Int J Adv Manuf Technol (2015) 78:1347–1360
DOI 10.1007/s00170-014-6705-7

ORIGINAL ARTICLE

Sustainable manufacturing process planning

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Received: 21 January 2014 / Accepted: 11 December 2014 / Published online: 9 January 2015

Abstract Environmental factors have a major role in selecting an optimal process planning schema. However, the systems that are currently available are barely capable of dealing with these environmental issues. In this paper, an automated evaluation tool based on environmental standards has been developed so that it is capable of identifying and quantifying the environmental impacts of a set of feasible manufacturing process plans and is able to select a near-optimal solution (out of the feasible set) for a desired process plan of a given part. The selection methodology is based on the analytic hierarchy process (AHP) and has considered three main factors: emission, waste production, and hazardous materials to arrive at a selection. The proposed technique has been written in detail in the following paper and has been illustrated with appropriate case studies.

Keywords Strategic environmental assessment · Process knowledge customization · Analytic hierarchy process · Sustainable manufacturing · Automated process planning

1 Introduction

Sustainable manufacturing process planning is both an integral component as well as a crucial aspect to the advancement of the manufacturing industry. Process planning is needed for the setup of manufacturing plants that produce everyday products; however, responsibility must be taken when taking into account environmental impacts. The knowledge of environmental impact currently provides little foresight on where one chooses to build these plants. A set of standards should be created that can address current and future environmental impacts associated with producing a manufacturing plant in only processes that have a certain criteria. One issue with the current means of planning for manufacturing is the lack of accuracy in the current assessment of product life cycle for any producer. This issue leads to inefficiencies in adoption of sustainable product development practices. A sufficient implementation must take into account the producer projections of emissions, the possibility of hazardous materials and waste production, and the impact their machines may have on the environment. The current manufacturing standards are scattered and disorganized. Though laws and regulations do exist, they are loosely enforced and difficult to locate. This paper presents an additional model that takes into account environmental needs as well as covering some of the ambiguities in the current process. In the manufacturing process, this model is superior because it incorporates factors frequently left out such as equipment, reduction in emission, waste production, and hazardous materials. With this information, a manufacturing process plan (MPP) can be easily derived and edited when necessary. Flaws can be found when investigating the development process of an integrated information model system. The model presented can be applied to find the optimal manufacturing process of any product in production. At the highest level, this model shows current productivity of machines, operations, and equipment, as well as showing projected environmental impacts. At the lowest level, it shows manufacturing component assemblies and detailed process planning components. Companies worldwide will find this tool useful, primarily, due to its basis in

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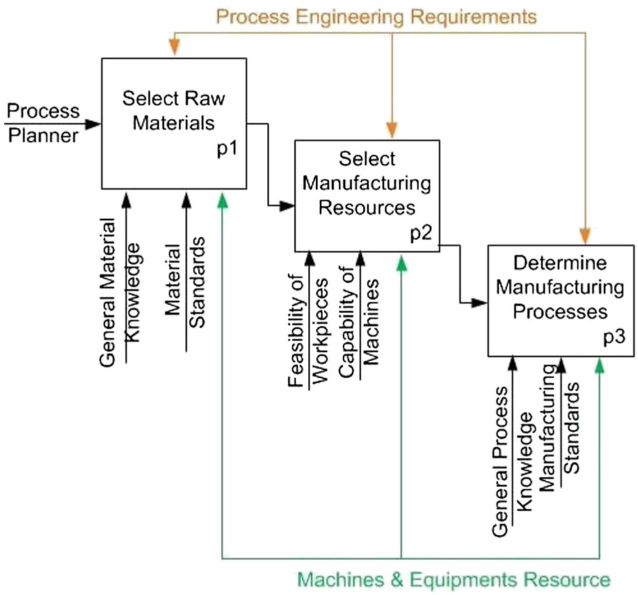


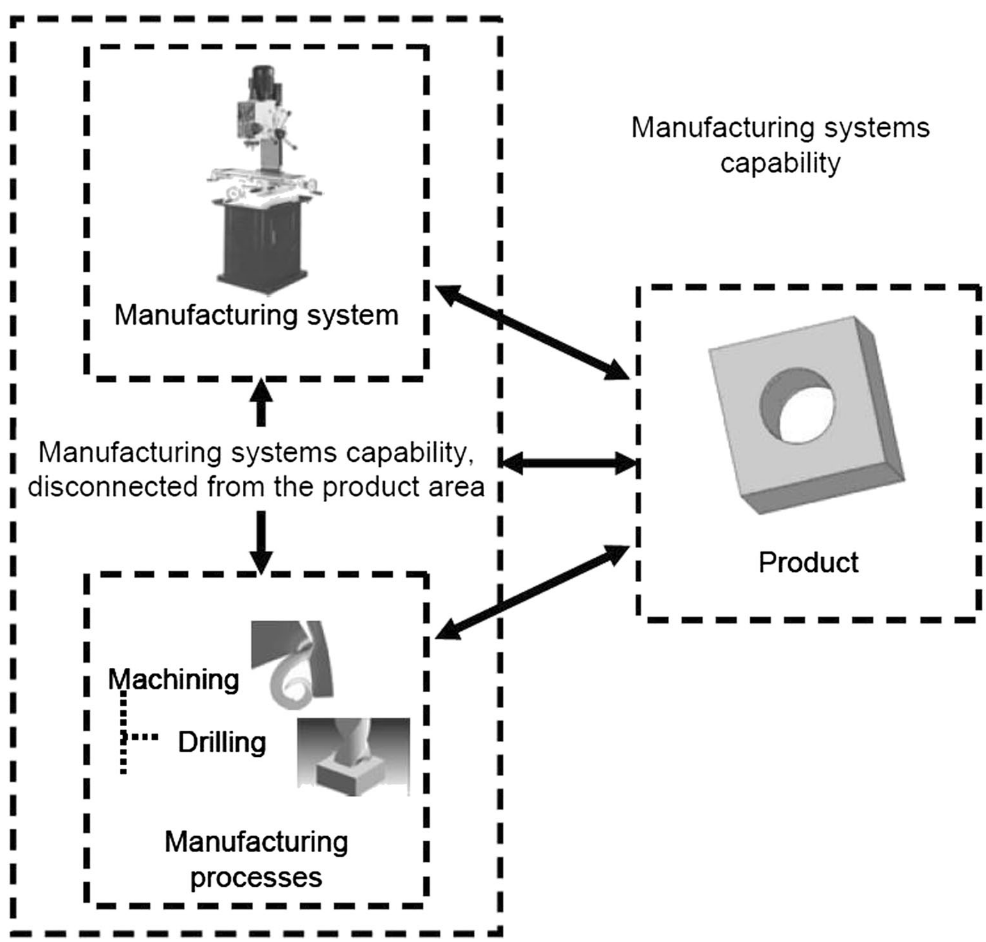
Fig. 1 Information requirements for preliminary process planning with IDEF0

environmentally availability of production resources and equipment. The first step of this model is to define the "objectives" of the project and solve it. The first three basic tasks include (i) identifying information requirements for process planning, (ii) defining connections between processes in regards to process planning, and (iii) arriving at an optimal plan for the manufacturing process in relation to environmental factors.

2 Review of related research

Literature has been published in regards to manufacturing process planning and its impact on the environment. The main focus of previous review has been on ways to minimize environmental impact with respect to manufacturing resources. The initial stage of the research process is aimed at creating a broad understanding of the specific domain, as well as to find a research gap. There are five levels into which the current process planning information can be

Fig. 2 Manufacturing system capability is divided into a number of sub-process with manual relationship [12]



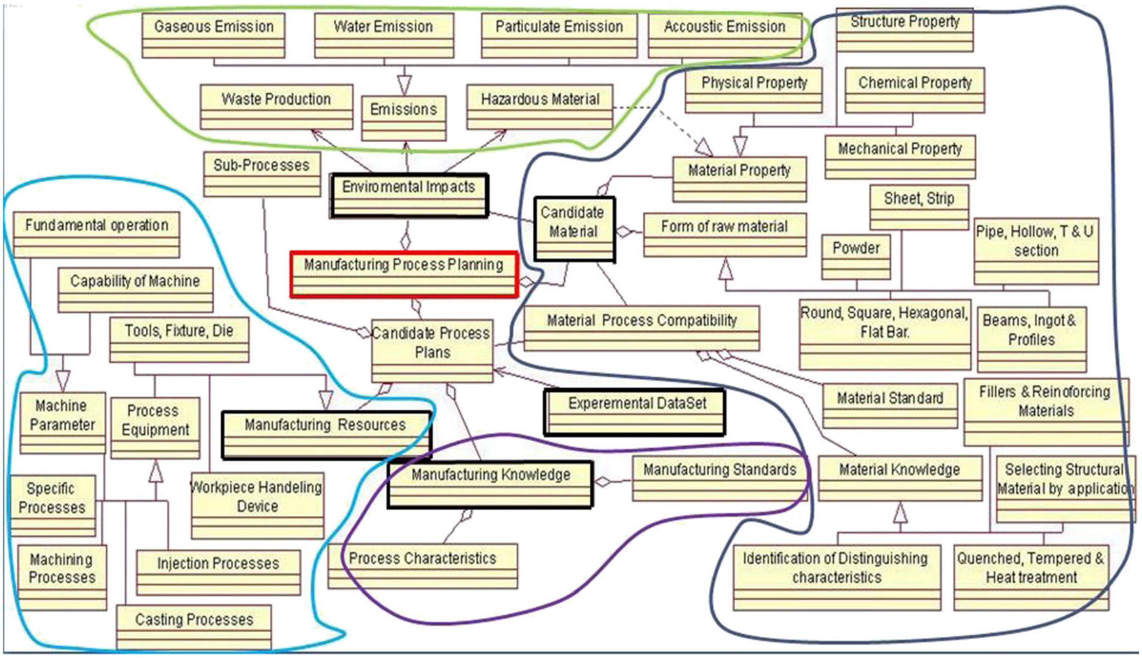


Fig. 3 The manufacturing process information UML model

categorized [1]. They are structure-based, geometry-based, feature-based, and knowledge-based and focused on integration process planning models. In this proposal, we deal with the knowledge-based and integration product models. The integrated process planning models are the unique models that could be used throughout the life cycle assessment (LCA) of a product. ISO 10303-21 [2] gives such a product information model and it is an industry standard for the exchange of product model data.

2.1 Information model

Process plan modeling describes the process plan strategy of a manufacturing process. A process plan model comprises of hierarchically structured process plan which denotes a structured process plan: generic, macro, detailed, and micro [3, 4]. A language for process specification (ALPS) has been created to be a data support model, used in discrete manufacturing industry. The design goals of ALPS is the support function decomposition, parallel tasks, synchronization tasks, alternative tasks, sequences, resource relations, critical task sequences, and informatics manipulation operatives [5, 6]. As shown in Fig. 1, preliminary process planning is the first step to be taken during early manufacturability assessment on an early design of a product. It supports the optimization of product form, resource selection, and material selection in order to reduce manufacturing cost and production time. This step can be broken into three substeps: select manufacturing process, select manufacturing resources, and estimate a time period that the process will take from start to finish [7, 8].

Table 1 The AHP scale of pairwise comparison

Numerical values	Scale values	Explanation
1	Equal importance of both element	Two contribute equally
3	Moderate importance of one element over another	Experience and judgment one element over another
5	Strong importance of one over another	An element is strongly
7	Very strong impotence of one element over another	An element is strongly dominate
9	Extreme impotence of one element over another	An element is at least an order of magnitude strongly dominate
2, 4, 6, 8	Intermediate values	Used to compromise between two judgments

Table 2 The average R_I of random matrices

Size	1	2	3	4	5	6	7	8	9	10
R_I	0.000	0.000	0.523	0.891	1.112	1.256	1.354	1.401	1.453	1.498

2.2 Process planning

The manufacturing resource database is a database that provides information pertaining to certain tools and equipment used in the machining process. The database functions off of a series of related underpinnings of each component. This database can be accessed through the Java database connector. In the database, tools are

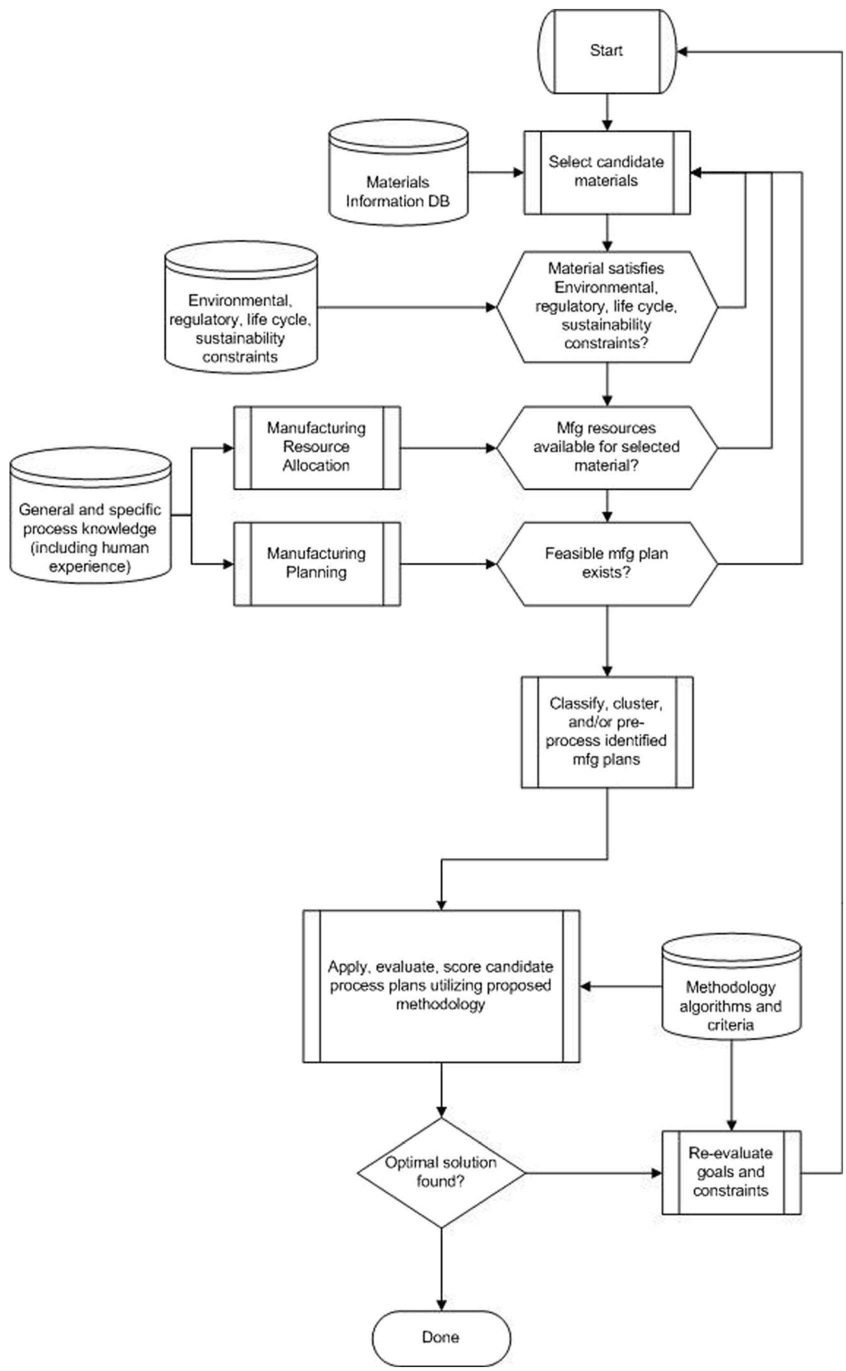


Fig. 4 A detailed algorithm for selecting the optimal process schema

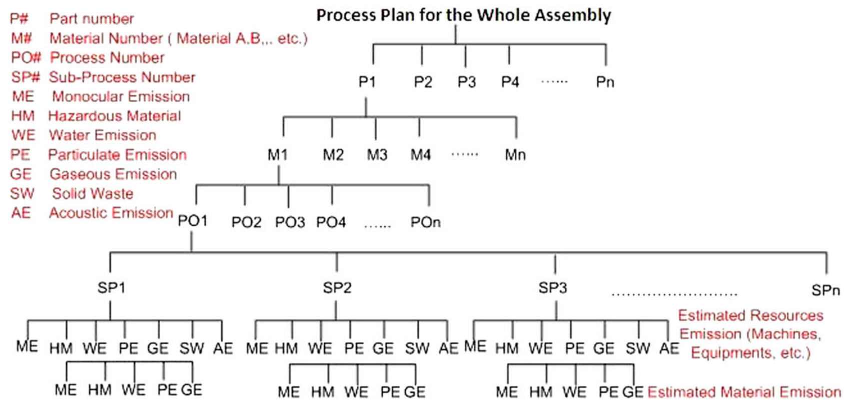


Fig. 5 Hierarchy matrix for sustainability of process planning and selection material

broken down and placed into categories such as power output, cutting force, workspace dimensions, cutting axes, spindle speed, and available cutting tools. Other pieces of information that can be found in this database include necessary operator skills and workspace materials. A model on machining resource information is included in [9]. The knowledge base of MPP contains rules that denote behaviors and workpiece forms. Manufacturing recourses and directions on how to perform certain tasks are considered MPP knowledge. Machining stability analysis, tool material selection, and tool life evaluation are all functions that can be classified as special tasks. The rules for tool material evaluation are typically located in the closing section of process planning [10, 11].

2.3 Manufacturing resources

A manufacturing resource information model is regularly used in selection of resources. A manufacturing resource capability model represents the information on the function and the characteristics of its function. Several manufacturing capability models have been developed; these models focus on the design in regards to manufacturability on the factory level [12]. The two manufacturing capability models on the workstation level have been created by Liu et al. [13]. A model for CAD/CAPP has been integrated to optimize the production of machine and cutting tools as shown in Fig. 2.

3 Development of information models for manufacturing processes

Currently, various computer application models are available in addition to existing company standards when assessing process planning. These methods are different form different application point of view; however, there are numerous components that are similar between these method, the similarities show that there are connections between products, manufacturing resources, and manufacturing processes across an entire field. There are specific factors that differ between process models for product production, which can be separated into several categories (shown in Fig. 3). These include different sets of information such as input of a process plan, gathering appropriate information about the environmental impact for every component of the product, and concluding a generic schema for each production derived from output information. Therefore, it is imperative that the process planner collects the correct information about the requirements for manufacturing each product. The purpose of information modeling of manufacturing process is to expedite the process selection, while product planning is taking place. Information regarding process planning of the product must be integrated with the function of the product.

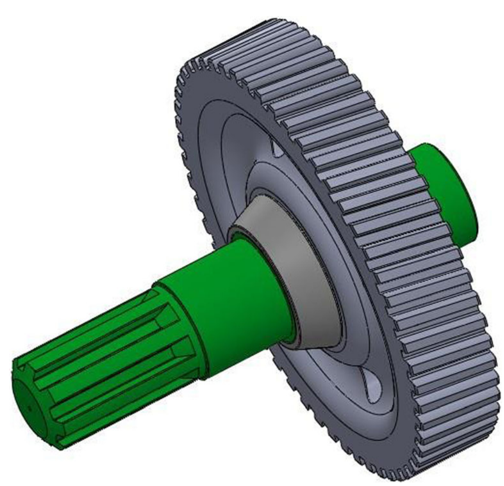


Fig. 6 Typical driving gear-shaft part

Table 3 Material matrix selection for process planning shaft gearbox using the manufacturing standards

Sub-class	Material (A)	Material (B)	Material (3)
Process of main shaft	Steel "AISI 4340" [17] (for hot forging)	Steel "AISI 4140M" [18] (for cold forging)	Steel "AISI 1045" [19] (machining Shaft)
Processes of gear	Brass "C85700" [21] (for casting brass)	Gray Cast-iron "G4000" [22] (for casting cast-iron)	Brass "Alloy 360" [23] (brass bar)
Process of special bushing	Steel "AISI 303SS" [20]	None	None

Manufacturing process planning information is included: (1) information for martial, (2) information for environmental impact, (3) information for manufacturing process resources, and (4) define and availability of manufacturing knowledge base and standards. As shown in Fig. 3, the manufacturing process model has three major environment components: (i) development of an analytic hierarchy process (AHP) approach for producing an optimum process sequence that can be adopted with reasonable efficiency, (ii) a comprehensive representation schema of work piece models, and (iii) a representation of different manufacturing operations and their effects on the environment. These models also acquire information for product behavior. This product behaves further influence and determines the next steps of the process plan.

3.1 The AHP methodology: the basic definition

The AHP methodology is assisting in making as well as creating measures of this decision the AHP. Saaty [14] delivers a hypothetical basis for the AHP that formulates a methodology that allows one to decide even the most complex of decisions while incorporating both tangible and intangible characteristics. Consequently, it supports decision-makers to make decisions involving their understanding, knowledge, and instinct. The AHP breaks down the decision problem into various aspects, separating them into similar characteristics and levels. These correspond to the similar characteristic of the aspects of the problem. The highest level is the pertinent point of the problem or ultimate goal; the intermediary levels relate to both the criteria and the sub-criteria, while the lowest level contains the "decision alternatives." If each aspect of each level depends on all the elements of the upper level, then the hierarchy is complete; otherwise, it is defined incomplete. The aspects of each level are associated pairwise with respect to a certain aspect in the immediate upper level. Table 1 shows the pairwise comparison scale that is used in the AHP developed by Saaty [14]. The scale permits qualitative and descriptive measurements that also show intangible characteristics. When calculating the priorities of the aspects, a judgmental matrix is assumed as the

Table 4 List of manufacturing resources

Process	Machine parameters	Total equipments	Process	Machine parameters	Total equipments
Late machine	Turret Lathe CNC Lathes	3	Hobbing machine	CNC vertical hobbing machine	2
Milling machine	CNC Universal 20″×50″×30″	9	Broaching machine	Horizontal broaching machine	1
Die-casting machine	1350 Kn	2	Cylindrical grinding	Outside diameter (OD) grinding	1
Electromagnetic furnace (melting)	Furnace capacity 410–450 kg	1	Forging press machine	20 T	2
Electromagnetic forging furnace	10″×15″×17″	2	Drilling Machine	Radial drill, Jig boring machine	2
Jig and fixture and workpiece handling device	Assembly part, drilling, milling, hobbing	6	Cleaning equipments	Tanks with cleaning liquid	3
Die	Die for casting, die for forging	4	Tools	Machining, etc.	168

Table 5 Estimated of all emission for process3 from Fig. 7 (change scale units from zero to nine)

Process3	Sub-process1	Sub-process2 [25]	Sub-process3	Sub-process4	Sub-process5	Sub-process6	SUM per unit
Liquid emission (LE) v/t	0.00	0.00	1.52 [30, 31]	1.03	0.78	0.12	3.42 v/t
Air emission (GE) m/l	0.00	1.21 [26, 27]	0.00	0.00	0.00	0.00	1.21 m/l
Production waste (PW) [33] m/t	0.00	2.12 [28]	1.87	0.89	0.62	0.14	5.64 m/t
Acoustic emission (AE) v/t	2.12 [24]	0.70 [29]	0.12 [32]	0.35	0.20	0.07	3.56 v/t

following:

$$A = \begin{matrix} a11 & a12 & \cdots & a1n \\ a21 & a22 & \ldots & a2n \\ \vdots & \vdots & \cdots & \vdots \\ an1 & an2 & \cdots & ann \end{matrix} \quad (1)$$

where a_{ij} represents the pairwise comparison rating between certain elements of a given matrix, element i and element j. The elements a_{ij} are governed by the following procedures.

The principal eigenvector w of the matrix A can be found by using the following equation:

$$A_w = \lambda_{max} W \quad (2)$$

Once the vector W is normalized, it becomes the vector of priorities of elements of one level in comparison to the upper level. λ_{max} is the hugest eigenvalue of the matrix A.

In the work of Saaty [14], it has been shown that there are certain consistencies when calculating priorities from paired comparisons; the number of elements being considered must be less than or equal to nine. The AHP model permits for some discrepancy yet offers a measure of the discrepancy in each set of judgments. A consistency ratio (C_R) can then be formulated by observing and tabulating the consistency of the judgmental matrix; it is defined as the following:

$$C_R = C_I / R_I \quad (3)$$

where C_I is called the consistency index and R_I is the random index. Additionally, Saaty [14, 15] provided average consistencies (R_I values) of generated matrices that he computed randomly (Table 2). C_I for a matrix of order n is defined as

$$C_I = \lambda_{max} - \frac{n}{n-1} \quad (4)$$

The acceptable range of the consistency ratio is 0.1 or less; this threshold is 0.08 for matrices of size four and 0.05 for matrices that consist of a size three. If the consistency ratio is any higher, it is not reliable and should be repeated for an improved accuracy.

Once the local priorities of elements of different levels are accessible, to acquire final priorities of the alternatives ai, the priorities are combined as the following:

$$S_{ai} = kwk_k \mathrm{SK}_{ai} \quad (5)$$

where wk is the local priority of the element k and SK_{ai} is the priority of alternative ai with respect to element k of the upper level.

4 Application of analytic hierarchy process techniques to manufacturing process planning alternatives

The AHP is a decision-making process that takes into account process planning for the environment. One of the advantages of applying AHP matrices is that it has the capability to compare multiple products or processes. The algorithm in Fig. 2 leads to the optimal selection process schema. One of the AHP's many features is its ability to perform sensitive analysis. The results from this analysis can help alleviate some environmental concerns. The algorithm in Fig. 4 shows the optimal manufacturing process model. At the start, the algorithm selects candidate material for minimizing environmental impacts. This step is followed by tool selection (Table 4) for testing alternative material in the manufacturing process (Figs. 5 and 6).

Table 3 start with material selection. The materials to be used are to be taken from a material database. In the next step, the environmental impact of the material in question is determined based upon its polymer component. The main advantage of this model is the ability to use multiple databases, if necessary. The final step

	Sub-Process 1	Sub-Process 2	Sub-Process 3	Sub-Process 4	Sub-Process 5	Sub-Process 6	Sub-Process 7	Sub-Process 8
Process (1)	Hot forging shaft	Die-casting Cast-iron	Turning the whole shaft	Hobbing machine of gear	Hobbing machine of spline	None	None	None
Process (2)	Turning the shaft	Milling of key on shaft	Hobbing machine of spline	Drilling the brass bar	Broaching the key	Turning the whole shaft	Hobbing machine of gear	Turning the special bushing
Process (3)	Cold forging shaft	Die-casting Brass	Turning the whole shaft	Hobbing machine of gear	Hobbing machine of spline	None	None	None
Process (4)	Turning the shaft	Hobbing machine of spline	Hot forging Gear	Turning the Gear	Broaching the spline	Hobbing machine of gear	Turning the special bushing	None
Process (5)	Cold forging shaft	Turning the shaft	Hobbing machine spline 2surface	Hot forging Gear	Turning the Gear	Broaching the spline	Hobbing machine of gear	Turning the special bushing
Process (n)	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Fig. 7 Process planning matrix for case study

Table 6 AHP matrix estimation of liquid emission for all process

Liquid emission (LE) v/t [30, 31]	Process1	Process2	Process3	Process4	Process5
Process1	1	1/4	1/5	1/4	1/2
Process2	4	1	1/3	3	1/5
Process3	5	3	1	3	4
Process4	4	1	1/3	1	3
Process5	2	1/3	1/4	1/3	1

of this model is to produce the most environmentally friendly material for one to use. Figure 7 shows the manufacturing process planning matrix, the sub-process, and environmental aspect arrayed in a four by n sub-process matrix (Table 5). The process planner uses a streamline matrix approach and answers a series of questions associated with each cell of the matrix [16]. The questions are intended to measure the degree of environmental impact of the material. An advantage of using this matrix is its ability to change to meet needs of any user. Environmental scores for procedures are found by summing all of the cells in the matrix. The information taken from the matrix can be used for optimization of process planning. The raw cells each have scores based on series of equations. Each cell should be assigned a weight; the greater the weight, the higher the importance. This is useful from an engineering stand point because it helps determine which factors in the process are most important and require the highest attention of detail. This model will be used in the two approaches earlier discussed “emissions and production waste,” both involving the comparison of *n* alternative processes. The matrix question approach will use hierarchy to value the cells in the process matrix of Table 1 regarding the sub-process. The result will be combined with the results of individually scoring matrices for the *n* alternative sub-process. The first step in the use of the hierarchy is to determine the goal or object then apply it to the model given. The output will give the user the best materials and process planning in respect to environmental impact.

4.1 Further discussion in multi-criteria decision

There are steps that one needs to take to make an organized and adequate decision. Using these following steps, one is able to prioritize and make an informed decision. The first step is composed of one defining a problem and then deciding the knowledge needed to solve the given problem. The next step involves understanding and creating a structure which hierarchical in nature. The goal of the outcome is obviously the most important aspect of the decision-making process, then the broad attributes and desired criterion, as well as the alternatives of the attributes. The next step requires one to create a comparison in the form of pairwise matrices. The upper levels are then compared to the next lowest element. Following that, one must use the acquired priorities to compare to the priorities of the next lowest element. These steps must be repeated until each element has been weighed in and one as acquired the overall priorities of each element.

Scalar numbers should be used, so one can clearly see the importance of one element over another. For example, one may be trying to answer the following question: What are the different emission rates in different manufacturing processes? How to compare the rates? One is then able to enter the number from the scale that is suitable for the judgment: for example,

Table 7 AHP matrix estimation of air emission for all process

Air emission (GE) v/t [26, 27]	Process1	Process2	Process3	Process4	Process5
Process1	1	2	1/4	1/2	2
Process2	1/2	1	1/3	1	1
Process3	4	3	1	1	2
Process4	2	3	1	1	2
Process5	1/2	1	1/2	1/2	1

Table 8 AHP matrix estimation of Production waste for all process

Production waste (PW) m/t [33, 28]	Process1	Process2	Process3	Process4	Process5
Process1	1	1/2	1/6	1	1/2
Process2	2	1	1/2	3	2
Process3	6	2	1	1/2	1/4
Process4	1	1/3	2	1	1/3
Process5	2	1/2	1	3	1

enter five in the (gaseous emission, water emission, etc.) position, meaning that process3 is four times process1. It is automatic that 1/4 is what one needs to use in the (process 1, process 3) position. Process 3 is more efficient than the process. One must always enter the whole number in its position and simultaneously enters its reciprocal in the transpose position. Raising the given matrix to very large powers and tallying each row and dividing each by the total sum of all the rows can acquire priorities. Adding each row of the matrix and dividing by their total can also obtain the priorities. The efficiencies were acquired by databases and information modeling sections. We see that the answers are very close and pairwise comparison judgments of some process, who knows, can lead to very accurate results of reduction emissions (Tables 6, 7, 8, and 9).

4.2 Validation of AHP

Validation is easily acquired when using a scale that ranges from one to nine. An example of last scale is seen in Section 3. In terms of a group decision, panelists or group of people can compare and prioritize processes and arrive at a consensus to decide when process is most efficient in terms of low emissions and efficient in manufacturing process planning. The panelists are able to have statistical approval of their decision. The vector of the general emissions and the actual vector were calculated by normalizing the given data. These calculations are shown at the bottom of the table.

4.3 Ratings mode

Besides validation, there are other methods that one can use to prioritize. One may create rating categories; each category must cover the given criteria and be compared for preference. The rating categories for the emissions and efficiency criterion go as follows: high, medium, and low. One may compare the rating categories for preference while using a pairwise comparison matrix in a general way. To acquire the idealized prioritizes; normalize by dividing by the largest of the priorities given. These theoretical prioritizes are generally used for ratings. To establish a matrix containing the rating categories for the entire criterion covered. Results can be shown via verbal ratings of various alternatives on each covering criterion and results also have a corresponding numerical rating. The totals are then converted to priorities by dividing with their sum. These results can then be compared using the pairwise comparison method named relative model. The rating method allows one to rate huge numbers of various alternatives with brevity and with accuracy. Another process, primarily using paired comparisons can be used in a more broad sense. One can handle a decision using various perspectives. Some of these perspectives include environmental impacts (EI) that the decision conveys, the opportunities (O) it creates, the chosen candidate material (CM) that it incurs, and the manufacturing resources (RM). There is another similar process in making decisions that uses similar factors, which is called SWOT (strengths, weaknesses, opportunities, and threats).

Table 9 AHP matrix estimation of acoustic emission for all process

Acoustic emission (AE) v/t [24, 29, 32]	Process1	Process2	Process3	Process4	Process5
Process1	1	1	1/3	1/2	1
Process2	1	1	2	1	1/2
Process3	3	1/2	1	2	1
Process4	2	1	1/2	1	2
Process5	1	2	1	1/2	1

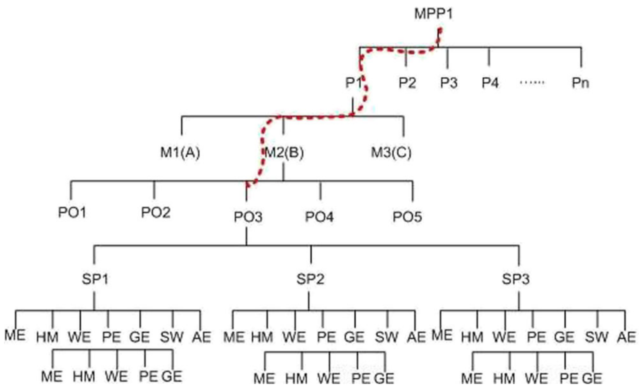


Fig. 8 Optimal solution process plan in the case study

The alternatives, as in before, are given a hierarchal relationship between other alternatives. These alternatives are prioritized based on four characteristics. These four characteristics are then joined into one sole prioritization by choosing the best alternative that some form of body chooses. Additionally, one must take into account if there is a certain dependence of the alternatives to one another or the criterion itself. If there is such a dependence, then the final decision must consider both of these dependences as well as the given feedback. For one to establish the final decision, there must be a certain amount of steps taken over a course of a few days.

4.4 Multi-criteria in decision-making

With group decision-making, there comes major issues when deciding the optimal rate of action. Two of these issues include how to accurately incorporate each individual's judgments into a sole, highly representative judgment as well as creating an overall group choice from each of the individual choices. The reciprocal property allows for one to combine each of the judgments in such a way that accurately depicts most of the judgments. The addition of these reciprocal judgments must equal the addition of the judgments. There are

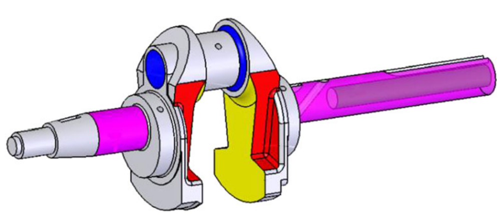


Fig. 9 A typical driving crankshaft

various proven ways of synthesizing the judgments. If the individuals are experts on a given problem, they may not wish and do not have to combine their judgments but only their final outcomes obtained by each from their own hierarchy. Thus, the final outcomes are dependent on the individual's experience with the subject and how the individual then sums up the judgments. An expert can simply take into account the final outcomes only by use of a geometric mean, whereas if an individual has a varied amount of priorities and limited experience, then one must rise their judgments (final outcomes) to the power of their priorities and then from there, the geometric mean is formulated.

5 Case study 1 (main shaft in a gearbox)

For first case study in this research is used a main shaft of a gearbox (as shown in Fig. 5). Using hierarchy methodology, the user creates a series of comparison matrices, which display relative importance. When looking at the AHP structure of the shaft example, weights of importance can be gained in respect to what role they play in the whole process. This results in one nx6 matrix for the six environmental impact areas with respect to each sub-process. Furthermore, this matrix can be directly compared to other matrices, which is found in the Supporting Information. This approach requires a comparison of factors and how they influence the output of this process. The user performs this comparison by assigning an integer ranging from zero to nine (or the reciprocal) to each cell of the matrix. This measures the relative importance of the factors in each cell. The cells along the diagonal are given the value one. The precise description is given in the Supporting Information. The user can also assign one to every cell; however, this will rank each component equally, making the information less organized. For the sub-process stage (SP1), emission, hazardous material, and solid waste were considered to be the three dominant environmental factors. The Supporting Information shows that the matrices for the manufacturing stages (SP1, SP2, Spn) are similar to each other with water pollution being the main concern. The next step is to apply mathematical algorithms to extract the appropriate eigenvalues and eigenvectors. These are used to determine the weights of various factors. The result can be used to assign weights to each cell of the main process matrix. If a sub-process is being evaluated by itself, the cells are scored zero to one and multiplied by the weight shown in Table 2. If n processes are being evaluated, then each matrix is separately analyzed, and then the results are compared.

Fig. 10 Modified crankshaft machining process

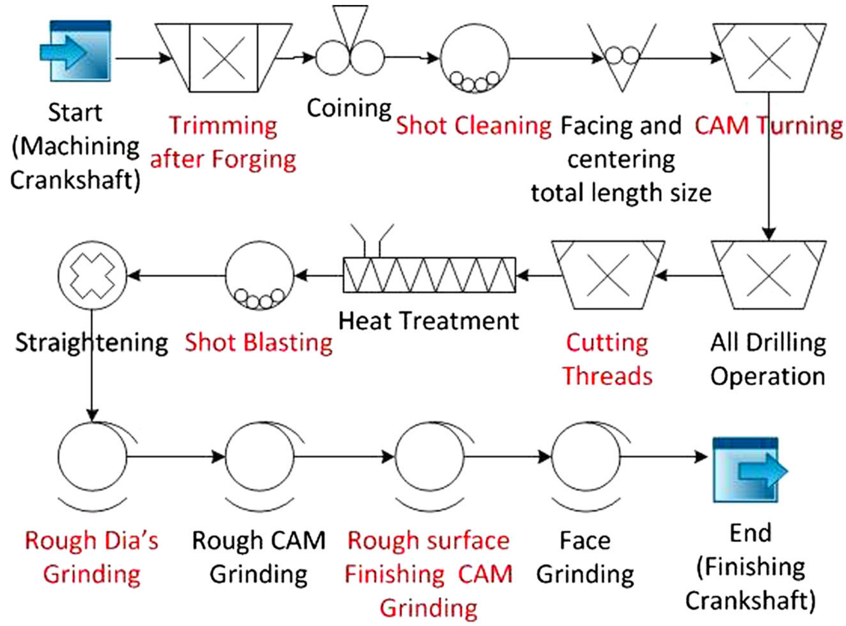


Table 2 represents the final cell weighting for the shaft production process. The numbers in the final column represent the sums of the other columns. The highest weighted environmental area of concern were emissions with a value of 0.75 (waste production column). Figure 8 shows a sample of an optimal process and material for the process number three (PO3) and mix material number three (M3). Thus, the weighting scheme has tended to raise the efficiency score and lower the emission score (improvement). However, the user should be more interested in directly comparing *n* alternative process than analyzing each process separately. As a result, AHP offers a convenient method to carry out this comparison.

6 Case study 2 (driving crankshaft)

For this case study, a typical driving crankshaft part is selected (as shown in Fig. 9), and also, we identify

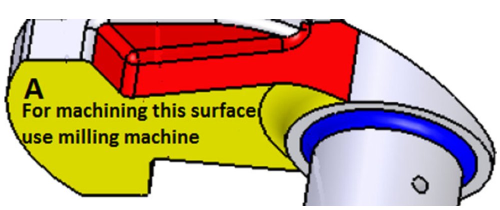


Fig. 11 Reducing the thickness of the crank web (surface A) for dynamic balance of the crankshaft

possible manufacturing processes for those machining proposes for this example (it has been highlighted of the machining process in Fig. 10). We considered the flexibility of producing the part with several machining processes. We followed the proposed procedure and created several process sequences. Strictly speaking, we should have only one-optimal (or near-optimal) solution at end of the process (as shown in Fig. 11). However, Figs. 8 and 9 illustrate the manufacturing activity involved in "Crank web" machining operation.

At this particular stage (for the process section (A), milling operation), the expected physical states of the part (including exact dimension and tolerance specifications for all of its manufacturing features) at both input and output states are given in Fig. 9. The resources including the milling machine, tool, etc. with detailed specification of cutting parameters are selected, and the expected "states" of the part along with calculated values of material wastage and energy usage figures have been displayed in Fig. 12.

In determining the optimal process sequence, researchers have tried to devise several mathematical programming techniques in the form of DMPP, MIP, etc. But the practical process planning problem is very difficult to solve in those forms because of their sizes and inherent complexities. In this paper, we have discussed a quick and efficient approach which is suitable for all practical purposes called ROP. Our concept permits interactions among several manufacturing information of process operations

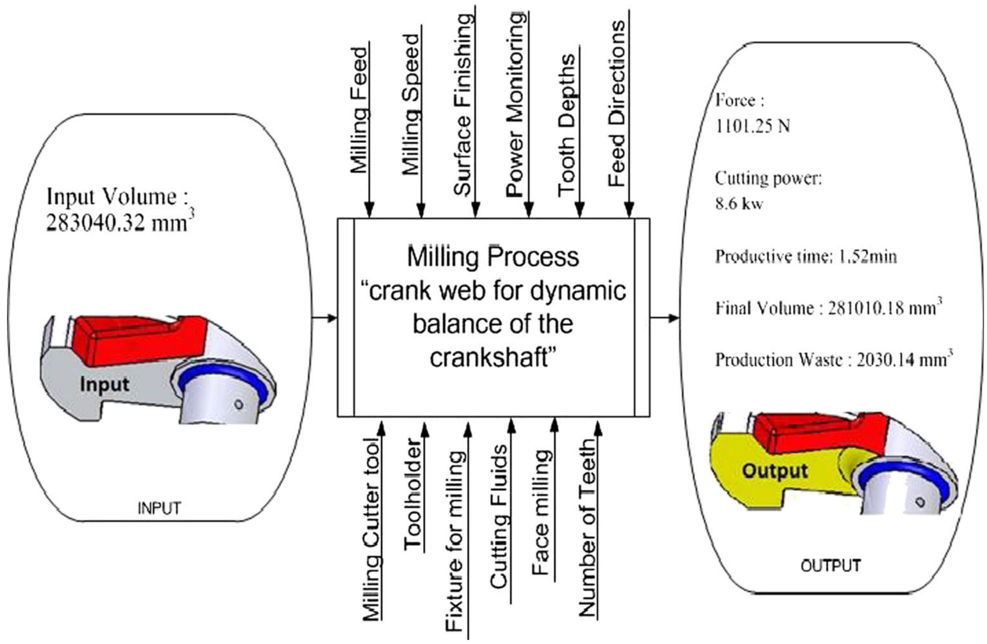


Fig. 12 Assessing MPP using product information modeling for feature (A)

and thus saves a significant amount of manufacturing cost and time producing an environment-friendly process plan.

7 Conclusion

In this paper, the contemporary knowledge-based process planning schema has been presented with examples from work previously performed. The primary benefits are listed below:

(i) The proposed hierarchy matrix is based on process knowledge customization. This integrates process knowledge with the manufacturing resources to aid in process planning. It provides a family for process planning and alleviates common problems associated with automated process planning.

(ii) Unlike common approaches, the proposed method is based on systematic methodology, which addresses process planning in regards to manufacturing resources. Therefore, the practicality of process planning can be improved.

(iii) Process reasoning is a complicated decision-making problem, and the customizable methodology greatly simplifies the process while making it more accessible to manufacturers. This study can further be applied to improve product industry and can aid in the development of new products. The sustainability analysis tool used in this study has certain limitations. These limitations are based chiefly based on the manufacturers' resources (e.g., cost, energy consumption, etc.).

7.1 Limitation base on the research objectives

The effectiveness of planning is sometimes limited because of external factors, which are beyond the control of the planners. External stringencies are very difficult to predict. Sudden breakout of war, government controls, natural havocs, and many other factors are beyond the control of management. They make the execution of plans very difficult.

Lack of high accuracy planning relates to future, and future is always uncertain and so prediction about future is so much difficult. Planning is based on data and information relating to past and as such, planning based on any wrong information may not be useful to the organization.

In limited flexibility, there may be some changes in planning only up to some extent because measure changes in plan will further attract the changes in supporting plans also, and as such, the whole system is disturbed moreover changes in plans time.

7.2 Future work

This work could be expanded to study:

- Selection of different materials for production.
- Development of redesign after assessing the new manufacturing process plan.

Acknowledgments The author would like to acknowledge Dr. Utpal Roy, at Syarcuse University, for his immense help and support. Thanks are also due to my colleagues, Mr. Yunpeng Li and Mr. Omar Yaman, for their suggestions on preparing the manuscript.

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