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Integration of Warranty as a Decision Variable in The Process of Recertification of Parts Resulting from End-Of-Life System Dismantling

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Abstract - **In this paper, a new approach to determine optimal disassembly plan of an end-of-life system by using Bayesian network is introduced. The best solution is called the optimal trajectory. A trajectory model is proposed which allows handling the different key factors and also makes it possible to manage uncertainties specific to system deconstruction. After having presented the disassembly planning issue, Bayesian networks instantiated to dismantling problem are introduced together with the influence diagram which allow the decision maker to proceed to the economic assessment of the different possible strategies. Among the various cost factors is the cost related to warranty of the recycled products. A warranty program management is described. Eventually, the global trajectory model, including the implementation of the warranty cost has a decision variable, is presented.**

Keywords – **end-of-life systems, dismantling, decision, Bayesian network, warranty management, recertification**

I. INTRODUCTION

For many years now, the end-of-life stage of systems has come the subject of more and more studies. This is due, on one hand, to legislative pressures in terms of environmental protection and, on the other hand, to possible economical profits that may be gained by implementing product recycling solutions. It is a designer responsibility to integrate recycling constraints by proposing disassembly processes for their systems at the design stage. Increasing value strategies must respond to all decisional problems raised during the retirement step. Mainly valuable products must be selected according to technical, economical, and environmental criteria and disassembly systems enabling the products to be obtained have to be defined and optimized.

Within this framework three types of decision are considered. The first relates to the determination disassembly level i.e. the best option of valorization and, for the subsets, the choice between disassembling or recycling. The second relates to operation sequencing which aims at fixing how to obtain the products and the logical sequence of the operations to obtain them. Finally the quantities of products and their obtaining date on a given horizon have to be determined. The decision support in disassembly must make it possible to handle these three types of decision and to establish the link between them to keep a total control of the strategy. A disassembly trajectory leads to the identification of valuable products of an end-of-life system, of their value increasing channels and of the way to obtain them. Modelling of disassembly trajectories requires taking into account the whole influencing factors. Among them is the warranty which is usually defined as the written guarantee of the integrity of a product and of the maker's responsibility for the repair and replacement of defective parts. This notion is interesting to be considered in order to provide the decision maker with a full integrated tool.

Based on this framework, this paper is divided into four parts. After a brief introduction on disassembly planning issues, bayesian networks applied to deconstruction problems are presented. Warranty aspects are then introduced before being implemented onto a global trajectory model.

DISASSEMBLY PLANNING PROBLEM

A. *Problem modelling framework*

In a deterministic context, there are many works that address these problems in the literature. We present a way of linking these different approaches.

Generally, the modelling of the disassembly planning problem requires three main steps. The first step concerns the structure modelling of the end-of-life system. The goal of these models is to represent the valuable parts and subassemblies and the connections between them [8].

The second step of the disassembly planning problem concerns the modelling of the disassembly process. The obtained model represents the different operations that can be made on the system to obtain the valuable part and subassembly.

The third step concerns the search of the optimal sequence among those identified in the process model. The purpose is to jointly determine the disassembly level and sequence.

The model must take into account the preferences of the different stakeholders involved in the end-of-life phase of the system. Classic approaches model the decision problem as a linear program and solve it by existing algorithms [7].

B. *Variables of the disassembly process*

Solving disassembly planning problem involves different models and algorithms. Most of the works on this subject we encounter in the literature propose their own method and modelling language. In most cases, the considered approaches do not facilitate the integration of uncertainties.

Our goal is not to propose one more approach to solve this problem but to integrate the uncertainties of the disassembly process on the basis of existing models in order to determine an optimal and robust solution. To achieve this objective, we will use concepts and entities utilized by different approaches and then add uncertainties using a modelling language that cope with uncertainties.

The main entities involved in the resolution of the disassembly planning problem are the following:

(i) components: they represent the composition of the end-of-life system and can correspond to parts, subassembly and/or intermediate disassembly states;

(ii) connections: in relation with the component, they complete the structural point of view by representing the joints and/or contact connections as well as relationships between components and subassemblies;

(iii) end-of-life variables: linked with each component, they describe the different recovery actions which can be recycling actions or disassembly operations;

(iv) contextual variables: attached to component and end-of-life variables, they model the recycling actors and other constraints on the recovery actions;

(v) decision variables: related to component and end-of-life variables, they represent the different actions of the decision-maker and give a framework to the decision process;

(vi) performance parameters: attached to end-of-life variables, they describe the consequences of the decision-maker actions.

On the basis of these entities, we propose in Figure 1 the generic framework of the modelling of disassembly planning problem (UML class diagram).

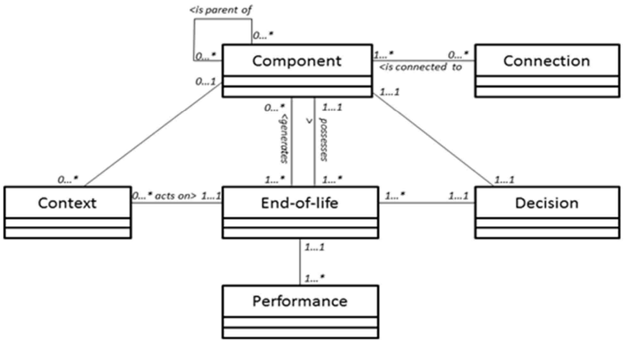

Figure 1. Structure of disassembly variables

At this stage, we have underlined the steps in solving disassembly planning problem and the different variables that decision-makers have to manage. We will introduce now Bayesian network to cope with uncertainties on some of these variables.

II. BAYESIAN NETWORKS FOR DISASSEMBLY PLANNING

A. *Bayesian networks and influence diagram*

We propose to use Bayesian networks as the modelling mathematical tool to solve the following decision problem: for a given end-of-life system, determine the disassembly levels and sequences on the basis of the process model while taking into account the uncertainties of the disassembly process.

We use the Bayesian network and their extension to influence diagrams because the problems we want to solve have the following features [3]:

(i) they can be represented graphically,

(ii) there is necessity to integrate and manage uncertainties,

(iii) there is necessity to solve an optimal uncertain problem.

The first reason is important in a multi-actors context as in the case of the problem considered here. Indeed, the Bayesian networks and the influence diagrams facilitate the understanding of the problem by all the actors by means of a simple and natural graphical representation.

Furthermore, they enable the interaction between these actors and the sharing of knowledge in a unique representation. Indeed, a Bayesian network is a graph model in which knowledge is modelled as variables and each variable correspond to a node in the graph. The directed arcs represent dependence relationship between the variables. The first step in developing a Bayesian network model consists in the elicitation of the interesting variables.

The second point corresponds to the purpose of our problem approach. The Bayesian networks enable inference that consists in the determination of probabilities for hidden variables of the problem given evidence. When decision-makers think there are uncertainties on some variables, they can evaluate them by probability formulation. Given the knowledge of the stakeholders, these probabilities can be conditional (they depend on some others variables) or marginal.

Once the uncertainties of the disassembly process have been evaluated, decision-makers have to determine the optimal solution according to several criteria. Decision and utility nodes are then added into the Bayesian network that becomes an influence diagram. It models the selection problem of end-of-life options for each component including the utility of these options. In [6], the authors propose inference algorithms that determine the optimal solution.

B. Modelling disassembly decision problem using influence diagram

In this work, we propose to use influence diagrams (ID) as a decision tool to model disassembly problem and we suppose that a process model is given. Disassembly Petri Nets (DPN) are used to model this disassembly process. DPN clearly describe the precedence constraints between operations in the disassembly process. The places represent system, components and subassemblies and the transitions represent joints and disassembly actions. The purpose is to represent all the possible sequences of operations. The decision problem is to determine the best sequence according to one or more criteria.

Once the DPN behaviour mechanisms has been translated into an influence diagram the states (retrieved components, subassemblies, joint states …) of the disassembly process have to be determined according to different decision's configurations [4].

Disassembly solutions are evaluated by means of utility nodes in the ID. They model the economic performance of the different recovery actions and disassembly operations. ID models enable the integration of utility in table forms. There are three types of nodes:

(i) disassembly cost nodes: linked to disassembly operation node, their value is function of disassembly operation realization,

(ii) recycling cost nodes: they evaluate each recycling action realization mode of recycling node to which they are linked,

(iii) recycling revenue nodes: they model economical flow that is generated when a recycling option is validated.

These different utility nodes allow the optimization of a criterion for selecting a disassembly plan. This criterion is decomposed at each product in order to select the option or operation for each of them. To achieve this goal, decision node of each product indicates the evaluation of each option. The decision rule consists in selecting the option that maximises the expected utility of the product and it is called end-of-life policy.

The set of all polities forms the strategy. It gives the products that have to be generated from the end-of-life system, the recycling options for these products and the disassembly operations that are needed to generate them. The purpose of optimization method is to determine the strategy for a given end-of-life system.

III. STRATEGIC WARRANTY MANAGEMENT

Among the different sources of costs and incomes, the determination of the disassembly strategy has to consider the ones associated with the warranty program proposed with the functional recycling of a system, subsystem or component. Determining an economic evaluation of a warranty program necesitates first assessing the risk associated with the different actions likely to be implemented and second, identifying the cost of the logistic support required to carry out the corrective tasks

A. Risk assessment

The warranty risk management is the systematic process of identifying, analysing, and responding to risk appeared during a program of warranty assistances. It includes maximizing the probability and consequences of positive events and minimizing the probability and consequences of adverse events to warranty objectives. Related to this point of view are for instance reference [1], which deals with issues regarding risk and spare parts estimation.

Warranty risk is understood as an uncertain event or condition that, if it occurs, has a positive or negative effect on the program objective. It includes both threats (negative effects) and opportunities (positive effects) to improve those objectives. Known risks are those that have been identified and analysed and may be possible to plan for their occurrence and mitigation.

In the case of the recertification of parts resulting from system deconstruction, the risk assessment is made easier since the decision maker has at its disposal the data corresponding to the history of the system being considered for possible second-hand life.

Risks that are threats to the warranty program may be accepted if they are in balance with the reward that may be gained by taking the risk. The Figure 2 illustrates the risk management process, divided in different steps.

In order to approach the risk management activities to a warranty program, a planning for such processes can help to ensure that the level, type and visibility of this management are proportional with both the risk and importance of the warranty assistance to the whole organization. Once the planning is done, the risk identification is the following step to follow. This is the process of determining which risks can affect to the warranty program and to document the characteristics of each one.

A qualitative analysis of risks must then be performed which is the process of assessing the impact of the identified risks in the warranty assistances [2]. It prioritizes risks according to their potential effect on the program objectives, determining the importance of addressing specific risks and guiding risk responses.

Following, a quantitative analysis of the possible risks during the application of the warranty assistance has to be carried out. This is a process which measures the probability and consequences of risks, estimating their implications for program objectives. It helps to analyse numerically the probability of each risk and its consequence during the warranty service.

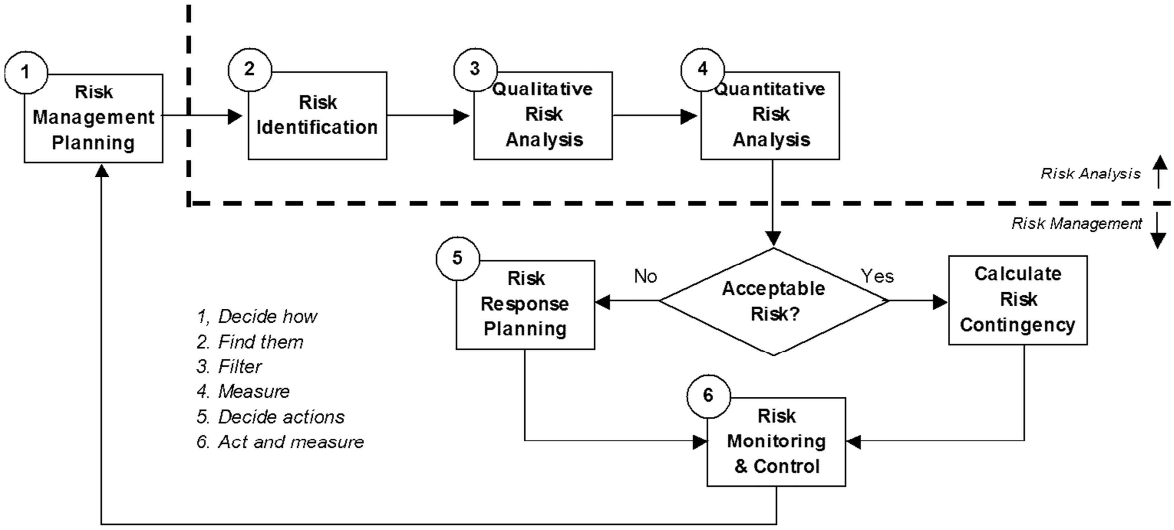

Figure 2: Risk management workflow

The following step on the risk management of a warranty program is the response planning, which is the process of developing options and determining actions to enhance opportunities, reducing threats to the program's objectives.

Finally, the last step is to monitor and control risks which is the process of keeping track of the identified risks, monitoring residual risks and identifying new risks, ensuring the execution of risk plans, and evaluating their effectiveness in reducing risks.

B. *Logistic support specification*

Once the risks have been identified and assessed and in order to launch a product to the market with a proper assigned warranty program, it is necessary during the very early stages of the product life cycle to identify and characterize the logistic support for such product. Some references and standards deal with this matter (e.g. [9]).

The logistic support analysis is an iterative process which can be very helpful for the business management board to organize the after-sales department, the qualification of the staff, the required materials etc. in order to provide to the customer the adequate technical assistance during the warranty period [5].

The identification and assessment of a new system or product involves to analyse the types and quantities of spare parts, the requirements of technical and skill levels, the tools and technical documentation to use... and many others, all focused to the application of a warranty program to a specific product positioned in the market. Therefore, in order to get as an output from the logistic support analysis the identification and justification of those types and quantities of spare parts, skill level requirements etc., it will be necessary a data base which compiles sources of logistical support such as the identification and procurement of logistic support elements.

IV. INTEGRATING WARRANTY IN A DECONSTRUCTION MODEL

We present in this section the trajectory model that is the model allowing the decision maker to define the level of disassembly optimizing the economic profit. The model used is a bayesian network. It has been first implemented in [WCEAM]. The originality comes here from the consideration of warranty costs likely to modify the decision in terms of disassembly level.

The disassembly trajectory problem is represented by Bayesian networks (BN). Indeed, they enable all the elements of this decision problem to be represented. Generally speaking, system disassembly modelling with Bayesian networks is described by the following items:

(i) "product" nodes representing end-of-life system components that have one or more recycling option

(ii) "activity" nodes representing disassembly operations or recycling action on each product,

(iii) arcs characterizing precedence and exclusion relationships between activities,

(iv) node parameters that make it possible to characterize disassembly process progress.

Decision variables are attached to each product. They indicate the direction of the disassembly trajectory towards one option (disassembling or recycling). Constraints are specified by the arcs. Economical parameters are associated with "activity" nodes by means of utility nodes. They represent costs and incomes potentially generated by the realization of an activity. They enable the economic profit of the various trajectories to be evaluated.

The set of nodes of the Bayesian networks disassembly model is noted N. The following subsets of nodes characterize the model structure:

(i) N_P is the set of "product" nodes with P an element of N_P,

(ii) N_A is the of "activity" nodes with :
- $N_{A_P^d}$ representing disassembly operations on P,
- $N_{A_P^v}$ representing recycling action on P,
- A an element of N_A,

(iii) N_U is the set of utility nodes. They are associated with each activity and U_A is the utility node associated with the activity modelled by node A.

The model represents the whole deconstruction trajectory that the decision maker has identified. The objective is to find an optimal trajectory that for each product, given its state, allows the best activity (further disassembly, functional recycling or material recycling) to be selected. In this network, Succ(A) represents the set of product node successors of a disassembly activity A. A disassembly policy model is drawn from the global model to evaluate each product separately. It enables the required defining recursive equation to be obtained to determine the optimal disassembly trajectory.

Disassembly policies are modelled by decision nodes associated with each product. These nodes are integrated in the model as presented in Figure 3(node PL_P). The considered product is modelled by node P and modalities of node PL_P characterize all the possible options likely to be selected on the product. Utilities $U(Q), Q \in Succ(A), A \in N_{A_P^d}$ (i.e. Q is a component of P) represent the evaluation of product components generated by each disassembly operation. A policy model being associated with each product, these utilities correspond to the optimisation result of the product component policies.

Warranty parameters are introduced through utility nodes related to the option of functional recycling, precising for each disassembly level, the cost of the resulting warranty program as well as the probability (that is the reliability of the considered system, subsystem or component) characterizing the chance of implementing the corresponding actions.

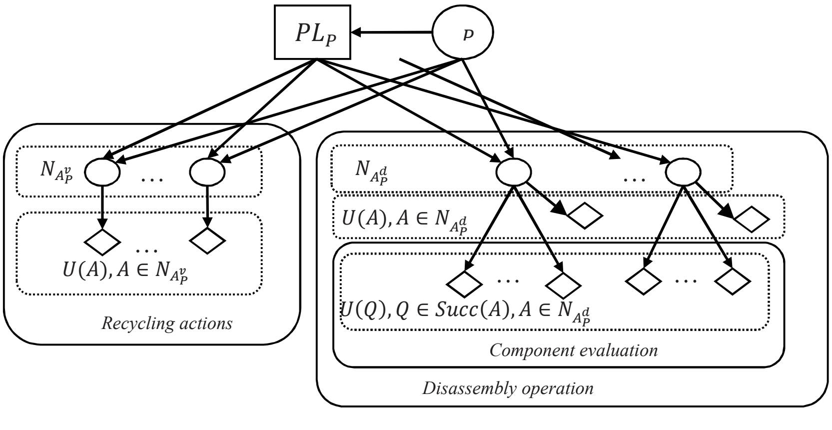

Figure 3: Disassembly policy model

V. CONCLUSION

We have presented in this paper a model for the determination of the dismantling optimal trajectories i.e. the optimal level of disassembly applied to the deconstruction of end-of-life systems. Disassembly solutions are evaluated by means of utility nodes in Influence Diagrams which are an extension of Bayesian networks. They enable the modeling of the economic performance of the different recovery actions and disassembly operations. Warranty parameters are integrated in the model in order to evaluate the real costs of the products in the case of a second-hand life.

In the proposed work, warranty parameters are considered as a known input. The perspectives of future works deal with the use of Bayesian network to determine the risks associated with the warranty. Through a bottom up approach (whereas the work presented here is a top down methodology), it should allow the decision maker to define the reliability of the different subsystems according to the decomposition level by associating the failure rate of the components with respect with their mode of association.

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