Journal of
INDUSTRIAL
TECHNOLOGY

Volume 15, Number 4 - August 1999 to October 1999

A Management-Support Technique for the Selection of Rapid Prototyping Technologies

By Dr. Marcello Braglia & Dr. Alberto Petroni

KEYWORD SEARCH

CAD
CIM
Management

Reviewed Article

The Official Electronic Publication of the National Association of Industrial Technology • www.nait.org

A Management-Support Technique for the Selection of Rapid Prototyping Technologies

By Dr. Marcello Braglia & Dr. Alberto Petroni

Dr. Marcello Braglia graduated in 1988 in electronic engineering at the Politecnico di Milano. In 1990 he obtained a grant to study numerical analysis at the Università degli Studi di Brescia. Since 1995 he has been researcher in mechanical technology and production systems at the same university. Since 1998, he has been a researcher in industrial plants at the Università degli Studi di Pisa. His research activities mainly concern manufacturing systems, production planning, statistical quality control, and equipment maintenance.

Dr. Alberto Petroni is a post-doctorate researcher at the University of Parma (Italy) where he is also teaching assistant in Business Economics and Organization. His education includes a M.S. in Business Administration from the Bocconi University of Milan and a Ph.D in Science of Industrial Innovation from the University of Padua with a thesis on the analysis of technological core competencies. His research interests and publications mainly relate to two areas: the management of technology and R&D.

Acknowledgements - This paper has been supported by INFM and MURST funding schemes. Dr. Braglia is a member of INFM, Section of Parma (Dipartimento di Fisica).

Abstract

This paper deals with the problem of investment evaluation and selection of Rapid Prototyping Technologies (RP), implying a complex multicriteria decision which is due to several reasons. Among these are: the low degree of experience of the decision maker with respect to the technology to be purchased, the high number of both qualitative and quantitative attributes that have to be considered in the selection process and the number and variety of the alternative technologies available on the market. This paper proposes a methodology that is based on Analytic Hierarchy Process. Data have been drawn from a survey of twenty-one end-users (consisting of both firms and service bureaus) of twenty different types of RP apparatus. The methodology has proved to be an effective tactical tool for selecting the technology that best fits the end-user's needs.

Introduction

The selection of Advanced Manufacturing Technologies (AMTs) is a hard and complex task because of the various attributes involved. The most important of these include cost, flexibility, complexity and the fact that many purposes and motivations have to be considered. The paper presents a method for technology selection which relies on the use of Analytic Hierarchy Process (AHP) which has proved to effectively encompass some of the major problems encountered when selecting a new technology:

- first, the selection of an appropriate technology might urge managers to face fairly complicated multi-criteria decision problems, due to both the plurality of available alternatives, selection criteria and the prevailing qualitative nature of many of the latter. A sound weighting of the importance placed on the different criteria therefore becomes a critical task in the selection process;
- second, problems are also related to the possibility of selecting a sub-optimal technology that performs well with respect to few criteria and does not compromise good overall practices.

The proposed methodology has been applied to the selection process of rapid prototyping (RP) systems using the data collected from 21 end-users and related to twenty different RP technologies. In the next section, rapid prototyping technologies are introduced and their diffusion in the manufacturing context is discussed briefly. In the final sections, the methodology is illustrated step by step and the results of its application are presented.

Rapid Prototyping

Global manufacturing and a consumer-driven market necessitate frequent design changes that often result in low volume production. This has presented industrial engineers with new challenges. The most significant of these is the pressing need for drastically reduced product development and the increased demand for industrial engineers to get things right first time.

Companies are closing the loop on integrated product development through the use of rapid prototyping. Rapid prototyping (RP) is a new weapon that can help industrial engineers to effectively wage the time compression war (Mills 1994). Rapid prototyping has many attractive industrial engineering applications, particularly for the manufacturing and the process engineer (Sriraman 1996). Four major application areas are described: 1. design verification, 2. concurrent engineering (CE), 3. prototype development, and 4. rapid tooling. These virtual prototypes not only help engineers design better products, they assist in communicating the concept to the rest of the enterprise so that everyone is informed.

Rapid prototyping is the direct conversion of an electronic computer-aided design model into a solid physical model. The creation of prototype models for design refinement is central to the new product development process. Two general methods - subtractive or additive - are used to produce prototypes during the design process. There are 2 general classes of rapid prototyping methodologies - layering methods and drop deposition methods. Rapid prototyping technology has the ability to cut the design-to-market time by 75%, or more in some cases (Balsmeier and Voisin 1997). Consumers should expect to see a proliferation of new product designs across the spectrum of manufactured products. Industry surveys indicate that the automobile and aerospace industries make up a significant portion of the world-wide RP customer base. Other major users of RP are the producers of industrial equipment, electronic devices, computers, business machines, medical devices and consumer products. Promising new developments are occurring in the field of medicine. In 1997, 1,057 rapid prototyping systems were sold worldwide, compared with 787 in 1996, according to the 1996 industry report by Wohlers Associates, Inc.. This represents a unit sales growth of 34% for the year, compared to growth of 46% for the previous year. Since 1988, a total of 3,289 RP systems have been sold to industrial, academic, and government sites around the world.

In order to attain the goals of cost reduction, lead-time cut and quality improvement, the selection of an appropriate RP apparatus becomes a critical issue. Since the selection of the appropriate technology addresses different functions within the organization, it is a decision problem with many objectives implying many quantitative and qualitative factors that can be expressed in a hierarchical manner. The evaluation of qualitative factors requires the assessment of expert judgements and the hierarchical decomposition and synthesis of these factors.

The Analytic Hierarchic Process (AHP) provides a framework to cope with multiple criteria situations involving intuitive, rational, qualitative and quantitative aspects. It first structures the problem in the form of a hierarchy to capture the basic elements of a problem and then derives ratio scales to integrate the perceptions and purposes into a synthesis. In the hierarchical structure, all the elements in a level are compared in a pairwise manner with the elements in the level above, and paired comparisons are used to elicit judgments. Then the synthesis of judgments is obtained as a result of hierarchic restructuring in order to find the optimal solution. This

Rapid Prototyping (RP)
Unit Sales Worldwide

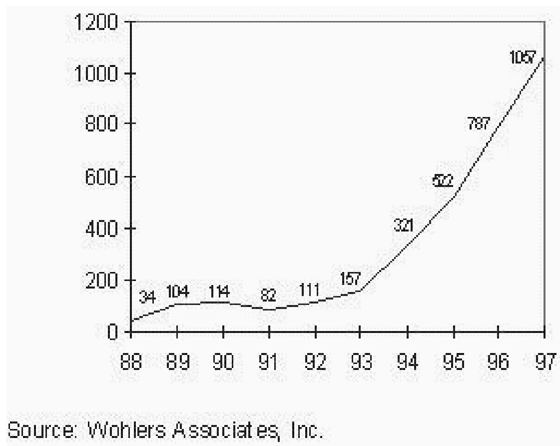

Figure 1. RP unit sales world-wide

Apparatus	Model
RP1	ACTUA 2100
RP2	EOSINT M250
RP3	EOSINT P350
RP4	EOSINT S700
RP5	FDM-1650
RP6	FDM-2000
RP7	FDM-8000
RP8	Genisys
RP9	KSC-50
RP10	LOM 1015
RP11	LOM 2030
RP12	MM 6-PRO
RP13	MM II
RP14	SGC 4600
RP15	SGC 5600
RP16	Sinterstation 2000
RP17	Sinterstation 2500
RP18	SLA-250
RP19	SLA-3500
RP20	SLA-5000

Table I: list of RP apparatus considered

is the main rationale for using AHP as a management-support technique for the selection of the most appropriate and suitable technology, which involves subjective and objective factors but still requires a logical and rational control of decisions (Saaty 1982).

The application of the AHP to the RP technology selection problem has been carried out using data drawn from a survey of 21 end-users of 20 different RP technologies. The full list of the RP apparatuses considered in the research is shown in Table 1 (see previous page).

Respondents included both end-user firms and service bureaus that represent almost the 75% of all the apparatus installed in Italy (ANRI, 1997). The design of the general model has been based on the needs and comments expressed by the respondents and the importance placed by these on the various factors that have been considered in the analysis.

Development of the AHP structure

In designing the AHP hierarchical tree, the goal is to develop a general framework that satisfies the needs of the end-users to solve the technology selection problem. The AHP starts by reducing a complex, multicriteria problem into a hierarchy where each level consists of few manageable elements which are then further reduced to another set of elements (Wind and Saaty, 1980).

With this purpose in mind, an initial RP assessment hierarchy was proposed to each of the 21 individuals involved without any initial brainstorming and a preliminary list of modifications was obtained based on their reactions. Each possible modification was discussed with each member until a consensus was reached. The hierarchy developed in this study is an incomplete four-level tree where the top level represents the main objective of technology selection and the lowest level consists of the alternative RP devices. The primary objectives which have an influence on the selection process are grouped under five categories: office friendliness, characteristics of the prototype, price, cost, and time. The criteria used to evaluate each of the primary objectives are included at the second level. The sub-criteria that are related to the second-level criteria are given in the third level. The overall AHP structure is shown in Figure 2. Each factor is described below.

Performance assessment

Office friendliness is related to the level of comfort in an office environment and the accessibility of those involved (i.e. for progress report purposes). This feature allows RP systems to sit next to CAD workstations thus reducing the risk of damage or formatting errors. It is a function of the size of the RP devices and of the employment of hazardous materials.

The *price* criterion is not split into further subcriteria and includes, besides the purchasing cost of the mechanical apparatus, all the user-equipment interface software packages. *Cost* is the unit production cost of an object. Cost has been split into four elements: materials, operator, post-curing and support structures. *Time* is the unit production lead time of an object. Cost and time are strongly influenced by the type of object to be processed and, in turn, impact heavily on design planning.

Item characteristics are strictly related to the intrinsic quality of the objects obtained and to their potential applications. Some RP systems are in fact, almost exclusively aimed at obtaining raw prototypes to test the geometric features of the object (concept modellers), while others are almost exclusively aimed at obtaining prototypes to test the functional properties of the object (functional prototyping). A third type consists of devices that are almost exclusively aimed at obtaining prototypes of mechanical devices and tools. Depending on the type of RP system considered, the prototype has to have different geometric and functional features. This first-level criterion (*Item characteristics*) is further split into such sub-criteria as the maximum and minimum size of the object, its shelf-life, its complexity and surface texture. This latter feature is in turn dependent upon accuracy, resolution, layer thickness and the availability of support structures.

Finally, *variety* is a measure of the system versatility, both in terms of the number of materials to be processed and the properties of the same materials. In order to solve the resulting AHP model in an easy and practical way, a commercial software package was used.

Implementation of the AHP framework

The second step is to use a measurement methodology to establish priorities among the elements within each level of the hierarchy. A face-to-face iteration was performed by each respondent to obtain value judgements. In case of inconsistency, the assessment process for the inconsistent matrix was repeated immediately. A face-to-face iteration was performed with each participant and it was observed that the decisions became more stable and the consistencies of the matrices increased. Instead of using the results obtained in the last iteration, the judgements that were reported more frequently were selected as the final matrix scores for each decision maker. The individual

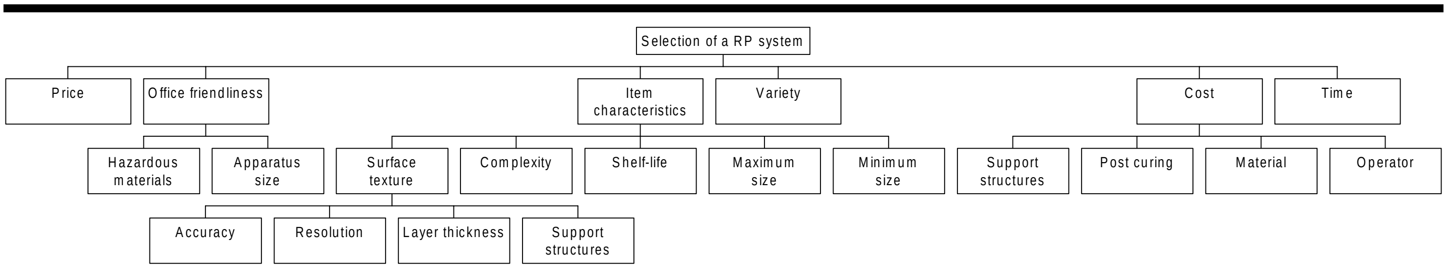

Figure 2. The AHP hierarchy

judgements were aggregated using the weighted geometric mean to provide the final matrix element.

The third step was to synthesize the priorities for the decision alternatives. The prioritization of performance criteria was achieved by the composition of pairwise comparisons. AHP is based on the assumption that a decision maker can more easily place a comparative rather than an absolute value. The verbal judgements are then translated into a score via the use of discrete 9-point scales. The final prioritization was reached by calculating the normalized components of the right eigenvector of the final matrix corresponding to the maximum eigenvalue of the same matrix. This step is reiterated for all the hierarchical levels.

The final step of the AHP methodology is to use the framework to evaluate different RP apparatus with respect to the criteria considered and to aggregate all the judgements over the hierarchical tree.

Results

The priorities of primary objectives with respect to the main goal of technology selection are computed as 0,199 for price, 0,192 for item characteristics, 0,189 for cost, 0,089 for time, 0,025 for office friendliness and 0,306 for variety. The relative relevance of each sub-criterion on the upper-level criterion is obtained as the synthesis of aggregate sub-criteria assessments and is shown in Table 2.

From these data, it is worth noting that office friendliness as well as time have a relative low score. This might be due to the fact that, when dealing with general purpose machines, the end-users are probably more willing to accept inconveniences if these are more than compensated for by a quality increment. Also, the sum of price and cost has a greater relevance than variety, which bears witness to the importance placed both by the end-user and the service bureaus on the economic aspect of the investment.

The most relevant element in defining item characteristics is the volume of the object (maximum size). In the context investigated, and especially for service bureaus, it is critical to process as many items as possible within the same time-cycle. As for the end-user, the justification is related to the need to obtain bigger objects without external support or scale models. In order to be effective, the device is required to provide highly complex parts, with limited volumes for detailed parts. Lower importance, though not negligible, is placed on surface texture and shelf-life.

Final ranking

Once the prioritization of performance criteria had been achieved by the composition of pairwise comparisons, the final step was to use the AHP framework to evaluate the different RP systems. It is important to note that the evaluation of alternative devices mostly depends upon recorded data and the pairwise weights are obtained by computing ratios between actual figures. Thus the comparison process at this level is enforced to be more objective based upon available manufacturing data. Table 3 reports the final ranking for the twenty systems considered.

Since the performance of a specific technology and the relative importance of performance criteria may change over time, the selection and evaluation

Primary objective	**Criterion**	**subcriterion**	Local priority	Total priority
Price				**0,199**
Office friendliness				**0,025**
	Hazardous materials			0,007
	Apparatus size			0,018
Item characteristics				**0,192**
	Complexity		0,264	0,050
	Shelf-life		0,057	0,011
	Maximum size		0,419	0,080
	Minimum size		0,154	0,030
	Surface texture		0,106	0,020
		Accuracy	0,400	0,008
		Resolution	0,136	0,0027
		Layer thickness	0,391	0,0079
		Support structures	0,073	0,0014
Cost				**0,189**
	Material			0,058
	Operator			0,103
	Post-curing			0,016
	Support structures			0,012
Time				**0,089**
Variety				**0,306**

Table 2. Priorities of evaluation criteria and subcriteria with respect to primary objectives

procedure should be thought of as a dynamic decision process.

Conclusions

The presented AHP-based approach provides a systematical framework with the following characteristics for the selection process of the most suitable rapid prototyping technology. First, the strategic importance of different performances can be evaluated using multiple, both quantitative and qualitative, criteria rather than profitability alone. Second, by structuring the numerous, both tangible and intangible, elements of a specific technology in the form of a hierarchy, the importance of the service elements for the end-user can be analyzed. The use of ratings makes it possible to evaluate the utility of different service levels for the end-user and to analyze the performance levels provided to the user by different devices. Third, both the analysis of the strategic importance of the performance and the service analysis performed by a firm, together with the defining of the service objectives, strategies, and action plans are often the collective effort of groups of executives. The AHP-method helps to conduct a group session in a systematic and analytical manner addressing every element in the hierarchy in turn. Qualitative and subjective judgements by many people can be included in the priority setting process. Fourth, the use of the AHP provides an effective way of documenting the different phases of the selection planning and management process. Fifth, the proposed approach forms a basis for a continuous process of planning and managing technology selection and implementation because the hierarchies and the priorities of the elements can easily be modified and updated.

References

APRI - Italian Association of Rapid Prototyping, A questionnaire survey on the implementation of rapid prototyping systems in Italy, 1997.

Saaty, T.L., *Decision Making for Leaders*, Lifetime Learning Publications, USA, 1982.

Saaty, T.L., Priority setting in complex problems, *IEEE Transactions on Engineering Management* Vol. 30, No. 3, pp. 140-155, 1983.

Wind, Y. and Saaty, T.L., Marketing applications of the analytic hierarchy process, *Management Science*, Vol. 26, No. 7, pp. 641-658, 1980.

Balsmeier P. W., Voisin, W. J., Rapid prototyping: State-of-the-art manufacturing, *Industrial Management*; Vol. 39 No. 1, pp. 1-4, 1997.

Mills, R. The road to enterprise success, *Computer aided Engineering*, Vol. 13, No. 7, pp. 1s,3s, 1994.

Sriraman, V., Rapid prototyping and the IE, *Industrial Management*, Vol. 38, No. 3, pp. 12-14, 1996.

Apparatus	Evaluation	Percentage evaluation
RP16	0,63600	100
RP17	0,62545	98,34
RP7	0,61080	96,04
RP20	0,58262	91,61
RP5	0,57462	90,35
RP6	0,57462	90,35
RP19	0,56168	88,31
RP14	0,55484	87,24
RP15	0,54354	85,46
RP3	05,53389	83,94
RP18	0,53069	83,44
RP13	05,52835	83,07
RP2	0,52440	82545
RP11	0551518	81500
RP9	0,50852	79,96
RP8	0550496	79540
RP10	0550468	79535
RP4	0,49767	78,25
RP1	0546846	73566
RP12	0,46837	73,64

Table III: The final ranking