**

The independent variable of this study is a CU of production machineries directly involved in production; and dependent variables are efficiency of machineries and waste both in raw materials and finished products. Other explanatory variables are defined in 3.1.1 below.

3.1.1 **Actual Output And Potential of Machinery**

Actual outputs (Q_A) are defined as the average output of machinery; and it represents an average of normally distributed outputs and quite fit in within 3-standard deviation limit. Q_A is presented in Figure 1 and in equation (1). Q_P is potential output and represents a yearly peak output of machinery [1], [13]. In this study, one peak for each year is considered. Figure 2 presents $Q_{P.}$

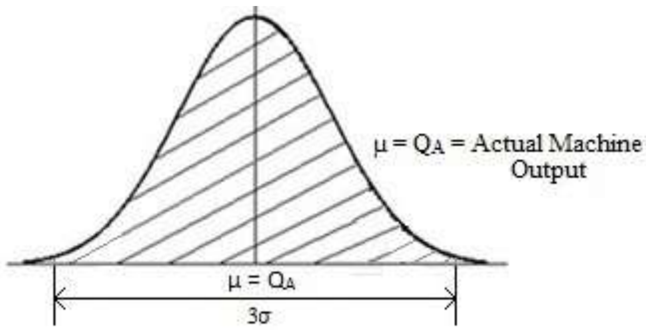

Figure 1 Actual output of machinery

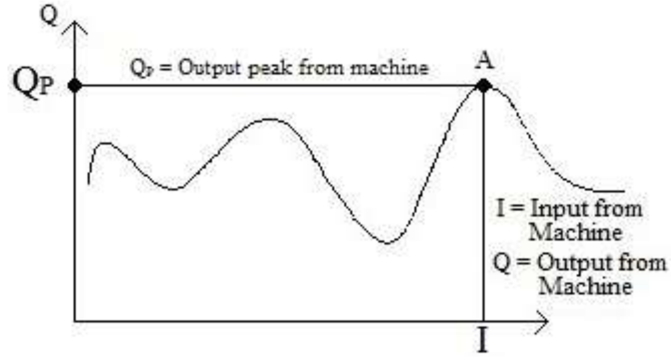

Figure 2 Potential outputs of machinery

$$Q_A = \frac{\sum \text{Outputs within } 3\sigma \text{ limit}}{\text{No.of operating days relevant to } 3\sigma \text{ outputlimit}} \tag{1}$$

3.2 **Empirical Model for Measuring Capacity Utilization of Production Machinery**

Based on short run production function and engineering concept, a CU measurement model for machinery is developed and expressed by equation (2):

$$CU = \frac{Q_A}{Q_P}\ , \quad CU \geq 0 \tag{2}$$

3.3 **MEASURING IMPACT OF Capacity Utilization On PRODUCTION EFFICIENCY**

Output of production machinery relates to the efficiency of the production system and it is an indicator of production performance. Logically, if capacity utilization of production machineries increase obviously it exhibits high level output and vice versa. It implies that output of production machinery depends on the utilization rate of production machinery; this phenomena present in the Figure 3 and equation (3):.

Figure 3: Input output model

$$\eta = \frac{Q_A}{Mi}\ , \quad \eta \geq 0 \tag{3}$$

Based on equation 2, the value of $Q_{A\ \text{could}}$ be replaced by $CU_M.Q_P$

$$\eta = CU.\frac{Q_P}{Mi}\ , \quad \eta \geq 0 \tag{4}$$

3.4 **Measuring Impact of Capacity Utilization on Environment**

Output of production machinery depends on the utilization rate of production machinery. Figure 3 is an input-output model; from this model it can be stated that the supply of raw material as inputs must be equal to outputs and wastage. Mathematical expression of this statement is:

$$M_i = Q_A + W_A \quad \text{, or} \quad W_A = M_i - Q_A \tag{5}$$

3.5 Case Description and Data Collection

Inputs–outputs data productions have been collected from a plastic ware manufacturing industry. Machinery such as blow molding machine is maintenance intensive. It is evident that quality of products and waste is highly dependent on maintenance.

4 Data Analysis

The objective of this research is to investigate about the impact of degree CU on production efficiency and the environment. Edited manufacturing information on potential outputs and actual output of year 2008 to 2012 have been used to estimate explanatory variables and reported in Table 1 and Table 2.

4.1 Measuring Impact of CU On Efficiency of Production Machinery

Equation (2) and Equation (4) have been estimated to get empirical result on production machinery efficiency. Equation (2) has been estimated to evaluate CU machinery involved in production. Equation (4) has been estimated to measure impact of CU on efficiency of production machineries. Estimated results are listed in Table 1.

Table 1 Statistic on CU and its impact on physical efficiency of production machinery

Year	$\mathbf{CU}_M = \frac{\mathbf{Q_A}}{\mathbf{Q_P}}$	$\boldsymbol{\eta}_{\mathbf{m}} = \mathbf{CU}_M \cdot \frac{\mathbf{Q_P}}{\mathbf{Mi}} \mathbf{100}$
2008	68	71.5
2009	67	70.1
2010	71	73.8
2011	73	76
2012	69	71.5
Average	69.6	72.6

Table 1 demonstrates that machineries involved in the production process itself CU is about 70%; and this amount of CU has contributed to achieving about 73% efficiency of production machinery. The model of CU and efficiency is presented by equation (6).

Production efficiency (η) = 66.792ln (CU) - 210.77 (6)

4.2 Measuring Impact of CU on Wastage and Environmental Sustainability

Equation (5) has been estimated to determine percentage of wastage of inputs; and results are listed in Table 2.

Table 2: Matrices of CU and wastage

Capacity Utilization (CU)						Wastage (%)					
2008	2009	2010	2011	2012	Average	2008	2009	2010	2011	2012	Average
63.1	63.0	62.5	63.5	62.8	63.9	5.0	4.9	4.8	4.9	5.1	4.9
64.5	65.0	66.2	65.5	66.4	64.6	3.5	3.8	4.0	3.6	3.7	3.9
70.3	71.5	70.0	72.5	71.0	70.8	2.75	2.80	2.79	2.82	2.76	2.76
75.1	75.9	75.0	75.7	74.8	75.4	1.5	1.4	1.6	1.5	1.7	1.5
79.5	79.1	78.0	78.5	79.0	78.6	1.0	1.1	0.9	1.1	1.0	0.9

Estimated value of CU of production machineries of years 2008 to 2012 is listed in Table 2 which demonstrates that waste is reduced with increasing of CU of production machineries. These findings suggest that CU is negatively correlated with the waste of inputs namely raw materials and final products.

4.3 **Impact of CU on Wastage and Manufacturing Sustainability**

Practically higher percentage of wastage has a higher degree of negative impacts on the environment; because, either waste is disposed of or recycle to produce products. However, disposal is not acceptable as sustainable economy and environment is deeply concerned. In this context, wastage has to be recycled or reused for attaining economic and the environmental sustainability.

4.4 **Impact of CU on Environmental Sustainability**

Either recycle or dispose of both cases require additional electricity that produces greenhouse gases which negatively impacting on the environment. In order to reduce negative impact on the environment, CU of machinery must be increased. Based on this scenario analysis, it can be hypothesized that high degree of CU and lower percentage of wastage will contribute to attain environmental sustainability.

4.5 **Scenario Analysis of Findings**

This study investigates the impact of CU on production machinery efficiency and environmental sustainability. For achieving research goals, a short-run production function relating to CU has been estimated. The research outcomes are reported in Table 1, Table 2 and equation (6). Table 1 shows that average CU of plant machineries was 70% and machinery was operated at 73% efficiency. Table 2 indicates at lowest CU (63.9%) and highest CU (78.6%) wastage rate was 4.9% and 0.9% respectively.

Findings indicate CU and production efficiency is positively associated; it is because during production process inputs are transformed into outputs at higher rates. Volume of output with respect to input is dependent on a few production parameters such as transformation capacity of machineries, degree of skill of machining operations, working environment, level of machinery maintenance, raw material quality and many others. It implies that these factors contributed to increase CU of production machineries [15]. On the other hand, Table 2 shows that CU and wastage are negatively associated, it is due to malfunctioning of the production process including machinery operations. When we consider the rejection of raw materials and finished products we mean quality appears lower than expected value. Practically, a machine starts malfunctioning when it operates at a lower degree of maintenance and turning with under capacity utilization and poor quality products. It implies a lower level of CU could produce poor quality products which could be the potential reasons of a lower degree of production efficiency and higher degree of wastage. This finding could be justified with other findings; Fang [24] mentioned that the condition of machineries has high impact on the quality of product. In this regards, Basim's report has stated that maintenance need to carry out in order to eliminate potential hazards at an early stage for ensuring good quality and reliability of products [25]. Patrik also concluded that maintenance programs primarily execute by plant managers to have quality products from the machinery [26]. In this context, Nakajima's argument [27] is that total productive maintenance contributes to achieve ideal performance with zero waste and appears a contributory factor in saving environment. Indeed, machinery operations with higher degree of CU, the probability of wastage would be lower. In this context, the Christian's argument is [28] that well maintained machinery could contribute to reduce recycling processes, minimizing the threat to the environment and additionally supporting sustainability.

5 Conclusion and Direction for Future Study

This study has addressed sustainable issues of production performance and th environment; both are indeed linked to the economic sustainability. Basically, this study has revealed a twofold empirical relationship of CU with productionthe efficiency and the environment in microeconomic perspective. This is an important piece of study because previous all studies were focused on the macroeconomic perspective and study on the microeconomic perspective is very rare in the literature. However, sufficient benchmarks are not available to compare the findings of this study with others. This research concludes that optimization of capacity utilization of machinery is essentially important for achieving sustainable production performance and environment. However, information gathered from this study and model developed indeed may not represent the whole manufacturing industry and bt for developing a general model to be useful in manufacturing sector. However, this study recommends for further in-depth study on some other relivant industries.

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