A DECISION SUPPORT SYSTEM FOR THE CONCEPT DEVELOPMENT OF RIM PARTS

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ABSTRACT
The aim of this paper is to present a research project currently underway which seeks to identify and organize the knowledge required in the development process of Reaction Injection Molding parts at the early product development stage, specifically the material selection, mold design and the process planning for mold making and molding operation. The purpose of the research is to verify if an Expert System, a computer program that uses knowledge and inference procedures to model the RIM development process, provides the necessary insight into metrics such as development lead time and manufacturing costs to deal with the decision makings required at that stage. As this is a work-in progress, the paper will focus on the first three tasks carried out: 1) Structure the downstream processes and procedures of developing product design concepts for RIM parts; 2) Define the dimensions of knowledge required in the concurrent concept development of RIM parts; and 3) Present the theoretical implementation framework, the methodologies and procedures of an ES which we believe will help deal with concurrent concept development decision makings at the early design stage of RIM parts.

Keywords: Concurrent engineering, expert system, cost modeling, reaction injection molding

1 INTRODUCTION

Early assessment of a material and its inherent production technology applicability in a particular product is fundamental for it to be considered in further product development steps. With the pressure to reduce the product development cycle, it is even more important to make the right choices early on, in order to avoid rework and consequent increase in time-to-market.

Since the 1990s many researchers have advocated that the emphasis of manufacturing companies must be on how to speed up the development process of a new product or, how to reduce the time-to-market [1-5]. Many competitive advantages can be accrued from a fast product development cycle. If a product is introduced early, the product's life cycle is usually longer with extra revenues and profit. Moreover, early product introduction can increase the market share and profit margin as there is less competition at the introduction stage. Such an emphasis on the time-to-market can be further justified as product life cycles are rapidly shortening due to technological improvements and breakthroughs [6].

The time-to-market strategy, while emphasizing time, does not imply that other factors such as product performance, quality, reliability and cost are less important in product development. Because time-to-market is supplementing rather than replacing other development objectives such as design for quality or low manufacturing cost, it must be seen as one more, but nevertheless important dimension to competitive advantage.

The Reaction Injection Molding (RIM) process is noticeably under this paradigm. It is mostly applied in product development, prototyping and low to medium volume production, in markets such as automotive and medical equipment where time-to-market is highly valued.

RIM is a process to produce plastic parts from the injection of a reactive low viscosity mixture into a mold, allowing the production of parts with complex geometries, mainly polyurethanes (PU). The heart of the RIM process is the intensive mixing of two monomers introduced from two opposite jets into a semi-confined mixing chamber. The resulting reacting mixture is discharged into a mold, where most polymerization takes place [7]. The main limitation of the RIM industrial process is related to the mixing stage, which results in the traditional RIM machines' lack of flexibility for formulation changes and great dependence on operational conditions.

Aiming to make RIM a robust and more flexible process a series of studies were developed at the Laboratory of Separation and Reaction Engineering, LSRE, in Faculdade de Engenharia da Universidade do Porto, FEUP [8, 9]. From these studies a new technology was introduced, RIMcop® – RIM with Control of Oscillation and Pulsation, protected by patent PCT WO 2005/097477 [10]. The RIMcop® technology controls the mixing dynamics from pressure measurements of the monomer feeding lines to the mixing chamber, which allows a real time control of the process, a feature not yet available in state of the art RIM technology. Furthermore the mixing is also ensured from a set of design changes to the mixing chamber and from the opposed jets forced pulsation [11-15].
Developers of this technology are now eager to understand of how the RIMcop® process can influence design, manufacturing and cost when compared to traditional RIM process.

2 OBJECTIVES

The research design addressed primarily the RIMcop® technology and how to position it competitively in the production of multifunctional auto parts. Although RIMcop® has proven to be successful in controlled environments and testing, we verified that it is still not ready for industrial implementation. Furthermore, an initial literature review revealed that there is very little information on the RIM process, especially regarding the interaction between part design features and the cost of the downstream processes. As such, before considering RIMcop® as a technological development of the RIM process, we first acknowledged the need to identify and organize the knowledge required in the development process of RIM parts and processes. Only after will it be possible to understand how the RIMcop® process can influence design, manufacturing and cost. The research was then redesigned to address exclusively the development of parts to be produced with RIM technology.
The main aim is then to identify and organize the knowledge required in the development process of RIM parts at the early product development stage, specifically in terms of material selection, mold design and the process planning for mold making and molding operation. We will try to verify if an expert system (ES) is an appropriate tool to deal with the decision-makings required at that stage. The system will not cover the technical design aspect as well as the evaluation of the design itself, but aims to facilitate the decision making throughout the product development process of RIM parts with concurrent considerations of mold design, process planning of mold-making and production planning of molding parts in both technical and economical areas.
Hence, the current research project focuses on the following research questions:

- Can an ES help with decision-makings (regarding material selection, mold design and process planning for mold making and molding operation) in the early product development stage (conceptual design) of RIM parts?
- Is it feasible to develop an ES including not only technical expertise but also accurate economical predictions in the early product development stage? How? By establishing an implementation framework, the methodologies and procedures?
- Is it feasible to use ES technology together with process-based cost modeling (PBCM) methodology to support the decision makings in concurrent RIM part concept development process?

3 RESEARCH METHODS AND PROCEDURES

In order to study the feasibility of using ES technology simultaneously with PBCM methodology for concurrent RIM part concept development at the early product design and development stage, the research underway focuses on the evaluation of 1) manufacturing processes, 2) development lead time and 3) cost. The purpose is then to develop a system to determine whether the development of individual product concepts is practical and reasonable from these three perspectives. It also aims to provide a benchmarking tool for comparison among alternative product concepts and to supply information feedbacks for further improvement of the product concepts.
The first two tasks lie under the paradigm of inductive research, and are based on field research and open-ended interviews to the experts working at the US companies. Qualitative data was collected, synthesized and organized in datasheets so as to:

1. Structure and formalize the downstream (from the concept development stage) processes and procedures of developing product design concepts for RIM parts, including the mold design and the process planning of mold manufacture and molding operation. Although the gross of the data

has been collected in visits to the US companies and through literature review, details and specific questions will be addressed in the near future in the second round of interviews.

2. Identify and define the dimensions of knowledge required in the concurrent product concept development process of RIM parts. With a small programming effort more data can be added to the ES's knowledge databases at any time. We will return, once again, to this second task in the second round of interviews and during an internship period that will take place in the selected company.

The third task consisted in the development of a theoretical implementation framework, the methodologies and procedures of an ES which helps deal with concurrent concept development decision makings at the early design and development stage of RIM parts. The next section of this paper will present a synthesis of these three tasks, which reflects the current situation of the project.

4 FINDINGS

4.1 Development of RIM parts

A visit to two US RIM companies (Armstrong Mold Corp. and RIM Manufacturing, LLC) and conversation with experts within each company allowed us to better define the scope of our study and the objectives of the research. The RIM process, including design and manufacture, was studied in two different industrial environments. Differences and commonalities were identified and conclusions were made as to the positive and negative attributes of RIM (Figure 1); the qualitative positioning of RIM when compared to the competing processes (Figure 2); RIM applications (such as medical equipment parts, automotive and trucks parts, and agricultural, construction and utility machinery parts); and the process flow (Figure 3).

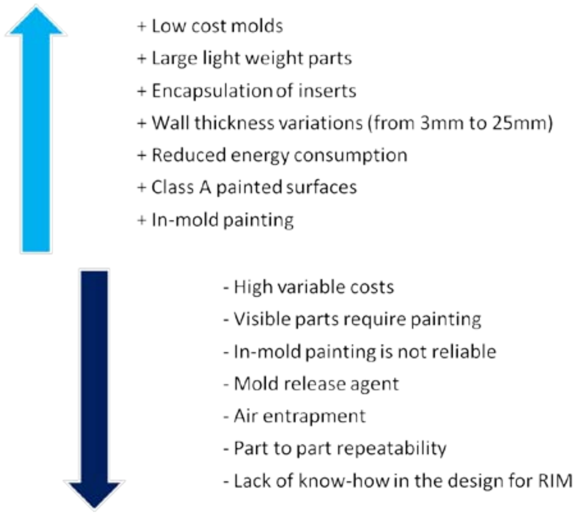

Figure 1. Positive and negative attributes of RIM process

During the visits we confirmed the general lack of explicit consideration of the downstream processes in the concept development stage. These interrelations are done in the minds of the different experts involved and consulted during the concept development stage. Often the expert makes the decisions without any explicit explanation as to the motives and reasoning behind them.

Based on these findings, the literature review was refined to include the state-of-the-art in product development, the appropriate tools to effectively incorporate expert knowledge in the part and process design, and the cost estimation techniques. We found that Concurrent Engineering (CE) is the appropriate method to consider the downstream processes in the concept development stage [16-18]. This method also has the benefit of reducing the time-to-market [19]. It was also found that an ES is the appropriate tool to incorporate the knowledge of the different specialists involved in the decision making process [20-22]. The CE implementation can be improved by capturing, storing, processing and retrieving pertinent design, engineering and manufacturing knowledge in an integrated and artificially intelligent manner using ES technology. Finally, we found that PBCM (also called technical cost modeling) is a widely proved technique for materials selection and processing cost assessment because it has the ability to explicitly link cost and technical data [23-25]. Furthermore, the literature review revealed a gap regarding the concurrent consideration of the design and production knowledge together with cost modeling in supporting concept development decisions.

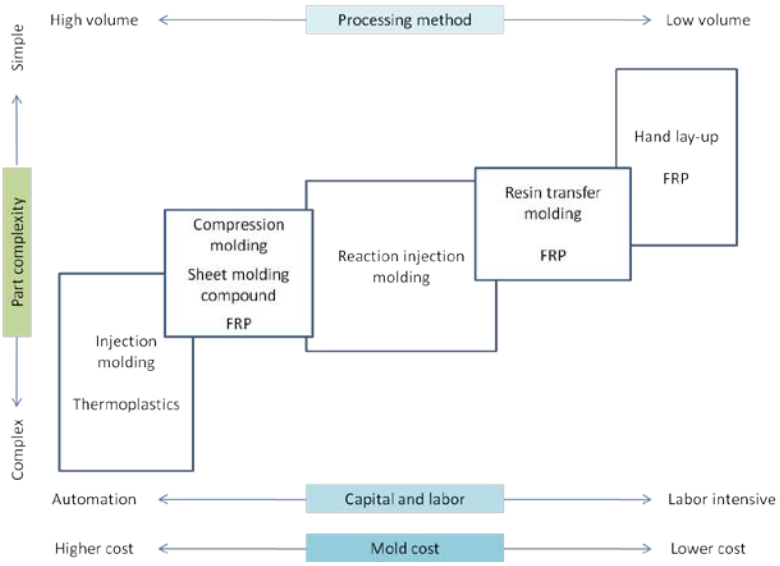

Figure 2. Qualitative positioning of RIM process

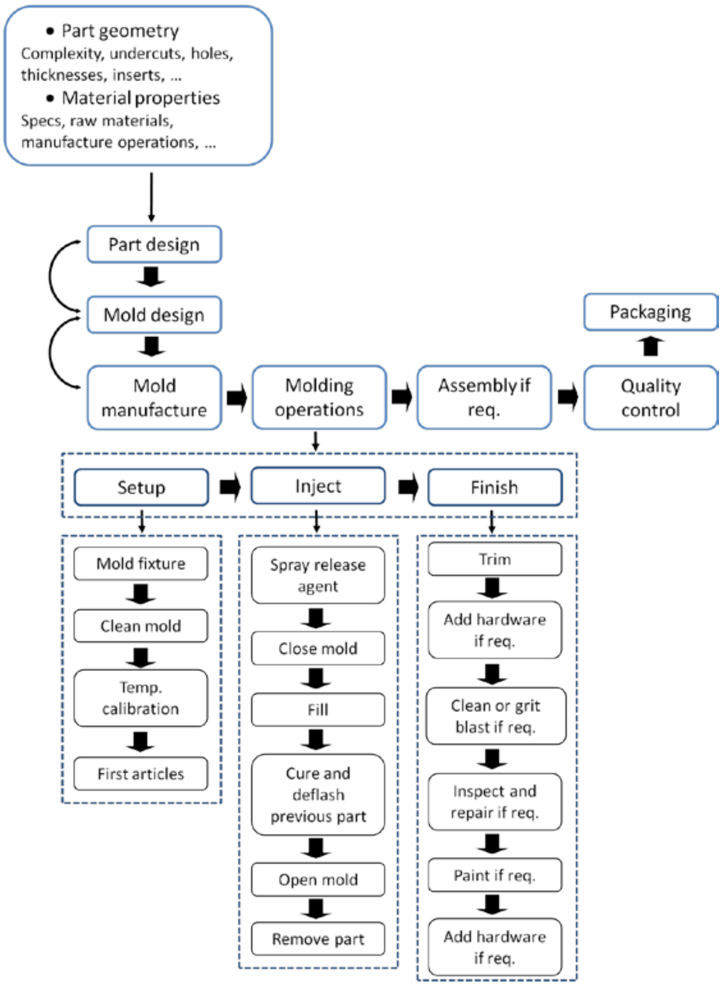

Figure 3. RIM process flow

In this research we were able to acknowledge that for the development of a RIM part, the part design features is usually the dominant factor in mold design while the mold design characteristics, in turn, dominate the process plans of mold manufacture and molding operation. As a result, most of the costs of mold making and molding operation as well as the quality and reliability of molds and moldings are determined in the concept development stage (Figure 4) of a new RIM part development project. Therefore, there is a need for a verified design that will provide the necessary insight into metrics such as development lead time and manufacturing costs to deal with the decision makings required in early stage design in order to reduce the subsequent redesigns and reworks. Based on the characterization of the industrial practice of RIM the concurrent concept development is the appropriate approach to achieve this goal.

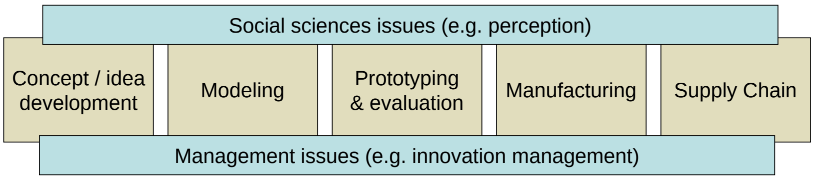

Figure 4. Innovation value chain

However, the concurrent development of RIM parts involves a substantial practical knowledge component (heuristic knowledge) on the relationship among part features, mold design requirements, mold-making processes characteristics and the selection of production molding equipment. The designs and process plans involved are predominantly based on the experience of designers. The processes rely heavily on engineers to define their designs in detail. Extensive mathematical analysis is often not used as analytical models with sufficient accuracy and efficiency are not available. Calculations are limited to empirical rules. Hence, the designers of parts and molds are required to have a high standard of specific knowledge and judgment. Moreover, most decisions concerning the details of the design demand knowledge of the mutual influences between the various quantities. Changing one quantity in order to achieve better results, for example part design features, may have a negative effect on other influencing factors, for example the mold design and mold making process. This implies that knowledge and expertise of more than one specific area are required to have an optimum solution. Unfortunately, it is not easy to find such experienced engineers who possess all the required knowledge and expertise. The inherent complexity and intensive knowledge requirements of this concurrent development problem, as well as the scarcity of good human experts in the field are crucial aspects. Providing a good knowledge base for the industrial implementation and validation of RIMcop® technology is also an important facet for this study.

Moreover, as compared with other tools, the ES approach, a computer program that uses knowledge and inference procedures to solve problems or support decision making, has few applications in injection molding aspects, and especially in RIM. Thus, there is a need to develop an ES for the concurrent design of RIM parts that starts with inputs of customer requirements on product features, both functional and aesthetic, and ends with outputs that determine part material, mold design features, mold-making processes, molding processes, and cost estimations of mold fabrication and molding operation.

Although there is previous research works in the use of ES in product development, gaps were found concerning the lack of research in the concept development stage and lack of integration with other methodologies [20, 21]. Therefore, this research contributes to the existing literature on two levels 1) by studying the application of an ES in the conceptual stage of RIM parts development and 2) the ES's integration with PBCM methodology.

4.2 ES for the concurrent concept development of RIM parts

Based on the results obtained in the first two tasks, we defined the phases required for the concurrent concept development process of RIM parts, the knowledge inputs required to start each phase and the outputs of each phase. Upon those requirements, a framework was developed for the ES including the proposed architecture and a first approach for the procedures of the system.

4.2.1 Concurrent concept development process of RIM parts

The development process is in sequence, because each phase needs the output of the previous one, together with additional knowledge, as shown in Figure 5. Two tasks can be performed simultaneously, mold making process planning and molding production plan. After the evaluation the process can be repeated until a good result is achieved.

The material selection phase involves the translation of part requirements (functional and manufacturing) into material properties. Then a screening of candidate materials is made based on the properties necessary to fulfill the requirements. In the material selection phase the following aspects need to be considered: Mechanical and physical properties; Thermal properties; Appearance properties; Electrical properties; Chemical properties; Environmental performance; Manufacturing requirements (molding, assembly and finishing) and; Economics (estimation of total cost, includes material and manufacturing costs).

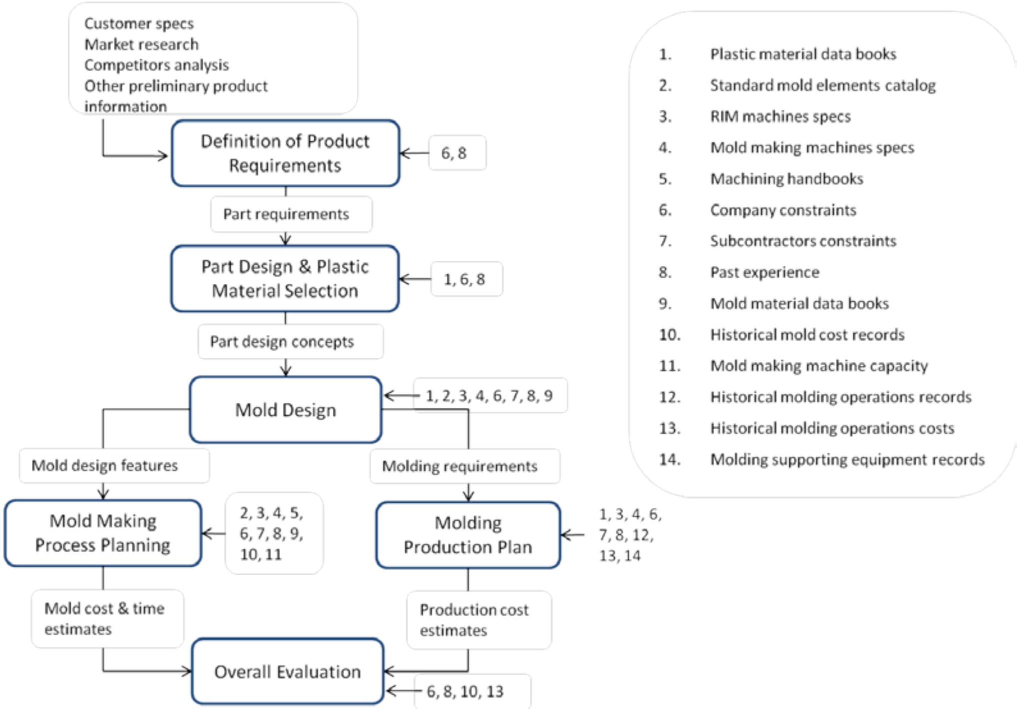

Figure 5. Concurrent concept development process of RIM parts

In the mold design phase, the part features (for each concept) are translated into mold features and molding requirements. This phase is critical in the concept development process, because it is the one that is worst to model (a large number of variables and of feasible outcomes) and is the one where decisions contribute most to the cost of the part. The aspects to be considered in this phase are: Type of mold structure; Ejection system; Feeding system; Temperature control system; Mold material selection and; Mold size determination.

At the mold making process planning phase, the mold features are converted into a plan for the manufacture of the mold; the major output is the mold cost and lead-time estimation. The aspects to be considered in this phase are:

1) Mold making processes: Material removal processes (drilling, milling, CNC milling, EDM, etc.); Forming processes (casting, SLS, etc.); Heat treatment processes (hardening, nitriding, etc.); Surface finishing processes (polishing, blasting, etching, etc.); Assembly processes (tapping, fitting, etc.).
2) Mold components: Cavity; Core; Remaining components; Standardized components.

The molding production planning phase involves the translation of molding requirements into molding operations to produce the part. The major output of this stage is the estimation of the part production cost. The aspects to be considered are:

1) Molding cycle
2) Molding parameters: Machine; Components (system) preparation; Molding temperatures (Control of components temperatures and Control of mold temperatures); Injection pressure, flow rate and duration (time); Cure time.
3) Finishing operations: Trimming; Cleaning; Painting.

The final evaluation consists in adding up the costs and lead-times for mold making and molding operations. A decision is made whether one or more of the concepts are selected for further development. At this final stage it is also possible to change features of the concept(s) although this implies repeating the process from the beginning.

4.2.2 Expert system framework

The ES should reflect the process explained in Figure 5. As such, the division into modules seems to be the most appropriate option for developing the inference engine. One module is set for each phase. The cost estimation module will be introduced after going through each product development module. The knowledge base is subdivided into two: one pertaining to knowledge related with product development; another with the knowledge related to cost estimation. Modularization facilitates the development of ES and will not jeopardize the performance of the toll because the modules reflect the process (see Figure 6).

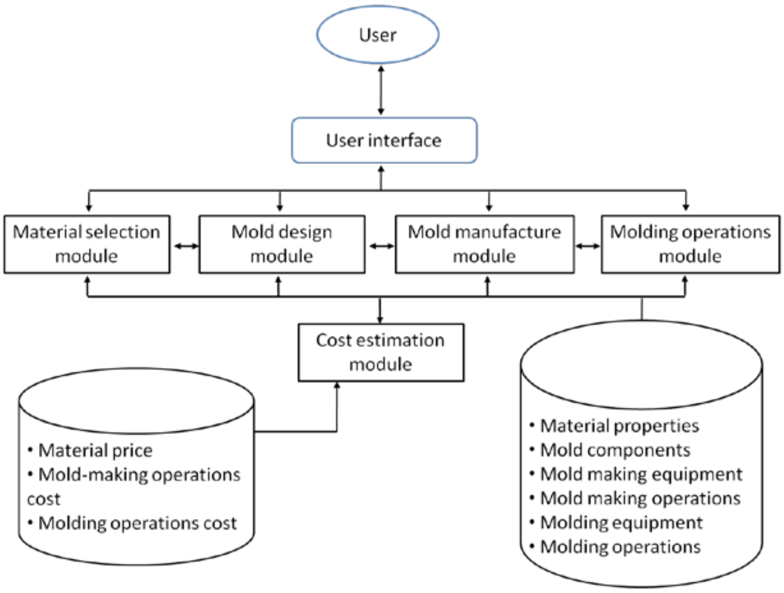

Figure 6. Expert system architecture

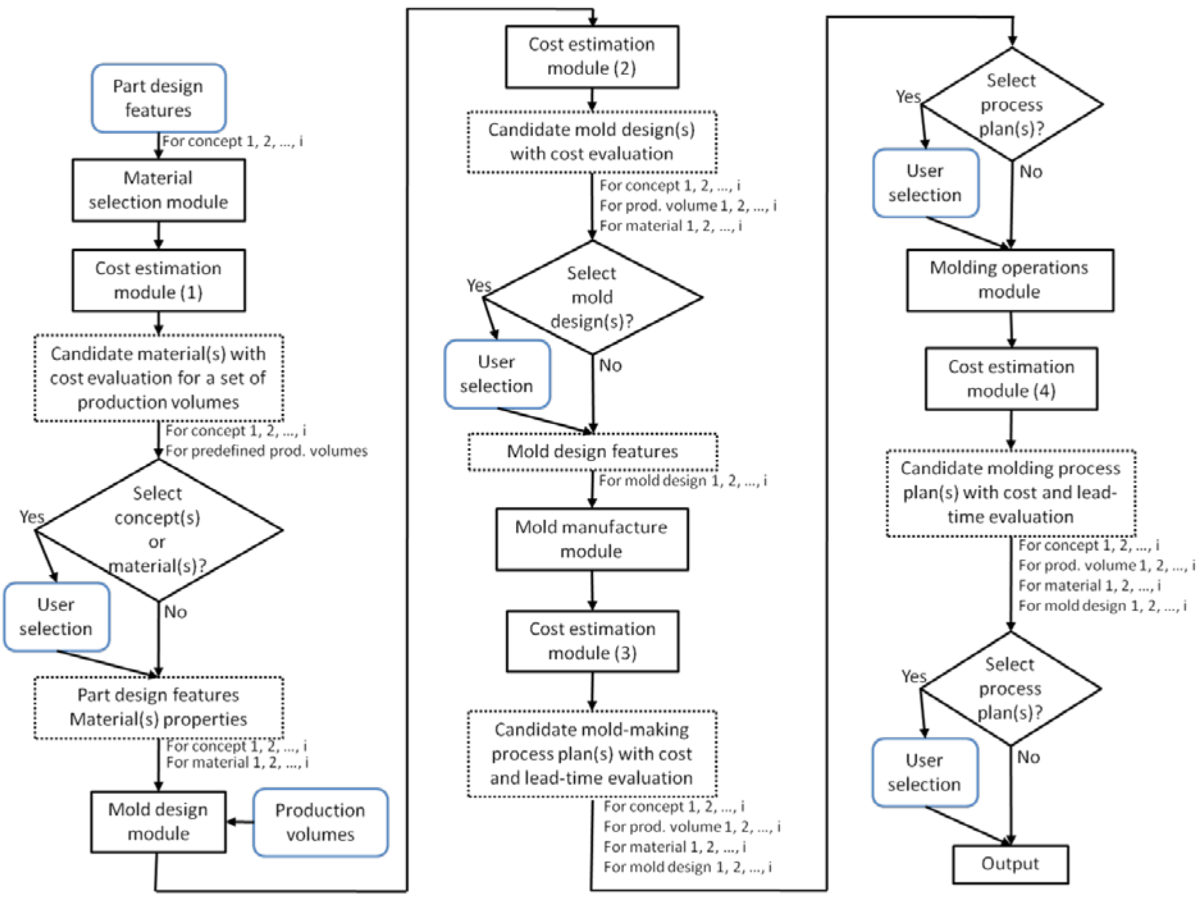

Figure 7. Expert system framework

How the ES operates is explained in Figure 7. Before the implementation of each module of the inference engine, the user must insert the data requested by the system. Cost estimation is made after the execution of each module. Although fuzzier at first, cost estimation will gradually become more accurate because of the inputs placed into the system by the user as it progresses. The final output of the system will be similar to Figure 8. For each concept and each production volume introduced by the user, the system will make suggestions based on the inferencing and knowledge of the ES.

	Concept 1	Concept 2	...
Production volume 1	$Material_{11}$ $Mold\ design_{11}$ $Mold\text{-}making_{11}$ $Molding_{11}$ $Cost_{11}$ $Lead\text{-}time_{11}$	$Material_{12}$ $Mold\ design_{12}$ $Mold\text{-}making_{12}$ $Molding_{12}$ $Cost_{12}$ $Lead\text{-}time_{12}$	
Production volume 2	$Material_{21}$ $Mold\ design_{21}$ $Mold\text{-}making_{21}$ $Molding_{21}$ $Cost_{21}$ $Lead\text{-}time_{21}$	$Material_{22}$ $Mold\ design_{22}$ $Mold\text{-}making_{22}$ $Molding_{22}$ $Cost_{22}$ $Lead\text{-}time_{22}$	
...			

Figure 8. Expert system output

5 CONCLUSIONS

From the research carried out we can conclude that there is very little literature on the RIM process. Although there have been technological developments made to the RIM process, namely RIMcop®, this technology is not yet ready for industrial implementation.

In order to identify and organize the knowledge required for the development process of RIM parts and processes, two US RIM companies were visited and their experts provided valuable information which enabled us to redefine the scope of study and the objectives of the research. These visits revealed that RIM is mostly applied in product development, prototyping and low to medium volume production, in markets like automotive and medical equipment where time-to-market is highly valued. During the visits we also confirmed the general lack of explicit consideration of the downstream processes in the concept development stage.

Considering:

1. The literature review on product development and tools to incorporate expert knowledge in the part and process design, and the cost estimation techniques;
2. The need for a validated design that will provide insight into metrics such as development lead time and manufacturing costs to deal with the decision makings required in early stage design in order to reduce the subsequent redesigns and reworks.

It is our belief that the concurrent concept development is the appropriate approach. Nevertheless, the inherent complexity and intensive knowledge requirements of this concurrent development problem, as well as the scarcity of human experts in the field, raises the need to develop an ES for the concurrent design of RIM parts (that starts with inputs of customer requirements on product features, both functional and aesthetic, and ends with outputs that determine part material, mold design features, mold-making processes, molding processes, and cost estimations of mold fabrication and molding operation).

An ES architecture and framework, which we believe emphasizes the concurrent concept development process of RIM parts, was developed.

6 FURTHER WORK

The next steps in the research will be to validate the framework by means of the prototype production and test on a company to be selected. It is our intention to develop a PBCM capable of receiving the technical inputs from the ES and sending the economical outputs to the ES, as well as develop a prototype ES to test the validity of the implementation framework.

The prototype system should contain sufficient knowledge to generate automatically mold design and process plans, with interactive user inputs. The knowledge base that will support the ES will be

developed according to the expertise and data provided by the involved companies, the published information and the author’s opinion. All the knowledge and rules acquired will be presented in form of decision tables and then build in a computer program with the aid of an ES shell to be selected.
The objective is to study the feasibility of applying ES technology in concurrent product concept development of RIM parts and to establish a general system framework, a prototype, rather than to build a comprehensive industrial-use system. The custom RIM parts manufacturers located in the USA and Europe were chosen for study; because of the availability those companies have demonstrated to participate in the project.
A real-life ES, however, is always application-specific, i.e. only workable in a specific environment. It is because the effectiveness of the knowledge acquired from the domain experts is often greatly related to the specific domains that the experts are familiar with. The prototype system will be built for a specific domain which is a company that will be selected out from the three manufacturers, but can be easily modified to other companies according to the generic framework.

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