

RAPID APPLICATION DEVELOPMENT OF PROCESS CAPABILITY – SUPPLIER MODELS

S. Karthik

School of Industrial Engineering, Purdue
University, West Lafayette, Indiana

C.W.Chung, K. Ramani

School of Mechanical Engineering, Purdue
University, West Lafayette, Indiana

ABSTRACT

Rapid changes and specialization in technology make it increasingly difficult for designers to keep track of the current capabilities of manufacturing processes and choose the appropriate one. Improper process selection leads to higher costs, lower quality and wrong choice of supplier. Currently, there is no software advisory system to help the design/procurement personnel in process and supplier selection. The complexity involved in building an application encompassing the capabilities of dozens of processes and its associated suppliers acts as a deterrent for application service providers.

This paper discusses a technique to rapidly develop web applications to identify a suitable manufacturing process and supplier/s using Rapid Application Development (RAD). RAD refers to a new computing paradigm to develop software applications within a short time frame. The technique has been verified by developing an advisory system to identify a suitable plastic process and supplier/s. The methodology is currently limited to common manufacturing methods such as castings, forgings, sheet metal and plastic/composite manufacturing. Benefits realized using RAD include shorter design and development times, code reusability and standardization.

NOMENCLATURE

RAD: Rapid Application Development
PPA: Plastic Process Advisor
MPA: Metalcasting Process Advisor
MPSA: Manufacturing Process and Supplier Advisory system
ASP: Application Service Provider

INTRODUCTION

Decisions made during the design stage have a significant impact on the final cost and quality of the product. Studies have indicated that although the cost of product design is only around 5% of the total product cost, decisions made during the design stage affect 70-80 % of the final product cost [13]. Some of the important decisions made concern manufacturing process selection. It is essential for the designer to select a process whose capabilities best match with the design. A survey of designer's knowledge of processes [3] indicated that more than 90% knew little or nothing about plastic processes such as injection molding and extrusion. The figures were equally high

for other processes such as sintering and cold heading. This indicates the need for a software tool to help designers become aware of the factors governing process selection and the capabilities of the various processes. The factors that influence process selection [7] are cost of manufacture/life cycle cost, quantity required, complexity, material, quality and availability/lead time/ delivery schedule. All these are called user requirements. For example, the user requirements for a part that needs to be cast can be expressed in terms of casting complexity, pattern and die cost, order quantity, surface finish, tolerances, cost of machining, strength, weight and choice of material [12]. These requirements should be matched with the capabilities of various casting processes and a proper casting process selected. Processes belonging to other manufacturing methods such as forgings and sheet metal may also need to be investigated. Once the process is decided, the next stage is to select a supplier capable of using the process. Criteria for supplier selection include technical capability of the supplier, supplier production facilities and capacity, suppliers' geographical location etc. [6]. Some or all of these form the user requirement for supplier selection.

MPSA (Manufacturing process and supplier advisory system) is a web based process/supplier advisory system that we have developed. MPSA evaluates these user requirements and suggests an appropriate process and supplier/s to manufacture a part taking into consideration the process and supplier capabilities. It currently consists of Metalcasting Process Advisor (MPA) and Plastic Process Advisor (PPA). The latter was developed using the RAD model discussed in this paper.

Previous Research

Advisory systems developed earlier include the Manufacturing Advisory System (MAS) used for process and material selection [8]. MAS clubs *processes* (sand casting, closed die forging etc.) from different *manufacturing methods* (castings, forging, sheet metal etc.) together for consideration. For Example: Metalcasting processes such as sand casting and die casting are combined with forging processes like closed die forging. The input attributes for process selection such as geometry, material, desired tolerance, finish etc. are the same irrespective of the specific manufacturing method. Other process and material selection applications include the system proposed by Boothroyd *et.al* [4] where the inputs to the system

are geometry and material constraints. The output includes a set of process sequences and suitable materials. Here too, the inputs are the same across manufacturing methods. Such applications give a good overall comparison of processes across methods, but lose the unique characteristics of each method. For example: Metalcasting processes generally can make more complex parts than most plastic processes indicating that shape complexity considerations are different for casting process selection compared to plastic process selection. Some plastic processes such as blow molding can only make hollow parts whereas no metalcasting process has this limitation. All major metalcasting processes can make parts with bosses but some plastic processes such as vacuum forming cannot. Similarly user requirements such as flatness, angular tolerance, surface finish etc. may need to be considered for process selection in one manufacturing method and not in another. In effect, the set of rules that determine which manufacturing process should be chosen may differ across manufacturing methods.

Problem definition and need for RAD

The main problem in developing separate applications considering the unique characteristics of each method is the lengthy software development times needed to develop the process/supplier database and develop a program to access the database. A web based system developed by the authors to suggest a casting process and supplier/s took several highly experienced personnel around 5 months to develop [9]. Design and development time for the plastic process and supplier advisory system was shortened to a month using RAD. RAD refers to a (Software) development life cycle designed to give much faster development and higher quality results than the traditional life cycle [10]. Effectively meeting user needs and lower maintenance are the hallmarks of RAD [15]. A RAD tool was developed to generate database designs of process and supplier capabilities for different manufacturing methods. Another component of the RAD system consisting of reusable object oriented Java classes was used to interact with these databases and suggest a suitable manufacturing process. These classes are called from browser interfaces. One such interface, the Plastic Process Advisor (PPA) used to suggest a suitable plastic process is shown in Figure 1a. The user has indicated that he wants to order 1000 units of ABS material. Other inputs are weight, thin section, thick section, surface finish, tolerance, cycle time, lead time, draft and shape complexity. The user has indicated that the design is for a hollow axi-symmetrical part.

Once the user fills in the required details and submits the web page, the output of PPA is as shown in Figure 2a. It shows that blow molding is the suggested plastic process. All processes are ranked on a scale of 100 based on how suitable they are with respect to the input and shown in the bar chart.

Plastic Process advisor

Criterion	Value	Weight	
Category	Thermoplastics		
Material	ABS Material		
Order quantity	1000	5	
Approximate weight (lbs)	10	5	
Thinnest section(inches)	0.01	5	
Thickest section (inches)	0.01	5	
Surface finish (micro inches)	120	5	
<i>Tolerances</i>			
Linear Dimension (inches)	Length(in.)	Tolerance(in.)	Weight
Linear Dimension 1	3	0.03	5
Linear Dimension 2	1.8	0.04	5
Linear Dimension 3	2.6	0.04	5
Cycle Time(Seconds)	30		5
Lead Time(Days)	4		5
Draft (Degrees)	2		5
<i>Shape Complexity</i>			
<input type="checkbox"/> Inserts	<input type="checkbox"/> Uniform Cross Section		5
<input type="checkbox"/> Bosses	<input checked="" type="checkbox"/> Hollow		
<input type="checkbox"/> External Undercut	<input checked="" type="checkbox"/> Axi-Symmetrical		
<input type="checkbox"/> Internal Undercut			

Metalcasting Process advisor

Criterion	Value	Weight	
Material	Aluminum-Magnesium (500 Series)		
Order quantity	2500	5	
Approximate weight (lbs)	10	5	
Thinnest section(inches)	0.025	5	
Thickest section (inches)	1	5	
Surface finish (micro inches)	35	5	
<i>Tolerances</i>			
Linear Dimension (inches)	Length(in.)	Tolerance(in.)	Weight
Linear Dimension 1	3	0.03	5
Linear Dimension 2	1.8	0.04	5
Linear Dimension 3	2.6	0.04	5
<input checked="" type="checkbox"/> Consider Premium Tolerances			
Flatness (inch per square inch)	0.005		5
Straightness (inch per inch)	0.005		5
Angular Tolerance (Degrees)	0.5		5
Draft (Degrees)	0.5		5
<i>Output graphs</i>			
<input checked="" type="checkbox"/> Process Comparison	<input checked="" type="checkbox"/> Tolerance		<input type="button" value="Submit"/>
<input checked="" type="checkbox"/> Quantity and Weight	<input checked="" type="checkbox"/> Surface Finish		
<input checked="" type="checkbox"/> Thick and Thin Section	<input type="checkbox"/> Miscellaneous		

Figure 1a and 1b: Input forms for PPA and MPA

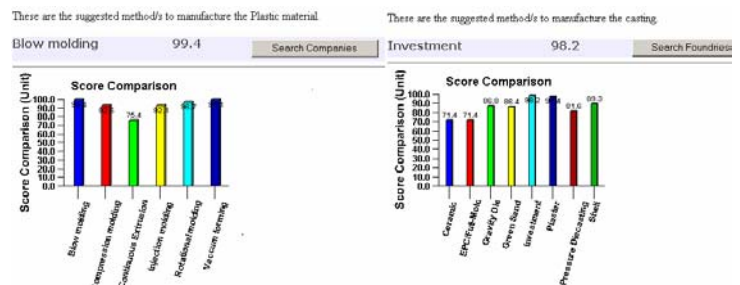


Figure 2a and 2b: Web based output of PPA and MPA

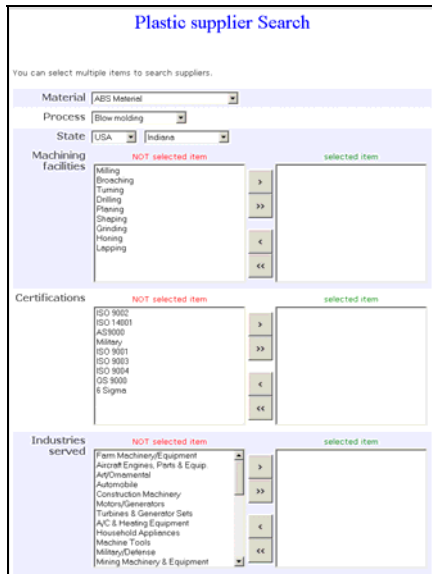


Figure 3: Plastic supplier search

After the process is chosen, the user can find a supplier for blow molding by clicking on “Search companies”. The supplier search screen enables the user to search based on various capabilities of the supplier such as testing facilities, manufacturing facilities, rapid prototyping facilities, quality certifications, industries served and processes/materials. For example, it is possible to retrieve injection molding suppliers from Indiana with experience in automobile industries having plastic machining facilities. Figure 3 shows a partial view of the supplier search screen for plastics

Advisory systems similar to PPA exist or are being developed for other manufacturing methods such as castings, sheet metal, composite manufacturing and forgings as part of MSPA. The input form for the Metalcasting Process Advisor (MPA) is shown in Figure 1b and the output is shown in Figure 2b. In figure 2b, investment casting is the suggested metalcasting process. A casting supplier search similar to the plastic supplier search will allow the user to search for investment casting suppliers based on the capabilities of casting suppliers.

The user requirements in input forms 1a and 1b are different. For instance, PPA requires several shape complexity attributes as inputs such as presence of bosses, inserts etc. that MPA does not require. Although the input considerations are different, the outputs in terms of the process ranking and suggestion are similar as can be seen from Figures 2a and 2b. Additionally, the supplier search screens for castings and plastics are different since their capabilities are different. However, the capability modeling of plastics and casting suppliers is similar in terms of the interface and database. This is because of the common developmental methodology adopted in both cases with rapid development, standardization and code reusability as the main objectives.

The paper discusses an approach to quickly develop database-centric manufacturing advisory systems using RAD. For this, an understanding of the algorithm that the advisory system uses to suggest a suitable manufacturing process is described below.

ALGORITHM FOR THE WEIGHTED APPROACH

Consider the plastic advisor interface in Figure 1a. Each of the input criterion (such as “Surface finish”) is assigned a weight between 0 and 5, 0 being “Unimportant” and 5 being “Very important” with the sum of all weights adding to 38. This weight is used for two purposes:

- To indicate importance of an input criterion relative to other criteria. Higher the weight, more likely it is that PPA will favor a plastic process that can satisfy the criterion at the expense of not satisfying other criteria with lesser weight.
- To favor a process known to meet the input criteria within the normal or typical limits of the process.

Each plastic process is checked to see whether it satisfies the specified criteria and given an overall score. A score is the weight assigned to the plastic process for each input criterion depending on how well the plastic process can satisfy the particular criterion. Scores for each individual criterion are summed up to arrive at an overall score for each plastic process with the maximum score being 100. If a plastic process cannot satisfy an input criterion, then the score for that criterion is not added to the overall score. For example: In figure 1a, the desired lead time is 4 days and the weight for lead-time is 5. Processes can be said to have approximate lead times depending on process characteristics. If a particular process is not known to have lead times within 4 days, then its score will be $((38 - 5)/38) * 100 = 86.8$. If it were able to meet all requirements, then its score would have been 100. Similarly, other processes are evaluated based on how well they meet user requirements and are ranked in decreasing order of their scores. Figure 4 gives a simplified flowchart used to assign the overall score to a plastic process (Note that some requirements like lead-time and draft are not shown in the flowchart, although they are considered by the program.). Processes are ranked based on their overall scores and the process with the highest score is suggested by the advisor. For example, if the overall scores for injection molding, blow molding and vacuum forming are 92.1, 99.4 and 98 respectively, then blow molding is recommended as a possible process.

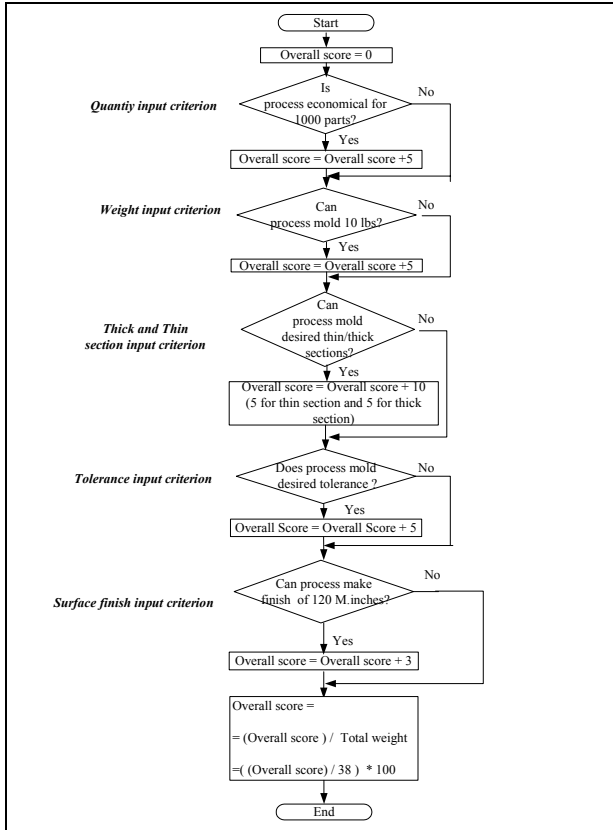


Figure 4: Flowchart to assign score to a process.

Another feature of the weighted approach is to favor a process known to meet the input criteria within the normal or typical limits of the process. For example: Rotational molding can typically make thin walls of 0.05 in., but in extreme cases can manufacture thin walls of up to 0.02 in. If the user's design has thin walls greater than or equal to 0.05 in., then rotational molding is given the full score of 5 for the criterion "Thin section". If the design has thin walls less than 0.02 in., then it is assigned a score of 0. Between these two ranges, the score assigned is linearly decreased between 5 and 80% of 5, that is 4.2. The figure 80% can be changed by the user and indicates the sensitivity of the model to variations from what is typical for the process. This is graphically shown in Figure 4. This will favor processes that manufacture the desired section typically as opposed processes that can manufacture it using special equipment or with higher costs. Figure 5 can be considered an example of a user requirement (thin section) being modeled using one typical limit and one extreme limit. Similarly, a requirement can be modeled using just one typical limit in which case either the full score or no score is assigned depending on whether the input is above or below the limit. User requirements can also be modeled as two typical limits or as two typical limits with two extreme limits.

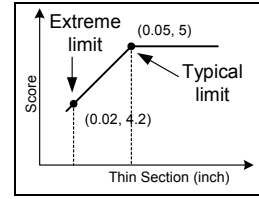


Figure 5: Assigning scores to thin sections for Rotational molding.

DEVELOPING APPLICATIONS USING RAD

Developing the application to identify a process and supplier/s can be broadly be classified into two steps:

1. Designing the database.
2. Developing the web application to access the database.

DESIGNING THE DATABASE

An application built using database is constrained by the design of the database. The RAD tool can design databases to model the process and supplier capabilities of common manufacturing methods listed earlier. A wizard (Figure 6) leads the user through the steps involved in identifying the database entities, attributes and relationships. Steps 1-5 involve modeling the process capability and steps 6-10 involve modeling the supplier capability. The tool was written using Visual Basic 6.0.

Generating database for process capabilities

The inputs for designing the process capability model include the method the user wants to model, the user requirements for that method and the way the each requirement needs to be modeled. A flowchart to generating the process capability model (Steps 1-5 of the wizard) is given in figure 6 and an explanation of each step is given below

Step 1 Select the manufacturing method: Available options include castings, forging, sheet metal and plastic/composite processes. To illustrate the approach, assume that the user chooses to model Plastics.

Step 2 Select user requirements for chosen method: This step is used to select the user requirements that cause processes within the selected method to vary. For Example: Selection of a plastic process depends on several factors like material, weight, thin and thick sections, shape complexity, desired lead time, order quantity etc. These are selected in Step 2 (Figure 7). Available requirements are shown in the left side list box. Selected requirements are shown in the right side list box (refer arrow in figure).

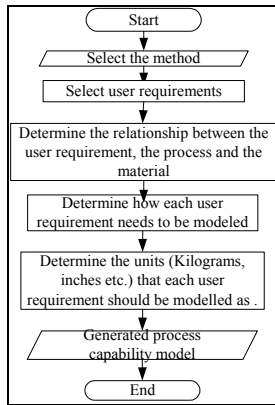


Figure 6: Flowchart to model Process capabilities

Available requirements suggested by the tool are grouped into three categories:

1. Geometric features: Includes weight, thin section, thick section, tolerance, flatness, straightness etc.
2. Economic and Production considerations: Includes order quantity, lead-time, cycle time, production rate etc.

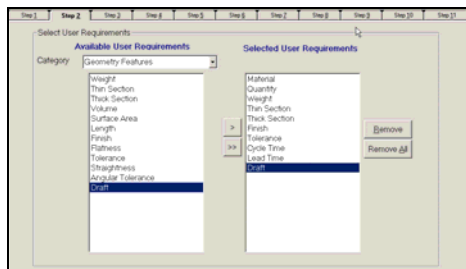


Figure 7: Selecting the user requirements (Arrow)

The user requirements selected in Figure 7 (Arrow) correspond to the input form of PPA shown in Figure 1a.

3. Shape complexity considerations: Some user requirements are expressed in terms of shape complexity rather than numerical values. For example, the user may need a plastic process to make a part with certain shape features (inserts, bosses, axi-symmetrical). To do this, the database needs to store shape features possible for each plastic process. Additionally, some processes require some shape feature to be present for it to be suitable. For example, blow molding requires the presence of the shape feature “Hollow” for it to be suitable. To select these shape features, the RAD tool uses the shape complexity classification proposed by Ashby [1]. This system classifies shapes into prismatic, sheet or 3D. These divisions are further classified into sub divisions. A partial diagram of Ashby’s complexity scheme is given in the left hand side list box in Figure 8. The user can select the shape features needed for process selection. For example: Some plastic processes cannot make parts that are not axi-symmetrical. In this case, the user will select “Axi-symmetrical”. Other shape complexity

constraints not in Ashby’s system that can be modeled include inserts, bosses, external/internal undercuts etc.

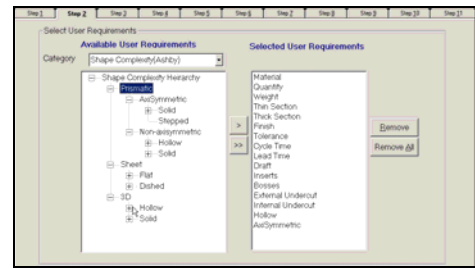


Figure 8: Selecting shape requirements

Step 3 Determine the relationship between the user requirement, the process and the material: This step (Figure 9) will decide the database entities and attributes by classifying user requirements into two categories:

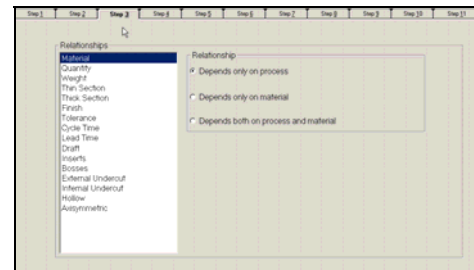


Figure 9: Determining the relationships

User requirements that depend only on the process: For example: Rotational molding can typically mold thin sections of 0.05 in. and in extreme cases can make thin sections of 0.02 in. In this case, the user requirement “Thin section” is considered to depend only on the process since the typical and extreme values do not depend on the material chosen.

User requirements that depend on both process and material: For example: Injection molding can mold from 0.02 lbs to 55 lbs for thermoplastic materials and 0.02 lbs to 13 lbs for thermosets [11]. In this case, the user requirement “Weight” is said to depend on both process and material. Generally, requirements such as weight, tolerances, thin sections and quantity depend on both material and process whereas surface finish, thick sections, draft and geometry complexity generally depend only on the process.

The RAD tool generates two entities for modeling process capabilities. The first one is the *Process* entity with attributes consisting of user requirements that depend only on the process and the second one is the *ProcessMaterial* entity with attributes consisting of user requirements that depend on both process and material.

Step 4 Determine how each user requirement needs to be modeled: In this step (Figure 10), user requirements are translated into database attributes. The number of attributes is decided for each requirement along with datatype, width, scale and default values. *Each* user requirement can be modeled in

several ways. If $i = 1, 2, 3, \dots, n$ are processes within a method, the user requirement “Approximate weight” can be modeled using any one of the four rules:

1. One typical limit: This rule indicates that any process P_i has a single value X_i indicating the maximum or minimum part weight that can be made by the process. Consider the following rules for plastic processes:

- Compression molding cannot make more than 35 lbs
- Injection molding cannot make more than 55 lbs.

This option is chosen when the user requirement needs to be modeled as a single value beyond which the process is not feasible. A single attribute is generated for the user requirement in the corresponding entity (*Process* or *ProcessMaterial*).

2. One typical limit with one extreme limit: This rule is chosen when the capability to manufacture part weights by any process P_i can be represented as being between 2 values, one typical value X_i and one extreme value Y_i . Two attributes are generated in the corresponding entity, one to store the typical value and the other to store the extreme value. This rule is illustrated in Figure 5 for thin sections.

3. Two typical limits: This rule is chosen when the capability to manufacture part weights by any process P_i can be represented as being between 2 values, X_i and Y_i . Two attributes are generated in the corresponding entity to store the two typical values for each process if this option is chosen.

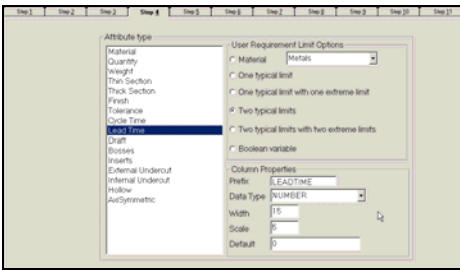


Figure 10: Modeling user requirements

3. Two typical limits with two extreme limits This option is chosen when the capability to manufacture part weights by any process P_i can be represented as being between 2 values X_i and Y_i under normal circumstances, but in extreme cases can be represented as being between U_i and V_i where $U_i < X_i$ and $Y_i < V_i$. For Example: Assume that the user is using the RAD tool to model castings. Plaster casting can be used to cast between 0.05 lbs to 2200 lbs, but typically operates between 0.2 lbs to 150 lbs [11]. If other processes within castings can be modeled similarly, then this rule is selected.

Generating the columns for the typical and extreme limits make it possible for queries to be run on the database. For example, questions such as “Can injection molding normally make a part weighing 15 lbs?” can be answered.

Shape complexity variables: Shape features are usually modeled as boolean attributes in the *Process* entity. These features can later be queried from the database. For instance, it is possible to retrieve all plastic processes that make hollow

parts or check whether a plastic process needs a certain shape feature for it to be suitable.

Attribute names, datatype, width, scale and default for the user requirements, both numerical (“Approximate weight”) and boolean (Shape complexity variables) are automatically decided by the RAD tool. The user has an option to override the suggested values. For example, the scale for “Weight” can be changed from 0 to 2, which means that weight can be stored up to 2 decimal places in the database. In addition, this step decides the how the weighted approach works for each user requirement. As explained in Figure 4, the weighted approach works based on the rule that is adopted for that user requirement. The type of rule the user chooses for each requirement depends on the detail needed as well as the ease of data gathering. For example: If the user is modeling thin sections and is unable to get data on the extreme limits of all processes, then the rule chosen would be “One typical limit” rather than “One typical limit with one extreme limit”.

Step 5 Determine the units in which the user requirement will be modeled: This step (Figure 11) decides the units with which a particular requirement is stored. For Example, the user can choose to model “Tolerance” in inches. Attributes are suffixed with the unit name to indicate what is stored in it. Step 5 finishes modeling of the process capabilities for plastics.

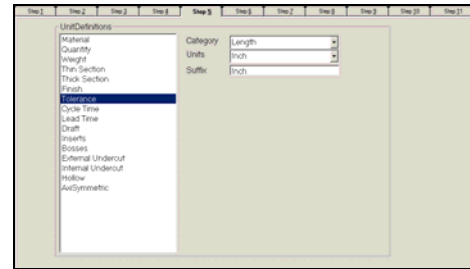


Figure 11: Selecting the units for user requirements

Generating database model for Suppliers

Steps 6- 10 involve generating the database model for the suppliers for the method chosen in Step 1. The detail of modeling the user chooses in these steps decides the supplier attributes that can be searched in the database later.

Step 6 Select basic information: In Step 6 (Figure 12), the user decides the basic supplier information such as name, address etc. that needs to be in the database. The program generates a single entity called *Supplier* with the basic supplier information chosen in this screen as attributes.

Step 7 Model the supplier manufacturing capabilities: Information regarding supplier capabilities is useful to customers wanting to know about the capabilities of the supplier before sending a Request for Quotation (RFQ) or making the decision to purchase. Literature surveyed to build the supplier modeling algorithm included supplier selection criteria by Dickson [6] that lists 23 criteria for supplier

selection including technical capability, quality record, geographical location etc. Weber *et.al* [14] list criteria by importance taking into consideration the number of papers published for each criteria listed by Dickson.

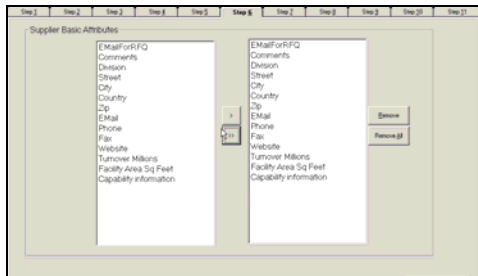


Figure 12: Selecting basic supplier attributes

A more detailed model for metalcastings by M.M Akarte *et. al* [2] proposes that casting suppliers be evaluated based on four capabilities- product development, manufacturing, quality and cost/time. For example, quality capability of a supplier is considered to be consisting of testing facilities, certifications etc. Criteria among these amenable to database modeling was built into the RAD tool. Apart from literature, plastics, castings, forging and sheet metal industries were studied and their capability knowledge incorporated into the tool.

Step 7 (Figure 13) will create the database entities modeling these capabilities. The user has to select the supplier capabilities relevant to the method being modeled.

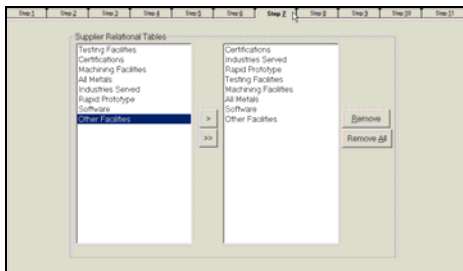


Figure 13: Modeling supplier capabilities

For example: When modeling plastics, the user has to select the supplier capabilities relevant to the plastic industry. This may include one or more of the following:

- Processes: Includes the processes the supplier can use. Example: Injection molding, Vacuum forming
- Materials: Includes the materials the supplier can use. Example: Acetal, PVC.
- Machining facilities: Example: CNC plastic machining, Panel saws, Milling, Boring etc.
- Testing facilities: Example: Flammability testing, Rockwell Hardness, Dielectric strength etc.
- Software capabilities: Example: CAD, Unigraphics, IGES etc.
- Quality capabilities: Example: ISO 9001, ISO 9002 etc.
- Other facilities: Example: Paint shop, Pattern shop etc.
- Industries served: Example: Automobile, Shipping etc.
- Rapid prototyping facilities: SLA, LOM etc.

Converting capabilities into database entities involves creating parent and relation tables. For Example: Selecting “Testing facilities” in this step will create an entity called *Testingfacilities* to store all possible testing methods for plastics (Rockwell hardness, Dielectric etc.). Additionally, an associative entity called *Testingfacilityrelation* is created to store the “Many to many” relationship between the *Supplier* entity and *Testingfacilities* entity.

Step 8 Select other supplier user requirements: Suppliers are also differentiated based on several manufacturing characteristics such as weight, finish, tolerance etc. For example: Some sand casting suppliers can only make small castings whereas some specialize in making castings weighing several tons. Figure 14 shows the selection of these attributes.

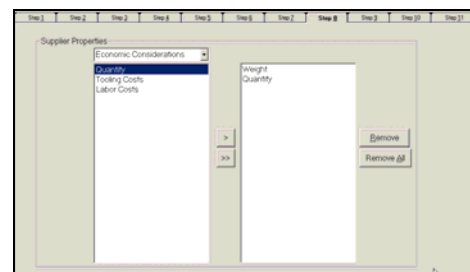


Figure 14: Modeling supplier characteristics

In effect, Step 7 and Step 8 determine the criteria based on which one supplier can be differentiated from the other by database queries. For example: When modeling plastics, if the user selects “Weight” as an differentiating characteristic among suppliers, it is possible to query the supplier database later for suppliers specializing in small plastic parts or very large plastic parts.

Step 9 Determine how each supplier user requirement needs to be modeled: In this step (Figure 15), the user decides how the supplier attributes chosen in Step 8 are modeled. Similar to process modeling, each attribute can be modeled in several ways, namely one typical limit, one typical limit with one extreme limit, two typical limits or two typical limits with two extreme limits. The attributes generated in this step belong to the *Supplier* entity. The data types, widths and scale of each attribute are automatically suggested by the program.

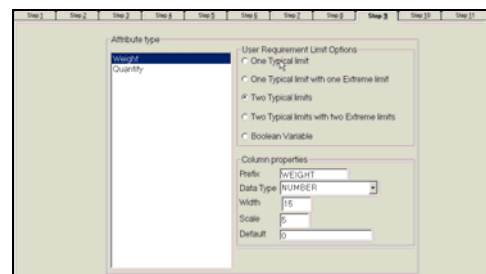


Figure 15: Modeling the supplier capabilities

Step 10 Determine the units in which the user requirement will be modeled: In step 10, the units (such as kilograms) for the attributes selected in step 9 are chosen. At the end of Step 10, the Oracle database script is generated to create the database (Figure 16).

```

Database script
DROP TABLE PLY_PROCESSMETHODS CASCADE CONSTRAINTS;

CREATE TABLE PLY_PROCESSMETHODS(
  PLYM_ID NUMBER NOT NULL,
  PLYM_DESCRIPTION VARCHAR(2000) NOT NULL,
  PLYM_WEIGHTLOWPOUND NUMBER DEFAULT 0 NOT NULL,
  PLYM_WEIGHTUPPOUND NUMBER DEFAULT 0 NOT NULL,
  PLYM_FINISHLOWMICRONCH NUMBER DEFAULT 0 NOT NULL,
  PLYM_FINISHUPMICRONCH NUMBER DEFAULT 0 NOT NULL,
  PLYM_CYCLETIMELOWSECONDS NUMBER DEFAULT 0 NOT NULL,
  PLYM_CYCLETIMEUPSECONDS NUMBER DEFAULT 0 NOT NULL,
  PLYM_LEADTIMELOWSECONDS NUMBER DEFAULT 0 NOT NULL,
  PLYM_LEADTIMEUPSECONDS NUMBER DEFAULT 0 NOT NULL,
  PLYM_DRAFTLOWDEGREES NUMBER DEFAULT 0 NOT NULL,
  PLYM_DRAFTUPDEGREES NUMBER DEFAULT 0 NOT NULL,
  PLYM_INSERTFLNONE SMALLINT DEFAULT 0 NOT NULL,
  PLYM_BOSSESFLNONE SMALLINT DEFAULT 0 NOT NULL,
  PLYM_EXTUNDERCUTFLNONE SMALLINT DEFAULT 0 NOT NULL,
  PLYM_INTUNDERCUTFLNONE SMALLINT DEFAULT 0 NOT NULL,
  PLYM_FL SMALLINT DEFAULT 0 NOT NULL,
  PLYM_FI SMALLINT DEFAULT 0 NOT NULL,
  PRIMARY KEY (PLYM_ID));
  
```

Figure 16: Database script for Oracle

Explanation of Database diagram of process capability: The database diagram generated by the tool for the process capability of plastics is given in Figure 17.

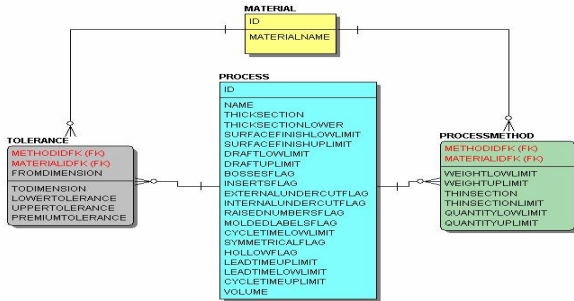


Figure 17: Database diagram of process capability

Four entities are generated by the RAD tool. A database table is created corresponding to each entity. The tables are:

MATERIAL TABLE: This is derived from the *Material* entity. Instances of this table include all possible materials that can be manufactured by plastic processes. For Example: Acetyl, ABS etc. This is shown in yellow in Figure 17.

PROCESS TABLE: This is derived from the *Process* entity. Instances of this table include all possible plastic processes along with their capabilities. This is shown in the center box in Figure 17. User requirements that depend only on the process constitute columns of this table. The method in which the columns are modeled follows from the definition in Step 3 and Step 4. Rules used are:

One typical limit with one extreme limit: Two database columns are created for every user requirement that correspond to this rule. Example: For the user requirement “Thick section”, (Refer arrow in figure) the first column *Thicksection* stores the typical value and the second column *Thicksectionlower* stores the extreme value.

Two typical limits: Two database columns are generated to store the lower typical value and upper typical value. Surface finish, lead time, draft etc. are modeled using this rule.

Boolean Variables: Shape complexity variables such as bosses, inserts etc. are modeled as *Smallint* columns and suffixed with “flag” to indicate that it is a flag or a boolean variable. For example, the column *Bossesflag* is for bosses. *Bossesflag* is set to 1 if a process can make parts with bosses and 0 if it cannot.

PROCESSMATERIAL TABLE: This is derived from the *ProcessMaterial* entity. All user requirements that depend on both process and material constitute columns of this table. This is shown in green in Figure 18. The columns *Weight* (Refer arrow in figure) and *Quantity* are modeled using the rule “Two typical limits” whereas the column *Thinsection* is modeled using the rule “One typical limit with one extreme limit”. The table for this has a composite primary key made up of two foreign keys from the *Process* and *Material* tables. These keys are automatically generated by the RAD tool.

TOLERANCE TABLE: A separate entity is created to store tolerances. Generally, tolerance obtainable increases with the dimension of the part. In figure 18, the achievable tolerance at A is S, at B it is L and at C it is U.

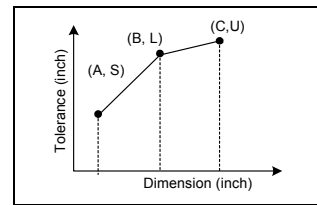


Figure 18: Modeling tolerances

To get the tolerance for any dimension between A and B, we need to know the lower dimension $\rightarrow A$, the upper dimension $\rightarrow B$, the lower tolerance at A $\rightarrow S$ and the upper tolerance at B $\rightarrow L$. A similar logic holds true for the tolerance between B and C. A tolerance table is created to store this information. Table 1 gives a sample from the tolerance table corresponding to this entity.

The *From dimension*, *To dimension*, *Lower tolerance* and *Upper tolerance* are columns in the table. From this table, the tolerance for any linear dimensions can be obtained by linear interpolation. In some processes like injection molding, tolerance increases non-linearly with the length of the part. The representation of the entity allows for non-linearity as non-linear lines can be approximated by several linear lines. The table has a composite primary key made up of two foreign keys from the *Process* and *Material* table and the attribute *From dimension*. Both the table and the keys are automatically generated by the RAD tool.

Table 1: Format of storing linear tolerances

The *Casting dummy* class would access the metalcastings database instead of the plastic database. In effect, this architecture is reusable across manufacturing methods whose process capabilities are modeled differently. The only difference between the plastic advisor and the metalcasting advisor would be the HTML interface, the dummy class and the database.

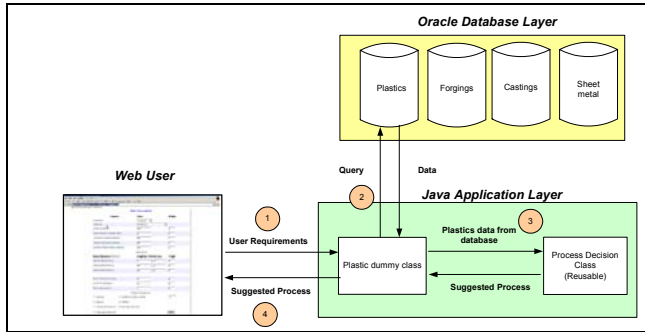


Figure 21: Application layer for process selection

RESULTS

For the PPA, blow molding is the suggested process as shown in figure 2a. Apart from this, PPA displays a variety of web reports on how inputs such as quantity, weight, tolerance, thin and thick section, surface finish, draft, cycle time and lead time are satisfied by the different processes. Figure 22 shows PPA’s output for “Quantity” and “Weight” user requirements.

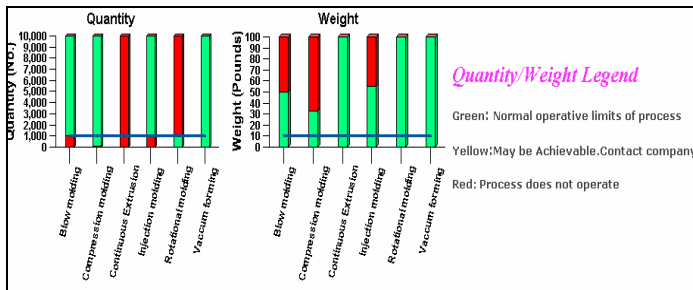


Figure 22a and 22b: Web based graphical reports

User input is given by the blue line. Green bars denote feasible regions and red bars indicate infeasible regions. Figure 22a indicates that that blow molding and injection molding are considered economical for a quantity of 1000 pieces.

The reports also include a text description on how various shape complexity requirements are satisfied by each plastic process. The shape complexity report for blow molding is given in figure 23. The text reports also indicate why a process was not suggested. For example, the text report for extrusion indicates that it was not chosen as only uniform cross section parts can be produced.

```
blow molding
Overall Score 99.4
Shape feature Inserts is not present and will not be used to discriminate between processes
Shape feature Bosses is not present and will not be used to discriminate between processes
Shape feature External Undercut is not present and will not be used to discriminate between processes
Shape feature Internal Undercut is not present and will not be used to discriminate between processes
Shape feature Uniform cross section is not present and will not be used to discriminate between processes
Shape feature Hollow can be manufactured. Assigned score is 5.0
Shape feature Axii-Symmetrical can be manufactured. Assigned score is 5.0
```

Figure 23: Web output for blow molding

If the user decides to use blow molding process, searching for blow molding suppliers using the supplier search screen (Figure 3) gives the address and other details of the supplier from the supplier database as shown in Figure 24. Capabilities can be viewed by clicking on the supplier name.

Company/Contact	Address/Description	Phone/FAX
PLASTICS CORPORATION	2009 Office Park Circle Birmingham Alabama,USA 35223	Phone: (111) 111-1111 FAX: (111) 111-1111
email	The best plastics are produced here	

Figure 24: Web output of plastic supplier search

For MPA, investment casting is the suggested process as shown in Figure 2b. Reports are produced regarding how requirements such as quantity, weight, thin/thick sections, linear tolerances, finish, flatness, straightness, angular tolerance and draft are satisfied by the casting processes. Supplier search screens provide functionality to search for investment casting suppliers.

DISCUSSION

The MPSA effectively models process and supplier capabilities. This information is converted into useful knowledge that the design professional and buyer can use to make informed purchasing decisions. This promotes the ability of the OEM to effectively engage in a meaningful dialogue with the supply chain. Several websites offer services to search for manufacturing suppliers based on their capabilities. However, supplier capability is one aspect of supplier selection. The RAD methodology emphasizes on not only supplier capabilities but also process capabilities. Application service providers (ASP’s) currently providing only supplier search facilities can use the RAD methodology and provide better service as RAD will enable them to quickly develop web based applications matching the needs of the customer from the design stage to supplier capabilities. The RAD approach allows for modeling of different manufacturing methods considering the uniqueness of each method without losing on design and development time. Although databases across manufacturing methods differ, they are standardized in terms of naming of entities /attributes, relationships and attribute properties such as width. In addition, the tool reduces the complexity involved in database design. The user need not be concerned with identifying entities, relationships and attributes. At the same time, he/she has the flexibility to change the way the RAD tool works by tweaking the master repository. The application layers need not be rewritten for each manufacturing method. Classes containing the logic of the weighted approach are reused leading to short development times and less maintenance. In addition, reports - both textual and graphical are provided as Java classes and integrated into the reusable classes. Although reports produced by different advisory systems differ considerably, only a single set of decision and reporting Java classes are used. In sum, the benefits to the programmer utilizing the RAD approach to model

manufacturing methods include standardization, code reusability and lesser maintenance.

ACKNOWLEDGMENTS

National Science Foundation Partnership for Innovation award to Prof Ramani (NSF-PFI EHR 0227828).

REFERENCES

1. Ashby, M.F., "Materials Selection in Mechanical Design", Pergamon Press, 1992.
2. Akarte, M.M, Surendra, N.V., Ravi, B. and N Rangaraj, "Web based casting supplier evaluation using the analytical hierarchy process", Journal of Operational Research Society, 2001.
3. Bishop, R., "Huge Gaps in Designer's Knowledge revealed", Eureka, October 1985.
4. Boothroyd, G., Dewhurst, P. and Knight, W. A. "Selection of materials and processes for component parts", Proceedings of the 1992 NSF Design and Manufacturing Systems Conference, 1992.
5. Degarmo, Paul E., Black, JT., Kohser Ronald A., "Materials and Processes in Manufacturing", Prentice-Hall, 1995.
6. Dickson, G.W., "An analysis of vendor selection systems and decisions", Industrial Marketing Management, 1966
7. Dieter, George. E., "Engineering Design" Mcgraw-Hill, 2000.
8. Giachetti, R.E., Jurens, K.K., "Manufacturing Evaluation of Designs: A Knowledge-Based Approach," Proceedings of the Third Joint Conference on Information Sciences (JCIS), Research Triangle Park, NC.
9. Karthik, S., Chung, C.W., Ramani, K., Tomovic, M. M., "Methodology for Metalcasting Process Selection", Society of Automotive Engineers, Inc., 2002
10. Martin, J. "Rapid Application Development", Macmillan, New York, 1991.
11. Swift, K.G and Booker, J.D., "Process Selection", Arnold, 1998.
12. Trucks, H.E., "Which Casting Method is best", Precision Metal, November 1969.
13. Ullman, D. G., "The Mechanical Design Process", McGraw Hill, New York, 1992.
14. Weber, Charles A., Current John. R. and Benton.W.C., "Vendor selection criteria and methods", Elsevier Science Publishers, 1991.
15. <http://sysdev.ucdavis.edu>