An Activity and Resource Advisory System for Manufacturing Process Chains Selection at the Early Stage of Product Development

Jaya Suteja The[1*,a], Prasad KDV Yarlagadda[1,b], Azharul Karim[1,c] and Cheng Yan[1,d]

[1]Science and Engineering Faculty, Queensland University of Technology, Australia

[a]jaya.the@student.qut.edu.au, [b]y.prasad@qut.edu.au, [c]azharul.karim@qut.edu.au, [d]c2.yan@qut.edu.au

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Abstract. Designers need to consider both the functional and production process requirements at the early stage of product development. A variety of the research works found in the literature has been proposed to assist designers in selecting the most viable manufacturing process chain. However, they do not provide any assistance for designers to evaluate the processes according to the particular circumstances of their company. This paper describes a framework of an Activity and Resource Advisory System (ARAS) that generates advice about the required activities and the possible resources for various manufacturing process chains. The system provides more insight, more flexibility, and a more holistic and suitable approach for designers to evaluate and then select the most viable manufacturing process chain at the early stage of product development.

Background

In designing a product, designers must not only consider the functional issues of a product, but also the production process issues at the early stage of product development. For that reason, designers should not only know various concepts that can be used to satisfy the functional requirements of a product, but also the various production processes that can be used to produce the product and its components. Designers are familiar with various concepts that can satisfy functional requirements of a product. However, it is difficult for them to select the most viable production process for the following reasons. First, there are a large number of existing manufacturing and assembly processes. Second, there is usually more than one process that can be used to manufacture the components and assemble them into a product. Third, most of the components and products require a sequence of process or process chain. Last, most designers are familiar with a very limited number of manufacturing and assembly processes. As a result, designers face the challenges of satisfying both functional and production process requirements.

In the next section, the work of various researchers on manufacturing process chains selection is reviewed. Then, this paper will describe a framework of an Activity and Resource Advisory System (ARAS) that is not only able to generate the viable manufacturing process chains, but also to assist designers in evaluating the viable manufacturing process chains at the early stage of product development. In the last section, conclusion is presented.

Literature Review

According to Lovatt and Shercliff, there are two approaches in selecting the manufacturing process [1]. In the first approach, the existing manufacturing processes are evaluated in parallel. It means that manufacturing processes are screened and eliminated based on all design requirements simultaneously. Then, the viable manufacturing processes, which meet all the design requirements, will be retrieved and suggested. In the other approach, the existing manufacturing processes are

[*] He is a lecturer at University of Surabaya, Indonesia and is currently on study leave to undertake his PhD at Queensland University of Technology, Australia

evaluated in sequence. The manufacturing processes are screened and eliminated stage by stage based on the design requirements until viable manufacturing processes are selected. Most of the research works found in the literature implement the sequential selection approach. Compared to the parallel approach, this approach allows greater detail to be shown at each stage and designers can access more refined manufacturing process information [1]. It allows designers to consider more information before selecting the most viable manufacturing process. However, the use of this approach requires more time during the selection process compared to the parallel approach.

A large number of manufacturing processes exist in practice. For that reason, they need to be classified into a hierarchy to make the selection process more organised and efficient. According to the classification proposed by Esawi and Ashby, there are four hierarchy levels of manufacturing processes, which are kingdom, family, class, and member [2]. The kingdom of manufacturing processes contains many families. Each family contains many classes. Lastly, each class has many members, which are characterised by a set of attributes. Most of the research selects the manufacturing process alternatives at the class-level. The lower the manufacturing process level, the more specific the information that is available. The more specific the information, the more accurately the manufacturing process can be ranked.

As already explained in the introduction, most of the components are rarely manufactured by only conducting a single process. Instead, they mostly require a sequence of processes or process chain. For that reason, it is necessary to generate viable manufacturing process chain alternatives instead of single process alternatives. Various research works found in the literature had been conducted to select and rank the viable manufacturing process chain alternatives. Esawi and Ashby considered the process chain at the conceptual design stage by combining the individual processes to build up the process chain [2]. This approach adds a considerable amount of complexity to the selection problem. To reduce the complexity, another suggested approach is to choose from common or widely used process alternatives, either single process or process chain [3]. Dimitrov, Wijck, Beer, and Dietrich propose a model to select the best process chain from several common process chains, which are unlikely to change in the near future [4]. They use a chart to show the most suitable process chain that meets the requirements. A similar approach is also proposed by Liu, Cui, Meng, and Li in their paper [5]. This approach can only be applied if several process chains can be used to manufacture a component and each process chain is always performed in the same sequence. Research by Gupta, Chen, Feng, and Sriram, develops a system that can generate advice about process sequences and material selection [6]. The approach first generates several combinations of primary processes and materials. Then, the approach adds secondary, tertiary and surface treatment processes into each combination based on the detailed form requirements and then constructs several process sequences. This research also provides the cost of each process at the generated process chains. Blanch, Ferrer, and Garcia-Romeu propose a model to build manufacturing process chains during the embodiment design phases [7]. First, a list of manufacturing processes that can satisfy most of or all design parameters and feature design parameters are generated. If there is at least one unresolved design parameter, a new list of processes will be added to the first process to create a process chain. The sequence of the process is defined by using manufacturing process sequencing rules. The output of this research work is a ranking of the manufacturing processes based on the estimated manufacturing cost.

None of the research gives designers more insight than just a ranked list of viable manufacturing processes or process chain. They do not give any understanding of the influence of the design requirements to the ranking criteria. This understanding is useful when a trade-off is required in selecting the manufacturing processes. The existing research uses fixed data and assumptions to determine the rank. None gives any flexibility to designers in adjusting the data or assumptions. This approach could lead to an error in ranking the manufacturing process if the ranking is based on data or assumptions that are not matched with the actual situation of the company. Another weakness of the research described above is that most concerned only with the economical aspects, especially the manufacturing cost, to rank the viable manufacturing process chains. To calculate the manufacturing cost, most of the research uses the traditional cost estimation method. The traditional cost estimation method is simple to use, but could result in undercosting or overcosting. Last, only manufacturing process information is taken into consideration to rank the viable manufacturing process chains. As process chain comprises a sequence of processes, information such as how to do the material handling and how to store a work-in-process component also needs to be considered.

In summary, none of the research has provided any assistance for designers to evaluate the manufacturing process chains according to their particular circumstances. For that reason, it is important to develop a system that is not only able to select the most viable manufacturing process, but also assist designers to evaluate them according to their individual situations.

A Framework of Activity and Resource Advisory System

This paper describes a framework of Activity and Resource Advisory System (ARAS) that not only generates a list of viable manufacturing process chains, but also advice about the required activities and the possible resources for each process chain. The aim of the system is not to provide the ranking of the manufacturing process chains, but to assist designers in evaluating the manufacturing process chains at the early stage of product development. At the early stage of product development, there is only a rough idea of the shape, material and scale of production [3]. Therefore, the inputs of the system are production volume, material, main shape, envelope size, minimum thickness, and additional features of a component. Size tolerance, surface roughness, material properties, and surface finish can be inputted if it is required. In developing the system, manufacturing processes are classified into primary, secondary, and tertiary types according to classification by Esawi and Ashby [2]. A primary type forms the shape to a component. A secondary type modifies and adds a feature to an already shaped component. Finally, a tertiary type adds quality to a component without affecting its shape and the feature geometry. The system consists of the member-level primary, secondary, and tertiary manufacturing processes databases, which are viable for various materials, production volumes, main shapes, common shapes of raw material, additional features, size tolerance, surface roughness, material properties, and surface finish. It also consists of activity and resource databases for various manufacturing processes. In addition to these databases, the system implements a knowledge-based system to generate the viable manufacturing process chains.

Figure 1 shows the framework of the system. The framework consists of the following steps:

- Step 1. Generate all primary processes that can be used to form the required main shape of a component with its material, envelope size, and minimum thickness in the required production volume.
- Step 2. Generate all secondary processes that can be used to modify the common shape of raw material into the required main shape of the component with its material, envelope size, minimum thickness, and size tolerance in the required production volume.
- Step 3. Generate all primary processes that can be used to add the additional features to the already shaped component.
- Step 4. Generate all secondary processes that can be used to add the additional features to the already shaped component.
- Step 5. Generate all tertiary processes that can be used to achieve the required size tolerance of the component and achieve its required surface roughness if it is not achieved without affecting the shape and features geometry of the component.
- Step 6. Generate all tertiary processes that can be used to achieve the required material properties and improve surface finish of the component without affecting the shape, features geometry, size tolerance, and surface roughness of the component.
- Step 7. Create a list of viable manufacturing process chains. First, the system starts listing the generated processes from Steps 1 and 2. Then, the system adds the generated processes from Steps 3 and 4 as the second process, third process, and so on in process chains. If the same process is generated from Step 1 and Step 3, then the system only list the first process

from Step 1. The system also performs a similar action for Steps 2 and 4. After that, the system adds the generated process from Steps 5 and 6 sequentially. The generated process from Steps 5 and 6 will not be added on the list if the required size tolerance, surface roughness, material properties, and surface finish are already achieved in the previous step.

- Step 8. Generate the required activities for each viable manufacturing process chain and possible resources that can be used to perform each activity.

The Activity and Resource Advisory System uses a different approach to systems found in other research for selecting the process chains. In selecting the manufacturing processes, the system implements a combination of the parallel and sequential selection approaches. The system accommodates the common shape of the existing raw material in selecting the process chains as outlined in Step 2. The viable manufacturing process alternatives are selected at the member-level instead of the class-level. In addition, the system generates the activity and resource advice for various process chains instead of a ranked list of the process chains.

The activity and resource advice generated by the system are useful for designers when making a trade-off. Designers can adjust the activity and resource data or assumptions to match with the actual situation of the company. By using this advice, the designers can evaluate the process chains based not only on the cost aspect, but also other aspects, such as the resource availability and environmental aspects. The system can be integrated with the existing Activity Based Costing System in order to estimate the manufacturing cost more accurately. Designers can evaluate the process chains based not only on manufacturing process activities, but also other activities between the processes, such as material handling and storage activities.

Conclusion

The Activity and Resource Advisory System (ARAS) is able to generate not only the list of viable manufacturing process chains, but also advice about the required activities and the possible resources for various manufacturing process chains. The system provides more insight, more flexibility, and a more holistic and suitable approach for designers to evaluate and then select the most viable manufacturing process chain at the early stage of product development.

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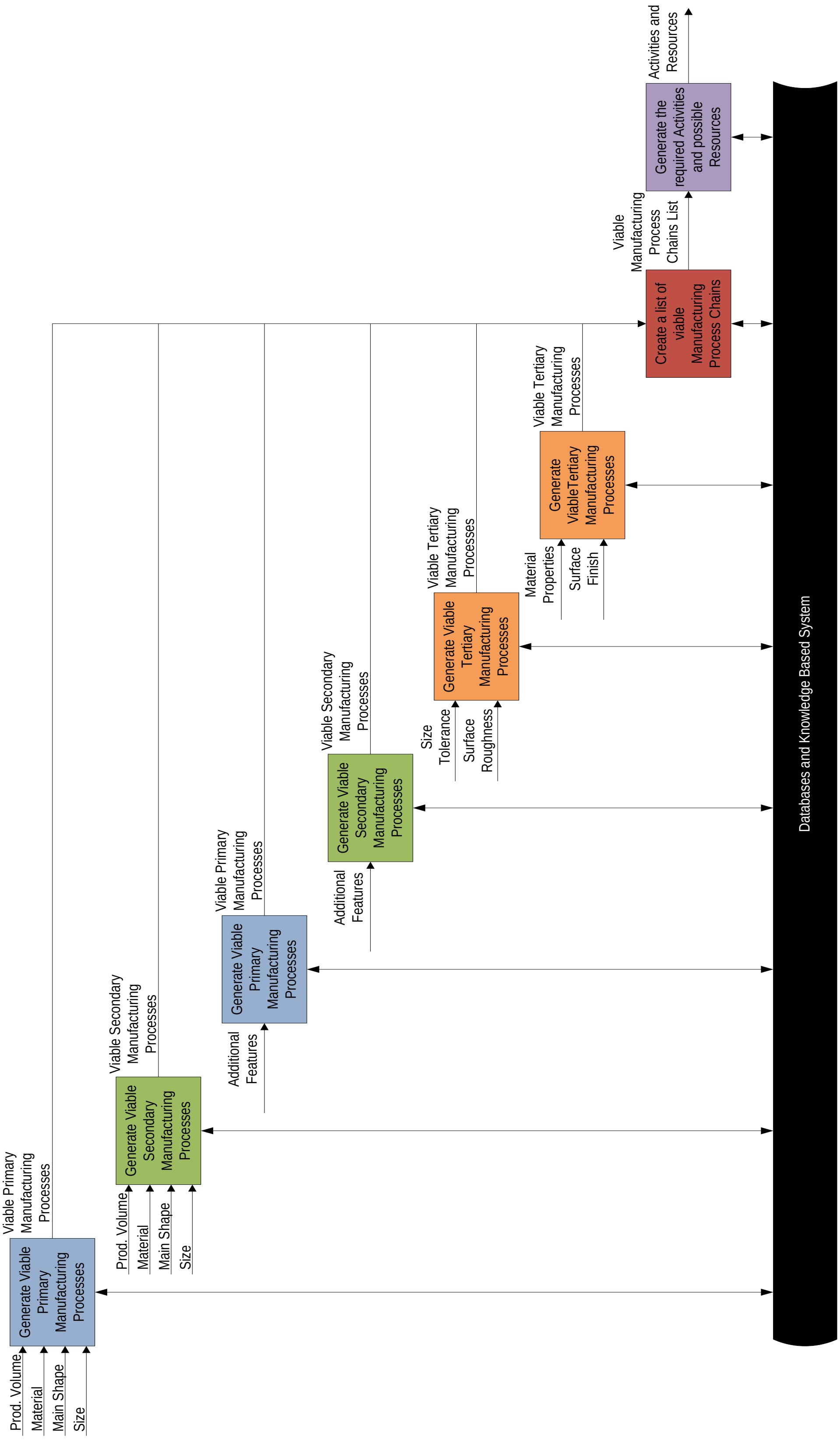

Fig. 1. Activity and Resource Advisory System Framework