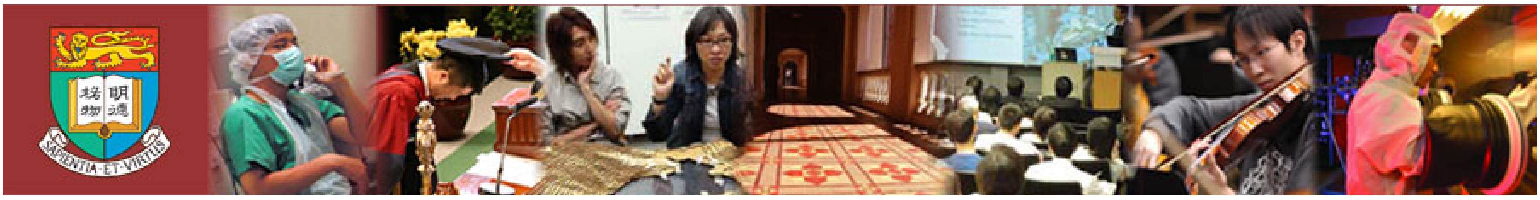

# A FRAMEWORK TO DEVELOP AN EXPERT INJECTION MOLD PLANNING SYSTEM FOR EARLY PRODUCT DESIGN DECISIONS

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ABSTRACT

This paper aims to explore the applicability of expert systems technology to today's competitive environment in injection molding product development with respect to the increasing trend of concurrent engineering practice. The proposed framework ESPIMP-1 is the phase one of a research work focusing in developing expert system for injection mold design and development with emphasis in the early design decisions. The ESPIMP-1 covers the areas of plastic material selection and injection mold design. With the inputs of rough part design features and requirements, the system will automatically select the appropriate plastic material and generate the major injection mold design features.

## 1. Introduction

The plastic products manufacturing industry has been growing very rapidly in recent years. The growth will be accelerated by the tendency of substituting plastics for metal which is appearing throughout the world. The injection molding process is one of the most effective and advance molding process for plastic products. In traditional practice, the mold design relies on the experience of engineers and designers. It is always the case that many changes of the product are required during the mold design stage due to the manufacturability requirements of the mold as well as the molding production which undoubtedly leads to longer lead time and higher cost. The key problem is that there is little consideration for mold design/making at the early product development stage.

The injection mold design has to deal with the issues of product requirements, material selection, and mold design simultaneously as they interact with each others. Changing one aspect for better results, for instance product design feature, may have a negative effect on the other influencing factors, for instance the mold design. The design process involves a substantial practical knowledge component (heuristic knowledge). Knowledge and expertise of more than one specific area are required to have an optimum solution. It thus relies heavily on the human experts, the product designers and mold designers, who are required to have a high standard of specific knowledge, experience and judgement. Unfortunately, the growing demand in industry for such experienced designers and engineers far exceeds the supply.

Expert systems (ES) can be defined as computer programs that capture the expertise of human experts in particular application domains. They are designed to manipulate information, including knowledge, facts and reasoning techniques, in a high level way, and emulate or assist users to solve problems that normally require the abilities of human experts. There is obviously a potential to utilize ES technology to solve the product development problems at the early design stage. The authors have developed an implementation framework ESPIMP-1 for using ES to help making the decisions of material selection and injection mold design at the early stage of plastic parts development in a concurrent approach, i.e. simultaneous consideration of the feasibility of mold design is made prior to the confirmation of product design details.

## 2. Brief Review of Plastic Material Selection and Injection Mold Design

### 2.1 Plastic Material Selection

Whenever a new product development project begins, the design engineers starts with a conceptual design of the part and then decides which plastic material should be used. Designers must select the material not only with the customer requirements, such as physical functions, aesthetics, durability, etc., but also that will produce a high quality part in an efficient manner. The selection requires extensive knowledge and experience. The basic steps of the plastic material selection process are i) determine the needs and conditions to be fulfilled, ii) search alternative materials, and iii) evaluate the alternatives in terms of needs and conditions.

### 2.2 Injection Mold Design

Once the material is determined, the mold designers will start the mold design by determining the number of cavity and the location of parting line. A molding machine will then be chosen based on some simple calculation. This is followed by the selection of dimensions and material of the mold base; design of the feed system which consists of a sprue, runner and gate; design of cooling system and ejection system.

## 3. Application of Expert Systems in Injection Molding

Researchers have started to adopt ES in solving the injection molding problems in recent years. For instance, several systems for problem diagnosis of injection molding, such as those of Shanghai Jiao Tong University [Qiang et.al. (1991)] and New Jersey Institute of Technology [Jan & O'Brien (1992)], etc., are being developed. Capturing injection molding part design features from CAD models, advising plastic material selection, automating the mold design process, developing design for manufacturability in mold design, etc. are popular research topics. GERES [Nielson (1986)], CIMP [Jong & Wang (1989)], HyperQ/Plastic [Beiter et.al. (1991)], the ES of Shanghai Jiao Tong University [Ying & Ruan (1991)], PLASSEX [Agrawal & Vasudevan (1993)] etc. were developed for selecting plastic materials based on part requirements. Most systems possess searching mechanisms and heuristic rules to assist designers in selecting a candidate material by both quantitative and qualitative evaluations. They were, however, developed in a standalone manner, not integrated into the part design, mold design or process planning, that unable to address issues of part design for moldability and mold design. Systems like IMPARD [Vaghul (1985)], ICAD [Clinquegrana (1990)], the ES of Drexel University [Tseng et.al. (1990)], the ES of University of Massachusetts at Lowell [Meckley et.al. (1992)], etc. were developed for injection mold design. They are, however, limited to simple parts and not mature enough to cover general mold design issues. More importantly, part design details, such as three-dimensional geometrical profile and dimensions, are compulsory inputs to these systems so they are not appropriate for the early product planning purpose. There is a potential need to develop an expert planning system for the injection mold in an integrative manner for early design decisions.

## 4. The Proposed ESPIMP-1 Framework

In real life, the mold designers are always required to determine the mold designs according to a rough part design or merely a mock up, i.e. in the absence of part design specification and other molding details, at the early design stage for evaluation of different design alternatives or for replying a customer quotation in a very short time interval. A framework to develop an expert system called ESPIMP-1 (Expert Injection Mold Planning System) has been proposed to help the design engineers in selecting the plastic materials and determining the major injection mold design features in such an environment. The ESPIMP-1 mainly consists of two modules; namely, the Expert Plastic Material Selection Module (ESMATL) and the Expert Mold Design Module (ESMOLD). The overall structure of the ESPIMP-1 is shown in figure 1. The inputs to the system are the product requirements initiated by the external customers or internal development. If the part material is not yet specified in the product conception stage, the ESMATL will help making the material selection decision based on the product requirements. Once the material is selected, the material properties together with the product requirements become the inputs to the ESMOLD to determine the design of injection mold. The outputs of the ESMOLD are the features and characteristics of the injection mold that on one hand are important for proceeding to detailed mold design work and on the other hand can be extended to determine the mold cost estimation, mold making process planning, production molding planning, etc..

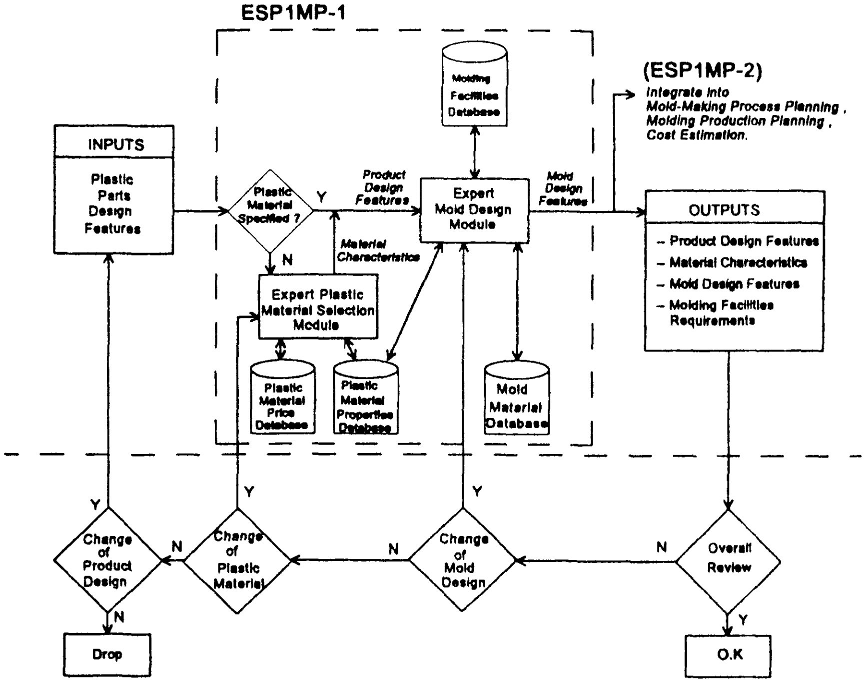


Figure 1 The Structure of the ESPIMP-1

## 5. The Plastic Material Selection Module (ESMATL)

### 5.1 General Structure

The selection module aims to assist the designers in selecting a set of thermoplastic materials those comply with the product requirements, including both quantitative and qualitative requirements. It is designed for product designers with little experience in plastics. The decision making logic follows the usual process used by the designers in material search and selection. Designers usually prioritize the material properties according to product requirements and then choose the most important property for the first iteration of search. In the searching process, those materials whose properties do not conform to the requirement will be eliminated. Another property will be used for next iteration until all properties match or there are no more material for search.

The functions of the ESMATL include (a) searching individual plastic material property when a specific plastic material is selected by users, (b) selecting the appropriate materials by inputs of quantitative property value or inputs of qualitative property requirements through interactive questions, and (c) ranking the alternative materials. The existing properties included in this system are divided into eight categories, namely; physical, mechanical, electrical, thermal, environmental, molding, assembly and finishing. The last three categories are concerned with the manufacturability of the molding part. Each category consists of several properties. There are totally 42 properties, as listed in figure 2.

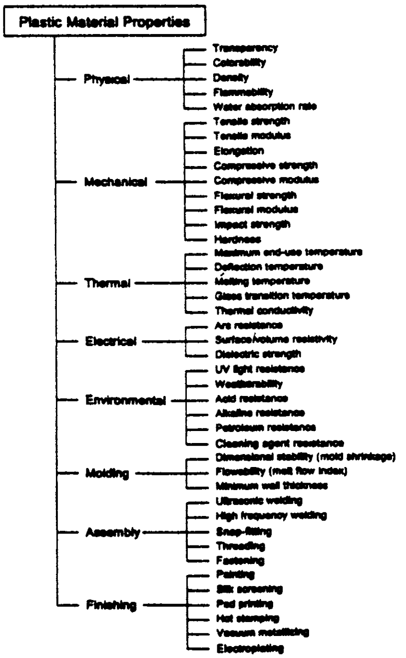


Figure 2 Plastic Material Properties in ESMATL

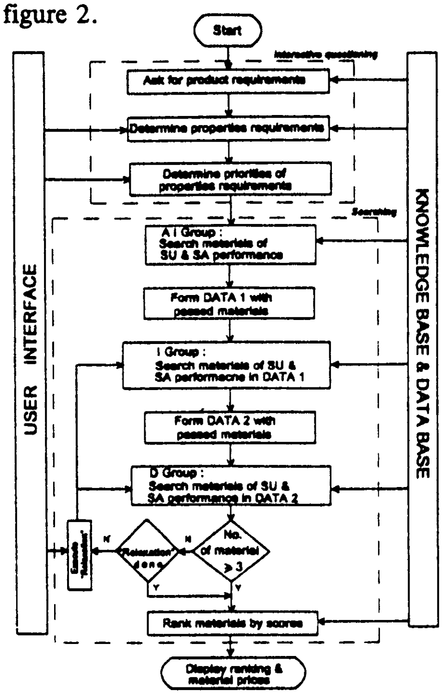


Figure 3 The Search Flow in ESMATL

### 5.2 The Search Logic

The ESMATL deals with both quantitative and qualitative requirements. ESMATL firstly asks a number of questions about the user requirements of the plastic part. If the input is a quantitative value, it is simple to search alternative materials by comparing the required value with the property databases of individual material in the system. In addition to storing up all the quantitative value of individual property of each material, the system also builds in a comparative qualitative measure of each property by classifying their performance in four grades, namely; SU (superior), SA (satisfactory), M (marginal) and US (unsatisfactory). The users are also required to prioritize the property requirements of target material into three grades, namely; AI (absolutely important), I (important) and D (desirable). The system will then begin to search appropriate materials according to the information gathered. The searching sequence follows the logic shown in figure 3.

In case there is no sufficient material selected in the first searching process or the selected materials are not in the favour of the users, the system can do "relaxation" to seek alternative materials. For quantitative requirements, the "relaxation" will not be done automatically. For qualitative requirements, if the number of materials selected is less than three, the system will do "relaxation" automatically until sufficient materials are found or the "relaxation" process is completed.

5.3 The Ranking Mechanism

The objective of the ranking is to prioritize alternative materials relative to the order of importance of their attributes to the designers. It combines multiple attributes into a single measure and ranks the candidate materials by this measure. Weighting scales, AI, I and D, which reflect the designer requirements are used to evaluate the relative importance among different material property requirements. The following quantitative scoring system is proposed for the ranking.

Priorities : AI = 3 points, I = 2 and D = 1

Performance ratings : SU = 3 points, SA = 2, M = 1, US = 0

Score = Summation of the products of the priorities and the performance ratings

## 6. The Expert Mold Design Module (ESMOLD)

6.1 The System Logic

The main objective of the ESMOLD is to enable the design engineers to create the major injection mold design features quickly according to the inputs of product requirements and plastic material characteristics. Figure 4 illustrates the flow chart of the system logic of ESMOLD. A series of questions are set to ask for the part design features. Based on the part features such as part size, major part shape and undercut requirements, etc., the system will automatically determine the mold structure, number of cavity, mold insert material, designs of gating, ejection and cooling systems. The logic basically follows the similar decision making approach being used by the professional mold designers in the industry. The user has the options to integrate the execution of ESMOLD with ESMATL or just to run the ESMOLD alone. In the integration of ESMATL, the properties information of the selected plastic material will be passed from ESMATL to ESMOLD through the heritance property of expert system in making the mold design decisions.

6.2 The Knowledge Base

The ESMOLD uses the feature approach to bridge the information flow between product design and mold design. There are four feature groups in ESMOLD to describe the product requirements of plastic part, namely; geometric features, outer shape, appearance and plastic materials.

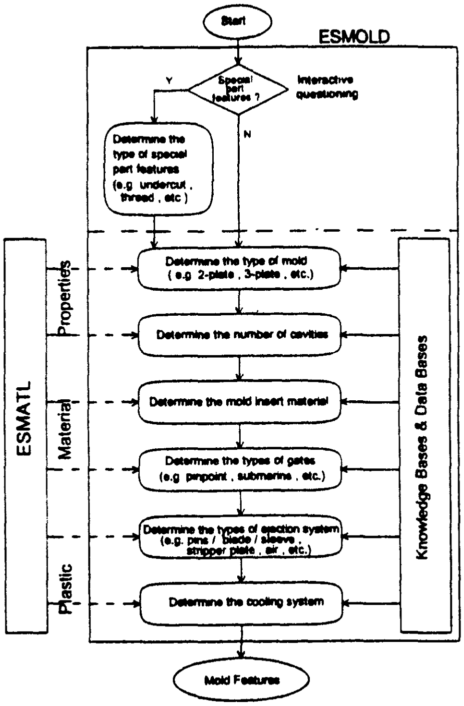


Figure 4 The System Flow of ESMOLD

Table 1 shows the items in the geometric features and outer shape groups. The features of injection mold are categorized into six major groups including mold construction type, special mechanism, mold material, feed system, cooling system and ejection system. Table 2 show part of the standard mold design features in ESMOLD. Having regard to different product features and mold designs, decision rules are developed for determining the mold construction, special functional mechanism, choice of mold material, runner and gate design, ejection and cooling systems design, etc.. Table 3 shows examples of these rules.

| Geometric Features : | Outer Shape : |
|---|---|
| G1 = Part without special features | F1 = Cylindrical shape |
| G2 = Light non-cylindrical internal undercuts | F2 = Semi-circle |
| G3 = Light cylindrical internal undercuts | F3 = Rectangular block / cubic |
| G4 = Permissible depth of non-cylindrical internal undercuts | F4 = Ellipse |
| G5 = Permissible depth of cylindrical internal undercuts | F5 = Pyramid |
| G6 = Light external undercuts | F6 = Cone |
| G7 = Permissible external undercuts | F7 = Irregular shape |
| G8 = Light internal threads | |
| G9 = Permissible internal threads | |
| G10 = Light external threads | |
| G11 = Permissible external threads | |
| G12 = Part size (length / width / height) | |

Table 1 Plastic Part Features

Mold Type :
X1 = Two-plate mold
X2 = Three-plate mold
X3 = Runnerless mold

Special Mechanism :
Y1 = No special function
Y2 = Sliding split action by angle pin / cam
Y3 = Split core for cylindrical internal undercut
Y4 = Split core for non-cylindrical internal undercut
Y5 = Unscrewing (rack and pinion)
Y6 = Unscrewing (electrical or hydraulic motor)

Feeding Systems :
Z1 = Side gate/ sprue gate/ disk gate/ ring gate
Z2 = Submarine gate
Z3 = Pin-point gate
Z4 = Insulated runner
Z5 = Hot runner (heater)

Mold Material :
M1 = Tool steel
M2 = Alloy steel
M3 = Stainless steel
M4 = Medium carbon steel

Ejection Features :
E1 = Ejector pin / blade
E2 = Ejecting sleeve
E3 = Stripper plate
E4 = Air-assisted ejection

Cooling Systems :
C1 = Cooling the shallow core / cavity inserts
C2 = Cooling the deep core / cavity inserts

Table 2 Standard Injection Mold Design Features

| IF (Plastic Part Features & Other Conditions) | THEN (Mold Structures) |
|---|---|
| 1. Common plastic part without any specific feature; OR<br>2. (Light cylindrical internal undercut OR Light non-cylindrical internal undercut OR External undercut OR Internal thread's depth OR External thread's depth < 2% of Diameter / Width / Length) AND the plastic material is HDPE OR PP; OR<br>3. (2% < Light cylindrical internal undercut OR Light non-cylindrical internal undercut OR External undercut OR Internal thread's depth OR External thread depth < 3% of Diameter / Width / Length) AND the plastic material is HDPE. | Y1 = No Special Mold Features Required |
| 1. Light external undercut < 2% of length/width, but the plastic material is not HDPE or PP; or<br>2. 2% < Light external undercut < 3% of length/width, but the plastic material is not HDPE; or<br>3. External undercut > 3% of length/width | Y2 = Sliding splits action by angle pin/cam |

Table 3 Excerpted Rules for Part Features & Mold Types

## 7. Conclusion and future work

This paper described a proposed framework to develop an expert system for injection molding part development at early design stage. The system helps design engineers selecting thermoplastic materials according to the product requirements and determining the mold design features. During the material selection and mold design processes, feedbacks can be conveniently given to the original conceptual product design for modification. It thus realizes the concurrent engineering philosophy at the early design stage and can minimize the early design errors so as to reduce subsequent costly reworks. The authors' current research is the development of a prototype expert system based on the proposed ESPIMP-1 framework. The future direction of this research is of two folds, namely; further enhancement of the ESPIMP-1 and extending the ESPIMP-1 to the mold making process planning, mold cost estimate and production molding planning.

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