OPTIMAL ECONOMIC PRODUCTION QUANTITY MODEL FOR A CNC NIBBLING PROCESS

BY

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ABSTRACT

Full Name : [Anas Al-Dawalibi]

Thesis Title : [Optimal Economic Production Quantity for CNC Nibbling Process]

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The research aims to solve a general production system of a single product (part) on a single machine with the objective of minimizing the total production cost including setup and holding costs and other related to manufacturing (machining) such as: cost of the part, quality cost, die maintenance cost, die life cost and opportunity cost. This research proposes a mathematical model to minimize the total cost associated with both manufacturing and production costs for the CNC nibbling process.

ملخص الرسالة

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يهدف هذا البحث لأيجاد حل رياضي لنظام إنتاج القطعة واحد بأستخدام آلة القضم بهدف تقليل التكلفة الإجمالية المرتبطة بتكاليف الإنتاج (EPQ) بما في ذلك تكلفة الإعداد والتخزين والتكاليف المتعلقة بتكاليف التصنيع (المعالجة) ومنها: تكلفة خسارة جودة القطعة ، وتكلفة صيانة أداة القطع ، وتكلفة العمر الافتراضي لاداة القطع وتكلفة التشغيل. ومع ذلك. سيقترح هذا البحث نموذجًا رياضيًا لتقليل التكلفة الإجمالية المرتبطة بكل من تكاليف التصنيع والإنتاج لعملية القضم .

CHAPTER 1

INTRODUCTION

The nibbling process is a separating manufacturing process by which the part is cut off using a cutting punch (Boschrexroth, 2014). Nibbling CNC machines are used in a machining process to produce individual cutouts in the required shape. Nibbling produces complex shaped parts that involve functional holes, which makes it more efficient and more practical in comparison with other cutting processes. Moreover, what makes this study unique is that it will focus on the production system of a single product (part) that is produced by using a CNC nibbling machine with the objective of minimizing the costs related to nibbling, as well as costs related to production (EPQ). As known, the traditional Economic Production Quantity (EPQ) - which uses other cutting processes - does not consider preventive maintenance in calculating EPQ, whereas the nibbling process - which uses the tool (die) - should take into consideration the element of preventive maintenance (grinding process). Periodic maintenance is essential for the die in the nibbling process as it will inevitably preserve the die for longer periods of time while also maintaining the high quality of the production. Also, in manufacturing processes that involve metal cutting, the production rate can be directly controlled by different cutting speeds that can be determined from the machine operator. However, most EPQ models that are related to metal cutting operations assume a fixed production rate and do not consider its impact on the quality of

cost. However, in nibbling, it is difficult to ignore the relation between production rate and scrap percentage. On the other hand, the CNC nibbling machine has a very high running cost compared to other cutting machines. Consequently, a trade-off policy was developed to determine the optimal production rate that balances between product quality cost and CNC machine running cost.

In general, classical Economic Production Quantity (EPQ) balances between the holding cost and the setup cost for each production cycle. In fact, the literature includes many different settings and extensions to improve the classical EPQ. These extensions include but are not limited to: variable holding cost (Alfares, 2012), integrated models (Ettaye et all, 2018); (Drexl and Kimms, 2010), variable machine rate, and product quality (AlDurgam, et al 2019), and different machine operations such as turning (Hui et al, 2010).

In contrast, this work aims to optimize the EPQ model specifically for the CNC nibbling process. Intuitively, the nibbling process is not explicitly stated in the literature, the Nibbling process is defined according to (Black & Kohser 2017, p. 428) as: a series of overlapping punches that are performed on the perimeter of the part, to separate the part from the raw material sheet. Moreover, the nibbling machine has different punching speed settings, providing that the time required for production relies on two factors: punching speed and die size (in this case rectangular die shape). A Rectangular die allows for the reduction of the redundant and out-of-shape edges, which would otherwise have to be scrapped if we used a circular die, naturally this minimizes or eliminates waste. Secondly, a rectangular die reduces the number of punches by covering a greater segment of the part with each punch.

This research is concerned with the production of a part that is manufactured by a CNC nibbling machine, where rectangular sheets are cut into standard sizes and shapes. The part will be used as a consumable for a general product. The part is produced for stocking and withdrawal from the stock as needed.

Ultimately, this research aims to solve a general production system of a single product (part) on a single machine with the objective of minimizing the total cost associated with production (EPQ) - which includes setup and holding costs, as well as costs related to manufacturing (machining) - which includes costs of the part quality loss, die maintenance cost, die life cost, and opportunity cost. The specific product (part) will be introduced as a case study. Additionally, this paper will optimize the following decision variables: batch size, punching speed, die diameter size. Thus, resulting in minimizing the above-mentioned costs for the nibbling process.

1.1 Research Objective:

The research objectives are to determine the optimal:

1. Batch size
2. Punching speed
3. Die diameter size
4. Number of maintenance interruptions for the selected die

Determining the above optimal objectives will minimize costs associated with the nibbling process listed as: part quality loss, die maintenance cost, die life cost, and opportunity cost. In addition to the EPQ holding and setup costs.

1.2 Research Questions:

The thesis is attempting to address the following research questions:

1. What is the optimal batch size?
2. What is optimal punching speed?
3. What is the optimal die size for the nibbling process?
4. What is the optimal periodic maintenance interruption number?
5. How much will the new model minimize the annual nibbling process cost?

1.3 Problem statement

A large sheet of metal is cut into pieces of given sizes using a nibbling process by a CNC machine. Parts can have different numbers of given holes as shown in figure 1. The production of the part starts with punching the functional holes in the part, followed by nibbling the boundaries of the part to separate the part from the raw material sheet. The time required to separate the part from the metal sheet depends on three factors: punching speed, die size, and die geometry (As mentioned in the Introduction). Accordingly, as the

die size increases, the number of the required punches decrease. Ultimately, reducing the time required and vice versa.

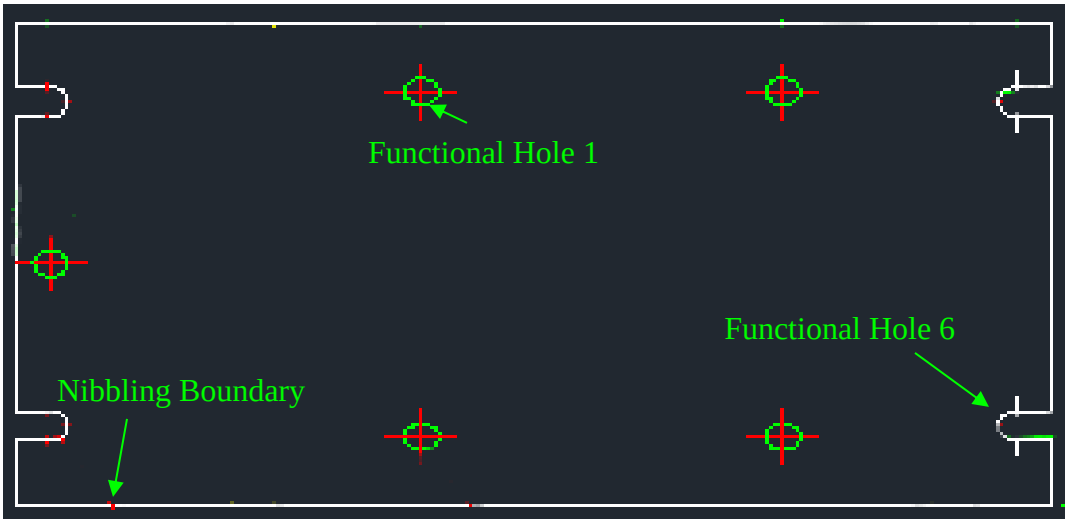

Figure 1: Nibbling process for fabricating the part showing the design of the part including the nibbling boundaries and holes location.

On the other hand, a higher punching speed will result in a higher quality cost, but a lower machine running cost. Accordingly, determining the ideal punching speed that will result in minimizing the cost associated with the machine running cost, product quality cost, and other EPQ costs is the prime objective of this thesis.

This research proposes a mathematical model to minimize the total cost associated with both manufacturing and production costs for the CNC nibbling process under the following assumptions:

- Demand is deterministic.
- Die size influences cutting speed, thus affecting the production rate as well.

- Rectangular dies are widely used, both to reduce waste and allow the covering of a greater segment of the part with each punch.

- The time for punching the functional holes is negligible since it requires a very small number of punches compared to the circumference of the part.

- Practically, punching speed is changed stepwise (moving in integers). On the other hand, and for our purposes, we assume a continuous punching speed.

- Preventive maintenance will be applied to the die (grinding process).

- Precise time segments/schedule need to be allotted for die preventive maintenance (grinding) for each production cycle.

CHAPTER 2

[LITERATURE REVIEW]

The literature addresses the problem of minimizing the processing time related to the punching operation and different solution approaches are proposed for determining an optimal punch sequence (Kumar and Veeramani, 1995). However, Veeramani and Kumar, (1998) addressed the problem of minimizing the required time for the nibbling operation for a given nested parts order, where they try to minimize the die (tool) travel time within the sheet. Veeramani and Kumar, (1995) concluded that to minimize the processing time, punching operations must be completed first followed by nibbling part boundaries. Further

literature review concerning costs related to the nibbling process is discussed in the following sub-sections.

2.1 Part Quality

A very small number of EPQ models in the literature consider the production rate and most of those models ignore the impact of the production rate on the quality cost. Hui et al, (2001) considered in their research the effect of deviation from the targeted roughness and dimensions in the quality, but this model did not consider EPQ. Owen and Blumenfeld, (2008) studied the effect of cutting speed on non-confirming parts as a result of increasing the production rate. This relationship shows that the fraction of nonconforming products is a function of production rate (as the production rate increases nonconforming products increase and vice-versa). Furthermore, Xu and Cao, (2015) proposed a tool maintenance model using the logistic function based on getting the best trade-off between tool maintenance cost and product quality loss that is associated with the die wearing. Specifically, the logistic function is primarily proposed by (Verhulst, 1838), researchers have used the logistic function to mimic the growth events in which these events can be limited by some constraints (Tsoularis and Wallace, 2002). Obviously, in our case, the product/part failure rate growth limitation is equal to one, as one is the highest value for the failure rate. Additionally, in the literature Taguchi loss function has been used widely for estimating the product/part loss such as: (Jeang and Yang, 1992); (Makis, 1995); (Jeang,1998); (Hui et al, 2001); (Zhang et al, 2009); and (Hrnčiar and Budaj, 2016).On other hand, Salameh and Jaber, 2000 developed an EOQ model which assumed that non-conforming products will follow a certain probability distribution under 100% inspection. (Sana, 2016) developed this model where the fraction of non-conforming products depends

on the production rate. Many EPQ model with imperfect quality has been provided in the literature such as: (Wee et al, 2007); (Recently, Oztu¨rk et al, 2016) ; (Yassine et al, 2012) and (Papachristos and Konstantaras, 2006)

The study by Y. V. Hui, L. C. Leung & R. Linn (2001) examined the cost of machining quality. According to the authors, there are a lot of papers that studied machine tool economics; however, cost machine quality did not receive enough attention. For this reason, in this paper, the main objective of this study was to emphasize the importance of quality cost and how can the absence of the quality factor lead to misguided machining practices. Furthermore, using the economic model for single-pass turning that they have developed, the authors represented the quality cost of tool-cutting in terms of the deviation of target roughness and deviation from target dimension. In addition to that, they have examined the trade-offs between the quality cost and other cost factors, the impact of quality machining, and the modeling of other types of machining operations. Moreover, and as a result of this work, the authors found out that the single-pass operations are not practical, and that multi-pass machining can be more efficient when put in real-world use. This is because of the need for multi passes to achieve the targeted finish quality for a number of cutting operations.

On the contrary, the paper by D. Veeramani & S.Kumar (1998) is mainly focused on finding a solution to the nibbling problem, referred to as (NIB). The proposed solution in the paper is primarily associated with minimizing the total time of a nibbling operation that is designated for a particular sheet configuration. Originally, the nibbling problem stems

from two main sub-problems: 1) the part sequence determination (PSD) problem, 2) the pierce point determination (PPD) problem. After all, finding a solution to the nibbling problem depends on finding a prior solution to the PSD and PPD sub-problems, which together comprise the NIB problem. Two approaches were presented to solve the nibbling problem (NIB), namely COUPLED and HIERARCHICAL. In the two mentioned approaches, the 2-Opt procedure was employed to solve the PSD sub-problem, whereas the Vertex and Midpoint based Focused Sampling (VMFS) procedure was employed to solve the PPD sub-problem. Having the two procedures employed together will ensure a successive solution of sub-problems (PPD & PSD); consequently, solving the main nibbling problem (NIB). To test the proposed approaches, two cases of the nibbling problems were examined. The first case displayed independent parts on the sheet, while the other case displayed some parts with shared boundary edges. The coupled solution approach used in the nibbling problem can be effectively used in other coupled sub-problems as well, to enable the generation of control decision frameworks and unified processes.

2.2 Periodic Maintenance Plan Cost for the (Tool/Die) :

As mentioned earlier, EPQ model was studied under different conditions and circumstances, but most of these papers assume that production planning never allocates time for any maintenance procedures. For instance, (Rosenblatt and Lee 1987) studied the joint control of production cycle and maintenance by inspection, where they considered production lot size and the number of inspections per cycle as decision variables. Additionally, (Ben-Daya 1999) developed a joint model of EPQ that integrates the control chart with the optimal maintenance plan. Furthermore, (Salameh and Jaber 1997) added to

the EPQ model the idea of preventive maintenance in order to perform a regular maintenance interpretation for each production cycle. Certainly, the preventive maintenance (grinding) for the die in the nibbling process is essential as it improves the die condition and hence minimizes the part quality loss during production. Accordingly, in this research, the parodic maintenance time will be identified and the maintenance cost for each production cycle is optimized.

2.3 Die Life Cost

Regarding cutting operations, Al-Fawzan and Al-Ahmari (2004) developed a relationship that shows that the tool life decreases as the production rate increases. However, in the nibbling process, the die life is a function of the number of punches.

2.4 Opportunity Cost

The effect of the batch size on the optimal cutting speed was first addressed by (Wysk et a, 1980) where they found the lot size quantity by finding the optimal cutting speed. According to (Kalpakjian S and Schmid S ,2014) cutting speed is a key decision variable in machining economics, and it has a direct link to the production rate (Glock, 2010) considered the production rate as a decision variable in determining the single-product EPQ, where his work shows how the production rate can play important rule on the optimal quantity production quantity. Al-Durgam et al. (2019) stated that a higher production rate can decrease machine running time, which in turn will reduce the machine running cost. On the other

hand, increasing the machine speed has an impact on other costs such as: optimal production quantity, quality, and tool costs.

CHAPTER 3

Mathematical Model Development

The EPQ model, in general, assumes a yearly demand for the part/product, and the goal is to find the best trade-off between inventory holding cost and production setup cost (as these two costs are associated with batch size. Where the batch size is the number manufactured per production run). However, this research will be more practical and specialized (for the nibbling process). Moreover, other costs will be added to the model (as stated above) such as: part quality loss, tool life cost, and maintenance cost. In this section, each of these costs will be discussed.

3.1 Relation Between Punching Speed and Production Rate in Nibbling Process:

The first step to develop a mathematical model for the nibbling process is to identify the relationship between machine punching speed and production rate

Notations:

Indices

$\{1, \cdots I\}$: Number of dies (tools)

Decision Variables:

x_i: Equal to 1 if die i is selected for a punching, 0 otherwise

v: Punching Speed (punch / min)

Parameters

D: Part demand (part/year)

d_i: the diameter of the die i (mm)

r: Production rate (part/min)

v_{max}: Maximum punching speed (punch/min)

pr: Perimeter length of the part (mm)

w: Part width (mm)

l: Part Length (mm)

n: Number of punches required to separate the part from the metal sheet

C_T: Cutting time (min / part)

To find the relation between the punching speed and the production rate in the nibbling process, the time needed to separate the part from the metal sheet should be calculated first. As a second step, the requird number of punches should be calculated by finding the part's

perimeter. Then it should be divided by the die diameter size to identify the actual number of punches required to separate the part from the metal sheets.

$$n = \frac{pr}{\sum_{i \in I} x_i d_i} \tag{3.1}$$

The rectangular part perimeter is:

$$pr = 2(w + l) \tag{3.2}$$

Therefore, the cutting time per part can be calculated as:

$$C_T : \frac{n}{v} \tag{3.3}$$

Accordingly, the production rate can be found as:

$$r = \frac{1}{C_T} \tag{3.4}$$

Finally, by plugging equations (3.1) and (3.3) into equation (3.4) we will get the relation bunching speed and production rate in nibbling:

$$r = \frac{v \sum_{i \in I} x_i d_i}{Pr} \tag{3.5}$$

Table 1 shows examples of different dies sizes in which they affect the number of punches and cutting time.

Table 1: Number of punches and cutting time, where *V*= 65 punch/min

Die Size(mm)	thickness (mm)	Length (mm)	Width (mm)	Perimeter	# of punch needed	Cutting Time
50 mm	2	943.3	507	2901.6	58	0.89
40 mm	2	943.3	507	2901.6	72.54	1.178
25 mm	2	943.3.	507	2901.6	116	1.78
20 mm	2	943.3	507	2901.6	145	2.23

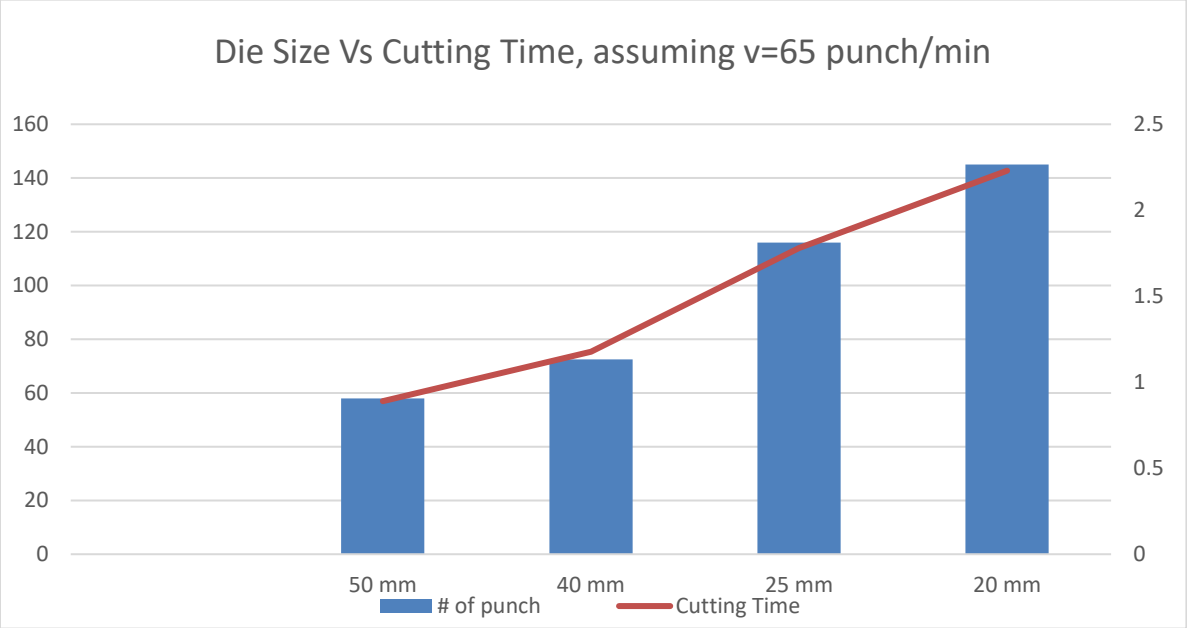

Figure 2: Die Size Vs Cutting time assuming v=65 punch/min

3.2 Setup Cost for the Batch Size

The setup cost includes costs incurred to configure a machine for a production run. Such as: preparing dies, preparing parts' drawing, machine programming, and adjusting metal sheets inside the CNC machine. However, this cost is considered a fixed cost of the

associated batch which means that the cost will be divided over the number of parts produced within the batch for each production cycle.

Notations:

Decision Variable

y: Number of units produced per unit cycle, batch size (part/year)

Parameters:

A: Setup cost ($/ setup), assuming that a setup cost is incurred each time a batch is produced

D: Part demand (part/year)

d_i: Die dimeter size (mm/punch)

For the set-up cost, it will be assumed that a setup cost will take place whenever a batch is produced so the yearly setup cost simply is:

$$\frac{A}{y} \times D \tag{3.6}$$

3.3 Holding Cost with Regular Maintenance (grinding)

Notations:

Indices

$\{1, \cdots I\}$: Number of dies (tools)

Decision Variables:

x_i: Equal to 1 if die i is selected as punching die, 0 otherwise

v: Punching Speed (punch / min)

y: Number of units produced per unit cycle, batch size

j : Number of maintenance (grinding process) interruption

Parameters:

E(A) the average inventory level per production cycle

r Production rate (part/min)

A: Setup cost ($/ setup), assuming that a setup cost is incurred each time a batch is produced

D: Part demand (part/year)

t_g Fixed period of time to do the maintenance (grinding process)

G Number of units in stock at the end of grinding process

h Holding Cost

L The period of time starting from the last die maintenance (grinding process)

As mentioned above, the nibbling process requires regular preventive maintenance for the punching die to know the number of maintenance interruptions that are needed for each production cycle which will result in improving the condition of the die as well as preventing any die failure. Moreover, it is assumed that the grinding process will take a

fixed period of time. Knowing that the production cycle is defined as the time required to meet the batch size. In practice, the production in the nibbling process needs periodic maintenance to be continuously scheduled at a fixed time interval. As shown in figure 3, when the machine reaches the maintenance time, the inventory level will start decreasing by the demand rate. On the contrary, when maintenance time is over, the machine will increase by the inventory level subtracted from the demand rate, assuming that the production rate is greater than the demand rate. The following figure explains the production cycle batch as a result of a regular maintenance interruption.

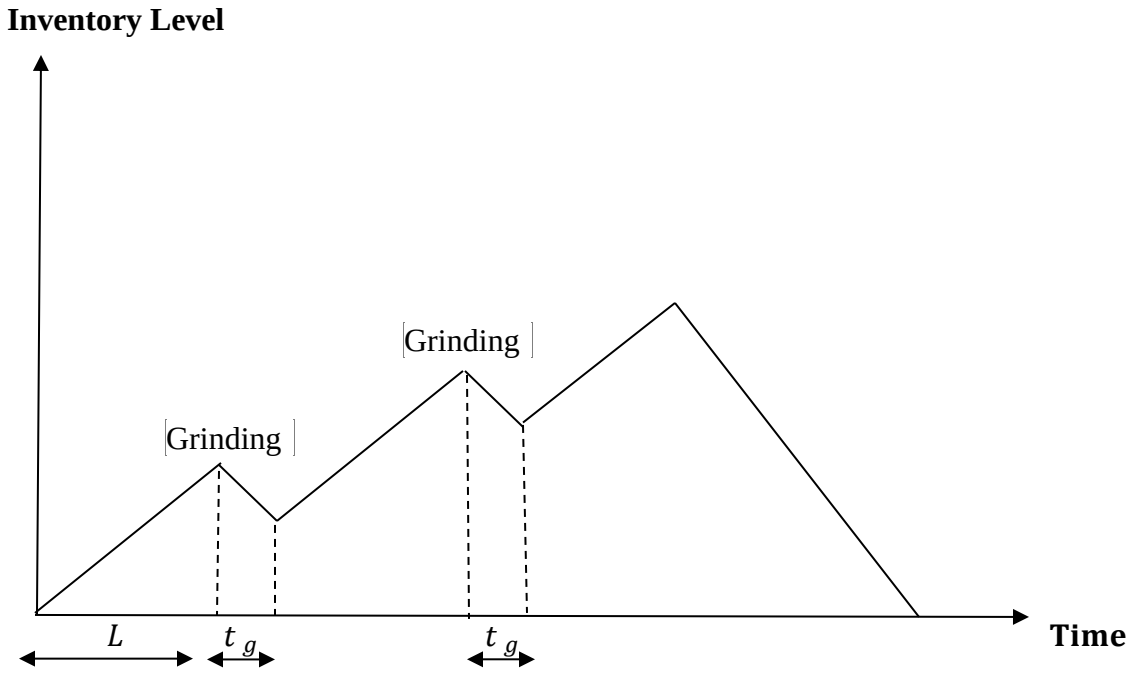

Figure 3: One production cycle with grinding maintenance interruption.

It is observed from figure 3 that the average inventory level per production cycle is the area under inventory level E(A). Accordingly, the $\text{holding cost} = \text{part holding cost} \times$ E(A) and j is the number of maintenance interruptions. Consequently, the maintenance = j $\times$ $die\ mantinance\ cost$, where die maintenance (grinding) cost is a function of the die size.

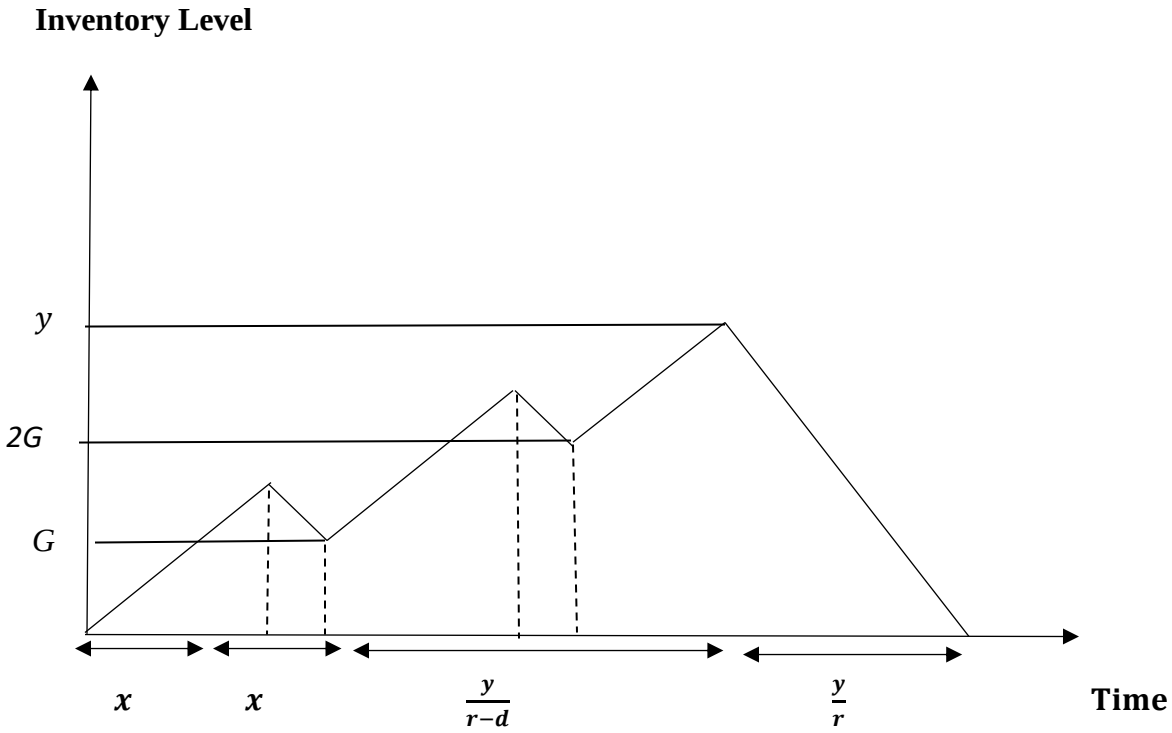

Figure 4: The inventory level in different grinding interruption periods for one production cycle**.**

From figure 3, we can see that the first interruption of production occurs at the end of time L where from figure 4 the inventory level $\mathrm{I(t)} = (\mathrm{r} - \mathrm{D})\mathrm{L}$. The maintenance period is fixed, and it lasts t_g minutes, during the die maintenance and replacement. For the period $L + t_g$, the inventory level reduces to G units, where $\mathrm{G} = \left[(\mathrm{r} - \mathrm{D})\mathrm{L} - \mathrm{D}.\mathrm{t_g}\right]$. We assume that the startup inventory at the beginning of each cycle is zero. Also, this project assumes no shortages, $t_g \leq \frac{y}{D}$. Let h be the holding cost per unit time, $\mathrm{C_g}$ as the maintenance and resetting cost per maintenance interruption, and i as the number of maintenance interruptions in one production cycle, where i is an integer value.

From figure 4, the average inventory level per production cycle is the area under the inventory level curve, see figure 4, and from the similarity of triangles, we get $x = \frac{t_g}{(1-D)}$

$$E(A) = Big\ Triangle + (\sum i\ Parallelogram\ area + \sum i\ triangle\ ) \quad (3.10)$$

$$E(A) = \frac{y}{2}.\left(\frac{y}{r-D} + \frac{y}{D}\right) + \left(G.x + \frac{x.D.t_g}{2}\right) + \cdots + \left(j.Gx + \frac{j.x.D.t_g}{2}\right) \quad (3.11)$$

$$E(A) = \frac{y^2}{2d(r-D)} + jGx + \frac{jxDt_g}{2} \quad (3.12)$$

Now, we are substituting in equation (3.12) $G = \left[(\mathrm{r} - \mathrm{D}).\mathrm{L} - \mathrm{D}.\mathrm{t_g}\right]$ and $x = \left[\frac{t_g}{\left(1-\frac{D}{r}\right)}\right]$ in the above equation and we get:

$$E(\mathrm{A}) = \frac{\mathrm{y}^2}{2\mathrm{D}.(\mathrm{r}-\mathrm{D})} + \mathrm{i.r.L.t_g} - \frac{\mathrm{D}.(\mathrm{i.t_g})^2}{2\left(1-\frac{\mathrm{D}}{\mathrm{r}}\right)},\ \text{Where } r = v.\frac{\sum_{i\in I} x_i d_i}{pr}\ \text{in nibbling Process}$$

The total holding cost per cycle for the j grinding maintenance interruption is

$$HC_j = h * \left[\frac{\mathrm{y}^2}{2\mathrm{D}.(\mathrm{r}-\mathrm{D})} + \mathrm{i.r.L.t_g} - \frac{\mathrm{D}.(\mathrm{i.t_g})^2}{2\left(1-\frac{\mathrm{D}}{\mathrm{r}}\right)}\right], \text{Where } r = v.\frac{\sum_{i\in I} x_i d_i}{pr}\ \text{in nibbling process}$$

And, the total cost per cycle for j grinding maintenance interruption is

$$MC_j = j.\sum_{i\in I} x_i\, C_g \quad (3.13)$$

So, the total cost for the EPQ for the j maintenance interruption, TC_{EPQ} is the sum of the total setup cost per cycle, total holding cost per cycle, HC_j, and total maintenance cost per cycle, MC_j

$$TC_{EPQ} = setup\ cost + HC_j + MC_j \quad (3.14)$$

$$TC_{EPQ} = \frac{A}{y} \times D + h * \left[\frac{\mathrm{y}^2}{2\mathrm{d}.(\mathrm{r}-\mathrm{D})} + \mathrm{j.r.L.t_g} - \frac{\mathrm{D}.(\mathrm{i.t_g})^2}{2\left(1-\frac{\mathrm{D}}{\mathrm{r}}\right)}\right] + j.\sum_{i\in I} x_i\, C_g \quad (3.15)$$

3.4 Quality Cost Estimation:

Notations:

Indices

$\{1, \cdots I\}$: Number of dies (tools)

Decision Variables:

x_i: Equal to 1 if die i is selected as punching die, 0 otherwise

y: Number of units produced per unit cycle, batch size

v: Punching Speed (punch / min)

Parameters:

p Fraction of nonconforming products in a batch

r Production rate (part/min)

r_{max}: Maximum Production rate (part/min)

d_i: Die dimeter size (mm/punch)

Quality cost is the cost of producing nonconforming products, which is related to the machine speed. Increasing machine speed will reduce the time the machine runs, and this will result in increasing both batch size and the number of non-conforming products.

(Owen and Blumenfeld, 2008) suggested a relation to expressing the fraction of nonconforming parts, p, as a function of the production rate, where

$$p = k\left(\frac{r}{r_{max}}\right)^{a} \tag{3.16}$$

The parameters a and k are process-dependent. This relation assumes that the nonconforming is proportional to the production rate.

Recalling that D products are produced per year, where at each production cycle, py nonconforming units are produced. Hence, the annual number of nonconforming products is pD. Using this relationship, the number of nonconforming products per year is

$$\text{nonconforming products per year} = k\left(\frac{r}{r_{max}}\right)^{a} \times D \tag{3.17}$$

By plugging the production rate in equation (3.17) we have:

$$\text{nonconforming products per year} k\left(\frac{v\sum_{i\in I} x_i d_i}{v_{max}\sum_{i\in I} x_i d_i}\right)^{a} D \tag{3.18}$$

3.5 Die Life Estimated Cost:

n: Number of punches that is required to separate the part from the metal sheet

F: Number of punches a die can make before failure

y: Number of units produced per unit cycle, batch size

C_i: Purchasing cost of die i

There are many models used to estimate tool life cost for different types of the machining process. In this study, the cost is estimated as follows:

$\left[\frac{\text{total \# of punches consumed the demand}}{\text{number of punches the die can make before failure}}\right] * die\ Purchasing\ cost$. The purchasing cost is directly proportional to the die diameter size.

So, die life cost is:

$$\frac{n.D}{F} . \sum_{i \in I} x_i C_i \tag{3.19}$$

Where $n = \frac{pr}{\sum x_i d_i}$

3.6 Opportunity Cost:

Notation:

Indices

$\{1, \cdots I\}$: Number of dies (tools)

Decision Variables:

x_i: Equal to 1 if die i is selected for the punching process, 0 otherwise

v: Punching Speed (punch / min)

Parameters:

C_0: Machine Opportunity cost ($/ min)

D: Part demand (part/year)

d_i: Die dimeter size (mm/punch)

Finally, the opportunity cost of the machine is associated with the machine run time

$$\frac{D.c_0}{r} \tag{3.20}$$

where $r = v.\frac{\sum_{i\in I} x_i d_i}{pr}$, $in\ nibbling\ process$

plugging r in equation 3.22 we will have the opportunity cost of nibbling machine

$$\frac{D.c_0}{v.\sum_{i\in I} x_i d_i} \tag{3.21}$$

3.7 Objective Function:

The objective of the model is to determine the function that minimizes the total cost of production. This can be expressed as follows.

Minimize Total Cost Per Unit Time:

Notations:

Indices

$\{1, \cdots I\}$: Number of dies (tools)

Decision Variables:

x_i: Equal to 1 if die i is selected as punching die, 0 otherwise

v: Punching Speed (punch / min)

j number of maintenance (grinding process) interruption

y: Number of units produced per unit cycle, batch size

Parameters

A: Setup cost / min

D: Part demand (part/year)

t_0 The first stage, when the failure rate is constant (see the figure below)

pr perimeter of the part (mm)

d_i Die diameter size (mm/punch)

n: Number of punches required to separate the part from the metal sheet

F: Number of punches made by the die before failure

C_i: Die i purchasing cost

C_0: Machine Opportunity cost ($/ min)

v_{max}: Maximum possible punching speed (punch/min)

s_1: Selling price of conforming products ($/product)

s_2: Selling price of nonconforming products ($/product)

3.8 Forumulation:

The objective function of minimizing the cost per year can be expressed as follows:

$$\boldsymbol{Min\ Total\ Costs} = EPQ\ Cost + Nibbliing\ Process\ Costs =$$

$$Setup\ cos\ + Holding\ Cost + Die\ mantinance\ cost + Part\ qualiry\ loss\ cost + Die\ Life\ Cost + \text{Opportunity}\ cost$$

$Where$

$$Setup\ costs = \frac{A}{y} \times D$$

$$Holding\ costs = h * \left[\frac{y^2}{2D.(r-D)} + \text{ i. r. L. } t_g - \frac{D.(i.t_g)^2}{2\left(1-\frac{D}{r}\right)}\right]$$

$$Die\ maintenance\ cost\ (Gridding) = j.\sum_{i\in I} x_i\, C_g$$

$$Quality\ \ costs\ = k\ (\frac{v\sum_{i\in I} x_i d_i}{v_{max}\sum_{i\in I} x_i d_i})^a D(s_1 - s_2)$$

$$Die\ life\ cost = \frac{n.y}{F}\ .\sum_{i\in I} x_i\, C_i\ , where\ n = \ \frac{pr}{\sum x_i\, d_i}$$

$$\text{Opportunity } cost = \ \frac{D.c_0}{v.\sum_{i\in I} x_i d_i}$$

Total Cost $= \frac{A}{y} \times D + h * \left[\frac{y^2}{2D.(r-D)} + \text{ i. r. L. } t_g - \frac{D.(i.t_g)^2}{2\left(1-\frac{D}{r}\right)}\right] + k\ \left(\frac{V.d}{V_{max}.}\right)^a D(s_1 - s_2) +$

$\frac{n.y}{F}\ .\sum_{i\in I} x_i\, C_i + \frac{D.c_0}{v.\sum_{i\in I} x_i d_i}$

With the following Constrains:

$$v.\frac{\sum_{i\in I} x_i d_i}{pr_i}\ \ \geq\ D \qquad (1)$$

$$v.\sum_{i\in I} x_i d_i \leq v_{max}.d_{max} \qquad (2)$$

$$\sum_{i=1}^{I} x_i = 1 \qquad (3)$$

$$x_i = 0\ or\ 1 \quad for\ all\ i \in I \qquad (4)$$

$$x_i, y, v, j\ \geq 0 \qquad (5)$$

Constrain (1) ensures that the demand is fulfilled. Constrain (2) ensures that the production rate does not exceed the machine capacity. Constrain (3) ensures that only

one die is selected for the nibbling process at any period of time. Constrain (4) is the binary constraint. The last Constrain (5) is the non-negativity constraint.

3.9 Model the Problem Without Mantinance Interuption:

The only difference we have here is in the holding cost. Figure 10 shows inventory buildup during a cycle of length (T) and a batch size (y). The problem is to select the optimal values of y and r that minimize the total production cost per unit time. However, $T = y/D$ and production cycle time $T_P = y/r$.

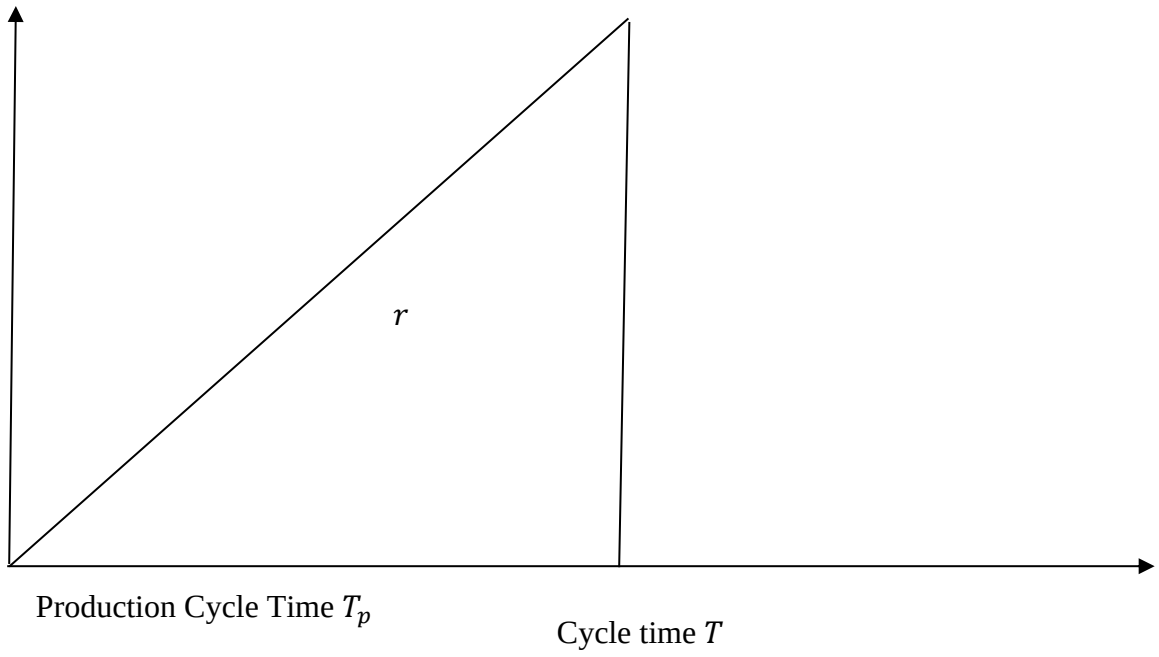

Figure 5: Inventory level without maintenance interruption

From figure10, the average inventory level per production cycle is the area under inventory level.

$E(A) = Big\ Triangle\ Area$

$E(A) = 0.5 \times y \times (\frac{T_p}{T})$

$$E(A) = \frac{y.D}{2r}$$

The total holding cost per cycle for maintenance interruption is:

$$Holding\ cost = \frac{h.y.D.}{2r}$$

Our model for the cost reduces to the following:

Total Cost= $\frac{A}{y} \times D + \frac{h.y.D}{2r} + k\ \left(\frac{V.d}{V_{max}.}\right)^a D(s_1 - s_2) + \frac{n.y}{F}\ .\sum_{i\in I} x_i\ C_i + \frac{D.c_0}{v.\sum_{i\in I} x_i d_i}$

<u>With the following Constrains:</u>

$$v.\frac{\sum_{i\in I} x_i d_i}{pr_i} \ \geq\ D \qquad (1)$$

$$v.\sum_{i\in I} x_i d_i \leq v_{max}.\, d_{max} \qquad (2)$$

$$\sum_{i=1}^{I} x_i = 1 \qquad (3)$$

$$x_i = 0\ or\ 1 \quad for\ all\ i \in I \qquad (4)$$

$$x_i, y, v, j\ \geq 0 \qquad (5)$$

Constrain (1) ensures that the demand is fulfilled. Constrain (2) ensures that production rate does not exceed the machine capability. Constrain (3) ensures that only one die is selected for the nibbling process. Constrain (4) is the binary constraint. And the last Constrain (5) the non-negativity constraint.

CHAPTER 4

Case Study

This study is carried out on an electric production company that produces electric power distribution products. The company adopts make-to-order, where production is not carried out until a confirmed order is received. However, each product requires fabrication of different customized parts. One of these parts has a standard specification and it is shared in all the company's products. Accordingly, the company decided to perform a make-to-stock policy for this standard part as its consumption rate is high. Therefore, this research will focus particularly on that specific fabricated part (figure5, illustrates the part's drawing). In fact, the standard part is produced using a CNC Nibbling Machine.

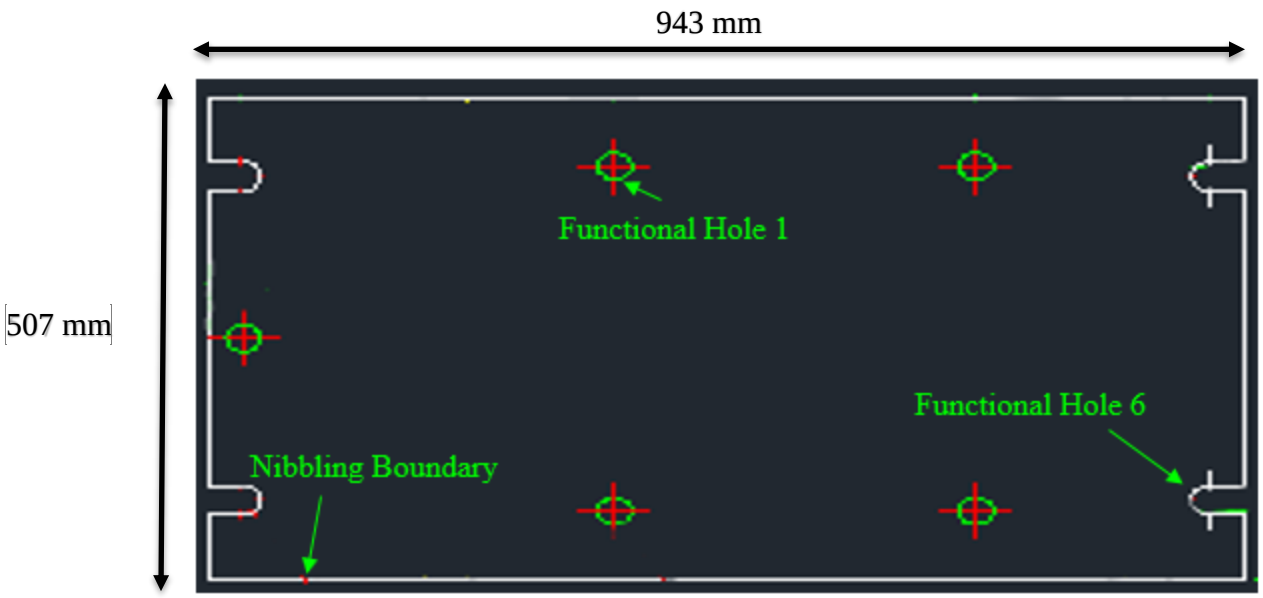

Figure 6: The Standard Fabrication Part

The CNC machine will run for a maximum of 8 hours, L = 8 before it is interrupted for one hour , t_g = 1, for maintenance (assuming that the machine or system needs no more than one hour in a year to be maintained and that one year = 8,760 hours) the tool life is $F = 1000000\ punches$ in a year.

The parameters of the case study are shown in tables 2 and 3.

Table 2: Case Study Parameters

A	$(10\ SR\ /\ setup)$	a	1
C_0	(2 SR / min)	k	0.4
D	40000 (parts/ year)	S1	0.5
h	(part/year)	S2	0.25
v_{max}	(100 punch/min)		

Table 3: Parameters different types of dies

Die size	Maintenance cost	Purchasing Cost
75 mm	50 SR	4000 SR
50 mm	50 SR	2500 SR
25 mm	50 SR	1500

4.1 Result and Disscussion:

This problem can be solved through different optimization software such as AMPL, GAMS, and Excel solver. However, in this paper, we used Excel solver, where we found that the total cost per year is 6768.26 SR, and the optimal decision variables are: $y^* = 1852\ part$, $v^* = 75$, $j^* = 1$, $x_i = Die\ number\ 2\ which\ is = 50\ mm$. It means that we need a die of $50\ mm$ diameter with a speed of 75 punch/min and 1 maintenance interruption

Table 4: Number of punches and cutting time, where v^*= 75 punch/min

Die Size(mm)	t (mm)	L (mm)	W (mm)	1/2 perimeter	Perimeter	# of punch	Cutting Time	Cycle Time*
50	2	943.3	507	1450.8	2901.6	58	0.77	0.0402 year

Where the optimal cycle time is: $\frac{y^*}{D} = 0.0402\ year$ and the optimal production is $= \frac{y^*}{r \times MPY} = 0.00483\ year$. However, in this example, 12% of the cycle time is used for production and the machine is idle 88% of the time.

4.2 Sensitivity Analysis

To show the effect of setup on the optimal solution, the problem is solved for different values of setup costs, resulting in an increase of the total cost as shown in figure 6.

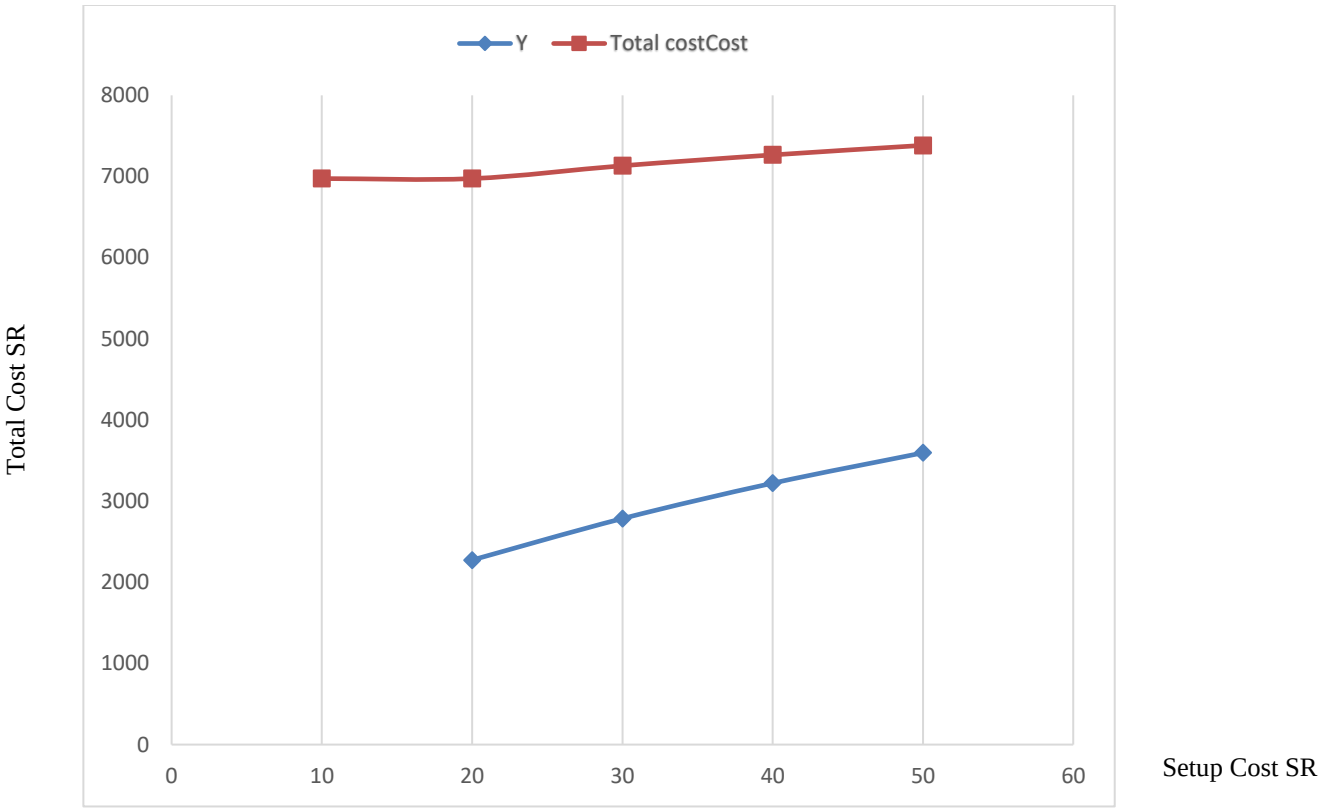

Figure 7: Effect of the setup cost

Similarly, the optimal solution was found for different holding costs as an increase in the total costs as shown in figure 7.

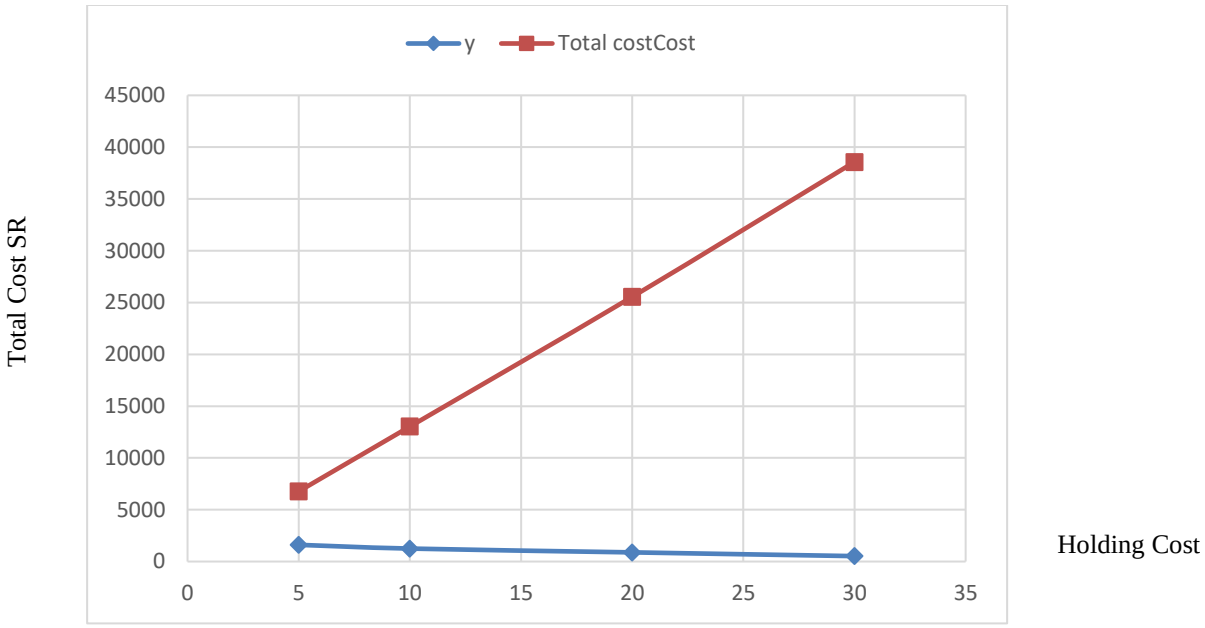

Figure 8: Effect of the changing holding cost

Moreover, when the optimal production quantity decreases, the cutting speed and the fraction of nonconforming products increase.

However, increasing C_0 is compensated for by increasing v^* to reduce the time when the machine is running. This will result in increasing both $y^*$and nonconforming product number (quality cost).

Finally, the traditional inventory control management does not consider a preventive maintenance schedule in calculating the economic manufacturing quantity. In our case, we restrict preventive maintenance to be within 8 hours of continuous operation. Figure 8 shows that the optimal number of preventive maintenances is within the production cycle.

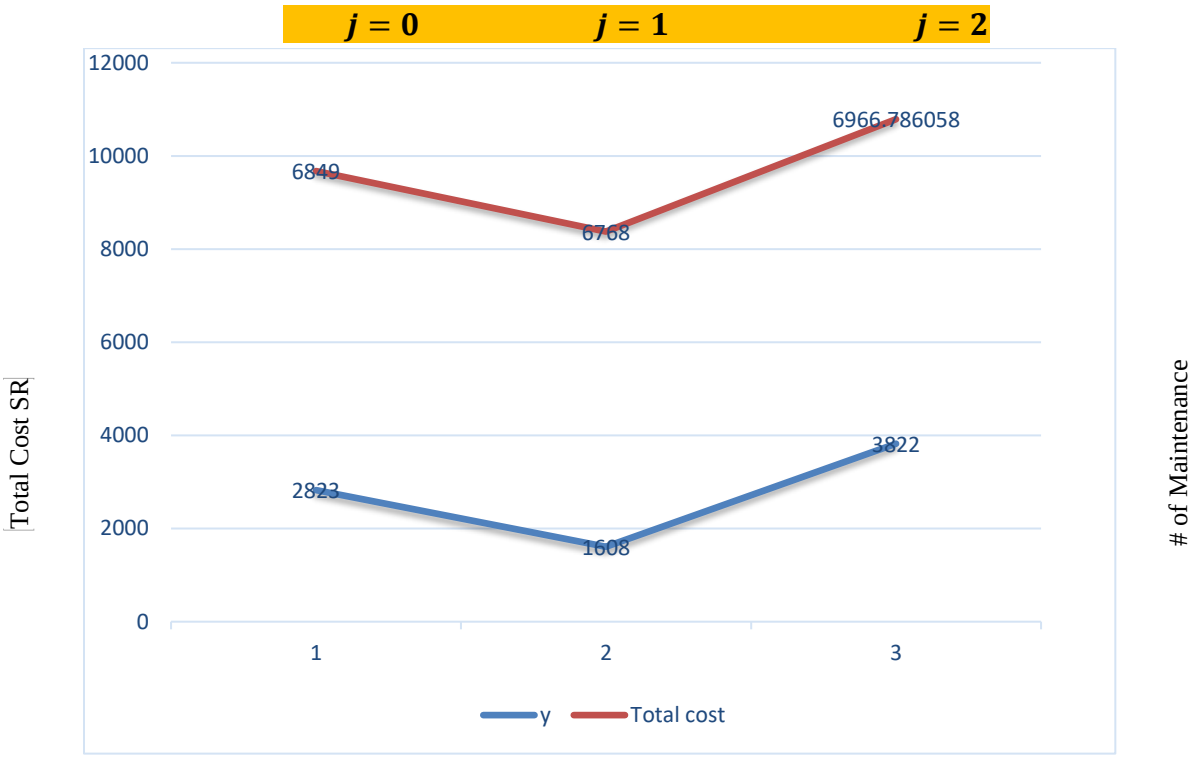

Figure 9: The total cost per unit time for different j grinding maintenance interruptions.

4.3 Result for Modeling the Problem Without Mantinance

Intruption:

Using Excel solver, we found the total cost per year which is equal to 6840, and the optimal decision variables are: $y^* = 2823$, $v^* = 75$, $x_i =$

$Die\ number\ 2\ which\ is = 50\ mm$

CHAPTER 5

Conclousion

This research aims to determine the optimal batch size, punching speed, die diameter, and maintenance periodic interruptions to minimize costs associated with metal sheet cutting by the nibbling process. Costs include part quality cost, die maintenance cost, die life cost, and opportunity cost in addition to the EPQ holding and setup costs. A comprehensive mathematical model is developed representing all costs with respect to different parameters of the problem. The model was solved using excel solver. Finally, a case study is used to demonstrate the resulting model in minimizing manufacturing costs.

5.1 Model Limitation:

The model limitations are summarized in the following points:

- This model is not applicable for multiple products or parts; however, this research only considers a single product
- Functional holes are neglected in our model.
- This model is considering a special case, as it assumed that the standard fabrication part will be produced only by a single CNC machine.

5.2 Further Work:

The thesis work can be extended as the following:

- Extend the model to the multi-item case where different parts of different specifications and quantities are produced.
- Extend the model to a case where there is more than one machine required to produce parts. The machine could be of the same capacity or different capacity.
- Extend the problem to a case that includes further operation in addition to the cutting operation. This may include punching holes, for example.
- Extend the case where the demand is stochastics with different probabilistic models and different stochastic machine availability models.

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- ***Confrence Publication :***

1. Anas Dawalibi, Ibrahim H. Al-Dali and Bandar A. Alkhayyal " Use of Fractional Factorial Design and AHP to Determining the Best Marketing Strategy for a Lubricant Company", *First IEOM GCC Riyadh Conference 2019*
2. Anas Dawalibi, Asim Sabatto, Irfan Manarvi, "Design and Development of a Praying Chair for Disabled Persons affording convenience to others", *2017 9th IEEE-GCC Conference and Exhibition (GCCCE), page 1153-1156*