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Product Design and Conceptual Process Planning Integration By Using Machining Features

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Abstract

The integration of conceptual process planning and early design stages is a vital activity in the modern industrial environment. Since major manufacturing time is committed in product specification and design, it is critical to be able to assess manufacturing as early as possible in the design process.

In this research, an algorithm is developed to build an (Integration of Product Design and Process Planning) system called IPDPP to demonstrate the integration of conceptual process planning and design using manufacturing features. The developed system (IPDPP) validates the calculation of manufacturing time using feature technology. The application of the prototype system improved communication between design and process planning. The (IPDPP) system has been tested on product (Shaft 8E-200) in State Company for Electrical Industries. It resulted in reduction of manufacturing time.

Keywords: Process planning, manufacturing features, machining parameters.

الخلاصة

ان التكامل بين مفاهيم تخطيط العملية ومراحل التصميم المبكرة هو فعالية مهمـــة فـــي بيئـــة التصنيع الحديثة. وان معظم وقت التصنيع مخصص لوضع المواصفات وتصاميم المنتج لذلك يصبح من الضروري تقييم تصنيع المنتج في مراحل التصميم المبكر.

في هذا البحث تم تطوير خوارزمية لبناء نظام (تكامل تصميم المنتج وتخطيط العمليــة) يــدعي (IPDPP) لعرض تكامل مفاهيم تخطيط العملية وتصميم المنتج باستخدام السمات التصنيعية الذي يتم فيه حساب وقت التصنيع باستخدام تقنية السمات. ان تطبيــق النظـــام يبـــرهن الاتصـــال بيـــن تصـــميم المنتـــوج وتخطـــيط العمليـــة. تـــم اختبـــار النظـــام على المنتـــج (Shaft 8E-200) في الشركة العامة للصناعات الكهربائية حيث أدى الى تقليل وقت التصنيع.

1- Introduction

Experienced designers often are able to create successful initial designs because of their years of design experience and their acquired knowledge of manufacturing processes. However, less experienced designers often require input from experienced personnel in both the design sector and the manufacturing sector. Ideally, the novice designer should be able to get manufacturing, design, cost estimation, and process planning input at all stages of design to aid in the design process. This can be burdensome to the rest of the personnel [1].

A typical design process includes customer requirements analysis, conceptual design, and detailed design. A corresponding manufacturing planning process includes conceptual process planning and detailed process planning. From conceptual design, data such as form, function, geometry, product quantity, form requirements (tolerances, surface finish), are sent to a conceptual process planner. These data describe the

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product and the reasoning behind certain design decisions, also referred as design rationale. The outputs from conceptual process planning; including selection of manufacturing processes/machining parameter and calculate manufacturing time/cost [2]. Academic researchers have also been looking into the product design and conceptual process planning problem. For example, Wong and Sriram developed an object-oriented framework for storing product and design processes. It allows the representation of multiple versions of parts; relations between function, form, and behavior for each part; part attributes; constraints; and assembly relationships [3]. Mukherjee and Liu presented an abstraction for conceptual design by using function-form relation matrices. The relation matrices provide a link between purely functional and purely geometric representations, and a means to carry out domain-dependent manufacturability evaluations [4]. Kimura and Suzuki attempted to capture and to represent product background information, which includes requirements, specifications, assumptions, constraints, decision history, trial-and-error processes, and other rationale rules [5]. Jeffrey and Mandar described a decision support tool that can help a product development team reduce manufacturing cycle time during product design. This design for production (DFP) tool determines how manufacturing a new product design affects the performance of the manufacturing system by analyzing the capacity requirements and estimating the manufacturing cycle times. Performing these tasks early in the product development process can reduce product development time [6]. Satyandra and Dana presented a methodology for analyzing product designs to estimate their manufacturability aspects. Our analysis provides feedback to the designer about possible manufacturability problems (such as manufacturing time, cost and resources), thereby providing an opportunity to redesign the product to improve its manufacturability characteristics [7].

The main goal of this research is to design a system which is developed as an approach to link design phase with conceptual process planning phase using machining feature. This helps the designer to explore alternatives at early design stage. The Integration Product Design and Process Planning system (IPDPP) improving communications between design and process planning activities in the early design phase. One of its focuses is on the interoperability between conceptual design and conceptual process planning activities, as shown in Figure 1.

A machining feature is a closed volume in space that is related to a machining operation as follows: when the operation is finished, there must be no material remaining inside the feature, and the operation may remove no material outside the feature [8]. Examples of machining features include faces, pockets, slots, bosses, and holes, some of which are shown in Figure 2.

2- Methodology

The architecture of the developed IPDPP system classifies the main task of conceptual process planning into four steps: description of part features, manufacturing process selection, machining parameters selection and manufacturing time calculation, shown in figure (3).

2-1 Part Features Description

The complexity of design and manufacturing usually determine the number and type of form features required to represent a part or an object. In this step the part is described as rotational or prismatic and all features are classified into holes, slots, pockets…etc. Each feature is classified into sub-classes as shown in Figure (4), the user identifies the dimensions, surface finish and tolerances for each feature, the results of this step are feature matrix database.

2-2 Process Selection

After describing the part, we need to select the suitable process(s) to produce each feature. Firstly the system selects a certain process depending on the feature type from the process database. In other words, if a feature is described as a form feature (slot, pocket, hole …etc) in the database, the system automatically selects the suitable process for the feature. This process output is suitable process, which can be selected by applying tolerance and surface finish. The final steps in manufacturing process selection step are determination of the cutting type (finishing or roughing).

2-3 Machining Parameter Selection

Process parameters for machining include feed rate, cutting speed, revolution per minute, and length of cut. The selection of process parameter depends on the tool material, work piece material and tool geometry. Since there are a very large number of material, diameter and length of cut combination, the storage of process parameter required a large database. The standard SANDVIK machining data Handbook gives tedious amount of machining data.

2-4 Manufacturing Time Calculation

Manufacturing time is the sum of the machining time **(TMachining)** and the nonproduction time or idle time (**TIdling**)**.** Appendix: show the structure of manufacturing time. Machining time can be calculated based on the cutting parameters, feature geometry and dimensions. It is used to estimate the manufacturing time, Figure (5) shows the machining time module. The idle time is the non production time means here the time that is necessary to make the value adding work possible. Idle time in machining consists of the following operations hand time, change time, set time and down time, these operations are depends in some parameters as shown in Figure (6).

3- The IPDPP System Testing

To examine and test the capabilities of the developed system are carried out through selecting mechanical part, which is considered as an example for testing the system. The part design models selected are taken from the real world problem chosen from the manufacturing environments of State Company for electrical Industries, which are shown in Figure (7).

Examining and testing the capabilities of the IPDPP system were performed through five levels as listed below:-

1- Describing the manufacturing feature of the part through output results of feature description module.
2- Selecting process that is required to manufacture features through output results of process selection module.
3- Selecting machining parameter.
4- Calculating machining time, idle time and manufacturing time. The interaction with the system and the results output will be given as shown in figure (8).

4- Conclusions

In this paper, conceptual process planning was defined as an activity that assesses manufacturability and estimates the manufacturing time of the concept of a product developed in the early design stage. The IPDPP system is addressing industry needs for the integration of design and process planning activities and functions. Initial prototype systems have been developed to test the concept of transferring design information to process planning and transferring process plans back to design for manufacturability assessment. The major practical results of this work include:-

1- Machining features that are used in this research correspond dirctly to machining operations. The process related information is incorporated in the features themselves. This will allow to estimate manufacturing time without going through a very complicated process planning steps.
2- The estimated processing time for each feature is based on information such as, the material used, process planning, the values of the defined parameters of each feature, tolerance and specified surface finish of each face of a feature.
3- The optimum determination of machining parameter (feed rate, cutting speed, depth of cut) is of a great importance especially for machining.
4- The main characteristics of the developed IPDPP systems are: -

- The ability to describe the part shape and all features of the part to form feature matrix database.
- The selection of the manufacturing processes that are required to produce each feature of the part.
- The optimum or near optimum machining parameter (feed, speed, RPM, length of cut) selection as shown in figure (8-b).
- Determining machining time, idle time and manufacturing time.
- Extending the prototype system using more industrial cases.

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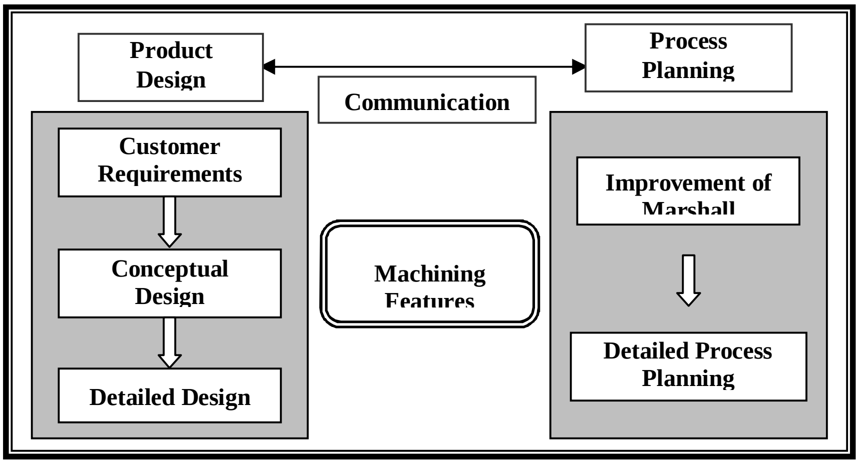

Figure (1): Design and process planning message exchange for Integration.

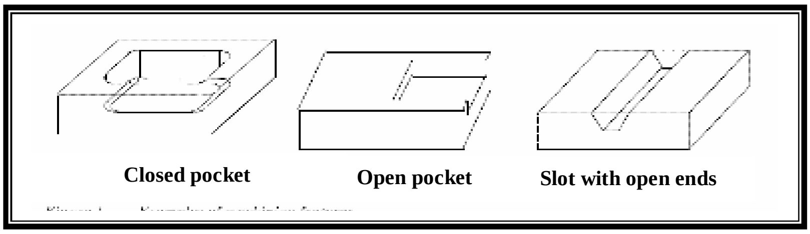

Figure (2): Example of machining feature [8].

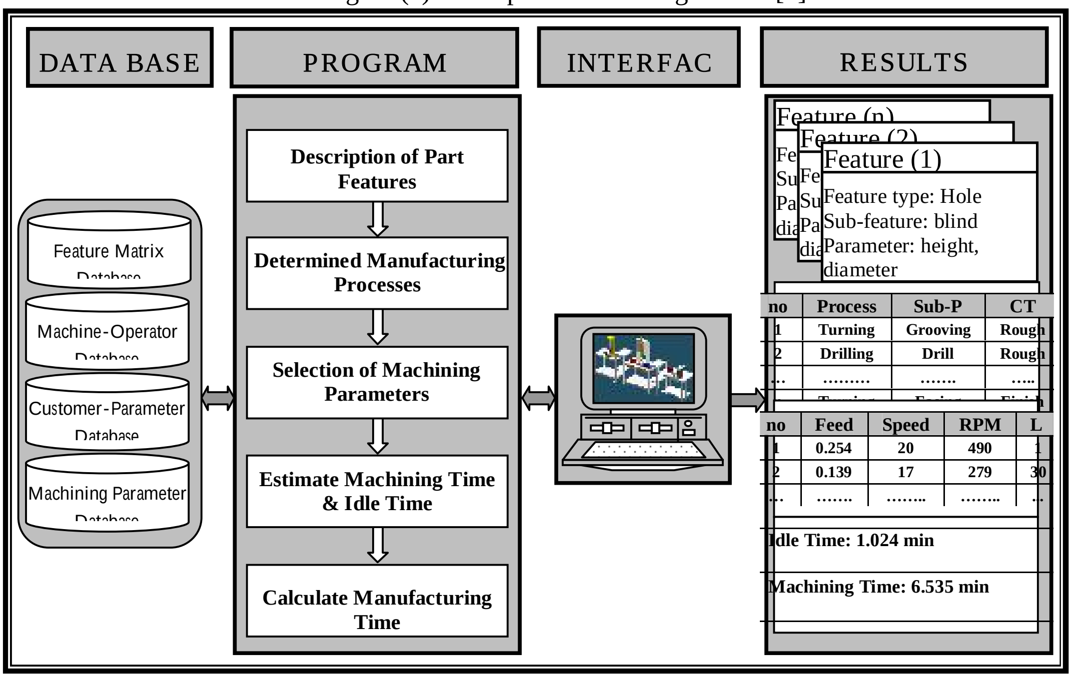

Figure (3): IPDPP system architecture.

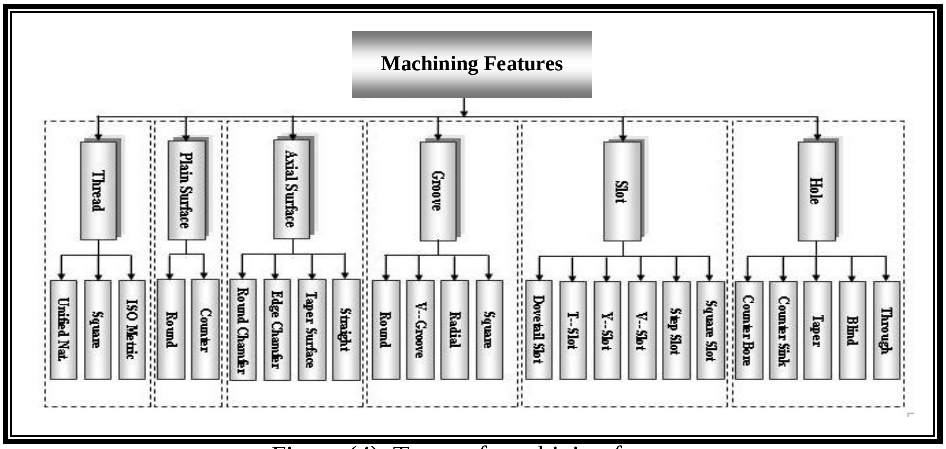

Figure (4): Types of machining features

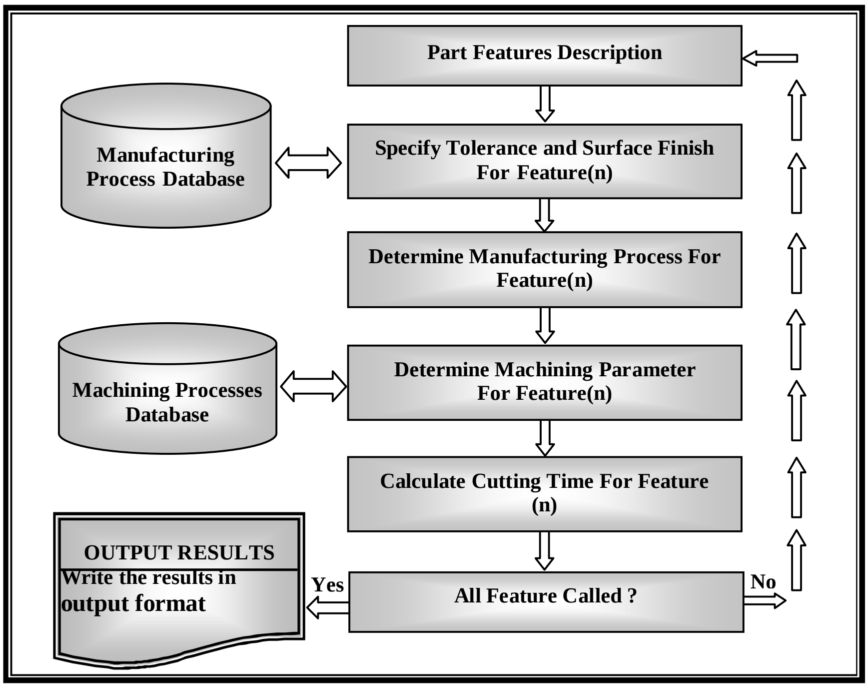

Figure (5): Machining time module.

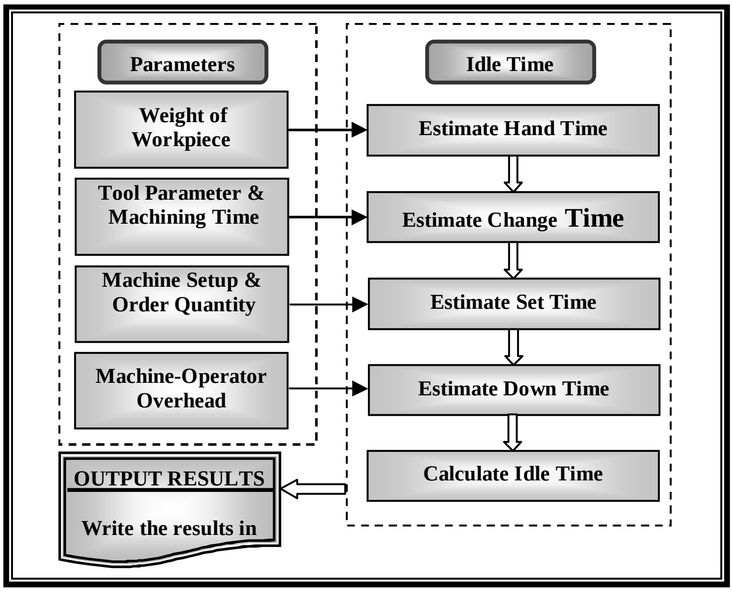

Figure (6): Idle time parameters.

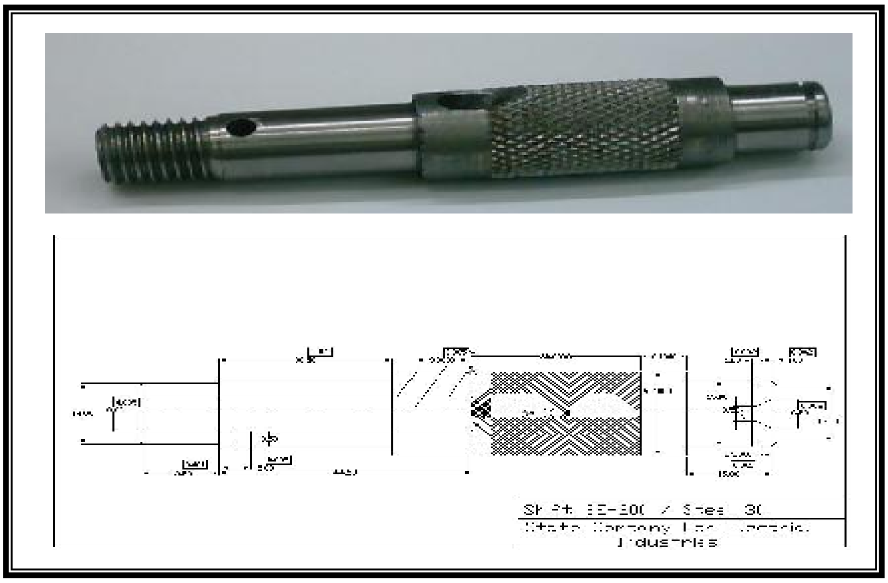

Figure (7): Shift (8E-200)

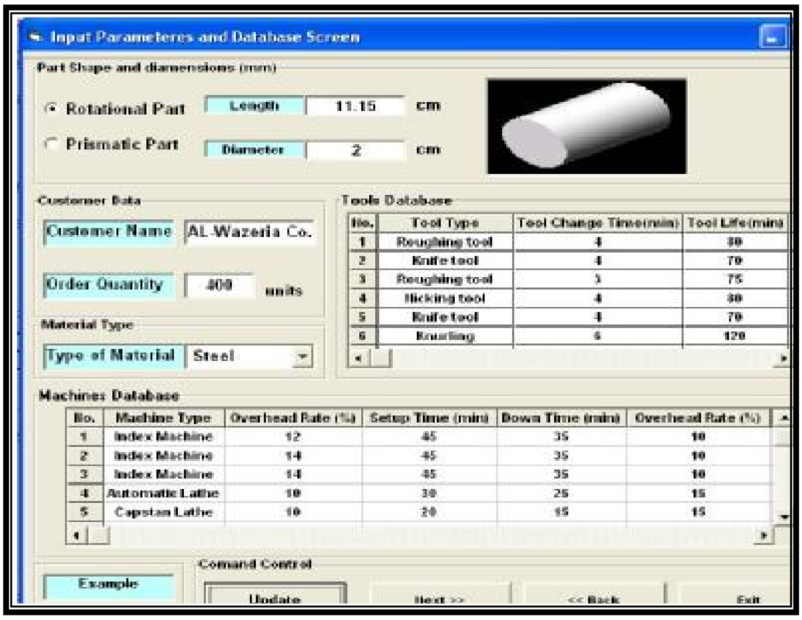

Figure (8-a): Input parameter and database screen.

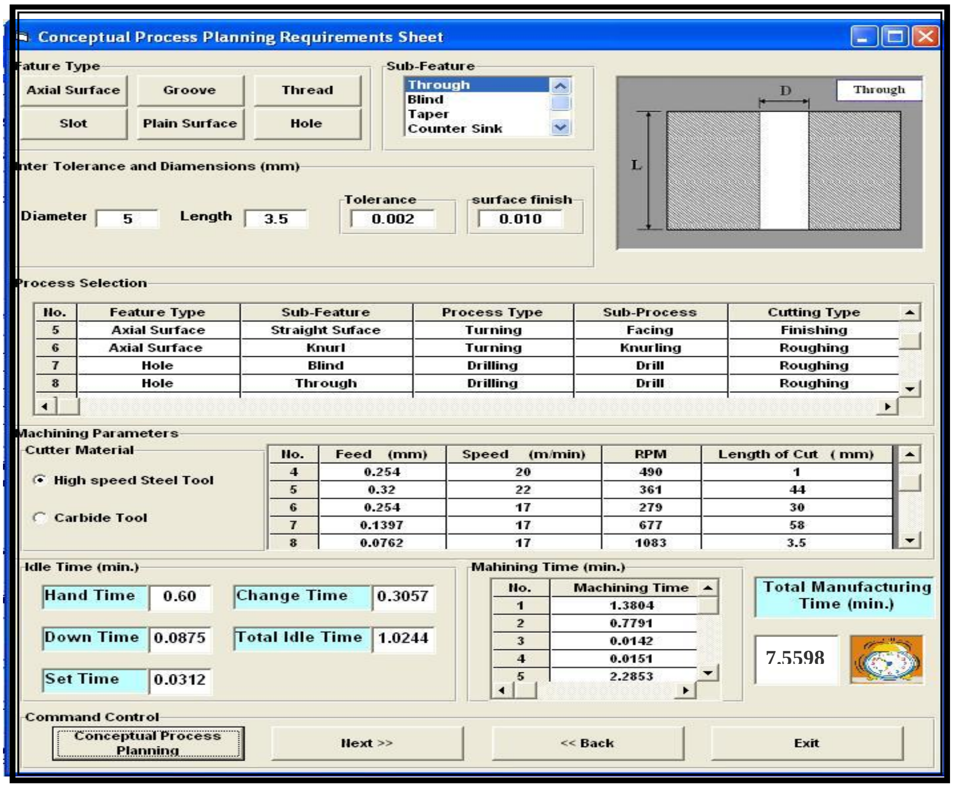

Figure (8-b): Conceptual process planning requirement sheet.

Appendix: Structure of The Manufacturing Time

T Manufacturing = T Machining + T Idling (1)

Machining time can be calculated based on the cutting parameters and the type of each feature.

$$\text{T Machining} = \sum_{i=1}^{N} \left(t^i Cutting \right) \qquad (2)$$

The cutting times are calculated with the following basic formulas [9]:-

For drilling: Blind hole $T = \frac{H + 0.3D}{F * N}$ Through hole $T = \frac{H + 0.3D}{F * N}$ (3)

For turning: $T = \frac{L}{F * N}$ (4)

For milling: $T = \frac{L}{F * N * No}$ (5)

where

T = machining time……..……..…(min)
L = length of cut……….……...…(mm)
H = hole depth…………………..(mm)
F = Feed per revolution……..…(mm/rev)
N = rpm…………………….……...(rev/min)
No = number of gear teeth.

In order to cutting time calculate the speeds and feed for the specific material must be selected from the standard tables and the Revolutions per minute (N) are determined by the following formula [10]:-

$$N = \frac{1000 * S}{3.14 * D} \qquad (6)$$

where:

N = RPM…………………….…(rev/min)
D = Diameter of work, cutter….(mm)
S = cutting speed…………..…....(m/min)

The idle time (T **Idling**) is the non-production time calculated by using the formula [10]:-

$$TIdling = \sum_{i=1}^{N} \left(t^i Setup + t^i Handling + t^i Down + t^i Changing \right) \qquad (7)$$

where:

t Setup: total time for job setup divided by number of parts in the batch.
t Handling: time the machine operator spends loading and unloading the work on the machine.
t Down: downtime lost because of machine or tool failure, waiting for maintenance operation.
t Changing: prorated time for changing the cutting tool. It can be calculated by using the following formula:-

$$t\,Changing = Tool\ changetime * \frac{t\,Cutting}{Tool\ life} \qquad (8)$$