Technical note

A framework for a flexible cutting-process simulation of a nuclear facility decommission

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ABSTRACT

Current methods for a process simulation cannot simulate the cutting-process flexibly. As is, to simulate a cutting-process, the user needs to prepare the cut product models of the cutting operation based on a cutting path and thickness with respect to a dismantling scenario in advance. In addition, the user need to build these preparations again as the scenario changes, which takes a lot of time.

To solve this problem, we proposed a flexible cutting-process simulation methodology containing an automatic cut-product generation in the cutting-process modeling procedure. The cut products are created through CAD operations with the selected device models and the cutting path, which is input by the user. In addition, we implemented the methodology on a commercial system used to test the methodology.

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1. Introduction

The dismantling of nuclear facilities takes a very long time and is a dangerous procedure (Kim et al., 2015). Thus, it should go through a process optimization procedure based on the process simulation. Using a process simulation, we can pre-evaluate the operation time and check the possibility of danger of the dismantling procedures from a kinematics point of view, such as movement of the device and checking the interference of the device, thereby enhancing the safety of the dismantling. Moreover, we can estimate the cost of the each dismantling scenario with the kinematic analysis results of the simulation and the mechanical properties of the cut products and secondary waste.

To determine the optimized dismantling scenario, it is necessary to simulate as many various cases of the scenario as possible. Thus, a flexible cutting simulation framework is required to ease the user when modeling the cutting process and to reduce the preparation time of the simulation.

To simulate the cutting-process with existing process simulation software, such as (Delmia Product, 2016), the user needs to go through two steps, a cut-product modeling procedure and a process modeling procedure, as with the IDEF0 model (Lightsey, 2001) shown in Fig. 1. During the cut-product modeling procedure, the user manually creates resulting products that will be created after the cutting operation and used for the process modeling. In the process modeling procedure, the user creates a device-cutting path, cutting operation, disposal path of the cut products, and visualization of the cut products using the resource models and the user-created cut-products in the previous procedure. Because there is no connection between both procedures, moreover, the user transfers the cut-products manually, if a procedure needs to be modified, and another procedure should then be modified. In the case of nuclear facility decommissioning, more than one-hundred cutting processes are applied, which causes a serious waste of time.

Therefore, we proposed a methodology to create cut products during the process modeling procedure, as shown in Fig. 2. To do so, in the proposed methodology, the cut-product creating procedure is dependent on the process modeling procedure and is executed automatically so that the user does not need to create the cut products before the process modeling procedure. In addition, if the simulation scenario is changed, the user only needs to re-model the process in the process modeling procedure and the cut products are automatically updated.

In the proposed methodology, the user models process manually, not automatically. The cut products generation and data transfer are done automatically. In addition, to calculate the mechanical properties of the cut products, we used a digital mockup of the nuclear power plant based on the CAD model. Table 1 shows a comparison between the existing and proposed methodologies.

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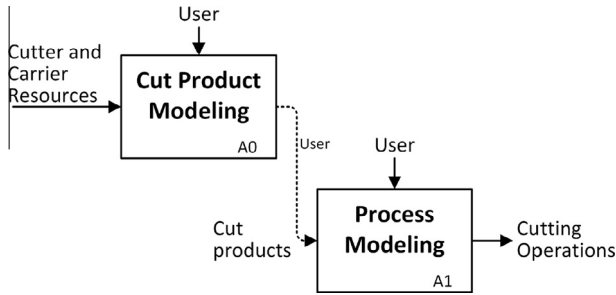 *E-mail address:* ikjunekim@kaeri.re.kr (I. Kim).

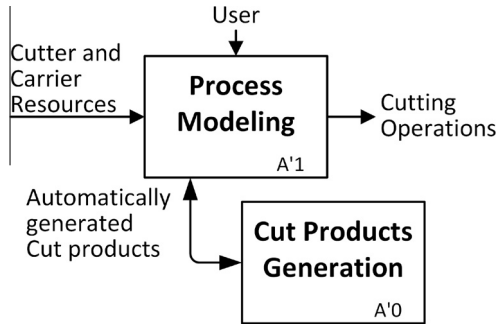**Fig. 1.** IDEF0 model of Existing Methodology.

Fig. 2. IDEF0 model of proposed methodology.

2. Related works

There have been many studies on the dismantling simulation of a nuclear facility. Park et al. studied a dismantling digital mock-up system to establish decommissioning processes for a nuclear facility (Park et al., 2007; Kim et al., 2006); in their study, the cutting scenario is predefined and is not changeable. Thevenon et al. studied a dismantle support system that is capable of calculating the radioactivity dose rate. It is specifically used to simulate scenarios in a nuclear environment (Thevenon et al., 2006, 2009). Iguchi et al. developed an Engineering Support System for decommissioning by adopting new information technologies such as 3-dimensional computer aided design (3D-CAD) systems and virtual reality (VR) systems (Iguchi et al., 2004). Moreover, based on VR technology, a dismantle support system was developed (Caroline Chabal and Idasiak, 2011; Szőke et al., 2015).

However, these studies are not concerned with a cutting the model with an arbitrary user input path or a visualization of the exact shape of the cut products.

In the field of medical surgery, we were able to find similar studies to our approach. Kühnapfel et al. studied surgical training systems based on virtual reality and simulation techniques based on a mesh model. They created an interaction module that allows grabbing, cutting, and clipping the organ model (Kühnapfel et al., 2000). Shi et al. and Lim et al. studied a mesh based cutting algorithm for a human organ model (Jiao-Ying and Li-Xia, 2001; Lim and De, 2004).

The mesh model is useful for visualizing the simulation results. However, using only a mesh based model, one cannot calculate the mechanical properties of the resulting model, such as the volume and weight of the product (Futagami et al., 1989). For a facility decommission process simulation, calculating the mechanical properties of the cut products is required, and thus we use solid models as resources of the process simulation.

3. Proposed methodology

Fig. 3 shows a detailed operation scenario of the proposed methodology, as shown in Fig. 2. We depict the *process modeling* procedure of Fig. 2 as two blocks, *resource selection* and *process modeling*. In addition, the *cut-product generation* procedure has three blocks, *cutting volume generation*, *cut target product*, and *volume separation* procedure. A detailed explanation of the operation scenario in Fig. 3 is as follows.

3.1. Process modeling

Before starting the process modeling procedure, the user needs to select the models of the cutting and carrier devices from the resource catalogue. The selected cutting device model has a pre-defined cutter profile and cutting depth. The cutter profile is a straight line composed of two points indicating the cutting position and depth, and the kerf width is defined in the model as a property with a real value. In addition, the selected carrier device has pre-defined kinematics information controlled by the user input. The user moves or operates the carrier device model using a GUI (Graphic User Interface) or haptic device to create a device-moving path of the carrier device that has the cutter device.

In the *process modeling* procedure, the user creates the movement of the carrier device, which is carrying the cutter device to create the cutting path. The cutting path is recorded by a simulation system and is used to create the cutting volume during the *cutting volume generation* procedure.

3.2. Cutting volume generation and cut

Based on the created moving path and cutter profile, the cutting volume is created. In this step, at first, the cutter profile is swept (Choi and Lee, 1990) along the user input moving path to create a surface of the cutting volume, as shown in Fig. 4. In addition, we apply the kerf width property into the swept surface to create the cutting volume. In addition, the user selects the cut target product and the created cutting volume is copied into the selected product. Next, we transform its coordinate into the target product to align both models for cutting. We then conduct a Boolean remove operation on the target product as a blank model by the cutting volume as a tool model.

3.3. Product separation

After the Boolean operation, the target product remains as two solid lumps in a product. To use it in the simulation process, it should be separated into different products because the product

Table 1
Comparison between existing and proposed methodologies.

	Existing methodology	Proposed methodology
Operation sequence	A0 → A1 (No connection between them)	A'1 include A'0 (A'0 is dependent to A'1)
Data Transfer	Manually	Automatically
User assisted procedures	A0 and A1	A'1
Automatic procedures	–	A'0