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Mathematical modelling of process planning problem

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Abstract: This paper discusses a mathematical modelling of process planning problem. As everybody knows, a component has a set of operations derived from its design. Each operation can be performed by a set of machines, which are associated with it. Each such machine has a setup cost and processing cost per unit period. The goal is to choose the machine for each operation in such a way that the total cost, which is the sum of the setup costs and processing costs of the machines associated with the operations of the component, is minimised by taking the desired production volume of that component per period into account. The topic of processing planning is explored in this study as a linear programming model.

1 Introduction

Companies are engaged with manufacture of products to satisfy the needs of households and also industries buying industry goods. Each product consists of a set of components. These are to be manufactured such that the total cost of manufacture of the components and in turn the product is minimized to have competitive advantage in the market.

Immediately after the design of a component of a product, the process planning function aims to select the cost-effective machine for each operation of that component in an effort to lower the component's overall manufacturing cost.

2 Literature review

This section reviews the literature in the field of process planning.

Hayes and Wright (1989) suggested directing search using future interactions to automate process planning. Automatic process plans for making metal parts on a CNC machine tool are created by an expert system known as Machinist. It is a part of an overall strategy to automate the workshop. It works with prismatic items that have one or more sides with carvings on them. When one group of traits is removed first, parts of this kind might interact. These linkages need to be appropriately considered while planning and organising the machining operations. The machinist programme, which has been created to be an essential part of CAD systems, facilitates the creation of manufacturing plans.

Mcginnis et al. (1992) a framework for planning the printed circuit card assembly process was created, and it was used to assess the state of the research on appropriate models and solutions. In the beginning, they provided a general review of the language, assembly methods, and assembly system functions that are essential to printed circuit boards. They then assessed the existing literature, proposed a decision hierarchy, and identified areas that still needed investigation.

Kiritsis addressed strategies and problems related to knowledge-based expert systems for process planning (1995). With some help from the author's survey research, it is mostly based on literature. The primary difficulties are categorised after a brief explanation of process planning, and the appropriate approaches and strategies for resolving them are given.

Sormaz and Khoshnevis (1997) A quick analysis of the knowledge representation techniques used in reported existing CAPP systems is followed by a full explanation of the process planning function and the knowledge it requires. Then, an object-oriented approach to knowledge representation is described. This approach makes it straightforward to interact with other CIM modules for computer integrated manufacturing and allows CAPP to be incorporated both upstream and downstream. In addition to their relationships to features, tools, and machines, the entities engaged in the machining process are explained. The network depiction of the process plan, which accommodates alternative plans, is explained. An example is used to demonstrate how the implementation of the scheme is done in a functional process planning system prototype. The suggested representation's benefits are listed.

Layered manufacturing is a new production technique with the potential to increase output scope (LM). A key element of LM is process planning. By Kulkarni et al., the literature in this emerging topic is described, conceptualised, and reviewed (2000). As the report draws to a close, predictions about probable future areas for research in this area are given.

The description of a disassembly plan includes a disassembly bill of materials (DBOM), the order of processing steps, the type of disassembly action, the component or fastener worked on each step, the tools used, and the outputs of material and pieces. The two aspects of the planning issue for the disassembly process are the development of a feasible plan and its implementation at a facility (DP3). The DP3 model was introduced and explained by Sanchoy (2002).

This model describes the construction of the disassembly process plan, documentation, and evaluation processes. One of the main advantages of this model is its framework for communicating product information from the original product manufacturer to the user and the end-of-life disassemble through the disassembly bill of materials (DBOM). Because it specifies a plan that a manufacturer can swiftly develop and successfully disseminate to the disassembly community, the DP3 is a descriptive model. The user can decide the sequence of the disassembly procedures, nevertheless. The model introduces a variety of standards for identifying unfastening operations, damaging acts, and the required equipment. The DP3 model also provides an economic evaluation of different ideas.

For instance, methods that combine additive and subtractive manufacturing processes have received a lot of interest recently. This is due to the fact that they can profit from the overall advantages of combining various processes. There are, however, few process planning approaches that can effectively mix additive and subtractive manufacturing processes. to enable the fusion of the inspection process with the advantages of additive and subtractive technologies.

Newman et al. (2014) the interactive framework was introduced. Through a range of case studies, Re-Plan, a system for process planning based on interactivity, illustrates the potential of combined process manufacturing.

CAPP, or computer-aided process planning, is a tool that process planners can utilise to assist them in their planning activities. For combining computer-aided design (CAD) and computer-aided manufacturing, it is regarded as a crucial piece of technology (CAM). Due to the globalisation of the market and industry, CAPP research currently faces new challenges.

Yusof and Latif (2014) aimed to present a comprehensive review of CAPP based on features, knowledge, genetic algorithms, artificial neural networks, fuzzy set theory, fuzzy logic, Petri nets, agents, the Internet, STEP-compliant methods, and functional blocks (FB) methodologies/technologies throughout the past 12 years (2002–2013). The objective of this study is to provide a current survey with a graphical representation of the past, present, and future of CAPP for easy understanding. This paper's format consists of an introduction, a survey of CAPP, a discussion, and a conclusion. It also includes an overview of CAPP and its methodology, procedures, and technologies.

Research Gap: According to the literature, the majority of researchers concentrated on the process planning domain using the component's shape and size. However, by considering its amount of production each period, the most cost-effective machine is not chosen for each operation of the component. In order to choose the most cost-effective machine for each operation of the component and reduce the overall cost for the specified volume of production, a linear programming model has been developed in this study.

3 Objective

The goal of this research is to create a linear programming model to choose an affordable machine for each operation of the component in order to reduce the component's overall cost for a certain volume of production each period.

4 Linear programming model

A component with m operations is an example. On a group of machines [j = 1, 2, 3,..., n _ i], where i = 1, 2, 3,...,m, any operation i can be processed.

Let, *m* be the component's total number of operations.

If i = 1, 2, 3,... m, then n_i is the total number of machines that can process the operation.

The setup cost per unit of the operation I on its approved machine is sc ij. j = 1, 2, 3,...,m and i = 1, 2, 3,......, n_ i

The processing cost per unit of the operation I on its qualified machine is denoted by the symbol pcu _ij. j= 1, 2, 3,......, n _i and i = 1, 2, 3,....

v is the component's monthly production volume, for example.

If an operation employs a machine, then y _ ij = 1, where I = 1, 2, 3,..., m and j = 1, 2, 3,.., and n _ i.

= 0, i = 1, 2, 3,..., m and j = 1, 2, 3,..., n_ i if the operation i does not employ the machine j.

Table 1 provides examples of setup times, processing times per unit for each qualified machine in each operation of the component, and production volumes for that component over a period of time, such as a month.

Table 1 Generalized data for process planning

Machine j	Operation Number i	1	2	3	.	i	.	m
	Number of qualified machines (nm_i)	n_1=4	n_2=2	n_3=3	.	n_i =3	.	n_m =4
	1	sc_{11}	sc_{21}	sc_{31}	.	sc_{i1}	.	sc_{41}
		pcu_{11}	pcu_{21}	pcu_{31}	.	pcu_{i1}	.	pcu_{41}
	2	sc_{12}	sc_{22}	sc_{32}	.	sc_{i2}	.	sc_{42}
		pcu_{12}	pcu_{22}	pcu_{32}	.	pcu_{i2}	.	pcu_{42}
	3	sc_{13}		sc_{33}	.	sc_{i3}	.	sc_{43}
		pcu_{13}		pcu_{33}	.	pcu_{i3}	.	pcu_{43}
	4	sc_{14}		.	.	.	.	sc_{44}
		pcu_{14}		.		.	.	pcu_{14}

A linear programming model to determine the cost-effective machine to process each operation of the component such that the total cost of manufacturing the component is minimized for a given volume of production say month of that component (1).

$$Minimize\ Z = \sum_{i=1}^{m}\left(\sum_{j=1}^{n_i} y_{ij}\left(sc_{ij} + v \times pcu_{ij}\right)\right) \quad (1)$$

Subject to

$$\sum_{j=1}^{n_i} y_{ij} = 1, i = 1, 2, 3, \dots, m$$

Where,

m be the component's total number of operations

i = 1, 2, 3... m, where n i is the number of machines that can process operation i.

The setup cost per unit of the operation i on its approved machine is sc ij. j = 1, 2, 3... m and j = 1, 2, 3,......, n i

The processing cost per unit of the operation I on its qualified machine is denoted by the symbol pcu ij. j = 1, 2, 3... n i and i = 1, 2, 3,.... m

v is the component's monthly production volume, for example.

If an operation employs a machine, then y ij = 1, where i = 1, 2, 3,..., m and j = 1, 2, 3,.., and n i.

= 0, i = 1, 2, 3,..., m and j = 1, 2, 3,..., n i if the operation i does not employ the machine j.

The goal function includes the sum of the setup costs and processing costs of the qualified machines chosen for each operation for the component's specified volume.

For i = 1, 2, 3...m and j = 1, 2, 3,...,n i, the constraint i in the constraint set selects just one machine from among n i machines to carry out the component's operation.

5 Illustration of model using sample data

Sample data is used in this section to illustrate the linear programming model for process planning of a component that was described in the previous section.

In Table 2, sample information for process planning is displayed.

Table 2 Process planning example data

Machine *j*	Operation Number *i*		1	2	3
	Number of qualified machines (n_i)		n_1=3	n_2=2	n_3=3
	1	Setup cost	1000	1500	2000
		Processing cost per unit	500	400	700
	2	Setup cost	800	1300	2500
		Processing cost per unit	400	300	900
	3	Setup cost	1200		1500
		Processing cost per unit	600		450
	4	Setup cost			1750
		Processing cost per unit			600
Volume of production of the component per period say month (*v*)					6000

A linear programming model for the process planning model is as follows, and it is based on the data in Table 2 given above.

Minimize Z =1000* y11+500*6000*y11 +
800*y12+400*6000*y12 +
1200*y13+600*6000*y13 +
1500*y21+400*6000*y21 +
1300*y22+300*6000*y22
+2000*y31+700*6000*y31 +
2500*y32+900*6000*y32 +
1500*y33+450*6000*y33 +
1750*y34+600*6000*y34

Subject to
Y11+ y12 + y13 = 1
Y21+y22 = 1
Y31 + y32 + y33 + y34 = 1

Where,
y_{ij} = 1, if the operation I uses the machine j, i=1, 2, 3, , m and
j = 1, 2, 3… n
= 0, if the operation I does not use the machine j, i =1, 2, 3 . . . , m
and j = 1, 2, 3, …, n
v is the volume of production per month of the component and integer

The linear programming model of the processing planning problem's data in the format of LINGO software is presented in Figure 3. The result obtained from LINGO software are presented in Figure 4. Table 1 summarises the process planning issue based on the outcomes of the linear programming model depicted in Figure 4.

```
min= y11*1000+500*6000*y11 + y12*800+400*6000*y12 + y13*1200+600*6000*y13
     + y21*1500+400*6000*y21 + y22*1300+300*6000*y22
     +y31*2000+700*6000*y31 + y32*2500+900*6000*y32 +
     y33*1500+450*6000*y33 + y34*1750+600*6000*y34;
y11+ y12 + y13   = 1;
y21+y22          = 1;
y31 + y32 + y33 + y34    = 1;
@gin(y11); @gin(y12); @gin(y13); @gin(y21); @gin(y22); @gin(y31); @gin(y32);
@gin(y33); @gin(y34);
```

Figure 3 Linear programming model of the processing planning problem's data in the format of LINGO software

```
LINGO/WIN64 20.0.8 (17 Oct 2022), LINDO API 14.0.5099.185
  Licensee info: Eval Use Only
  License expires: 16 MAY 2023
  Global optimal solution found.
  Objective value:                              6903600.
  Objective bound:                              6903600.
  Infeasibilities:                              0.000000
  Extended solver steps:                               0
  Total solver iterations:                             0
  Elapsed runtime seconds:                          0.04
  Model Class:                                      PILP
  Total variables:                      9
  Nonlinear variables:                  0
  Integer variables:                    9
  Total constraints:                    4
  Nonlinear constraints:                0
  Total nonzeros:                      18
  Nonlinear nonzeros:                   0
                                Variable           Value        Reduced Cost
                                     Y11        0.000000            3001000.
                                     Y12        1.000000            2400800.
                                     Y13        0.000000            3601200.
                                     Y21        0.000000            2401500.
                                     Y22        1.000000            1801300.
                                     Y31        0.000000            4202000.
                                     Y32        0.000000            5402500.
                                     Y33        1.000000            2701500.
                                     Y34        0.000000            3601750.
                                     Row    Slack or Surplus      Dual Price
                                       1        6903600.           -1.000000
                                       2        0.000000            0.000000
                                       3        0.000000            0.000000
                                       4        0.000000            0.000000
```

Figure 4 LINGO software's output from a linear programming model

Table 1 lists the outcomes of the linear programming model used to solve the process planning issue

Operation i	Value of y_{ij} which has value of 1	Machine selected (j)
1	$y_{11} = 1$	2
2	$y_{22} = 1$	2
3	$y_{33} = 1$	3
Total cost of the solution	Rs. 69,03,600	

6 Conclusion

Process planning is a vital exercise to minimize the cost of manufacture of components in companies. In this paper, the process planning problem has been dealt in two stages. In the first stage, a linear programming model has been presented for this problem by taking the following data.

i. Number of operations of the component (m) for which the process planning task is to be carried out.
ii. Number of qualified machines (n_i) to process the operation i, i = 1, 2, 3, …., m.
iii. Setup cost and processing cost per unit in the machine j of the operation i of the component, i = 1, 2, 3, . . . ,m and j = 1, 2, 3, . . . , n_i.

In the stage, the linear programming model of the processing planning problem considered in this paper had been solved using LINGO 20.0 software. Then the linear programming model as used in LINGO 20.0 and its results are presented.

The linear programming model presented in this paper becomes a handy tool for process planning, whenever a new component is introduced to reconfigure an existing product or that component is used in a new product.

References

[1] HAYES, C., WRIGHT, P.: Automating Process Planning: Using Feature Interactions to Guide Search, *Journal of Manufacturing Systems*, Vol.8, No.1, pp. 1-15, 1989.

[2] KIRITSIS, D.: A Review of Knowledge-Based Expert Systems for Process Planning, Methods and Problems, *The International Journal of Advanced Manufacturing Technology*, Vol. 10, pp. 240-262, 1995.

[3] KULKARNI, P., MARSAN, A., DUTTA, D.: A Review of Process Planning Techniques in Layered Manufacturing, *Rapid Prototyping Journal*, Vol. 6, No. 1, pp. 18-35,,2000.

[4] MCGINNIS, L.F., AMMONS, J.C., CARLYLE, M., CRANMER, L., DEPUY, G.W., ELLIS, K.P., TOVEY, C.A., XU, H.: Automated Process Planning for Printed Circuit Card Assembly, *IIE Transactions*, Vol. 24, No. 4, pp. 18-30, 1992. https://doi.org/10.1080/07408179208964231

[5] NEWMAN, S.T.: Process Planning for Additive and Subtractive Manufacturing Technologies, *CIRP Annals*, Vol. 64, No. 1, pp. 467-470, 2014.

[6] PANNEERSELVAM, R.: *Production and Operations Management*, 3rd ed., PHI Learning Pvt Ltd., Delhi, 2012.

[7] PANNEERSELVAM, R., SIVASANKARAN, P.: *Process Planning and Cost Estimation*, PHI Learning Pvt Ltd., Delhi, 2016.

[8] SANCHOV, K., DAS, S.K., NAIK, S.: Process Planning for Product Disassembly, *International Journal of Production Research*, Vol. 40, No. 6, pp. 1335-1355, 2002.

[9] SORMAZ, D.N., KHOSHNEVIS, B.: Process Planning Knowledge Representation Using an Object-Oriented data Model, *International Journal of Computer Integrated Manufacturing*, Vol. 10, No. 1-4, pp. 92-104, 1997.

[10] YUSOF, Y., LATIF, K.: Survey On Computer-Aided Process Planning, *The International Journal of Advanced Manufacturing Technology*, Vol. 75, pp. 77-89, 2014.

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