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In-Production Product Value: A New Method for Part Type Prioritization

Safwan A. Altarazi [a,*], Nabeel Mandahawai [b], Khaled Gharaibah [c]

[a] *Industrial Engineering and Management Systems Department, German-Jordanian University, Amman 11180, Jordan*

[b] *Industrial Engineering Department, The Hashemite University, Zarqa, Jordan*

[c] *Government Tenders Directorate, Amman, Jordan*

Abstract

Typically, the value of a product is addressed in the fields of marketing, neoclassical economics, or classical economics. Product value in these fields is associated with the final shape of a product. This paper presents a new different perspective for defining product value. It introduces a formula for evaluating product value while it is in production. Contributors of the proposed formula include the product revenue, the percentage of the product's finished-cycle time, the product criticality, and the due date of the product. Based on the "in-production product value" formula, an algorithm for "part type priority" and scheduling is presented. The algorithm was applied to a hypothetical manufacturing example and the simulation results proved the validity and applicability of the proposed algorithm.

Keywords: Part type priority, scheduling, product value, simulation.

Nomenclature

$CPV_{product}$	is the constraint product value for a product ($)
$CS_{product}$	is the constraint's occupation time for one
$\left(\frac{ATP}{CS}\right)_{constraint}$	is the average throughput per constraint time for all products on the constraint ($/sec)
$MC_{product}$	is the material cost of the product ($/unit)
$ATP_{constraint}$	is the average throughput for the constraint ($/unit)
K	is the number of products produced by the analyzed constraint
MC_i	is the material cost of the product ($/unit)
ASP_i	is the average selling price for product i ($/unit)
D_i	is the sold demand of product i (units)
CT_C	is the amount of completed product's cycle time
CT_p	is the product's total cycle time
%VAP	is the percentage of value added processes in CT_C
R_P	is a linear normalization factor of the considered product with respect to all produced products
CT_{min}	is the minimum cycle time among all produced products
CT_{max}	is the maximum cycle time among all produced products

1. Introduction

The value of a product can be viewed from various perspectives; accordingly, it can be defined differently. For example, in marketing, the value of a product is the consumer's expectations of product quality in relation to the actual amount paid for it. It is often expressed by the ratio of received quality to price or customer expectations. On the other hand, in neoclassical economics, the value of an object or service is often seen as nothing but the price it would bring in an open and competitive market [1]. This is determined primarily by the demand for the object relative to supply. In classical economics, price and value are not equal. According to Keen [2], value refers to "the innate worth of a commodity, which determines the normal ratio at which two commodities exchange." Ludwig von Mises [3] asserted that value is always a subjective quality.\ There is no value implicit in objects or things, and value is derived entirely from the psychology of market participants. Neap and Celik [4] emphasized that value reflects the owner/buyer desire to retain or obtain a product which introduces subjective aspects to the value of a product.

The above product's value definitions are associated with the final shape of a product in which the external customer is the one who perceives the product and evaluates it. The current research views the product's value from a different perspective, that is, it tires to evaluate the product's value during production phase. According to these two perspectives, the factors that affect the value of a product are different. For example, the final

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[*] Corresponding author. Safwan.altarazi@gju.edu.jo

customer perception of product value is the combined result of the product price, delivery time, and product quality-considering the eight dimensions of quality (performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality [5]). In contrast, the factors that contribute to the product value while the product is still in production include the product's production time, due date, and demand.

In literature, factors contributing to the "in-production product value" are linked to the parameters used for determining the machining sequence for a group of parts. For example, for determining part types priorities before machining Bilkay et al. [6] considered the bath size, due date, total processing time, and tool slots needed. Similar parameters were used in other studies, especially those focusing on throughput maximization and work in process (WIP) minimization [7-9]. These part-priorities algorithms are static in nature. They rank products based on pre-machining information and do not have the capability to accommodate changes of these information while the product is moving through the production line.

In this study, an attempt is made to define the value of products while it is still in production. Four factors, which contribute to this value, are considered: the product's revenue, percentage of completed-cycle time, due date, and criticality. An "in-production product value" formula is proposed and utilized to determine part type priorities. The formula can be used either at the starting of production or for products that have been partially machined and their priorities need to be reevaluated. Based on the resulted part type priority, a scheduling algorithm is presented and simulation is used to validate the applicability of the algorithm.

The present paper is organized in five sections. The next section introduces the "in-production product value" formula. Section three presents the proposed "part priority type" algorithm and its scheduling output. The algorithm applicability is demonstrated in the fourth section and the paper ends with concluding remarks in section five.

2. The "In-Production Product Value" Formula

The proposed "in-production product value" formula algorithm considered four inputs: product's revenue, product's percentage of completed cycle time, product's due date, and product's criticality. The factors are described below.

2.1. Product's Revenue (R)

The net profit generated by a product is essential in making the production decision for this product. The profit is a function of the total production cost of a product and its selling price. Traditionally, a product's revenue is represented either by subtracting the total cost from the selling price or by using the selling price/total cost ratio. Another way to analyze revenue is by using the thought process of Theory of Constraints (TOC) [10]. The TOC proposes that total throughput of a system is only affected by the throughput produced by the system's constraint. Because the production time of the constraint is limited, job scheduling for the constraint should be carefully performed in order to generate maximum throughput per the constraint's unit time. In addition, products which consume a large portion of constraint time should be assigned a higher value than products which use less constraint time.

Constraint Product Value (CPV) is a way to compare products based on their revenue contribution generated by a factory constraint. It combines the product's material cost and the product's throughput rate (revenue/unit time) on the constraint [11]. CPV for a given product can be defined as:

$$CPV_{product} = \left(CS_{product} * \left(\frac{ATP}{CS} \right)_{constraint} \right) + MC_{product} \tag{1}$$

To find the time required for one yielded product on the constraint ($CS_{product}$), the production rate of the product in the constraint, typically given in units per hour, is needed. For a product that visits the constraint one time, $CS_{product}$ in seconds per unit is given by:

$$CS_{product} = \frac{3600}{\text{Production rate(in units per hr)}} \tag{2}$$

For the calculation of the average throughput per constraint time for the constraint being analyzed, i.e., $\left(\frac{ATP}{CS} \right)_{constraint}$, the $ATP_{constraint}$ and the $CS_{constraint}$ are calculated as follows:

$$ATP_{constraint} = \sum_{i}^{k} (ASP_i - MC_i) \times D_i \tag{3}$$

Also, $CS_{constraint}$ can be found as:

$$CS_{constraint} = \sum_{i}^{k} CS_{product(i)} \times D_i \tag{4}$$

Once the $ATP_{constraint}$ and the $CS_{constraint}$ are calculated separately, the $\left(\frac{ATP}{CS} \right)_{constraint}$ can be found as:

$$\left(\frac{ATP}{CS} \right)_{constraint} = \frac{ATP_{constraint}}{CS_{constraint}} \tag{5}$$

Finally, for a group of products, the normalized contribution function of the revenue (PV_R) for product i, toward the in-production product value, is defined as the ratio of the difference of the CPV of product i and minimum CPV, to the difference of the maximum and minimum CPV.

$$PV_R = \frac{CPV_p - CPV_{min}}{CPV_{max} - CPV_{min}} \tag{6}$$

2.2. Product's Percentage of Completed Cycle Time (%CT)

The cycle time of a given product, also called flow time, refers to the average time a product spends as WIP, or the average time from the release of a job at the beginning of a product's route until it reaches the point of finished product inventory [12]. Considering the percentage of finished cycle time toward defining a product's value is very reasonable. For example, for the same product, a unit with a 90% finished cycle time is more valuable than a unit with a 10% finished cycle time. However, for two different products, 10%-finshed cycle time of product A can be more valuable than a 90%-finished cycle time of product B. Therefore, in a situation where multiple products are considered for production, both the percentage of finished cycle time and the product's total cycle time should be considered.

Although all processing times are counted in the cycle time, many of these times do not add any extra value to the product. In lean manufacturing terminology, these non added-value processes, such as WIP inventory, are labeled as waste. In contrast, processes which add to the value of a product are called value-added processes. Hence, only value-added processes should be considered to contribute toward the product's value.

Therefore, PV_{CT} is used to represent the contribution function of the percentage of completed cycle time, the total cycle time, and the value-added processes, toward the in-production product value.

$$\mathrm{PV}_{\mathrm{CT}} = \left(\frac{CT_C}{CT_p} \times \%VAP \times R_p \right) \tag{7}$$

where R_P can be calculated from:

$$\mathrm{R}_{\mathrm{p}} = \frac{CT_p - CT_{\min}}{CT_{\max} - CT_{\min}} \tag{8}$$

2.3. Product's Due Date (DD)

Due date should be strictly met in order to eliminate delay penalties. Hence, due date is an important factor for the generation of comprehensive definition of the in-production product value. It is assumed that the value of product i increases as its due date is earlier, that is, as the time remaining to deliver is shorter. For a single product, the due date effect toward its in-production value (DD_{effect}) is defined as the ratio of the time remaining to finalize production to the time remaining to deliver.

$$\mathrm{DD}_{\mathrm{effect}} = \frac{\text{Time to finalize production}}{\text{Time to deliver}} \tag{9}$$

Moreover, for a group of products the normalized contribution function of due date (PV_{DD}) for product i, toward the in-production product value, is defined as the ratio of difference of the DD_{effect} of product i and minimum DD_{effect} , to the difference of the maximum and minimum DD_{effect}.

$$\mathrm{PV}_{\mathrm{DD}} = \frac{DD_{effect\,(p)} - DD_{effect\,(\min)}}{DD_{effect\,(\max)} - DD_{effect\,(\min)}} \tag{10}$$

Product's Criticality (PC)

Product criticality is related to the classifications of product characteristics. A characteristics classification is applied usually during the first stages of product and process design. Yet, because of manufacturability, quality or handling considerations, the classifications may be upgraded by suppliers, the internal process, installation, or quality planners. A typical product characteristics classification is [13]:

- Critical: when a small deviation will produce or lead to a substantial safety hazard or a complete performance loss.
- Major: when a small deviation will produce or lead to some safety hazard, significant performance or reliability reduction or complete loss of further manufacturability.
- Minor: when a small deviation may produce or lead to minimal safety hazard, some performance or reliability reduction, or substantial manufacturability problems.
- Incidental: when a small deviation cannot produce or lead to any safety hazard, performance, or reliability reduction but may cause minimal manufacturability problems.

These classifications are often distinguished by reference to measures of process capability ratio (PCR), such as C_p or C_{pk}. A typical approach might have the critical characteristic classes assigned to a higher than 1.33 PCR processes, major characteristics assigned to 1.33 PCR processes, minor characteristics assigned to 1 to 1.33 PCR processes, and incident characteristics products assigned to a 1.00 PCR processes. In the current research, it is assumed that the criticality classifications of the analyzed products are known. Furthermore, the associated PCR ratios of these products are used as the criticality contribution to their in-production value, notated by PV_{PC}. Then, the normalized contribution function of product criticality (PV_{PC}) for product i, toward the in-production product value, is defined as the ratio of the difference of the PCR of product i and minimum PCR, to the difference of the maximum and minimum PCR.

$$\mathrm{PV}_{\mathrm{PC}} = \frac{PCR_p - PCR_{\min}}{PCR_{\max} - PCR_{\min}} \tag{11}$$

2.4. The Proposed PV Formula

Based on the previous discussion, a formula for the in-production product value which summarizes the effects of the revenue, percentage of completed cycle time, due date, and product's criticality is given by:

$$\text{Product Value } (\mathrm{PV}_{\mathrm{NET}}) = \left[w_1 \; w_2 \; w_3 \; w_4 \right] . \begin{bmatrix} \mathrm{PV}_{\mathrm{R}} \\ \mathrm{PV}_{\mathrm{CT}} \\ \mathrm{PV}_{\mathrm{DD}} \\ \mathrm{PV}_{\mathrm{PC}} \end{bmatrix} \tag{12}$$

where w_1, w_2, w_3, and w_4 are weights of the four factors. For determining these weights, expert's knowledge can be consulted.

It is worth mentioning here that the suggested PV_{NET} formula would return a dimensionless number between zero and one. Hence, this normalized number can be used as a selection criterion between products in applications where products priorities are needed. The next section shows the application of this formula in scheduling.

3. The Proposed "Part Priority Type" Algorithm and Scheduling

The proposed "part priority type" algorithm can be described by the following steps:

- Step 0-algorithm inputs: the available machines, the products to be produced, the process plan for each product associated with the cycle time at each operation (machine), the system's constraint (the bottleneck machine), product's raw-material costs, product's selling prices and demand, and product's delivery due dates.
- Step 1: at time equals zero (starting of the production), evaluate all products using the PV_{NET} formula. Then, generate products-machines assignments accordingly. That is, the product with the highest PV_{NET} will be firstly assigned the required machine. After that, the product with the next PV_{NET} will be assigned the required machine (if it was not assigned to the first part), and assignments will continue. Products with low PV_{NET} may wait if the machines they need are assigned to products with higher PV_{NET} values.
- Step 2: start the production of the products with the available assigned machines.
- Step 3: at any state when the processing time of any product on any machine is finished, reevaluate all products using the PV_{NET} formula. Then, generate a new scheduling plan for the products, run the production.
- Step 4: rerun step 3 until all products are finished. If any of the products has finished its process plan exclude it from the PV_{NET} calculations.

Step 5: output the scheduling plan of all products.

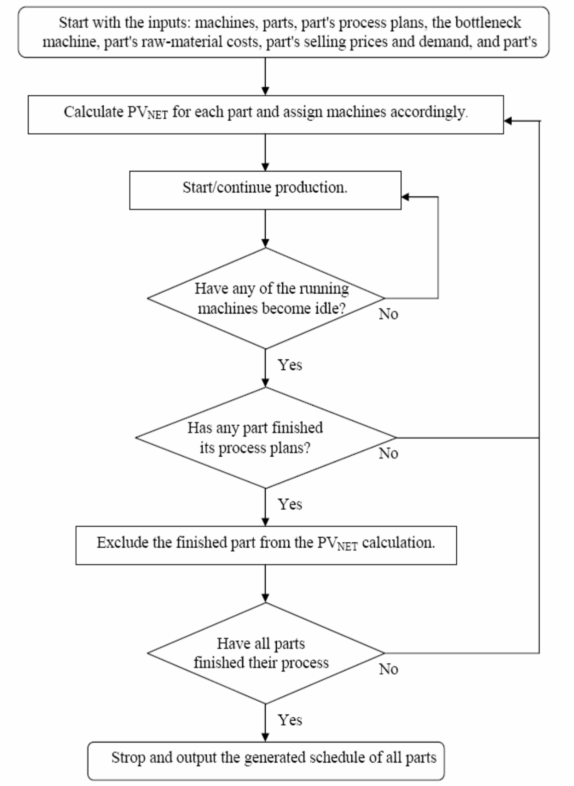

Figure 1. flowchart of the proposed scheduling algorithm.

Figure 1 presents the flowchart of the algorithm. A simulation model using Matlab 6.5 was generated to run the model. The next section presents a demonstration example for the algorithm application and the simulation results.

4. Demonstration Example

The validity of the proposed algorithm is tested by applying it to a hypothetical example that is described in the next subsection while subsection 4.2 introduces the scheduling plan resulted from the Matlab simulation.

4.1. Example Definition

This demonstration example considers a manufacturing facility with four machines and five products. Each product has different process plan to follow. Yet, all products need to go through the second machine which is assumed to be the system's constraint. Table 1 lists the process plans of each product associated with the processing times on each machine, hence, the production rate of each product on each machine can be calculated-especially for the system's constraint. In addition, table 1 includes the following information for each product: $MC_{Product}$, ASP_i, D_i, CT_P, the "time to deliver", and the product's characteristics. Note that CT_C is not tabulated as it equals zero for all products at the beginning of the production. However, CT_C would be updated as can be seen in step 3 of the proposed algorithm.

4.2. The simulation output

Figure 2 shows the scheduling plan resulted from running the simulation model for the current example. Several comments can be observed from the figure:

- At the beginning of the production, products 1, 4, and 5 had the highest PV_{NET} scores; hence, they were processed first. Products 2 and 3 were delayed since they required starting with machines that have been assigned to products with higher priorities, that is, higher PV_{NET} scores.
- PV_{NET} scores are reevaluated at any each situation when the processing time of any product on any machine is finished, and the assignments of machines will be based on these reevaluations.
- The on-line reevaluation of the in-production products value assures that no simultaneous machine assignments occur. That is, only one product will be assigned to a machine at particular time period.
- As the second machine was designed to be the system constraint, it has the highest utilization among the available five machines.
- The five products will finish production as the following: part 4, part 1, part 3, part 2, and finally part 5. Moreover, the makespan of the whole five products production is 42 min.

5. Conclusions

A new part type priority algorithm for products scheduling was presented in this paper. The algorithm is based on a new approach for defining the in-production products value. The proposed approach integrated the contribution of four parameters to product value. The parameters are the part's revenue, percentage of completed cycle time, due date, and criticality. Simulation results approved the effectiveness of the proposed algorithm.

The proposed algorithm can be improved and utilized in many ways. For example, the four considered parameters can be evaluated as linguistic variables; and then processed by using fuzzy logic. Furthermore, the suggested PV_{NET} formula can be integrated with process planning models to help in assigning high capable machines for high-value products.

Table 1. Input information of the demonstration example

Part No.	Process plan (machines sequence)	Processing time/ machine (min)	Production rate on 2nd machine, (unit/hr)	$MC_{Product}$, ($)	ASP_i, ($)	D_i, (units)	CT_P (min)	Time to deliver (min)	Part characteristics
1	1-2-3	10-8-4	10	50	400	30	22	10	Critical (PCR = 1.66)
2	2-1-4-3	8-3-5-6	5	30	350	50	22	15	Critical (PCR = 2.00)
3	1-2-4	4-7-3	8	60	800	10	14	7	Minor (PCR = 1.16)
4	2-3-4	10-2-3	12	35	700	75	15	4	Major (PCR = 1.33)
5	3-4-2-1	5-6-5-4	15	35	100	20	20	35	Incidental (PCR=1.00)

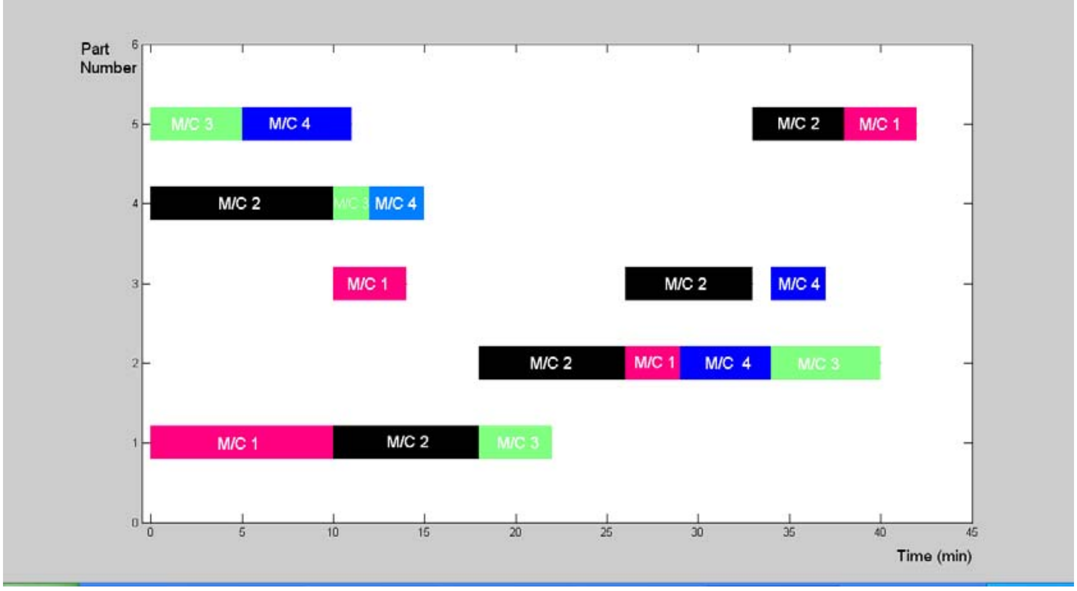

Figure 2. The scheduling plan resulted from the simulation model

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