Developing and Implementing a Model to Evaluate the Effect of Technological Changes on Productivity

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KEYWORDS

Aluminum Extrusion; Manufacturing Technology; Modeling; Productivity Technology; BALEXCO, Technology management.

ABSTRACT

Productivity is an important indicator of organizational performance and a prerequisite for national development. However, there are few published empirical studies that have provided and implemented a methodology to quantify the impact of technology changes on total productivity and partial productivities. This paper evaluates and quantifies the effects of technological changes on the productivity of (BALEXCO), as the largest aluminum extrusion company in Bahrain and one of the largest in the Arab countries. The technological changes in the company's three extrusion presses 1, 2 and 3 - that were established in 1976, 1994 and 1996 respectively, were analyzed, compared and identified. Data covering a period of ten years were collected and a differentiation technology model capable of evaluating the effect of technology changes on productivity was developed, validated and implemented. The results showed that the total and partial productivities improved dramatically as technologies were upgraded. It is concluded that the technology improvements have had positive effects on the total and partial productivities and that the developed model is capable of evaluating the effect of technological changes on total and partial productivities.

تطوير وتطبيق نموذج لتقييم تأثير التغيرات التقنية على الإنتاجية

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الكلمات الدالة

سحب الالومنيوم: البحرين ، تقنية التصنيع، الإنتاجية، التغيرات التقنية، بلكسكو، ادارة التقنية

المُستلخص

تعتبر الإنتاجية مؤشراً هاماً على أداء المؤسسات ولها الدور الرئيس في دورات النمو الاقتصادي الوطني، وعلى الرغم من ذلك فيلاحظ محدودية الدراسات التطبيقية التي تختبر تأثير التغيرات التقنية على الإنتاجية. الهدف من هذه الدراسة هو تطوير نموذج للتقييم الرقمي لتأثير التغيرات التقنية على الإنتاجية الكلية و الجزئية و تطبيق هذا النموذج على خطوط سحب الألمنيوم في شركة البحرين لسحب الألمنيوم (*بلكسكو*). والتي تعتبر واحدة من أكبر شركات سحب الالومنيوم في دول مجلس التعاون الخليجي. و قد تم تطوير نموذج تقنية تفاضلي لقياس الإنتاجية الكلية لخطوط السحب الثلاثة في شركة (بلكسكو) والتي تم إنشائها في السنوات 1976، 1994، و1996 على التوالي . كما تحث دراسة مواصفات التقنية الموجودة في هذه الخطوط الثلاث و تقييم التغيرات التقنية التي قد حدثت خلال 20 عاماً. كما تم تجميع و تحليل البيانات اللازمة و التي تغطى عشر سنوات سابقة و تم قياس الإنتاجية الكلية و الجزئية لكل من الخطوط الثلاثة. أظهرت النتائج أن الإنتاجية الكلية و الجزئية قد ارتفعت خلال العشرين عاماً في نوعية العمليات، نظم السحب، أنظمة التحكم، طاولات النقل، وغيرها. ومن ثم تم اختبار العلاقة بين التغيرات التقنية والإنتاجية الكلية و الجزئية وأظهرت النتائج أن للتغيير التقني تأثير ايجابي على الإنتاجية الكلية و الجزئية، كما تم تحديد قيمة التحسينات الرقمية. كما أثبتت الدراسة أيضاً أن النموذج المُتَطَور له القدرة على التقييم الرقمي لتأثير تغيير التقنية على الإنتاجية الكلية والانتاجية الجزئية بنجاح.

Introduction

Productivity is an important economic factor which plays a key role in economic growth. It is the foundation for economic prosperity, a prerequisite for national development and an important indicator of organizational performance. Almost half a century ago (Kendrick and Creamer, 1965) introduced productivity indices at the company level. They proposed two types of indices: total productivity index and partial productivity index. Fourteen years later, (Sumanth, 1979) proposed a total productivity model that provided a structure for finding partial productivities at the product level and aggregating them to company level productivity. (Zaied, 1990) proposed a total productivity model which considered the effect of partial weighting factors for all departments in an organization on the total productivity of the organization. (Owyong, 2003) suggested a model to measure total factor productivity growth. This model considered the weights assigned to inputs and output. (Wazed and Ahmed, 2008) suggested a multifactor productivity measurement model for manufacturing. It is an analytical model that contains nine major components to measure changes in productivity and break down the total variation into price and productivity effects.

The effects of technological changes on industries and enterprises were investigated by (Norsworthy and Jang, 1992). They formulated a general framework giving general assumptions about market structure and producer motivation with econometric methods to quantify economics of scale and scope, learning effects and sources of biased technological change. (Flynn, 2000) examined the components of past gains in productivity, including regional shifts, the existence of less productive producers and technological progress. The application of this study was on the marketing of manufactured products. (Pastor *et al.,* 2005) defined the Malmquist Index (MI), also called the Malmquist Productivity Index (MPI), as a bilateral index that can be used to compare the production technology of two economies. The (MI) is based on the concept of the production function. This is a function of maximum possible production with respect to a set of inputs pertaining to capital and labor. Another study (Rezagholi, 2006) investigated the effects of disembodied technical change on the total factor productivity in the US apparel industry during 1958-1996. The results indicated that the technical impact on the total factor productivity was 9% on average. (Guyomard *et al.,* 2006) investigated productivity changes experienced by French farms over the period 1995 to 2002. Using data from three categories of farms: crop, beef meat and dairy farms, Malmquist Productivity Indixes (MPI) were calculated and broken down into technical efficiency change and technological change. The results suggested that over the studied period, the annual average growth rates of efficiency, technological change and productivity were low for the three categories of farms. The results further suggested that technological progress is the dominant force for the three categories of farms, notably for dairy farms.

In the current published literature, there are few published empirical studies that have provided, implemented and validated a method capable of quantifying the impact of technology changes on total and partial productivity. The main objective of this paper is to develop a model capable of evaluating the effect of technological changes on the total and partial productivities of Bahrain Aluminum Extrusion Company (BALEXCO), which is the largest aluminum extrusion company in the Kingdom of Bahrain and one of the largest in the Arab countries.

Material and Methods

(1) Background to the Aluminum Extrusion-Process

Extrusion is defined by (Lea, 2003) as the process of shaping material, in this case aluminum, by forcing it to flow through a shaped opening in a die. Extruded material emerges as an elongated piece with the same profile as the die opening (Das, 2004). Press size determines how large an extrusion can be produced. Extrusion size is measured by its longest cross-sectional dimension, *i.e.* its fit within a circumscribing circle. A circumscribed circle is the smallest circle that will completely enclose the cross section of an extruded shape. The most important factor in the extrusion process is temperature as it gives the aluminum the desired characteristics, such as hardness and finish.

The factors affecting extrusion are identified by **(**Dixon, 2005). Shape is a determining factor in the ease with which it can be extruded. A wide variety of shapes can be extruded, but there are limiting factors to be considered. These include size, components of alloy being extruded, extrusion ratio (Das, 2004), tongue ratio (Lea *et al.,* 1999), tolerance, finish factor, and scrap rate (Lea, 2003). These factors that are interrelated in the extrusion process are: extrusion speed, temperature of the billet and extrusion pressure. If a part is beyond the limits of these factors, it cannot be extruded successfully. In general, as clarified by (King and Rebelo, 1999), extrusion speed varies directly with metal temperature and pressure developed within the container. Temperature and pressure are limited by the alloy used and the shape being extruded. As explained by (Das, 2004), the preferred billet temperature is that which provides acceptable surface and tolerance conditions and, at the same time, allows the shortest possible cycle time. The ideal is billet extrusion at the lowest temperature which the process will permit.

An exception to this is the so-called press-quench alloys. With these alloys, heat-treated temperatures within a range of 498.9°C-526.7°C must be attained at the die exit to develop optimum mechanical properties. At excessively high billet temperatures and extrusion speeds, metal flow becomes more fluid. The metal, seeking the path of least resistance, tends to fill the larger voids in the die face, and resists entry into constricted areas. Under those conditions, shape dimensions tend to fall below allowable tolerances, particularly those of thin projections or ribs (King and Rebelo, 1999). Another result of excessive extrusion temperatures and speeds is tearing of metal at thin edges or sharp corners. This results from the metal's decrease in tensile strength at excessively high temperatures. At such speeds and temperatures, contact between the metal and the die bearing surfaces is likely to be incomplete and uneven, and any tendency toward waves and twists in the shape is intensified (Das, 2004).

As a rule, the higher the mechanical properties of an alloy are, the lower the extrusion rates. Greater friction between the billet and the liner wall results in a longer time required to start the billet extruding. The extrusion ratio of a shape is a clear indication of the amount of mechanical working that will occur as the shape is extruded.

Extrusion ratio is defined as area of billet/area of shape (Dixon, 2005). As reported by (Lea, 2003), when the extrusion ratio of a section is low, those portions of the shape involving the largest mass of metal will have little mechanical work performed on them. This is particularly true on approximately the first ten feet of extruded metal. Its metallurgical structure will approach the as-cast (coarse grain) condition. This structure is mechanically weak, and shapes with an extrusion ratio of less than 10:1 may not be guaranteed regarding mechanical properties.

As might be expected, the situation is opposite when the extrusion ratio is high. Greater pressure is required to force metal through the smaller openings in the die and extreme mechanical working will occur. The normal extrusion ratio range for hard alloys is from 10:1 to 35:1, and for soft alloys is 10:1 to 100:1. These limits should not be considered absolute since the actual shape of the extrusion can affect results. The higher the extrusion ratio, the harder the part is to extrude, which is the result of the increased resistance to metal flow. Hard alloys require maximum pressure for extrusion and are even more difficult to extrude because of their poor surface characteristics, which demand the lowest possible billet temperature (Dixon, 2005). The difficulty factor is explained by (Das, 2004) as: it is the perimeter of shape divided by the weight per foot. Weight per foot is of primary importance in the consideration of profitable press operation. As might seem obvious, a lighter section normally requires a smaller press to extrude. However, other factors may demand a press of greater capacity, such as a large, thin-walled hollow shape. Though it has low weight per foot and it may take more press tonnage to extrude it. A higher difficulty factor means the part is more difficult to extrude, which consequently affects press production.

(2) Identification of the Factors Affecting Productivity

Bahrain Aluminum Extrusion Company (BALEXCO) was established in 1976 in Bahrain. The company has three extrusion presses which were established in 1976, 1994 and 1996 respectively. This company is the largest aluminum extruder in Bahrain and one of the largest in the Arab countries. To identify the factors affecting the productivity of the company's three extrusion presses, three steps were taken (Sayaar, 2010).

First, factors were obtained through the literature and the analysis of the company's cost and information center (BALEXCO, 1999 to 2008). Data from this center covering a period of six years (2003-2008) were collected for the three presses. These cost data were broken down into fourteen categories that reflected all the factors affecting the productivity of the presses. These categories were: raw materials; technology; labor; training; maintenance and repairs; energy; consumables; depreciation; land rent; amortization of die; insurance; research and development; good quality product and scrap.

Second, these 14 factors formed the basis of a questionnaire that was designed and given to the company experts to establish their opinions on the factors affecting productivity. They were given the opportunity to eliminate from, and add to, the factors in the questionnaire. The company's organizational structure consists of four departments: planning, extrusion, electrical maintenance and mechanical maintenance. There are 44 employees working in these departments, from top management down to technician level. A sample of 18 employees that represents the company's experts (40% of the total employees) was selected to respond to the questionnaire. They identified 12 factors affecting productivity. These were: raw materials; type of alloy; labor; training level; number of cavities of the dies; wall thickness of the die; energy; maintenance and repairs; consumables; good quality product; scrap and other operation parameters, such as the speed of the extrusion line, time of extrusion and cycle time.

Third, these factors obtained from experts, together with the factors obtained from the company's cost data and the literature, were analyzed and combined. A comprehensive list of 18 factors was produced and validated by the company's experts.

Further analysis of these 18 factors (Sayaar *et al.,* 2011) showed that ten of them have the same effect on the productivity of each of the three extrusion presses. This was checked and confirmed by collecting and comparing the cost effect of these factors on each press over a period of the six years 2003-2008. These ten factors were: type of alloy; number of cavities of small dies; wall thickness of the die; training level of employees; research and development; depreciation; insurance; land rent; amortization of die and the other operation parameters. The remaining eight factors have varied effects on each extrusion press. This was then confirmed by calculating the cost per working hour or the tonnage per year for each factor for each press. The results for these eight factors showed varied and fluctuating values on productivity. The final eight factors were then categorized as six input factors and two output factors. The two output factors were: good quality product and scrap. The six input factors were: raw materials, labor, energy, maintenance and repairs, consumables and technology.

(3) Development of Technology Differentiation Model

In this study, five of the input factors concluded above (all the input factors except technology) were used to develop the technology differentiation model. Total and partial productivities for the three presses in the period between 1999 and 2008 were calculated, based on the actual data collected from the company. These data were obtained from the company's Annual Financial Reports (BALEXCO-AFR, 1999-2008), Annual Production Reports (BALEXCO-APR, 1999-2008) and Annual Maintenance Reports (BALEXCO-AMR, 1999-2008).

The relative importance of each input factor was also calculated based on the collected data. The model was developed by solving five equations mathematically. The validity of the model was then verified. This was done by measuring the total productivity of each press for each year from 2004 to 2008 using the developed model and comparing the results with the corresponding total productivity calculated for the same period using basic productivity concept; the differences were minimal and could be ignored. The development stages of the model are explained in the following steps.

(3.1) Step 1: General form of the model and collection of the model Data considering the Basic mathematical concept:

$$\frac{Y}{X}+\frac{Y}{Z}=\frac{(YZ+YX)}{XZ}=\frac{Y(Z+X)}{XZ}\neq\frac{Y}{(X+Z)} \quad (1)$$

Then: Total productivity (TP)≠ summation of partial productivities (PP)

TP ≠ Σ PP of all productivity factors

TP = function (PP of all factors)

$$TP=\sum_{i=1}^{n} A_i f(PP_i) \quad (2)$$

Where: TP = Total productivity PP_i = *Partial productivity of input factor*

$$(_i)=\frac{Total\ output}{Input_i} \quad (3)$$

n = Number of factors, i = Input factor, A_i = Constant

Considering the basic definition of TP:

$TP = O_t/I_t$ (4)

Where: O_t = Total output, I_t = Total inputs

To develop the model values of the total and partial productivity of each of the three presses are needed. The required data were collected for the three extrusion presses for a period of ten years (from 1999 to 2008) from the company's Annual Financial Reports; Annual Production Reports and Annual Maintenance Reports.

By using these collected data the relative importance of each of the five input factors was determined. Total productivity and partial productivities were then calculated for the five input factors for each of the three presses during the 10 years from1999 to 2008.

(3.2) Step 2: Regression analysis and selection of the best correlation

Different regression methods, such as non-linear, logarithmic and linear, were used to find the best method to correlate the partial productivities and total productivity. figures 1, 2 and 3 show that for presses 1, 2 and 3, all the partial productivities for all the five input factors were in direct linear proportional relationship with total productivity. The correlation coefficient values for TP vs. PP_i for the three extrusion presses were calculated.

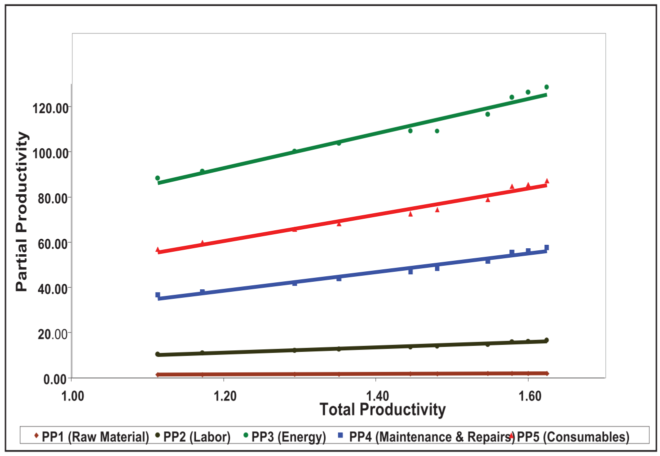

Figure 1: Partial Productivities VS Total Productivity for Press 1 (1999-2008)

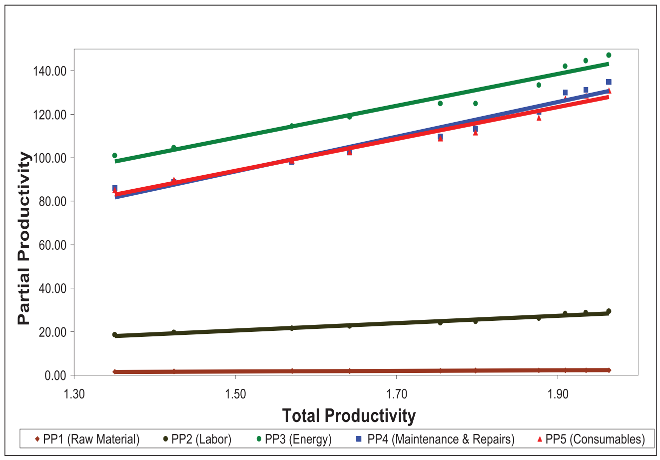

Figure 2: Partial Productivities VS Total Productivity for Press 2 (1999-2008)

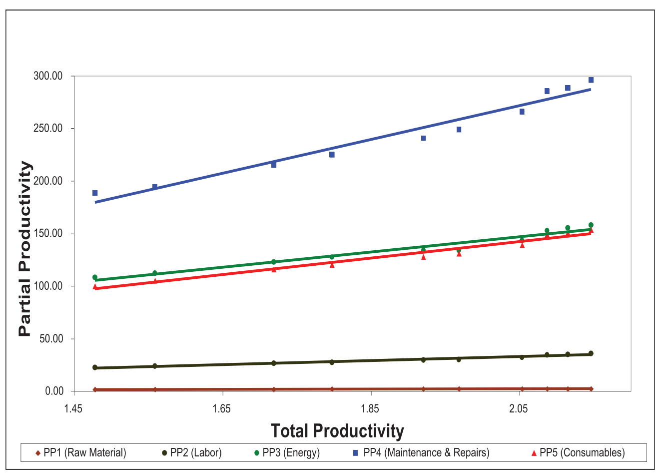

Figure 3: Partial Productivities vs. Total Productivity for Press 3 (1999-2008)

The results showed that the values were always close to + 1 as shown in table 1.

Table 1: Correlation Coefficients (R) for TP vs. PPn

Press	Factors	R
(1)	Raw Material	0.9991
	Labor	0.9850
	Energy	0.9806
	Maintenance & Repairs	0.9831
	Consumables	0.9855
(2)	Raw Material	0.9995
	Labor	0.9828
	Energy	0.9783
	Maintenance & Repairs	0.9808
	Consumables	0.9833
(3)	Raw Material	0.9997
	Labor	0.9820
	Energy	0.9774
	Maintenance & Repairs	0.9799
	Consumables	0.9826

Hence, perfect positive linear relationship can be assumed for the model development. The slopes of all the factors were analyzed as follows:

The general linear equation is presented as:

$$PP_i = C_i + D_i\,TP \quad (5)$$

Where: C is a constant and D is the slope of the line. Rearranging the equation:

$$TP = \frac{1}{Di}(-C_i + PP_i)$$

$$TP = E_i + \frac{1}{Di}PP_I \quad (6)$$

Where E_i is a constant**.**

When the slope D_i is increased the total productivity is decreased; and when the slope values for the different factors had a wider range, this had a greater positive impact on total productivity. The slope of each input factor was calculated. The results are illustrated in figures 1, 2 and 3. These sequences of slopes reflect the relative importance of the input factors of each press. The slope values of the input factors were in the following descending order:

Press 1: raw material, labor, maintenance and repairs, consumables and energy.

Press 2: raw material, labor, maintenance and repairs, consumables and energy.

Press 3: raw material, labor, consumables, energy and maintenance and repairs.

These sequences of the slope values showed that the materials factor has the strongest effect on TP for all presses, while energy has the least impact for presses 1 and 2, whereas maintenance and repairs has the least impact for press 3.

(3.3) Step 3: Development of the Model

Based on the linear correlation between the partial productivities for the five input factors and total productivity, the general form of the model, (equation 2), was rewritten as follows:

$$TP = \sum_{i=1}^{5} A_i PP_i \quad (7)$$

$TP = O_t / I_t$; *then:*

$$TP = A_1 PP_1 + A_2 PP_2 + A_3 PP_3 + A_4 PP_4 + A_5 PP_5 \quad (8)$$

Other form:

$$O_t / I_t = A_1 (O_t / M) + A_2 (O_t / L) + A_3 (O_t / R) + A_4 (O_t / C) + A_5 (O_t / E) \quad (9)$$

Where: O_t / M = *Partial productivity for raw material*

O_t / L = *Partial productivity for labor*

O_t / C = *Partial productivity for Consumables*

O_t / R = *Partial productivity for maintenance and repairs*

O_t / E = *Partial productivity for energy*

$A_i = a_i \,.\, b_i$, *for* $i = 1,2,\ldots,5$

a_i = *Relative importance of input factor on total productivity*

b_i = *Constant associated with factor* ($_i$) *for press 1,2,or 3*

Thus,

$$O_t / I_t = a_1 . b_1 (O_t / M) + a_2 . b_2 (O_t / L) + a_3 . b_3 (O_t / R) + a_4 . b_4 (O_t / C) + a_5 . b_5 (O_t / E) \quad (10)$$

$$TP = \sum_{i=1}^{5} a_i . b_i . PP_i \quad (11)$$

(a_i) was calculated using the collected cost data as follows:

(a_i) = (cost of input $_i$ / total operation costs) x 100

As the order of relative importance of the factors on total productivity was the same for presses 1 and 2 but slightly different for press 3, and because of the low values of the last three factors (energy, consumables, maintenance and repairs) compared to the other two factors (materials, labor), the relative importance was assumed constant for the three extrusion presses. Then, the average values of the results for (a_i) of the years from 1999 to 2008 were taken for each of the 5 input factors to develop the model. The values of the calculated relative importance (a_i) are summarized in table 2.

Table 2: Relative Importance of the Input Factors

No	Factor	Average (%)
(1)	Materials	74.33
(2)	Labor	6.38
(3)	Consumables	1.36
(4)	Maintenance & Repairs	1.30
(5)	Energy	1.15

The values of (b_i) were calculated based on mathematical matrix methods according to data pertaining to the period 1999 and 2008, using Polymath Software. The results of (b_i) for presses 1, 2 and 3 are given in table 3.

Table3: Values of b_i for Presses 1, 2 and 3

b_i	Press 1	Press 2	Press 3
b_1	0.9250351	1.0432275	1.0833332
b_2	0.1845920	0.0876962	0.0699045
b_3	0.0156205	0.0175310	0.0181770
b_4	0.0691833	0.0178740	0.0040401
b_5	0.0260499	0.0167702	0.0145671

(3.4) Step 4: Validation of the model

TP for each of the three presses were calculated for the period from 2004 to 2008 using the model's equation (11). The results were compared with the results of the TP that were calculated using basic productivity concept equation (3). Table 4 summarizes the results of the comparisons. The average differences between the TP for presses 1, 2 and 3 were 0.07 %; 0.05 % and 0.04 % respectively. These validate the proposed model, as the values are close and the differences are small.

(4) Technology Changes vs. Total Productivity

The specifications of the three extrusion presses are given in manuals of (Gia-Clecim, 1994), (Elhaus, 1996) and (Mechatherm, 2000). These specifications were analyzed and compared. The summary of the technology differences between the three presses is shown in Table 5. The comparisons showed that the technology improved between 1976 and both 1994 and 1996 and to a lesser extent between 1994 and 1996.

Table 4: Comparison between TP of the Three Extrusion Presses: Developed Model vs. Basic Concepts

Press No.	Year	TP (Model)	TP (Basic concept)	Difference (%)	Average difference
Press 1	2004	1.480	1.480	0.00	0.07%
	2005	1.547	1.547	0.01	
	2006	1.580	1.579	0.10	
	2007	1.601	1.600	0.10	
	2008	1.627	1.624	0.13	
Press 2	2004	1.798	1.798	0.00	0.05%
	2005	1.877	1.877	0.00	
	2006	1.911	1.909	0.07	
	2007	1.936	1.935	0.07	
	2008	1.966	1.964	0.09	
Press 3	2004	1.968	1.968	0.00	0.04%
	2005	2.053	2.053	0.00	
	2006	2.088	2.087	0.06	
	2007	2.116	2.115	0.06	
	2008	2.148	2.146	0.08	

Table 5: Summary of Technological Changes between the Extrusion Presses

Technology	Press 1 (1976)[1]	Press 2 (1994)[2]	Press 3 (1996)[3]
Number of Zones in Billet Heater	3	5	5
Type of Operation	Manual or semi- automatic	Manual or automatic	Manual or automatic
Billet Shear	Not available The size of the billet pre-defined and prepared before the billet heater.	Available The size of the billet can be defined automatically for each job.	Available The size of the billet can be defined automatically for each job.
Billet Loading Position	Back loading	Back loading	Front loading
Machine Control Room and Control Panels	Centralized control room is not available. - Separated billet heater, press machine, and handling table control panels are available. Mostly this press is controlled via Relay Logic Control panels. The handling table is recently controlled by Small Logic Controller (SLC). Ageing Furnace is controlled by (SLC).	The centralized control room is available where the main control panels are installed except the control panel of handling table. The handling table is controlled by Small Logic Controller (SLC). This press is mostly controlled via set of Programmable Logic Controllers (PLCs). - Ageing Furnace is controlled by (SLC).	The centralized control room is available where all the main control panels are installed. This press is controlled via set of Programmable Logic Controllers (PLCs). Ageing Furnace is controlled by (SLC).
Maximum Extrusion Line Length	45 m	55 m	60 m
Handling Table	Walking beams	Belt conveyor can move forward and backward	Belt conveyor can move forward and backward
Finish Saw Cut	8 m	9 m	10 m
Pullers	Run-out belt, without puller, manual control for stretcher	2 pullers, one of them is standby	2 pullers, one of them is standby

(*Sources:* [1](Mechatherm Manual, 2000), [2] (Gla Clecim, 1994), [3] (Elhaus Manaual, 1996))

By comparing the TP for the three presses, given in Table 5, it is shown that TP for press 3 is always higher than Press1 by an average of 32.41%; press 2 is higher than press 1 by an average of 21.18 % and press 3 is always higher than Press 2 by an average of 9.27 %. The higher percentage of improvement for TP of press 3 compared to Press 1 is due to the long period between their establishments (1996 and 1976). More technological changes occurred between 1976 and 1996 compared to the short period between 1994 and 1996. The modest improvement of 9.27% between TP of press 3 (1996) and press 2 (1996) is due to the short period between the establishments of each; there were fewer technological changes during this short period. This indicates that the technological changes have positive effects on the total productivity as shown in figure 4.

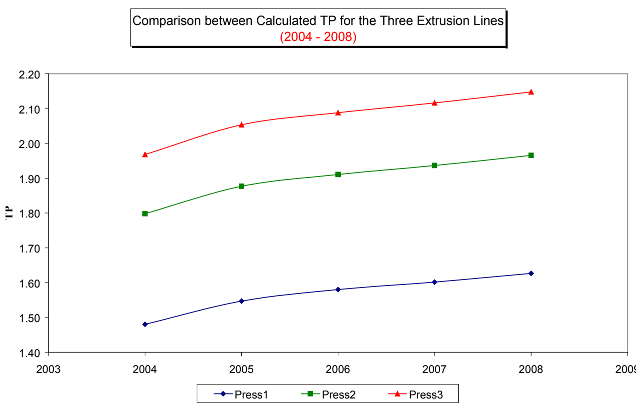

Figure 4: Technology Changes and Total Productivity for the Three Presses

(5) Technology Changes VS. Partial Productivity

(5.1) Materials Productivity

The effects of technology improvement on materials, labor, and energy productivities were investigated and analyzed. The analysis was carried out for the period from 1999 to 2008 for each of the three presses. The results, as illustrated in figure 5, show that annual materials productivity of press 3 was always higher than press 1 by an average of 22.85 %; press 2 was always higher than press 1 by an average of 14.37% and press 3 was always higher than press 2 by an average of 7.41 %. In addition, the results showed that materials productivity increased steadily between 1999 and 2008 for the three presses by an average increase of 4.175 %.

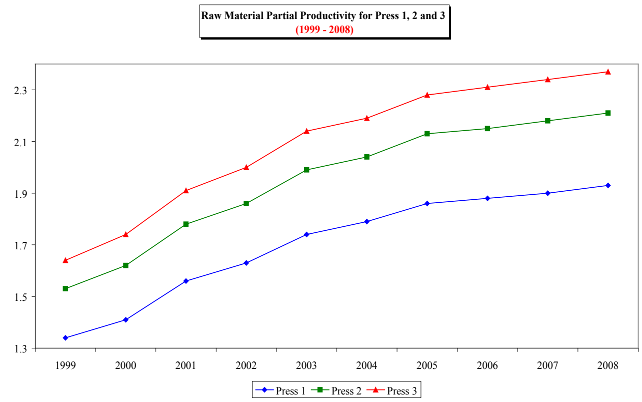

Figure 5: Raw Materials Productivity for Presses 1, 2 and 3 (1999-2008)

(5.2) Labor Productivity

The effect of technology improvement on labor productivity was evaluated; the results are presented in figure 6. Labor productivity of press 3 was higher than press 1 by an average of 117.33 %; press 2 was higher than press 1 by an average of 77.09% and press 3 was always higher than press 2 by an average of 22.72%. These results indicate that the labor productivity improved because the technology improved. In addition, the results also showed that labor productivity increased between 1999 and 2008 for the three presses by an average of 5.27%.

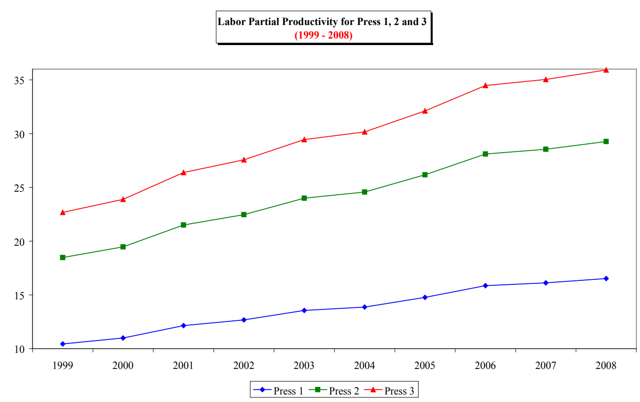

Figure 6: Labor Productivity for Presses 1, 2 and 3 (1999-2008)

(5.3) Energy Productivity

The effect of technology improvement on energy productivity was evaluated and the results are presented in figure 7. Energy productivity for press 3 was always higher than press 1 by an average of 22.85 %, press 2 was always higher than press 1 by an average of 14.37% and press 3 was always higher than press 2 by an average of 7.41%. These results indicate that the energy productivity improved as the technology improved. In addition, the results also showed that the value of energy productivity increased between 1999 and 2008 for the three presses with an average annual increase of 4.32%. Furthermore, it was observed that energy productivity in 2004 did not increase compared to 2003, there was in fact a negligible decrease. The investigation showed that this occurred because of some operational and production causes.

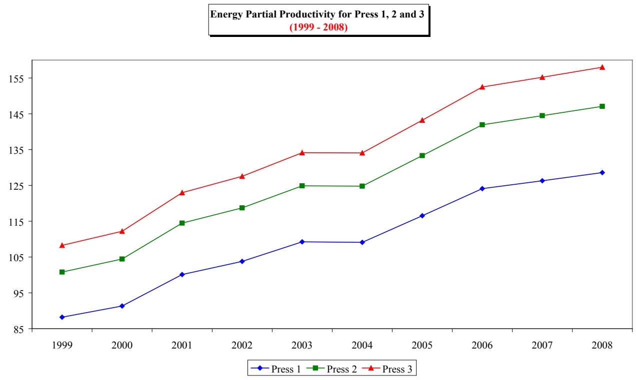

Figure 7: Energy Productivity for Presses 1, 2 and 3 (1999-2008)

(5.4) Maintenance and Repairs Productivity

The effect of technology improvement on maintenance and repair was evaluated and the results are presented in figure 8. The results showed that the maintenance and repair productivity of press 3 was always higher than press 1 by an average of 413.99%, press 2 was always higher than press 1 by an average of 133.94 % and press 3 was always higher than press 2 by an average of 119.71%. In addition, the results also showed that between 1999 and 2008 there was an average annual increase in the value of maintenance and repairs productivity for the three presses by 5.17%. These results indicate that the maintenance and repairs productivity improves as the technology improves.

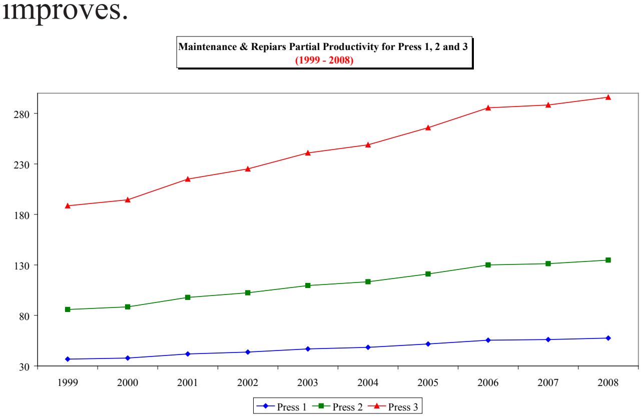

Figure 8. Maintenance and Repairs Productivity for Presses 1, 2 and 3 (1999-2008)

(5.5) Consumables Productivity

Figure 9 shows the differences between the consumables productivity for the three presses from 1999 to 2008. It is shown that consumables productivity of press 3 was always higher than press 1 by an average of 75.90%, press 2 was always higher than press 1 by an average of 50.11% and press 3 was always higher than press 2 by an average of 17.18%. The results further showed that the values of consumables productivity increased annually between 1999 and 2008 for the three presses by an annual average of 4.92%. These results indicate that consumables productivity improves when technology improves.

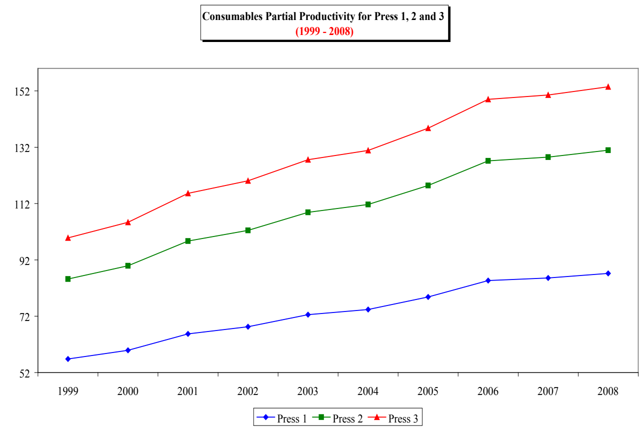

Figure 9. Consumables Productivity for Presses 1, 2 and 3 (1999-2008)

Discussion

The analysis of the partial productivities of presses 1 and 3, which reflect the technology specifications of 1976 and 1996, was carried out to highlight the effects of technology on partial productivities. In general, the results revealed that partial productivities improved dramatically as technologies were upgraded. Press 3 consistently showed improved productivity rates over press 1: for materials productivity the average improvement rate was 22.85%; for labor it was 117.33%, for energy 22.85%, for maintenance and repairs 413.99% and for consumables 75.9%.

The results of the comparisons between the three presses show that partial productivities for all the input factors were always higher for press 3, then press 2, then press 1. This indicates that technology has a positive effect on the partial productivity as well as on the total productivity. It is also noted that the partial productivities for all the input factors increased every year when they could be expected to decrease as the technology ages. The reason for this increase was the effect of the continuous labor and organizational learning.

The results shown in figures 5, 6, 7, 8 and 9 reveal that as the years progressed the differences between the partial productivities of press 1 compared to press 2, press 2 compared to press 3 and press 1 compared to press 3, were getting wider. This is because the technology of press 1 in particular has aged. It has been in use for 25 years and an investigation of the specifications of its technology revealed that press 1 was in the declining phase of its technology life cycle. In contrast, presses 2 and 3 were in the mature phase of their technology life cycles. Hence, the performance of presses 2 and 3 should be more than press 1, as was reflected in their productivity results. Likewise, press 2 is older than press 3. Hence, over time, the differences between their partial productivities were also increasing but to a lesser extent.

Conclusions

(1) A technology differentiation model was developed. This model is capable of evaluating the effects of the technological changes on the total and partial productivities of the three extrusion presses in one of the largest aluminum extrusion companies in the Arab countries. The three presses were established in 1976, 1994 and 1996 respectively, with varying levels of technologies.

(2) In order to develop the model, several steps were carried out. First, five factors were identified as having varying effects on the productivity of the three extrusion presses. Second, partial productivities and total productivity for the three presses in the period between 1999 and 2008 were calculated. This was achieved by collecting actual data for this period. Third, the relative importance of each input factor was determined. Fourth, the model was developed mathematically. The model was verified by comparing the model results with the calculated total productivity using the basic productivity concept. The differences were minimal.

(3) The technologies of the three extrusion presses were analyzed and compared. The technological changes that occurred within the 20 years between 1976 and 1996 were identified. The results showed that the technologies improved in both 1994 and 1996 compared to 1976, and to a lesser extent between 1994 and 1996.

(4) The model was implemented and the total and partial productivities of each of the three presses were measured for each year from 1999 to 2008. The results showed that over the ten years total productivity for press 3 was always higher than press1 by an average of 32.41%; press 2 was always higher than press 1 by an average of 21.18 %, and press 3 was always higher than press 2 by an average of 9.27 %. The results of the partial productivities measurements revealed that the partial productivities improved dramatically as technologies were upgraded. For example productivities related to materials, labor, energy, maintenance and repairs and consumables of press 3 improved by an average of 22.85%, 117.33%, 22.85%, 413.99% and 75.90% respectively compared to press 1. It is concluded that technology improvements have positive effects on the total and partial productivities and that the developed model is capable of evaluating the effect of technological changes on total and partial productivities.

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