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MULTI-PURPOSE DISASSEMBLY SEQUENCE PLANNING

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ABSTRACT
Efficient disassembly operation is considered a promising approach toward waste reduction and End-of-Use (EOU) product recovery. However, many kinds of uncertainty exist during the product lifecycle which make disassembly decision a complicated process. The optimum disassembly sequence may vary at different milestones depending on the purpose of disassembly (repair, maintenance, reuse and recovery), product quality conditions and external factors such as consumer preference, and the market value of EOU components. A disassembly sequence which is optimum for one purpose may not be optimum in future life cycles or other purposes. Therefore, there is a need for incorporating the requirements of the entire product life-cycle when obtaining the optimum disassembly sequence. This paper applies a fuzzy method to quantify the probability that each feasible disassembly transition will be needed during the entire product lifecycle. Further, the probability values have been used in an optimization model to find the disassembly sequence with maximum likelihood. An example of vacuum cleaner is used to show how the proposed method can be applied to quantify different users' evaluation on the relative importance of disassembly selection criteria as well as the probability of each disassembly operation.

1. INTRODUCTION
Products recovery has been becoming more and more important over the past few years, both from the environmental and emission reduction perspective as well as the economic and resource saving standpoint. The impact of product recovery has also been introduced to the product design. A proper design is the one that not only covers the requirement of manufacturing but also the End-of-Use (EOU) recovery and remanufacturing operations. However, starting from the product design to the end-of-life stage, there have been different sources of uncertainty always accompany products. Addressing the whole life span of a product and the uncertainties that complicate EOU recovery process is an important step toward sustainable design.

Among remanufacturing activities, disassembly has been the point of interest in different studies. Disassembly is conducted for various purposes including disassembly for repair, maintenance, reuse and material recovery. In fact, disassembly is as integral part of many remanufacturing operations.

There are studies with the main objective of improving the overall efficiency of disassembly operations. In 1999, Wiendahl et al [1] proposed a general concept to disassembly control and planning. Dong et al [2] studied the disassembly sequence planning using a hierarchical approach in which an assembly is recursively decomposed into subassemblies to improve the planning efficiency. In addition, there are studies that specifically have targeted 'disassembly for product recovery'. To name a few, Sung et al. [3] suggested a heuristic method for disassembly planning of EOU products. Wan et al [4] proposed to use the radio-frequency identification (RFID) technology to support disassembly decisions in end-of-life recovery operations. Behdad et al. [5] addressed the concept of optimum EOU decision and the optimum disassembly sequence planning by considering uncertainty in the remanufacturing systems parameters such as the number of used products available for recovery.

Although there are a considerable number of studies with focus on disassembly sequence planning and even disassembly uncertainty, very few studies have considered the concept of product lifecycle. As the concept of remanufacturing becomes popular and many products have several lifecycles, there is a need for not only considering the whole lifecycle of a product when determining the disassembly sequence, but also including the requirement of multiple lifecycles a product may go through. Fukushige et al. [6] emphasized on the importance of considering changes that may happen over the product life span. Designers should assess different lifecycle scenarios and the potential paths a product may go through at the early stage of design.

The objective of this paper is to provide a multi-dimensional assessment tool for determining the desired disassembly sequence incorporating the requirements of the entire product lifecycle. A fuzzy method has been suggested to quantify the probability of each disassembly transition over the product lifecycle considering different assessment criteria such as the degradation of product quality over time, complexity of disassembly, the need for repair and reassembly and other external factors (e.g. end-of-use market value, market share for used components, etc.). This paper aims at exploring a disassembly sequence that covers different disassembly purposes (repair, reuse, maintenance, etc.) over the product lifecycle.

The rest of this paper is organized as follows: Section 2 summarizes the review of literature. Section 3 provides a fuzzy method to quantify the probability of each disassembly transition needed over the entire lifecycle based on a set of evaluation criteria. To demonstrate the process, an example of vacuum cleaner is provided in Section 4. Finally, Section 5 concludes the paper.

2. LITERATURE REVIEW

The profitability of disassembly operations, as an essential part of recovery and remanufacturing process, is always affected by different sources of uncertainty. Two different categories of uncertainty have been covered in the literature: uncertainty in the recovery systems (e.g. number and condition of products available for disassembly) and uncertainty in disassembly operations (e.g. disassembly time and probability of damage). As multi-lifecycle products are becoming popular as a promising solution towards sustainability [7], the uncertainty problem becomes more important since more lifecycles means more unstable factors.

The review of related literature is presented under three main categories:

- Disassembly planning and sequencing
- Uncertainty modeling in remanufacturing and reverse logistic operations
- Uncertainty in quality of returned products

2.1 Disassembly Planning and Sequencing

Disassembly sequence planning is considered a critical action in minimizing the resource consumption and wastes. Optimal disassembly strategies help in increasing the economic value of recovery systems. In order to identify the appropriate disassembly sequences, various approaches have been adopted in the literature ranging from optimization algorithms [8] to design related studies aimed at facilitating disassembly and recovery operations [9]. Azab et al [10] developed a semi-generative macro disassembly process planning approach based on the traveling salesperson formulation to optimize the disassembly sequencing. Torres et al [11] proposed an algorithm to generate a non-destructive disassembly sequence for a product incorporating the precedence relations among assemblies. Lambert [12] provided a systematic review of the literature with the focus on disassembly sequencing.

Investigation of uncertainty in disassembly planning has been another line of research in literature. Reveliotis [13] proposed a learning-based method to cover the impact of uncertainty in the optimal disassembly planning. Behdad et al. [14] applied the statistical distribution of the number of component contacts as a measure of uncertain probability of damage and developed a mixed integer linear programing to identify the sequence with minimum damage. In another study, they constructed a multi-attribute unity function to consider the uncertainty in disassembly time as well as components damage [15].

2.2 Uncertainty Modeling in Remanufacturing and Reverse Logistic Operations

Recent studies that modeled uncertainty in the context of remanufacturing, have mainly applied a holistic approach considering the overall reverse logistic activities rather than disassembly operations. Different sources of uncertainties have been discussed in three phases of collection, remanufacturing and redistribution [16] including uncertainties in the quantity, quality and timing of returns [17].

To address the problems arisen from uncertainty, different approaches have been adopted. Kannan et al. [18] proposed a multi-criteria group decision making model to handle the uncertainty in the number of returns by appropriate selection of the reverse logistics providers. Zhang [19] presented a production-remanufacturing inventory model to handle the problem of uncertainty in the quality of returns and random market demand. Another example is the uncertainty in time. There are studies aimed at improving inventory control planning considering the difficulties that uncertain remanufacturing times may bring to the system [20].

The reason for investigating uncertainties in the remanufacturing operations ranges from designing reverse logistics network [21] [22] to increasing the efficiency of remanufacturing operations [23] and determining the best end-of-use option (reuse, refurbishment, material recovery, disposal, etc.) for return items [24].

2.3 Uncertainty in Quality of Returned Products

Among the sources of uncertainty, the variable quality of returned product is a factor that highly impacts the nature and type of remanufacturing operations including disassembly.

To understand the impact of uncertain quality of returns on the profitability of reuse activities, Zikopoulos and Tagaras [25] calculated the expected profit of a single-period refurbishing facility based on variable quality grades and uncertain demand for each quality grade. In another study, Zikopoulos [26] solved an optimal lot-sizing problem in a remanufacturing site considering quality information. Ferguson et al. [27] also addressed the production planning within remanufacturing facilities when returns have different quality conditions. Nakashima and Gupta [28] applied a Markov chain model to determine the ordering quantity in a remanufacturing systems where incoming products had two quality grades. Jin et al. [29] studied production planning in an assembly-to-order system, where the firm received products with variable quality and reassembled them to multiple classes to meet customer orders. In another study, they investigated the impact of uncertainties in timing, quantity and quality of modular products in policy planning within the assembly system [30].

To sum up, although the concept of uncertain condition of returns is not something new, the focus of previous studies was mainly on improving the policy planning in the reverse logistic network rather than remanufacturing operations such as disassembly. Moreover, the concept of quality condition of returns has not been sufficiently addressed in the disassembly literature.

In addition, very few studies have explored the disassembly requirements of a multi-lifecycle product. Therefore, a multi-dimensional assessment method is needed to identify the best disassembly sequence considering different purposes of disassembly by incorporating various factors such as product's quality condition, complexity of disassembly operations, need-for-repair, and the EOU recovery process.

3. MULTI-PURPOSE DISASSEMBLY SEQUENCE

As a product goes through several lifecycles (Figure 1), there might be different decision making points and milestones in which end users or remanufactures need to make disassembly decisions for various purposes such as repair, component reuse, and material recovery.

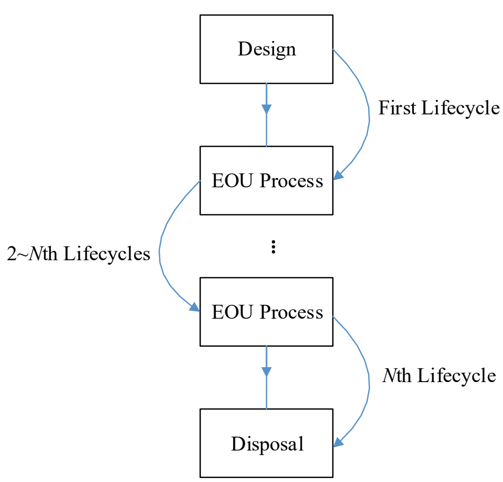

Figure 1. Different milestones for multi-lifecycle products

Depending on the purpose of disassembly, the evaluation criteria used in disassembly sequence planning would be different. While generating the disassembly sequence with minimum cost and time plays an important role when the product is disassemble for remanufacturing, probability of no components damage is important when disassembly is for the purpose of reuse or repair.

A sequence that is best in terms of disassembly time and cost, may not be the best in terms of ease-of-disassembly. Therefore, identifying a sequence that satisfies all the lifecycle requirements is desirable. Determining the best disassembly sequence is particularly important at the early stage of design, where designers have the ability to improve the design and reduce the total lifecycle cost.

3.1. Feasible Disassembly Transitions

The first step in disassembly sequence planning is to identify the feasible disassembly transitions. Often the feasible disassembly operations or transitions are identified by considering the topological and geometrical data of the original design. Different methods such as AND/OR graph and disassembly transition matrix are commonly used to graphically represent the possible disassembly operations and related subassemblies [31]. Figure 2 is an example of a simple product ABCDE and its feasible disassembly sequences.

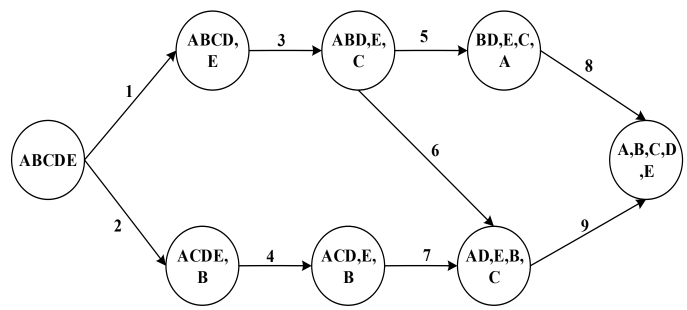

Figure 2. Example of disassembly graph

The matrix representation of the disassembly graph is known as Disassembly Transition Matrix [32]. Table 1 shows the equivalent disassembly matrix of Figure 2. In this transition matrix *T*, each column of the matrix (c) is a disassembly operation and each row represent a resulting subassembly (r). The element T_{rc} is set to 1 when subassembly *r* is created via operation transition *c*. It is set to -1 if subassembly *r* is destroyed via operation *c*, and zero otherwise.

Table 1 Transition Matrix of Network in Figure 2

	1	2	3	4	5	6	7	8	9
ABCDE	-1	-1	0	0	0	0	0	0	0
ABCD	1	0	-1	0	0	0	0	0	0
ACDE	0	1	0	-1	0	0	0	0	0
ABD	0	0	1	0	-1	-1	0	0	0
ACD	0	0	0	1	0	0	-1	0	0
AD	0	0	0	0	0	1	1	0	-1
BD	0	0	0	0	1	0	0	-1	0
A	0	0	0	0	1	0	0	0	1
B	0	1	0	0	0	1	0	1	0
C	0	0	1	0	0	0	1	0	0
D	0	0	0	0	0	0	0	1	1
E	1	0	0	1	0	0	0	0	0

3.2. Fuzzy Method to Calculate Disassembly Transition Probability

Once the list of all feasible disassembly operations is identified, we need to find a criterion to evaluate each sequence and then select the best sequence. As mentioned before, the aim is to select a multi-purpose sequence that covers the requirements of the whole life span. The criterion that has been used here is to the likelihood that each disassembly transition will be needed throughout the lifecycle. A fuzzy logic method has been applied to quantify this probability based on a list of evaluation factors. These evaluation factors include the requirements of the whole lifecycle.

Figure 3 provides an example of the list of factors that may affect the disassembly likelihood for each disassembly transition. In this paper, four main categories of factors [33] have been included:

- Quality condition: depending on the quality condition of product (physical or technical obsolescence over time), the chance of selecting a disassembly sequence would be different.
- Disassembly complexity: this category of factors is particularly important for the purpose of repair and maintenance when the end users may not have appropriate expertise to select the optimum sequence and they often go with the most intuitive sequence based on the number of components, joint types and technical complexity. This category is also called ease-of-disassembly which simply means the ease of implementing disassembly operations by regular users and non-technical consumers.
- Reassembly difficulty: there might be cases in which the best disassembly is not necessarily the reverse of best disassembly sequence, especially for destructive disassembly. In these cases, the ease of assembly operation should be considered when a product is dismantled for repair.
- EOU recovery and external factors: this category of factors covers the requirement of EOU recovery. For example, the market demand of specific used components, and user preference of conducting specific transitions may influence the likelihood of a disassembly action.

Each of the above mentioned categories can include many sub-factors. In fact, users can add sub-factors according to practical situations and requirements. Once the hierarchical structure of factors is constructed, one can use the fuzzy method to evaluate the probability of each disassembly transition.

The first step in applying fuzzy method is to compare each pair of criteria to obtain the fuzzy judgment matrix $R=\left(r_{ij}\right)_{n\times n}$, where n is the number of criteria, and r_{ij} is the importance value of criteria i compared to criteria j. The importance is a triangular fuzzy number, $r_{ij}=\left(l_{ij},m_{ij},u_{ij}\right)$, where $r_{ij}=1/r_{ji}=\left(1/l_{ij},1/m_{ij},1/u_{ij}\right)$.

u_{ij} and l_{ij} are upper and lower bounds of the triangular fuzzy number, and m_{ij} is the rating value defined in Table 2.

Table 2. AHP standard definition table

Rating Level	Linguistic values
1	Equal
3	Moderately more important
5	Fairly more important
7	Much more important
9	Absolute more important
2,4,6,8	Midpoint preference values lying between above values

Once the matrix R is obtained, the importance of ith criteria compared to all other criteria, S_i, can be calculated as follow:

$$S_i=\sum_{j=1}^{n} r_{ij}\otimes\left[\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}\right]^{-1} \qquad (1)$$

Consider the triangular fuzzy numbers $S_1=\left(l_1,m_1,u_1\right)$ and $S_2=\left(l_2,m_2,u_2\right)$. The degree of possibility of $S_1\geq S_2$ is defined as $V\left(S_1\geq S_2\right)$. This possibility can be calculated as follow:

$$V\left(S_1\geq S_2\right)=\begin{cases}1, & m_1\geq m_2\\ \dfrac{l_2-u_1}{\left(m_1-u_1\right)-\left(m_2-l_2\right)}, & m_1<m_2\ and\ l_2<u_1\\ 0, & else\end{cases} \qquad (2)$$

Then, let $d'\left(C_i\right)$ be the degree of possibility for criteria i (C_i) to be better than other criteria:

$$\begin{aligned}d'\left(C_i\right)&=V\left(S_i\geq S_1,S_2,\ldots,S_{i-1},S_{i+1},\ldots,S_n\right)\\&=\min\left\{V\left(S_i\geq S_k\right),k=1,2,\ldots,n\ and\ k\neq i\right\},\\ i&=1,2,\ldots,n\end{aligned} \qquad (3)$$

Once we find $d'\left(C_i\right)$ for each criterion, the rating vector is obtained:

$$w'=\left(d'\left(C_1\right),d'\left(C_2\right),\ldots,d'\left(C_n\right)\right)^T \qquad (4)$$

Through normalization we have:

$$w=\left(d\left(C_1\right),d\left(C_2\right),\ldots,d\left(C_n\right)\right)^T \qquad (5)$$

Where $d\left(C_k\right)=d'\left(C_k\right)/\sum d'\left(C_k\right)$

The normalized values give us the weight for each criterion. Then, we can calculate the probability (p_{tran}) of each disassembly transition:

$$p_{tran}=\sum_{k=1}^{n} p_k\cdot d\left(C_k\right) \qquad (6)$$

Where p_k is the average disassembly probability (for a specific disassembly transition) provided by a group of users based on their evaluation on kth criteria.

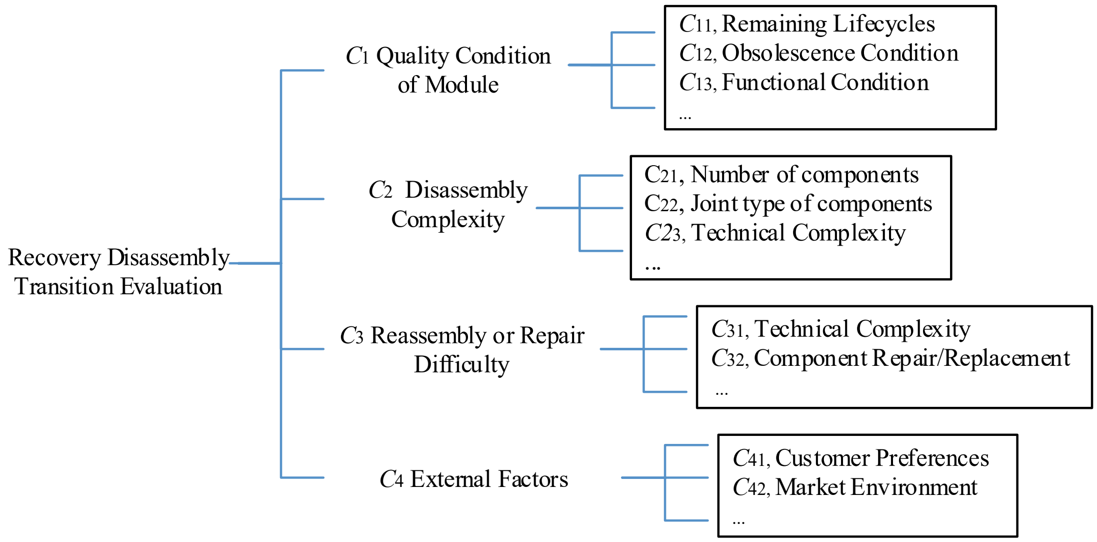

Figure 3. A hierarchical representation of the evaluation criteria used to assess disassembly transition probability

Once the likelihood of each disassembly transitions is estimated based on the list criteria and their weights, the next step is for designer to find the sequence with the maximum likelihood. Different optimization models can be developed to find the most likelihood sequence using the information provided by fuzzy method for the importance of each criterion. In this section, a simple optimization method based on the shortest path concept has been suggested:

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Index:

s: feasible disassembly transition, arc of disassembly graph
a: node of disassembly graph
I_a: the set of arcs entering node *a*
O_a: the set of disassembly transitions leaving node *a*
O_0: the set of disassembly transitions leaving the initial node
I_t: the set of arcs entering the last node (target node)

Parameter:

p_s: the disassembly probability of transition *s* obtained from fuzzy evaluation

Variable:

x_s: A {0,1} variable indicating whether disassembly transition *s* is performed or not.

Objective

The objective is to find the path with maximum likelihood:

$$\max \sum_s p_s x_s \quad (7)$$

Where, p_s is the chance that disassembly transition *s* (arc *s* in disassembly graph) will be needed and x_s is a binary variable controlling whether transition s is performed or not. Therefore, the summation of all feasible disassembly transitions can determine the likelihood of one sequence.

Constraints

There are several flow requirements from AND/OR graph for the initial node, the target node and the transient nodes. Except for the first and last node, the number of transitions entering a node must be equal to the number of transitions leaving a node [15]. The following equations represent the constraints using the shortest path method concept:

$$\sum_{s\in O_0} x_s = 1 \quad (8)$$

$$\sum_{s\in I_a} x_s = \sum_{s\in O_a} x_s \quad (9)$$

$$\sum_{s\in I_t} x_s = 1 \quad (10)$$

This method finds the sequence in which the summation of transitional probabilities is maximum.

4. EXAMPLE: VACUUM CLEANER

This section provides an example of vacuum cleaner to show the fuzzy model application. Vacuum cleaner has been selected since it can be viewed as a multi-lifecycle product where it may go through different disassembly operations for the purpose of repair, maintenance as well as material recovery. There are several disassembly sequences for this product.

Figure 4. Vacuum cleaner [34]

The vacuum clearer illustrated in Figure 4 mainly includes eight components listed in Table 3.

Table 3. Major components of vacuum clear

Label	Components
A	Shell
B	Push Key
C	Battery
D,E	Gears
F	Yellow Part
G	Inside Board
H	Digital Panel

Based on the structure of vacuum cleaner, the feasible disassembly transitions have been obtained as illustrated in Figure 5.

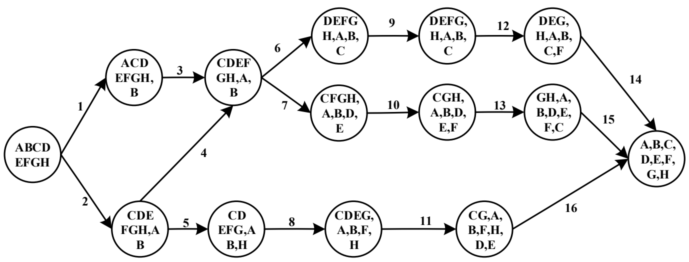

Figure 5. Network of possible disassembly operations

The next step is to find the likelihood of each disassembly operation based on the fuzzy method discussed in Section 3. This procedure will be discussed for one disassembly transition. The remaining probabilities can be calculated the same way.

First, three users or experts are asked to use the hierarchical model presented in Figure 3 to evaluate the importance of each criterion. The users give the judging score of four main factors according to their own experience. The fuzzy judging matrix is presented in Table 4.

Table 4. Fuzzy judging matrix of evaluation criteria

	Evaluation Criteria			
	C_1	C_2	C_3	C_4
C_1	(1,1,1)	(3/2,2,8/3)	(4/3,2,8/3)	(2/7,1/3,3/7)
	(1,1,1)	(4/3,2,5/2)	(1/5,1,8/5)	(3/11,1/3,2/5)
	(1,1,1)	(1/4,1,8/5)	(1/3,1,7/4)	(3/11,1/3,3/7)
C_2	(3/8,1/2,2/3)	(1,1,1)	(10/3,4,14/3)	(4/3,2,8/3)
	(2/5,1/2,3/4)	(1,1,1)	(7/3,3,15/4)	(1/3,1,3/2)
	(5/8,1/2,4)	(1,1,1)	(3/2,2,8/3)	(1/2,1,5/3)
C_3	(3/8,1/2,3/4)	(3/14,1/4 ,3/10)	(1,1,1)	(4/11,1/2,3/4)
	(5/8,1,5)	(4/15,1/3 ,3/7)	(1,1,1)	(3/8,1/2,2/3)
	(4/7,1,3)	(3/8,1/2,2/3)	(1,1,1)	(3/5,1,3)
C_4	(7/3,3,7/2)	(3/8,1/2,3/4)	(4/3,2,11/4)	(1,1,1)
	(5/2,3,11/3)	(2/3,1,3)	(3/2,2,8/3)	(1,1,1)
	(7/3,3,11/3)	(3/5,1,2)	(1/3,1,5/3)	(1,1,1)

After obtaining the judging matrix from each user, we can get the average fuzzy judging matrix as shown in Table 5. In Table 5, C_i is the summation of average values of each criterion.

According to Eqn. (1):

$$S_1 = (2.927, 4.333, 5.681) \otimes \left(\frac{1}{29.119}, \frac{1}{19.361}, \frac{1}{14.752} \right)$$
$$= (0.101, 0.224, 0.385)$$

With the same principle, S_2, S_3 and S_4 can be also obtained:

$$S_2 = (0.157, 0.301, 0.589)$$
$$S_3 = (0.077, 0.148, 0.397)$$
$$S_4 = (0.171, 0.327, 0.603)$$

Then using Eqn. (2), the degree of possibility of $S_1 \ge S_2$ is calculated:

$$V(S_1 \ge S_2) = \frac{0.157 - 0.385}{(0.224 - 0.385) - (0.301 - 0.157)} = 0.748$$

Using Eqn. (3):

$$d'(C_1) = V(S_1 \ge S_2, S_3, S_4) = \min(0.748, 1, 0.675) = 0.67$$

With the same equation:

$$d'(C_2) = 0.941$$
$$d'(C_3) = 0.558$$
$$d'(C_4) = 1$$

After normalization, finally the weight of each criterion in the hierarchy model can be obtained:

$$w = (0.213, 0.296, 0.176, 0.315)^T$$

Based on the practical condition of the vacuum cleaner, three experts also give the probability of one specific disassembly transition, for example, disassemble Gear from Cleaner. Table 6 lists the transition probabilities given by each expert based on Criterion i and the average probability.

Using the information provided in Table 6 and Eqn. (6) the disassembly probability of gear from cleaner can be obtained as follow:

$$p = \sum p_i w_i$$
$$= 0.213 \times 0.3 + 0.296 \times 0.33 + 0.176 \times 0.13 + 0.315 \times 0.2 = 0.2475$$

Table 5. Fuzzy judging matrix of average evaluation criteria

	C_1	C_2	C_3	C_4	C_i
C_1	(1,1,1)	(1.028,1.667,2.256)	(0.622,1.333,2.006)	(0.277,0.333,0.419)	(2.927,4.333,5.681)
C_2	(0.467,0.5,1.806)	(1,1,1)	(2.389,3,4.111)	(0.722,1.333,1.778)	(4.578,5.833,8.695)
C_3	(0.524,0.833,2.917)	(0.285,0.361,0.465)	(1,1,1)	(0.446,0.667,1.472)	(2.255,2.861,5.854)
C_4	(2.389,3,3.611)	(0.547,0.667,1.917)	(1.056,1.667,2.361)	(1,1,1)	(4.992,6.334,8.889)

Table 6. Disassembly Probability of Gear from Cleaner

	Disassembly Probability			Average
C_1	0.2	0.3	0.4	0.3
C_2	0.5	0.2	0.3	0.33
C_3	0.1	0.1	0.2	0.13
C_4	0.3	0.1	0.2	0.2

As illustrated, the fuzzy method can be used to determine the probability of each transition. After identifying the transitional probability for each arc of the disassembly graph, the best sequence with maximum likelihood can be obtained using the simple optimization method. One example is provided in Figure 6.

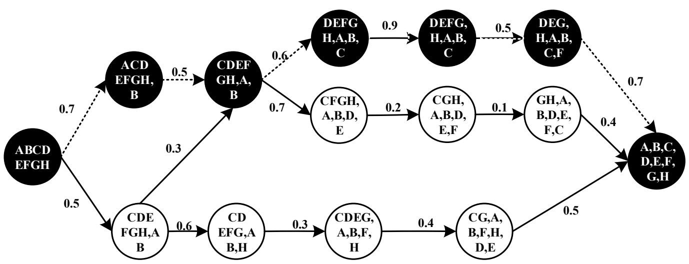

Figure 6. Disassembly transitions and optimal path

The most likely disassembly sequence for the vacuum cleaner is the one marked with black nodes shown in Figure 6. This sequence is derived using the evaluation provided by different users on the importance (weight) of different criteria as well as the likelihood of each disassembly operation based on each criterion. The most likelihood disassembly sequence provides some insights for designers on how to modify product design to facilitate disassembly operations during the entire product lifecycle. Determining the level of modulatory, the number of fasteners, and the type of joins components are examples of design modifications can be used to improve the efficiency of disassembly operations.

5. CONCLUSION AND FUTURE WORK

This paper proposed a fuzzy method to determine the likelihood of disassembly operations based on a set of criteria throughout the product lifecycles. The criteria that affect the likelihood/probability of disassembly range from the quality of products, disassembly complexity, and ease-of-reasssembly, to factors such as market demand for EOU components. The obtained probability based on the fuzzy method can further be employed in an optimization model to select the disassembly sequence with maximum likelihood. An example of vacuum cleaner is applied to illustrate the proposed method. The obtained sequence is expected to be a multi-purpose sequence which covers the requirements of disassembly through the entire lifecycle (repair, maintenance, material recovery, etc.).

The fuzzy method has been used here since it is easy to implement and it allows including the requirement of different users and stakeholders simultaneously ranging from consumers to OEMs and recyclers. Various parties may have different requirement and often conduct disassembly with different purposes during the entire product lifecycle. The fuzzy method not only helps to identify factors (criteria) important to different stakeholders, but also incorporates weights provided by different stakeholders for each factor. In addition, it quantifies the likelihood of each disassembly transition based on the opinions of different stakeholders induced from their experience and historical data. The advantages of fuzzy method over analytical design evaluation methods such as robust design and mathematical modeling is that the analytical models often have limitation on the number of factors incorporated and often require data on those factors.

This work can be improved in several ways. Firstly, different users may have their own interpretations about each criterion included in AHP structure. Therefore, developing a standard structure based on the common language between different stakeholders such as repair shops, recyclers, end users will improve the current study. Secondly, the set of evaluation criteria used in the fuzzy method can be extended to cover other factors such as user preference in conducting specific intuitive sequence and the availability of tools and equipment. Although the fuzzy method has been used for finding the maximum likelihood sequence, it can be applied for other objectives such as finding the sequence with minimum cost and component damage. The simple shortest path optimization method provided in this paper can be extended to cover multiple objectives.

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