Using work factor method for operational models of disassembly and reassembly evaluation

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ABSTRACT

The purpose of this paper is to study the disassembly task time in the maintenance and recycling context, knowing that only the reassembly task is needed in repairing operation. Dis/reassembly activities are delicate and need precise intervention due to the obligation of equipment refunctioning constraints. Time spent for dis/reassembling faulty components should be well-deducted and standardized. It is not always the case due to the various variant disassembly metrics and contexts. The Work Factor Method during dis/reassembly activities helps to develop the operational dis/reassembly time models. Two model cases have been proposed. The first model presents a function of \( n \) components with the same characteristics that multiply the corresponding time for a component in the context where the tool used is the robot, while the second model meets the conditions of manual disassembly where the proposed function estimates the time of disassembly and reassembly according to the coefficients of performance of technician. These models contribute to defining effective time as far as operational dis/reassembly activity is concerned and can help to optimize maintenance and recycling task planning.

1. Introduction

The purpose of this paper is to study the disassembly task time in the maintenance and recycling context, knowing that only the reassembly task is needed in repairing operation. Dis/reassembly activities are delicate and need precise intervention due to the obligation of equipment refunctioning constraints. Time spent for dis/reassembling faulty components should be well-deducted and standardized. It is not always the case due to the various variant disassembly metrics and contexts. During dis/reassemblable activities, the Work Factor Method is used to develop the operational dis/reassembly time model. These models contribute to defining effective time as far as operational dis/reassembly activity is concerned and can help to optimize maintenance and recycling task planning. When a failure arises, intervention is required. This process is subdivided into many intervals of time for the localization of the fault, diagnostic time, disassembly time, reparation/replacement time, reassembly time, control and final test time, and the other extra times (administrative, logistic, or awaiting for the necessary resources, for the preparation of work) François Monchy [1]. These times encompass TTR (Time To Repair), and they are known to be heavy and do not permit quick availability of the faulty equipment.
The main critical activity in the maintenance task is disassembly. Disassembly has been widely studied, starting from disassembly definition to disassembly sequencing, processing, planning, and modeling [13] [14] [15]. Major works have been done in the relevant literature and indicated the evaluation criteria and methodologies that address the problem in the context of recycling, such as disassembly sequence or economic analysis [16]—[25]. Various methodologies have been developed to evaluate the disassemblability of a product [3] [26] [29]. However, the disassembly spirit for maintenance is quite different from the one of recycling.

An evaluation method of disassembly time evaluation of a product using the work factor technic was proposed by Yi, HC, et al. [30]. This analysis is done to investigate the influencing factors related to disassembly time. Factors were quantified by a movement analysis system using a work factor system, and the operation time was obtained by applying predetermined values of time-based experience on basic human movement. The disassembly time was calculated by using the standard time on the disassembly base time depending on the sequence of disassembly operations. The disassembly time of each product component is the sum of preparation time, movement time, operation time, and post-processing time (see Table 1 for more details). Disassembly analysis is obtained using a work factor system table, considering moving body parts, moving distance, weight, and artificial regulation factors. This Method is not practically feasible due to many factors encountered in disassembly and reassembly, such as human factors, equipment factors, and logistic factors.

| Nomenclature |
|---------------|
| \( t \) | the disassembly or reassembly time (s) |
| \( \lambda \) | the disassembly or reassembly rate |
| \( n \) | Number of fasteners or components |
| \( TT_p \) | Total Time of Disassembly or Reassembly |
| \( T_p \) | The preparation time of disassembly or reassembly |
| \( T_m \) | Moving Time |
| \( T_d \) | Operation time of disassembly or reassembly |
| \( T_{pr} \) | Post-processing time of disassembly or pre-processing time of reassembly |
| \( n \) | Final state |
| \( x \) | state |
| \( i \) | State rank in a disassembly sequence |
| \( k_1, k_2 \) | Performance score |

**Table 1. Influence factors on standard time** [30]

| Base Time | Influence factors time |
|-----------|------------------------|
| Preparation Time (\( T_p \)) | Time for identifying joint elements (\( T_pb \)) |
| | Time for searching and identifying tools (\( T_pc \)) |
| | Time for gripping tools (\( T_pg \)) |
| Movement Time (\( T_m \)) | Time for moving between joint elements (\( T_md \)) |
| | Time for redirecting to the side of joint elements (\( T_ml \)) |
| Operation Time/Disassembly Time (\( T_d \)) | Time for aligning between tool and joint element (\( T_dd \)) |
| | Time for tool operation area (\( T_dp \)) |
| | Time for basic separation of joint element (\( T_d_b \)) |
| | Time for the intensity of work (\( T_d_w \)) |
| Post-processing Time (\( T_pr \)) | Time for post-processing due to weight and size of the disassembled parts (\( T_prsw \)) |
| | Time for post-processing due to movement of disassembled parts (\( T_prmp \)) |
| | Time for post-processing due to the hazard (\( T_prh \)) |

Work on maintenance disassembly time was presented Samon et al. [31]. The method "weighted voting" allowed anonymously gathering information in a consensual manner from working group members (maintenance actor, ergonomist, designer, and expert) on criteria or parameters linked to disassembly of each module or component of an electric hand drill during disassembly. As earlier mentioned, disassembly and reassembly are the most critical activities in analyzing the equipment maintainability during its useful life because of many uncertainties during dis/reassembly intervention as far as maintenance actors, equipment, and work environment. Precisely, the difficulty of recording effective time might be explained by the nature of human beings (maintenance actor skill), the uncertainties of dis/reassembly nature (due to corrosion, product complexity, etc.), and the equipment dis/re-assemblability decided at the design stage, the administrative Time, the logistic Time and the unpredictable Time. That is why it is essential to know how the TTR is deducted regarding only dis/reassembly activities as the maintenance is evaluated in hourly cost. The importance of analyzing and evaluating dis/reassembly time is then a welcome issue precisely in the maintenance and recycling context.
The main objective of this work is to propose a method for determining disassembly time, taking into account practical conditions that are generally absent in theoretical and simplified models in the literature. The activity time is a fundamental parameter in maintenance, especially in case of emergency intervention. The success of an operation should be based on a realistic time that integrates the practical vicissitudes such as micro-time, the nature of the working tools, and the operator’s performance. Taking these factors into account would complement the theoretical approaches of the literature. After presenting the analysis methodology based on the "Work Factor Method", a temporal analysis of the disassembly and reassembly activity times under experimental conditions will be illustrated.

2. Methodology

Selective disassembly is generally used for product maintenance. When used for repair, some components and modules are removed to ensure accessibility to other components or modules for repairing, testing, and maintaining. Here selective disassembly is always followed by reassembly, implying that damage to any disassembled component or module must be avoided. So to deduce the maintenance dis/reassembly time, the analysis is based on the following three main steps used here: (1) dis/reassembly definition system, (2) dis/reassembly temporal analysis using Work Factor Method (see Table 1). The dis/reassembly context should be defined because the time deducted should be given with a defined context accordingly.

It should be noted that dis/reassembly time depends on: Environment of work (suitable ergonomic workshop); Availability of convenient logistics; Qualified and professional degree of the operator; Level of integration of maintainability in the equipment design. Those factors bring in extra task time, which depends on the actual context of recycling and maintenance, knowing that the Work Factor Method is defined here as the basis time. Then, we deduced the extra time using the additional scoring factors in Table 2 Niebel, B. [32].

| Skill rating | Effort rating |
|--------------|--------------|
| +0.15        | A1 Superskill|
| +0.13        | A2 Superskill|
| +0.11        | B1 Excellent |
| +0.08        | B2 Excellent |
| +0.06        | C1 Good      |
| +0.03        | C2 Good      |
| 0.00         | D Average    |
| -0.05        | E1 Fair      |
| -0.01        | E2 Fair      |
| -0.16        | F1 Poor      |
| -0.22        | F2 Poor      |

3. Results and Discussion

The methodology scheme for disassembly and reassembly time for maintenance should be flexible and general. The Method is to analyze the dis/reassembly activities in the workshop practically. It should be noted that active dis/reassembly (to unscrew and to screw) time should be deducted, but some subactivities should be taken into consideration. For example, one has for disassembly (Setting in Safety, to drain, to clean, to locate, to lay down, to drive out, to extract, to unfold); and for reassembly (to engage, to reset level, to unlay down, to regulate, to test, to control). Time taken by those subactivities is masked time, which should be involved in total dis/reassembly time and should be added in Work Factor deducted Time on Table 1.

3.1. A literal description of dis/reassembly

They are three types of disassembly: selective, total, and destructive. The application of each type depends on maintenance or recycling tasks. Disassemblability and reassemblability measure the degree of dis/reassembly easiness. Disassembling is an operation having to unjoin or burst a product to the components while separating the connection elements from this unit, where reassembly is the reverse operation of the assembly except in certain cases where some adjustments are necessary. The simplest way to understand the dis/reassembly system can be represented by the basic actigram through Fig. 1 below.

![Diagram of dis/reassembly system](image-url)

The average time necessary for dis/reassembling is strongly related to the time taken to dis/reassemble a screw, a bolt, or a pin. Time is not the only parameter that depends on dis/reassembly activities. It depends on other parameters which constitute the product. These parameters can be related to the equipment, maintainer, logistic and unpredictable phenomenon.
3.2. Temporal analysis of dis/reassembly activities

The dis/reassembly activity is a random task because of unpredictable events, and it is manually performed. Let us assume that disassembly is a continuous activity because when a maintenance actor engages in dis/reassembly, he cannot stop the action until he finishes the sequence operation. In such a case, the probability of the event (to remove a screw) is equal to one. This description can be randomized with the exponential law, where dis/reassembly time is the fundamental parameter. Then let us be \( f(t) = \lambda e^{-\lambda t} \) the density (answer) of dis/reassembly, with \( E(t) = 1/\lambda \) the expectation or the mean of times.

In the operational context, let us be assuming two cases that appear in disassembly and reassembly operations:

- The case wherein the equipment design, the dis/reassembly sequence was imposed according to technical specifications' mentioned in the maintenance document;
- The dis/reassembly sequence is random, i.e., the maintenance and recycling actor has his sequence to reach the target component or fastener.

A case where disassembly and reassembly sequence is imposed

In this case, the network of disassembling a fastener or component from the product; \( X_i \) is complete disassembly state. Reassembly is opposite the disassembly sequence. Here, we can still distinguish two cases: the dis/reassembly operation occurs by a maintenance or recycling actor and one of the robots (electric tool).

- **Case of a robot**: If fasteners or components have the same physical parameters, the disassembly time is computed using:

  \[
  T_{D/R} = n \cdot \tau_{D/R}
  \]  (1)

  With \( \tau_{D/R} \), dis/re-assembly time from Work Factor System (Table 1)

  \[
  \tau_{D/R} = \tau_p + T_m + T_{(d/r)} + T_{pr}
  \]  (2)

- **Case of manual operation**: The maintenance or recycling actor is a qualified technician who follows suitable training under the activity that he should undertake. In addition, when he/she is experienced, this is appreciated by quickness, precision, quality, and the gaining of time. It must be known that the mechanical human being’s energy is not constant. Therefore, the dis/reassembly force and posture are not constant along the process. Potential and kinetic energy are usually changed. The graph of Fig. 3 tends to illustrate the experience constituent metrics and their evolution over time.

![Figure 3. Experience’s constituent graph over time](image)

In maintenance, the experience’s operator does not relate only to the number of a year spent in the same activities, but to a chronology according to (1) basic knowledge required, (2) basic working force required, (3) basic working environment required, (4) brainstorm skill or workability and thoughtfulness, (5) working age: Time spent doing the same work, and (6) biological age. This experience has the penalty with task time. The Mean Time of Disassembling is expressed as:

\[
MT_D = k_1 \left( \sum_{i=1}^{n} T_{x_i'x_{i+1}} \right) + \tau_D
\]  (3)

Where: \( n \) States \( (i=1,2,\ldots,n) \) \( i \) = state rank in a disassembly sequence

\( T_{x_i'x_{i+1}} = \tau_D \): Time is taken to move from one state to another, corresponding to the disassembling of a fastener or the component from the initial state \( x_i \) to the next state \( x_{i+1} \).

\( k_1 \): A score of micro-time, experience, and performance effect in the recording process time. That is defined according to Table 2 and computed as illustrated in Table 3.

![Table 3. Summary of each performance level](image)

Where the first score of \( k_1 \) is (high-performance score), the second is (high + excellent) scores, the third category is (The first + the second + good), the fourth is (the third + Fair), and the fifth is (the fourth + Poor performance score).

\[
k_1 = \begin{cases} 
0.38 & \text{micro - time + superskill performance worker} \\
0.66 & \text{micro - time + excellent performance worker} \\
0.80 & \text{micro - time + good performance worker} \\
1.02 & \text{micro - time + fair performance worker} \\
1.52 & \text{micro - time + poor performance worker}
\end{cases}
\]
The goal here is to find a way $X_i$ to $X_n$ associate with the total valuation weakest, knowing that the length of a way is equal to the sum lengths of each arc. Ford's algorithm is indicated for this type of graph to determine the way of optimal value because the network has only positive lengths (without circuits).

The implementation of this algorithm recommends:

- To number the tops in an unspecified order (except way $X_1$ and $X_n$): $\lambda_i = +\infty$ except $\lambda_1 = 0$.
- For any top $X_i$ for which $X_j > V(X_i, X_j)$ replace $\lambda_j$ by $\lambda_i > V(X_i, X_j)$. $V$ represents the valuation of the arc;
- To top when none $\lambda$ can be modified more.

Once having the shortest way, the above dis/reassembly time formula must be applied.

**3.3. Case study indication**

The application of those models is based on the Work Factor System, which is already applied in [30]. Among this primary Method, this paper estimates undefined factors that occur in the operational context of dis/reassembly operations. Therefore, some additional times must be taken into consideration: call masque time, micro-time (Preparation time, tightening verification, etc.), and human experience time.

**3.4. Discussion**

Literature worked on disassembly for recycling to save the environment and to limit raw materials process that is generally heavy and not economically viable. Higher values can only be achieved through reuse and re-manufacturing. This research area is quite interesting, but it should not be forgotten that maintenance has a beautiful and positive impact on extending life product use.

Maintenance constitutes a vital process in the product life cycle. It refers to the work carried out to restore the degenerated performance of a system, equipment, or product to a level that is closed to a so-called as good as new condition. That is why disassembly for maintenance is more accurate than disassembly for recycling due to the equipment refunctioning requirements. Then, the philosophy of disassembly for recycling is different from the maintenance one, where precautions should be taken to upgrade the working condition of faulty equipment, as illustrated in Table 4.

| Criteria                  | Disassembly for repairing | Disassembly for recycling |
|---------------------------|---------------------------|---------------------------|
| Human factors             | should be qualified       | not always sometimes no   |
| 1. Experiences required   | upgrade faulty equipment  |                           |
| 2. Upgrade faulty equipment |                           |                           |
| Equipment                 | in useful life            | end-of-life state         |
| Reassembly                | unavoidable               | not required              |
| Tools                     | special tools             | not required sometimes    |
| Time                      | selective/partial         | total disassembly         |
| Disassembly               | disassembly              |                           |

Table 4. Differences between disassembly for recycling and for repairing

Some partial literature works propose methods to determine the maintenance mean time to repair in the equipment downtime period, but these fail on preciseness how time is deducted. Because the disassembly context is variant and depends on some extra parameters affecting...
operational task time, this paper tends to highlight the flexible and precise operational task time either for maintenance or recycling. Then the masked time that appears in the maintenance operations has been considered.

4. Conclusion and perspectives

This work aims to model and evaluate the actual maintenance and recycling deduction time. Time becomes the fundamental parameter for maintenance and recycling evaluation because this is related to cost. Among the repairing operation process, disassembly and reassembly appear relevant. A comprehensive method analysis for modeling and estimating dis/reassembly time in maintenance issues have been structured. Two aspects are highlighted: robotic and human dis/reassembly time models, knowing that dis/reassembly activities are still human. The result is prominent at the product used or at the product end-of-life stages. Measuring task time involves efficient recycling and maintenance scheduling and planning. Future work should compare the gap between theoretical and practical task time models.

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