Inefficient Processing Time as Hidden Time Loss in Assembly Operations

Z. Ebrahim, A. H. A. Rasid and M. R. Muhamad
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100, Hang Tuah Jaya, Malaysia.
zuhriah@utem.edu.my

***Abstract*— Hidden Time Loss (HTL) occurs along the production processes that have a significant effect to productivity. Overall Equipment Efficiency (OEE) is the most popular performance measurement tool used in the production line. However, OEE doesn't really fit in measuring operation performance of manual assembly process and semi-auto assembly process. In this case, there would be the amount of HTL have occurred along the assembly processes that become critical when to involve high product variety in the same production line. Thus, the purpose of this paper is to introduce Inefficient Processing Time (IPT) as one of the component of Time Loss Measures (TLM) in the manual assembly process and semi-auto assembly process. The structure of IPT is developed through a thorough literature study on manufacturing operations and its performance measures. The IPT structure is validated by using case study at five automotive manufacturing companies. The results show that the IPT can contribute to HTL in the manual assembly process and semi-auto assembly process.**

***Index Terms*— Assembly Process; Measure; Processing Time; Time Loss.**

I. Introduction

To stay competitive, companies facing today's levels of unprecedented global competition must design and offer better products and services and improve their manufacturing operations [1]. Therefore, it is essential for a manufacturer to have an effective method of measuring and evaluating the performance of their manufacturing processes [2].

A set of tasks for each variant is assigned to each workstation on the line and is performed by the worker(s) available at this workstation for mixed- model assembly line balancing [3]. In this regard, the processing time for the tasks at each workstation is essential to be controlled properly to meet customer requirements. Indeed, the customer will confirm the supplier production capacity through the processing time. The capacity feasibility of the facility for producing an order on time will be clarified through the processing time as a major portion of lead time [4]. Cycle time presents the processing time of each individual process. The cycle time of processes can be defined as the time of the process from when process start until finished [5][6].

Thus, this paper introduces Inefficient Processing Time (IPT) as one of the components of Hidden Time Loss (HTL) through determination of internal process in the context of assembly process. The significance of this study is determination of IPT that could exist in the assembly processes of automotive components as the product variety continuously increases. Furthermore, this paper clarifies the effect of IPT on the assembly productive time in the context of assembly features such as left-right parts/components, front-rear parts/components, different products, and different models.

II. The Structure of Inefficient Processing Time

The Figure 1 presents the initial structure of IPT resulted from literature studies on manufacturing operations and its performance. Initially, Delivery Speed represents processing time that consists of Internal Process and External Process. Here, the Internal Process has been referred as processes occurred in an assembly that consuming a certain amount of time. While, External Process refers to processes after the assembly process.

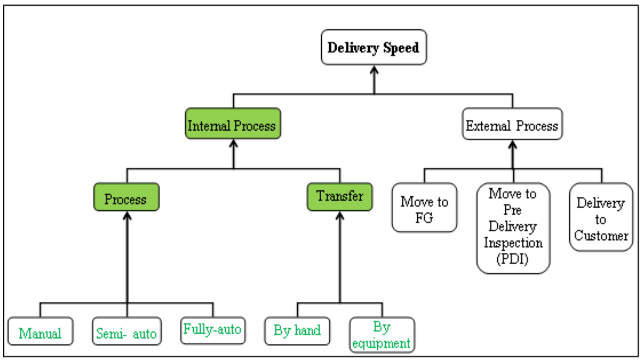

Figure 1: Initial structure of IPT

However, this study focuses on Internal Process in order to determine the IPT. Here, two main activities known as Process and Transfer. In this regard, Process is defined as the method of activities in the assembly process (i.e. manual assembly or semi-auto assembly or auto assembly). Transfer refers to the method of material handling in an assembly (i.e. by hand or by equipment). Thus, the processing time of an assembly consists of process time and transfer time. The processing time of one machine refers to the sum of man time and machine time, which will affect the capacity output of the machine [7]. Therefore, the IPT can be determined if actual processing time is longer than standard processing time.

A. Equation for IPT

The objective of IPT equation is to determine the total TL that caused by inefficient assembly processing time. The IPT equation has been developed based on the proposed IPT structure. Thus, the equation for IPT can be written as;

$$IPT = \sum_{i=1}^{n} t_{apct} WS_i - t_{spct} WS_i) \quad (1)$$

where: t_{apct} = actual process cycle time.

t_{spct} = standard process cycle time (based on company's standard)
P_i = actual total input quantity per day or month.
WS = a production workstation.

In this regard, IPT ≥ 0. Table 1 presents the conditions considered for IPT where Merit Time refers to the time that can be saved when the Actual Process Cycle Time is shorter than the Standard Process Cycle Time.

Table 1
Conditions for IPT

No.	Condition	Detail	Description
1	IPT = 0	$t_{apct} = t_{spct}$	Zero Time Loss
2	IPT > 0	$t_{apct} > t_{spct}$	Time Loss occurred
3	IPT < 0	$t_{apct} < t_{spct}$	Actual Process Cycle Time is shorter than Standard Process Cycle Time. In this case, the (-ve) value IPT is *Merit Time*

This study determines the total of *IPT* for t_{apct} as written in Equation (2).

$$t_{apct} = t_{process} + t_{transfer} \tag{2}$$

where: $t_{Process}$ = the time taken to complete a process before delivering to the next workstation.
$t_{transfer}$ = the time taken to transfer a component or product to the next workstation.

In this regard, $t_{apct} > 0$. This study determines the total of t_{apct} for $t_{Process}$ as written in Equation (3).

$$t_{process} = t_m + t_{sa} + t_a \tag{3}$$

where: t_m is time taken for manual process.
t_{sa} is time taken for a semi-automatic process.
t_a is time taken for an automatic process.

In this regard, minimum $t_{Process}$ = 1 and maximum $t_{Process}$ = 3. Table 2 presents the conditions considered for t_{apct} of $t_{Process}$.

Table 2
Conditions for t_{apct} of Process $t_{Process}$

No.	Condition	Description
1	$t_m = 0$	The process is not manually performed
2	$t_m = 1$	The process is performed manually
3	$t_{sa} = 0$	The process is not semi-automatically performed
4	$t_{sa} = 1$	The process is performed semi-automatically
5	$t_a = 0$	The process is not automatically performed
6	$t_a = 1$	The process is performed automatically

This study determines the total of t_{apct} for $t_{Transfer}$ as below:

$$t_{Transfer} = t_e + t_h \tag{4}$$

where: t_h = time taken to transfer a part between two workstations by hand.
t_e = time taken to transfer a part between two workstations by equipment.

In this regard, between two workstations $t_{Transfer}$ = 1. Table 3 presents the conditions considered for t_{apct} of $t_{Transfer}$.

Table 3
Conditions for t_{apct} of $t_{Transfer}$

No.	Condition	Description
1	$t_h = 0$	When a part or product is not transferred by hand
2	$t_h > 1$	When a part or product is transferred by hand
3	$t_e = 0$	When a part or product is not transferred by equipment
4	$t_e > 1$	When a part or product is transferred by equipment

B. Validation

The validation of IPT equation is carried out through case studies at five manufacturing companies from automotive industry in Malaysia named as Company A, B, C, D, and E. All the companies have involved in assembly production of automotive parts such as head lamp, rear combination lamp, intake manifold, door latch, right and left door inside, and fuel tank. There are four different position of the parts during the assembly such as front, rear, left, and right. Furthermore, the assembly processes have covered up to six different products and up to 25 different models. These are the factors that could contribute to hidden time loss (HTL) through inefficient processing time (IPT). Table 4 (a) presents the summary of operation characteristics for three companies; Company A, Company B, and Company C. Table 4(b) presents the remaining two companies, Company D and Company E.

In this case study, two types data have been collected; (i) Primary Data and (ii) Secondary Data. The primary data of Actual Process Cycle Time refers to the recorded historical Actual Process Cycle Time. The secondary data Actual Process Cycle Time is collected when historical data are not provided. The Standard Process Cycle Time refers to the company target.

In this study, data of Production Input are used to determine either IPT or Merit Time that occurred in a day or month. Hence, there are two conditions of Actual Process Cycle Time. Firstly, the Actual Process Cycle Time is longer than the Standard Process Cycle Time and it is considered as IPT. Secondly, the Actual Process Cycle Time is shorter than the Standard Process Cycle Time and it is considered as Merit Time. In this study, Merit Time is presented as value added time that a company uses for value added activities.

Table 4(a)
Summary of Operation Characteristics

Company Name	A		B	C
Product Name	Head lamp	Rear Combination Lamp	Intake Manifold	Door Latch
Main Position	Front	Rear	Front	Front and Rear
Detail Position	Right and Left	Right and Left	None	Right and Left
Product Variety	1	1	4	6
Model Variety	3	3	6	25
No. of Work Station	7	4	2	4
Man Power at Workstation (WS)	7	4	2	4
Regular Working Time (hours)	18.75	18.75	9.25	9.50
Productive Working Time (hours)	16.75	16.75	7.92	8.00
Capacity/day (pcs)	1,088	1,045	150	1,578

Table 4(b)
Summary of Operation Characteristics

Company Name	D		E	
Product Name	Front Corner	Fuel Tank	Right Hand Door Inside	Left Hand Door Inside
Main Position	Front	Back	Front and Rear	Front and Rear
Detail Position	Right and Left	None	Right	Left
Product Variety	2	2	1	1
Model Variety	1	1	2	2
No. of Work Station	5	5	4	4
Man Power at Workstation (WS)	5	5	4	4
Regular Working Time (hours)	24.00	9.50	9.00	9.00
Productive Working Time (hours)	21.00	8.25	8.00	8.00
Capacity/day (pcs)	993	257	1,753	1,767

III. Result And Discussion

In this study, data of Production Input are used to determine either IPT or Merit Time that occurred in a day or month. Hence, there are two conditions of Actual Process Cycle Time. Firstly, the Actual Process Cycle Time is longer than the Standard Process Cycle Time and it is considered as IPT. Secondly, the Actual Process Cycle Time is shorter than the Standard Process Cycle Time and it is considered as Merit Time. In this study, Merit Time is presented as value added time that a company uses for value added activities. Due to limitation of page number, this paper presents only example of plotted graphs that shows the result of IPT and Merit Time. Figure 1 (a), 1 (b), and 1(c) shows the results for Company E.

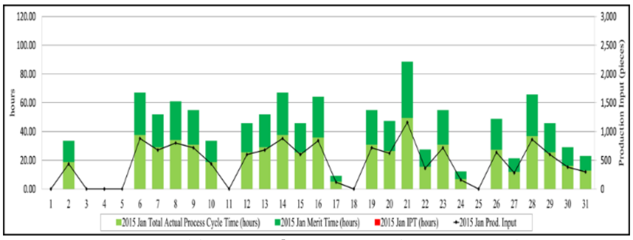

Figure 1(a): IPT and Merit Time (January 2015)

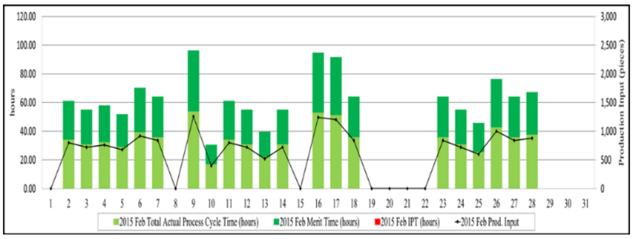

Figure 1(b): IPT and Merit Time (February 2015)

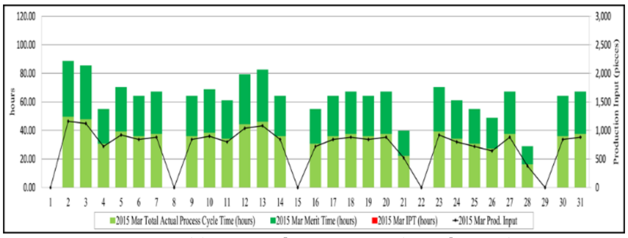

Figure 1(c): IPT and Merit Time (March 2015)

A. Company A

For Company A, the data analysis is executed for only two types of products: (i) Head Lamp (HL), and (ii) RL). Data of Monthly Quality Record, Actual Process Cycle Time Records, and Standard Process Cycle Time Records are used for analysis of IPT. In this case, the Actual Process Cycle Time Records are used to determine the processing time for each Workstation (WS). The Standard Process Cycle Time Records are used to determine the setting of the targeted processing time for each workstation (WS). The Monthly Production Input is used to determine how many units would be processed per month for a continuous period of five consecutive years (2009 until 2013). Following is the example how calculation of IPT for Head Lamp only.

Production Input = 11,690 units
Total WS = 7 (i.e. WS_1, WS_2, WS_3, WS_4, WS_5, WS_6, and WS_7)
Actual Process Cycle Time for WS_1:
t_{apct} _WS_1 = 42.30 seconds
Actual Process Cycle Time for WS_2:
t_{apct} _WS_2 = 50.40 seconds

Actual Process Cycle Time for WS_3:
t_{apct} _WS_3 = 49.30 seconds
Actual Process Cycle Time for WS_4:
t_{apct} _WS_4 = 47.50 seconds
Actual Process Cycle Time for WS_5:
t_{apct} _WS_5 = 48.20 seconds
Actual Process Cycle Time for WS_6:
t_{apct} _WS_6 = 37.10 seconds
Actual Process Cycle Time for WS_7:
t_{apct} _WS_7 = 55.40 seconds

In this case, the Standard Process Cycle Time of each workstation is equal to 62.30 seconds. Thus, IPT can be determined by using Equation 1. Therefore:

Monthly IPT = $\sum_{i=1}^{n} t_{apct}WS_i - t_{spct}WS_i)$
= Production Input $\sum_{i=1}^{n} t_{apct}WS_i - 62.30)$
= 11,690 (-92.10)
= -1,237,971.00 seconds @ -343.88 hours @ -14.33 days

In this case, IPT with negative value is equal to zero. The Merit Time constantly occurred. In total, there are 27,375.15 hours or 1,141 days for HL and 22,785.92 hours or 949 days for RL in five years (2009 to 2013). Through observation, experienced workers contributed to efficient cycle time. It might not be appropriate to compute the IPT of Company A based on experience of workers and the existing Standard Process Cycle Time. In this regard, it would be better to revise the existing Standard Process Cycle Time so that it is close to the Actual Process Cycle Time.

B. *Company B*

The data analysis is executed for only one type of product, which is Intake Manifold (IM). The Production Input is used to determine how many units would be processed per day for a continuous period of three consecutive months (i.e. November 2014, December 2014, and January 2015). Following is the example how calculation of IPT for Intake Manifold.

Production Input = 120 units
Total WS = 3 (i.e. WS_1, WS_2, and WS_3)
Actual Process Cycle Time for WS_1:
t_{apct} _WS_1 = 58.60 seconds
Actual Process Cycle Time for WS_2:
t_{apct} _WS_2 = 190.01 seconds
Actual Process Cycle Time for WS_3:
t_{apct} _WS_3 = 80.40 seconds

Standard Process Cycle Time for WS_1:
t_{spct} _WS_1 = 69.60 seconds
Standard Process Cycle Time for WS_2:
t_{spct} _WS_2 = 239.90 seconds
Standard Process Cycle Time for WS_3:
t_{spct} _WS_3 = 105.00 seconds

Daily IPT = 120 (-85.49)
= -10,258.80 seconds @ -2.85 hours

The result show that the Merit Time constantly occurred at Company B. In total there are 155.02 hours in three months (November 2014 until January 2015) that equal to 6.5 days. Similar to Company A, experienced workers contributed to efficient cycle time.

C. *Company C*

The data analysis is executed for only one type of product, which is Door Latch (DL). The Production Input is used to determine how many units would be processed per day for a continuous period of three consecutive months (i.e. November 2014, December 2014, and January 2015). Following is the example how calculation of IPT for Door Latch:

Production Input = 1,320 units
Total WS = 4 (i.e. WS_1, WS_2, WS_3, WS_4)
Actual Process Cycle Time for WS_1:
t_{apct} _WS_1 = 16.77 seconds
Actual Process Cycle Time for WS_2:
t_{apct} _WS_2 = 18.05 seconds
Actual Process Cycle Time for WS_3:
t_{apct} _WS_3 = 18.24 seconds
Actual Process Cycle Time for WS_4:
t_{apct} _WS_4 = 16.60 seconds

Daily IPT = 1,320 (-14.90)
= -19,668.00 seconds @ -5.46 hours

In this case, the Standard Process Cycle Time of each workstation is equal to 21.14 seconds. The results show that Merit Time had constantly occurred. In total, there are 352.61 hours in three months (November 2014 to January 2015) determined as company's Merit Time which equal to 14.7 days. Similarly, experienced workers contributed to efficient cycle time.

D. *Company D*

The data analysis is executed for only two types of products: (i) Front Corner (FC), and (ii) Fuel Tank (FT). The Production Input is used to determine how many units would be processed per day for a continuous period of three consecutive months (i.e. November 2014, December 2014, and January 2015). Following is the example how calculation of IPT for Front Corner only.

Production Input = 400 units
Total WS = 5 (i.e. WS_1, WS_2, WS_3, WS_4, and WS_5)
Actual Process Cycle Time for WS_1:
t_{apct} _WS_1 = 72.06 seconds
Actual Process Cycle Time for WS_2:
t_{apct} _WS_2 = 54.18 seconds
Actual Process Cycle Time for WS_3:
t_{apct} _WS_3 = 76.05 seconds
Actual Process Cycle Time for WS_4:
t_{apct} _WS_4 = 39.30 seconds
Actual Process Cycle Time for WS_5:
t_{apct} _WS_5 = 71.56 seconds

In this case, The Standard Process Cycle Time of each workstation = 180.00 seconds.

Daily IPT = 400 (-586.85)
= -234,740.00 seconds @ -65.21 hours

For Company D, in total there are 3,615.65 hours for FC and 265.33 hours for FT in three months (November 2014 to January 2015) that equal to 11 days. The same reason applied as Company A, B, and C.

E. Company E

The data analysis is executed for only two types of products: (i) Right-Hand Handle Door Inside (RH) and (ii) Left-Hand Handle Door Inside (LH). Following is the example how calculation of IPT for RH only.

Production Input = 720 units
Total WS = 4 (i.e. WS_1, WS_2, WS_3, and WS_4)
Actual Process Cycle Time for WS_1:
t_{apct} _WS_1 = 48.81 seconds
Actual Process Cycle Time for WS_2:
t_{apct} _WS_2 = 48.94 seconds
Actual Process Cycle Time for WS_3:
t_{apct} _WS_3 = 49.28 seconds
Actual Process Cycle Time for WS_4:
t_{apct} _WS_4 = 8.40 seconds
Standard Process Cycle Time for WS_1:
t_{spct} _WS_1 = 80.00 seconds.
Standard Process Cycle Time for WS_2:
t_{spct} _WS_2 = 80.00 seconds
Standard Process Cycle Time for WS_3:
t_{spct} _WS_3 = 80.00 seconds
Standard Process Cycle Time for WS_4:
t_{spct} _WS_4 = 35.00 seconds

Daily IPT = 720 (-119.57)
= -86,090.40 seconds @ -23.91 hours

For Company E, the Merit Time constantly occurred. In total there are 1,774.29 hours (74 days) for FC and 1,808.49 hours (75.4 days) for FT in three months (November 2014 to January 2015) which also due to experienced workers whom contributed to efficient cycle time.

IV. CONCLUSION

This paper proved that the IPT does exist in the assembly processes specifically for automotive parts. The results of five case studies at manufacturing companies in automotive industry show that the IPT has contributed to HTL but in a form of Merit Time. In this case, the root cause of the Merit Time is inappropriate Standard Processing Time (SPT) which experienced workers can complete an assembly process faster than the SPT. Hence, this paper concludes that IPT is one of the HTL component and its equation is valid for measuring the HTL. For the future work, it is necessary to develop a planning system related to production capacity.

ACKNOWLEDGMENT

The authors gratefully acknowledge funding of ERGS grant (ERGS/2013/FKP/TK01/UTeM/02/10/ E00030) by the Universiti Teknikal Malaysia Melaka in the research on sustainability and responsiveness of manufacturing operations. Also special acknowledgement to MyBrain15 scholarship from the High Education Ministry of Malaysia. Finally, special acknowledgement to Centre of Research and Innovation (CRIM) of UTeM for the publication of this article at Journal of Advanced Manufacturing Technology by using journal fund.

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