Non-Conformance Time As The Component Of Time Loss Measures In Assembly Processes

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Abstract: Hidden Time Loss (HTL) occurs along the production processes that have a big implication on productivity. Overall Equipment Efficiency (OEE) is one of the most popular performance measurement tool used in the production line. The HTL has been provided by quality as one of the measure components of OEE. However, OEE doesn’t really suitable in measuring operation performance of assembly processes mainly in the semi-auto assembly and the manual assembly processes. There would be the amount of HTL have occurred along the semi-auto assembly and manual assembly processes that become crucial when to achieve high product variety at the same production assembly line. Therefore, the purpose of this paper is to introduce the Non-conformance Time (NCT) as one of the parts of Hidden Time Loss Measures (HTLM) in assembly processes. Literature study on manufacturing assembly processes had been used to derive the structure of NCT. Then, two selected automotive manufacturing companies had been used as a case studies in order to validate the NCT structure. Based on semi-auto and manual assembly processes, the results show that the NCT is one of the parts of HTLM.

Keywords: Assembly Process; Performance Measure; Non-conformance, Non-value Added.

1. Introduction
Nowadays, in order to meet customers’ demands, product types has been recognized as one of the foremost competitive edges in manufacturing industries [1]. According to Liao et al. [2], the increasing demand from customers caused suppliers in all industries continually work hard. They also mentioned that one of factors could be overwhelming for suppliers is quality product, who do not possess the necessary knowledge to improve their operational performance.
Thus, the most challenge to the manufacturing companies is to achieve minimal time loss by offering a type of products. On the other hand, they are also involving a lot product quality, market price, and minimal lead time as intensive competition [3]. In order to sustain the efficient productivity, it is essential to recognize the non-value added activities along the manufacturing operation accounted for every type of products in manufacturing companies.

Therefore, the components of Non-conformance Time (NCT) as the measure of Hidden Time Loss (HTL) had been introduced through determination of internal process in the scope of operation at the automotive industries. The HTL due to assembly process activities as the number of product type in the automotive industries keep increasing had been determined as a significance of this study. In addition, the effect of NCT on the assembly operation time in the scope of assembly features had been clarified in this paper such as left-right components, front-rear components, different products, and different models.

This paper consists of six sections. Section 2, provides understanding on NCT as a component of HTLM. Section 3 discusses the final structure of NCT. Section 4, explains the development of NCT equations. In Section 5, discuss the results and discussions of case studies followed by Section 6 that presents the conclusion of this study.

2. The Non-Conformance Time

According to Jaber and Khan [4], rework is required and can be defined as perform work at least one additional time while a goods does not fulfil the quality standard. When do not fulfil the standard of quality, they also assumed that some reworked units are scrapped. Similarly, Shetwan et al. [5] claimed that after the completion of the component assembly process, certain actions will be taken during the quality inspection to rework or scrap a product when it does not conform to the specifications. Chen and Tsao [6] classified two types of defects such as rework able defects and non-rework able defects. Therefore, the defect refers to non-conformance product which is not conformed to the specifications. Earlier, Thomas and Pham [7] agreed that defect reduction can improve manufacturing efficiency.

Thus, the non-conformance products have given implication to the productivity as it causes non-value added activities such as rework. Sometimes, these products have to be scrapped when the quality does not meet the specification. In this case, the company operating time can have to be expanded to resolve the quality issues. In this study, the non-value added time known as NCT. Even if the planned production capacity had been fulfilled to meet the customer requirements, the quality issues might influence the actual production capacity through the quantity of product defects in the assembly process.

Quality of products is one of the vital issues in manufacturing operation, and improvement is needed through an appropriate preventive or corrective action. The statement is supported by Radharamanan et al. [8], who claim that possible actions are necessary to improve the quality of products and services. Uyar [9] pointed out that performance measures can be viewed from the aspects of quality performance such as the number of reworked units, the number of material inspections, the number of customer complaints, and quality cost. Murugaiah et al. [10] have highlighted that the scope of defects consists of generating scrap, rework or paperwork errors.

It can be noted that product quality is one of the important factors to produce a product
saleable in the marketplace. In short, quality can be considered as a fundamental driver of productivity and performance [11,12]. On the other hand, quality has never been measured through how long it takes to make a decision on the status of product quality such as an on-hold/KIV product. The waiting time for an action to be taken when a product quality problem arises generate a loss of time and can be considered as Hidden Time Loss (HTL).

As be mentioned earlier, Overall Equipment Effectiveness (OEE) is one of the performance measure tool that are commonly used among manufacturing companies. The OEE was devised by Nakajima [13]. He identified that the quality is one of the components for calculating OEE. The other components such as availability and performance. Raja and Kannan [14] have claimed that OEE is simply calculated by multiplication of availability, performance, and quality. Earlier, Lungberg [15] mentioned that the OEE is an effective way of analysing the efficiency of a single machine or an integrated machinery system. Similarly, Chand and Shirvani [16] stated that each piece of equipment can be operated to its full potential and maintained at that level by increasing equipment efficiency through OEE metric.

However, Chan et al. [17] agreed that, OEE still requires further modification on classification of losses, even it is seen to be a standard method for the measurement of equipment performance. Thus, OEE is not really fit for measuring operation performance of the overall assembly process, especially the manual assembly process and the semi-auto assembly process.

The NCT makes additional costs as well. In this regards, there is possibility for the NCT to cater the required volume. However, the NCT is the time taken regarding defects and can be considered as HTL. Therefore, the scope of this study is focused on the non-conformance of products in assembly process. Thus, this study clarifies NCT as a HTLM component.

3. Structure Of NCT
This section consists of three subsections. In Subsection 3.1, the initial structure of NCT is introduced. Then, the following subsection confirms the initial structure of NCT through verification from selected automotive companies. Finally, Subsection 3.3 discusses the results of verification.

3.1 Development of NCT
According to the outcomes of literature studies on manufacturing operations performance, Figure 1 presents the initial structure of NCT. Based on the NCT structure, it consists of Defect and On-hold/KIV. In this study, Defect refers to something is wrong with a product. Rework is defined as work out something minimum one extra time due to out of quality standard and it is defined as Rework-able defects. However, reworked units are scrapped when they do not fulfill the quality standard and it is defined as Non-rework-able defects. On-hold/KIV refers to an unknown quality status for finished goods and await concession from the customer.

3.2 Verification of NCT
In this study, the initial structure of NCT has been verified in order to achieve realistic situation. In this regard, the initial structure of NCT has been verified through an outcomes of face-to face interviews and comments by practitioners from manufacturing industries.
The practitioners have been selected from professionals in industries such as engineers, managers, etc. from two automotive manufacturing companies. In total, seven respondents had participated during the verification of NCT initial structure. Figure 2 shows an example of answered face-to-face survey for the initial structure of NCT. The face-to-face survey for the initial structure of NCT is based on three section: (i) Overall Non-conformance Time structure, (ii) Rework structure, and (iii) On-hold/KIV structure. Appropriateness of terms used and the NCT structure are based on Likert Scale: (i) 1 is equal to not appropriate, (ii) 2 is equal to partly appropriate, and (iii) 3 is equal to appropriate.

**Figure 1: NCT structure**

![Diagram of NCT structure]

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**Initial ‘Framework of Time Loss Measurement Structure’ Comments by Industrial Practitioner**

(Please tick [ ] your selection in applicable)

| Item | Slide No. | Appropriate Level | Comment |
|------|-----------|-------------------|---------|
| Overall Non-conformance Time structure suitability and affected to the Time Loss increasing. | 1a | 1 2 3 4 | |
| (a) Depending on time, rework structure has affected to the Time Loss increasing. | 1a | 1 2 3 4 | |
| (b) On-hold/KIV time structure has affected to the Time Loss increasing. | 1a | 1 2 3 4 | |

| Others comments |

**Figure 2: NCT Verification Checklist**

### 3.3 Structure of NCT

The results of verification has been presented in Table 1. Majority rule has been used to verify the NCT structure. The majority rule is one of the decision rule that choose an alternative which has a majority, that is, more than half the votes [18]. According to Fukuyama et al. [19], this rule is model by utilizing conflict analysis model. Three conditions are used in determining the result of verification:

i. If $\geq 50\%$ of appropriate, the initial fundamental items and their components will remain in the isolated model.

ii. If $\geq 50\%$ of partly appropriate, the initial fundamental items and their components will be
improved in terms of their descriptions.

iii. If ≥ 50% of not appropriate, the initial fundamental items and its components will be taken out from the isolated model.

| Table 1: Verification analysis results |
|---------------------------------------|
| Section                               | Not-appropriate | Partly-appropriate | Appropriate |
| Overall Non-conformance Time          | 0 (0.0%)        | 1 (14.3%)          | 6 (85.7%)   |
| Defect                                | 0 (0%)          | 2 (28.6%)          | 5 (71.4%)   |
| On-hold/ KIV                          | 0 (0%)          | 3 (42.9%)          | 4 (57.1%)   |

4. Equation of NCT

The NCT equation has been developed based on the proposed NCT. As shown in Figure 1, NCT is measured through the sum of NCT for Total Defect and On-hold/ KIV. In this regards Total Defect consists of Rework and Scrap. The On-hold/KIV refers to total period of On-hold/ KIV.

Figure 3 shows the common procedure for determining quality status which results in NCT. There are three levels of quality status (Good, No Good, and Unknown). For Good quality status, the NCT equals zero, No Good quality status NCT does not equal zero, and Unknown quality status NCT does not equal zero when it involves On-hold or KIV period of time. On-hold/KIV is on-hold time taken for defect settlement. This study determines the total of NCT as below:

\[ NCT = T_d + t_{ohp} + T_r \]  

\( T_d \): Total actual process cycle time multiply with total number of defects. 
\( t_{ohp} \): Time taken for defect settlement. 
\( T_r \): Time taken to rework multiply with total number of rework quantity.

In this regard, the rework time is taken as 50 percent from Total Standard Process Cycle Time. According to [4], it is assumed that per unit time of production and rework is 10 and 5 units respectively. In this regard, NCT ≥ 0. This study determines the total of NCT for \( T_d \) as below:

\[ T_d = \sum_{i=1}^{n} (t_{apct})_i \times d \]  

\( d \): Total number of defect at the end of assembly line. 
\( t_{apct} \): Actual process cycle time.

In this regard, \( T_d \geq 0 \). This study determines the total of NCT for \( T_r \) as below:

\[ T_r = 0.5(\sum_{i=1}^{n} (t_{spct})_i) \times r \]  

5
r: Total no of rework at the end of a process assembly line.
T_{spect}: Standard process cycle time.

In this regard, T_r ≥ 0.

![Diagram of NCT common procedure]

**Figure 2:** NCT common procedure

5. **Validation of NCT Equation**

The objective of validation is to validate the NCT equations that developed for determining HTL through operating time. The validation of NCT equation is carried out through case studies at two automotive manufacturing companies in Malaysia named as Company A and B with three products. The case studies are separated into three main segments:

5.1 **Collection of Data**

In this case study, data have been collected from primary and secondary data. The recorded historical data has been referred as a primary data of actual process cycle time. When the historical data is not provided, the data will be collected as a data of actual process cycle time and be referred as a secondary data. In this study, the NCT has been determined by using the data of actual process cycle time, standard process cycle time, and monthly quality report that occurred in a day or month.

5.2 **Analysis of Data**

The value of NCT will be determined through the data analyses at every case in the case study (i.e. A and B). In this paper, the Microsoft Office software (Excel) was used as a method of to analyze the data. In order to analyse the NCT the significant data will be used such as data of actual process cycle time, standard process cycle time, and monthly quality report. In this case, the total actual process cycle time has been determined through the actual process cycle time. The total standard process cycle time has been determined through the standard process cycle time. The monthly quality report are used to clarify how many units of defects occurred per month for a continuous period of five consecutive years (2009 to 2013) for Company A. Secondly, to clarify how many units of defects occurred per day for a
continuous period of three consecutive months (November 2014 to January 2015) for Company B.

6. Results and Discussion

Based on individual company's period of time analysis, the results of NCT for each company are presented in plotted graphs.

i. Company A

Figure 4 (a) presents the NCT outcomes for HL product and Figure 4 (b) presents the NCT outcomes for RL product from the year 2009 to 2013 which display the Monthly Production Input (Pieces) versus Monthly NCT outcomes.

![Graph showing NCT outcomes for Company A (2009 ~ 2013)](image)

The results of NCT are based on the Defect Depending Time, Rework Time, and On-hold/KIV period for products HL and RL. Based on Figure 4 (a) and Figure 4 (b), the NCT increases when Defect Depending Time, Rework Time, and On-hold/KIV period increase.

This study focuses on two main situations: (i) Maximum peak of Production Input versus NCT and (ii) Maximum peak of NCT versus Production Input.

Through observation, situation (i) occurs as can be seen for HL on April 2010 in Figure 4 (a), which is the maximum peak of Production Input versus NCT. For this situation, the NCT is in a low peak condition. Thus, workers’ skills are at an appropriate level and they make fewer mistakes. Therefore, the motivation of workers will rise through the increase in skills and knowledge. These workers have different skills which influence the processing times and line productivity. As a result, the productive efficiency increases through the appropriate skills and strong motivation.

Situation (ii) occurs as can be seen for HL on May 2012 in Figure 4 (a) with the maximum
peak of NCT versus Production Input. For this situation, the Production Input is in a normal peak condition. In contrast to situation (i), workers’ skills are at an inappropriate level and they frequently make mistakes. Therefore, the motivation of workers decreases through poor skills and knowledge. Lau and Roopnarain [20] agree that productive efficiency can be increased through cognitive factors such as increasing information, knowledge, creativity and encouragement among workers. As a result, the motivation to improve Production Input decreases. Thus, based on Figure 4 (a), it can be concluded that the productivity for situation (i) is better than that for situation (ii).

Situation (i) occurs as can be seen for RL on July 2013 in Figure 4 (b) with the maximum peak of Production Input versus NCT. For this situation, the NCT is in a high peak condition. In this case, when the Production Input is at maximum peak value with an increase in the setup frequency, workers can make mistakes easily and errors can easily happen in the machine. According to Li and Rong [21], the whole production system and just-in-time objective could be affected by a high frequency setup, which often leads to high risk of worker mistakes and machine failures. It is necessary the manufacturing industry should provide appropriate system in order to make the workers systematically follow the steps of operation. As explained by Muzaimi et al. [22], it is necessary for the organisation to adopt the new system applications in order to enhance the standards systems and procedures that were already established in the organisation. In this case, the workers could not absorb the overload of tasks. As a result, when overloading of tasks occurs, workers would not work properly and they make mistakes easily.

ii. Company B

The results of NCT for IM product (November 2014) had been presented in Figure 5 (a), the results of NCT for IM product (December 2014) had been presented in Figure 5 (b), and the outcomes of NCT for IM product (January 2015) had been presented in Figure 5 (c). Similar to Company A, each figures show the outcomes of Daily Production Input (Pieces) versus Daily NCT.
Like Company A, the outcomes of NCT was based on a Defect Depending Time, Rework Time, and On-hold/KIV Time for product IM. Based on Figure 5 (a), 5 (b), 5 (c), the NCT growth as Defect Depending Time, Rework Time, and On-hold/KIV period increase. This study focuses on two situations: (i) Maximum peak of Production Input versus NCT and (ii) Maximum peak of NCT versus Production Input.

Through observation, situation (i) occurs as can be seen on 3rd December 2014 in Figure 5 (b) and on 26th January 2015 in Figure 5 (c), that is maximum peak of Production Input versus NCT. For this situation, the NCT is in a low peak condition. In this case, the reason is similar to that of situation (i) of HL in Company A.

Situation (ii) occurs as can be seen on 1st December 2014 in Figure 5 (b,) that is maximum peak of NCT versus Production Input. For this situation, the Production Input is in a normal peak condition. In this case, the peak of NCT occurs because one unit of the product is On-hold/KIV for one day.

7. Conclusion
This paper introduced the structure of Non-conformance Time (NCT) and the equations of NCT that used to determine the Hidden Time Loss (HTL). In this regard, Defect and On-hold/KIV were considered as two major components of NCT. The case study at two manufacturing companies in automotive industry had been used to prove the equation of NCT. For the case of the manual assembly process and semi-auto assembly process in the automotive industry, it can be concluded that maximum production input would cause NCT due to workers’ capabilities such as skill, commitment, spirit, etc. Therefore, the systematic refreshment training is necessary to be conducted timely for improvement by the respective department. On the other hand, existing performance results related to quality in manufacturing only focus to the defect rate. In this study, the results of NCT includes the On-hold/KIV which interpreted to the unit of time. This study also concludes that the NCT can occur at any type of assembly feature in automotive manufacturing companies. Thus, this study introduces NCT as one of the components of HTLM for manual assembly process and semi-auto assembly process.

Acknowledgments
The authors special thanks to Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan of Universiti Teknikal Malaysia Melaka for the use of the facilities to complete this study. Besides, I would like to express my heartfelt thanks to the related companies for their advised.
References

[1] E. Nazarian, J. Ko, and H. Wang, “Design of multi-product manufacturing lines with the consideration of product change dependent inter-task times, reduced changeover and machine flexibility”, Journal of Manufacturing Systems, vol. 29, no. 1, pp. 35–46, 2010.

[2] K. Liao, Q. Tu, and E. Marsillac, “The role of modularity and integration in enhancing manufacturing performance: An absorptive capacity perspective”, Journal of Manufacturing Technology Management, vol. 21, no. 7, pp. 818-838, 2010.

[3] U. Dombrowski, T. Mielke, and C. Engel, “Knowledge management in lean production systems”, in Procedia CIRP: CIRP Conference on Manufacturing Systems, Athens, Greece, 2012, pp. 436 – 441.

[4] M.Y. Jaber and M. Khan, “Managing yield by lot splitting in a serial production line with learning, rework and scrap”, International Journal of Production Economics, vol. 124, no. 1, pp. 32-39, 2010.

[5] A.G. Shetwan, V.I. Vitanov, and B. Tjahjono, “Allocation of quality control stations in multistage manufacturing systems”, Computers and Industrial Engineering, vol. 60, no. 4, pp. 473-484, 2011.

[6] T.H. Chen and Y.C. Tsao, “Optimal lot-sizing integration policy under learning and rework effects in a manufacturer-retailer chain”, International Journal of Production Economics, vol. 155, pp. 239-248, 2012.

[7] A.J. Thomas and D.T. Pham, “Making industry Fit: The conceptualization of a generic ‘Fit’ manufacturing strategy for industry”, in IEEE Conference. on Industrial Informatic (INDIN), Berlin, Germany, pp. 523-528, 2004.

[8] R. Radharamanan, L.P. Godoy, and K.I. Watanabe, “Quality and productivity improvement in a custom-made furniture industry using kaizen”, Computers and Industrial Engineering, vol. 31 no. 1-2, pp. 471-474, 1996.

[9] A. Uyar, “Quality performance measurement practices in manufacturing companies”, The TQM Journal, vol. 21 no. 1, pp. 72-86, 2009.

[10] U. Murugaiah, S.J. Benjamin, M.S. Marathamuthu, and S. Muthaiyah, “Scrap loss reduction using the 5-Whys analysis”, International Journal of Quality and Reliability Management, vol. 27, no. 5, pp. 527-540, 2010.

[11] W.E. Deming, Quality, productivity and competitive position. Cambridge: Massachusetts Institute of Technology Centre, 1982.

[12] J.M. Juran, Juran on planning for quality. London, Collier Macmillan, 1988.

[13] S. Nakajima, Introduction to TPM: Total Productive Maintenance. Cambridge, Productivity Press, 1988.

[14] P.N. Raja and S.M. Kannan, “Evolutionary programming to improve yield and overall equipment effectiveness of casting industry”, Journal of Engineering and Applied Sciences, vol. 2, no. 12, pp. 1735-1742, 2007.

[15] O. Lungberg, “Measurement of Overall Equipment Effectiveness as a basis for TPM activities”, International Journal of Operations and Production Management, vol. 13, no. 5, pp. 495-507, 1998.

[16] G. Chand and B. Shirvani, “Implementation of TPM in cellular manufacture”, Journal of Materials Processing Technology, vol. 103, no. 1, pp. 149-154, 2000.

[17] F.T.S. Chan, H.C.W. Lau, R.W.L. Ip, H.K. Chan, and S. Kong, “Implementing Total Productive Maintenance: A case study”, International Journal of Production Economics, vol. 95, no. 1, pp. 71-94, 2004.

[18] M.K. Karasu, M. Cakmakci, M.B. Cakiroglu, E. Ayva, and N. Demirel-Ortabas, “Improvement of changeover times via Taguchi empowered SMED/case study on injection molding production”, Measurement, vol. 47, pp. 741-748, 2014.
[19] K. Fukuyama, T. Kawabata, and J. Na, “Conflict analysis on the enforced-move-by-majority rule in a group decision making situation”, in IEEE Conference on Systems, Man, and Cybernetics (SMC), Manchester, UK, 2013, pp. 2031 – 2036.

[20] C.M. Lau and K. Roopnarain, “The effects of nonfinancial and financial measures on employee motivation to participate in target setting”, The British Accounting Review, vol. 46, no. 3, pp. 228-247, 2014.

[21] S.G. Li and Y.L. Rong, “The reliable design of one-piece flow production system using fuzzy ant colony optimization”, Computers and Operations Research, vol. 36, no. 5, pp. 1656-1663, 2009.

[22] H. Muzaimi, S.R. Hamid and B.C. Chew, “Integrated management system for quality management system accreditation”, Journal of Advanced Manufacturing Technology, vol. 12, no. 1(1), pp. 87-99, 2018.