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# A distribution-free model for a disassembly line design problem under uncertain environment

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## Introduction

Recycling industries become increasingly important in the last decade due to its irreplaceable benefits in protecting the environment, saving non-renewable resources and reducing pollution and waste, etc. The rapid advancement of science and technology reduces the life cycles of products and intensifies the speed of waste streams (Movilla et al., 2016; Kazancoglu et al., 2018). Therefore, End-of-life (EOL) products need to be recycled to adapt this real-life phenomenon. As pointed by Güngör and Gupta (1999), specificities and complexities of disassembly operations require appropriate disassembly line designs, i.e., disassembly line balancing problems (DLBP).

In this paper, a stochastic DLBP is studied which mainly *decides an optimal disassembly process* and *assigns the corresponding operational tasks* to a number of opened workstations. Especially, the cycle time and the physical structure of products should be respected. The following FIG 1 depicts the main processed of a disassembly line. An EOL product is decomposed into subassemblies  $A_1$  and  $A_2$  by task 1 in workstation 1. Then tasks 2 and 3 are handled in workstation 2, outputting the final four components. Note that tasks 2 and 3 cannot be conducted before task 1.

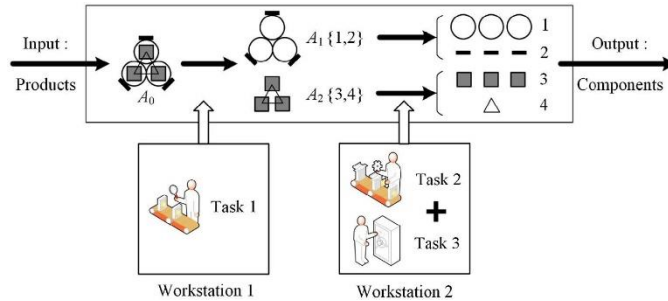


FIG. 1 A brief introduction of a disassembly line.

In real-life applications, there is a high uncertainty on disassembly task processing times in DLBP (Özceylan et al., 2018). Most existing works assumed that stochastic task processing times can be assumed to be probability distributions or fuzzy functions. However, it is extremely difficult to estimate stochastic task processing times because of a lack of historical data (Ng, 2014). Therefore, in this research, only partial information on stochastic task processing times, i.e., the mean, standard deviation, and upper bound, is accessible. In summary, *a profit-oriented stochastic DLBP with partial information of stochastic task processing times* is investigated.

## Contributions

- (1) A disassembly line balancing problem with stochastic task processing times is studied, where the decision-maker only needs the knowledge of the mean, standard deviation and an upper bound of task processing times, instead of the probability distribution.
- (2) A chance-constrained model P1 is formulated, which is further approximately transferred into a distribution-free model P2.
- (3) Several problem properties are established, a fast algorithm is devised for solving model P2.

## Main solution processes

- (1) Using the obtained historical data, the mean, standard deviation and upper bound of stochastic task processing times are calculated.
- (2) A mathematical model P1 is formulated to minimize the total line design cost, respecting all practical constraints. Note that a chance constraint is applied to define that the total processing time of each workstation is less than the cycle time. Here we present the stochastic model P1 in the following.

Objective:  $F = \min(\sum_{m \in M} c_m \cdot y_m + h \cdot \sum_{j \in H} \sum_{m \in M} x_{j,m})$  Minimize the total design cost

Subject to:

- |   |                                    |
|---|------------------------------------|
| ① $\sum_{j \in B_0} \sum_{m \in M} x_{j,m} = 1$   | Select one disassemble scheme      |
| ② $\sum_{m \in M} x_{j,m} \leq 1, \forall j \in J$  | Task assignment                    |
| ③ $\sum_{j \in B_s} \sum_{m \in M} x_{j,m} = \sum_{j \in A_s} \sum_{m \in M} x_{j,m}, \forall s \in S \setminus \{0\}$    | Product flow balance               |
| ④ $\sum_{j \in B_s} x_{j,n} \leq \sum_{j \in A_s} \sum_{m=1}^n x_{j,m}, \forall s \in S \setminus \{0\}, \forall n \in M$ | Precedence (via product structure) |
| ⑤ $\Pr(\sum_{j \in J} p_j x_{j,m} \leq CT, \forall m \in M) \geq 1 - \beta$   | Chance constraint (via cycle time) |
| ⑥ $\sum_{j \in J} x_{j,m} \geq 1 - G \cdot (1 - y_m), \forall m \in M$  | Judge whether a machine is used    |
| ⑦ $\sum_{j \in J} x_{j,m} \leq G \cdot y_m, \forall m \in M$  | Judge whether a machine is used    |
| ⑧ $x_{j,m}, y_m, \forall j \in J, \forall m \in M$  | Ranges                             |

- (3) It can be seen that the above stochastic model P1 cannot be linearly solved due to chance constraint ⑤. To linearly solve it, the method in Ng (2014) drives us to transfer constraint ⑤ into a new constraint ⑨  $\sum_{j \in J} (t_j + \mu_j) \cdot x_{j,m} \leq CT, \forall m \in M$ , using *the partial information* of stochastic task processing times. Then, model P2 is formulated with this new constraint ⑨, instead of constraint ⑤, and it can be linearly solved by commercial solvers.
- (4) It is seen that the parameters in constraint ⑨, related to the known partial information of stochastic task processing times, cannot be obtained directly (Ng, 2014). Therefore, we design a new fast algorithm to calculate values of the parameters in model P2.
- (5) Several benchmarks from existing literature are tested by model P2.

## Conclusions and perspectives

Conclusions: The instances in existing literature (from real-life applications) are utilized for the illustration of the proposed model. Numerical experiments show that it can effectively solve DLBP without the knowledge of known probability distributions.

Perspective: (1) consider multi-product disassembly line balancing problems; (2) consider U-type disassembly line balancing problems; (3) consider multi-objective optimization for more realistic perspectives; (4) consider the further scheduling problems after the line design.

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