Integration of An Irregular Cutting System into CIM. Part I - Information Flows

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Abstract: In this paper an Irregular Cutting System is described based on the paradigm of Visual Interactive Modelling. The system is described and a first analysis of its integration into CIM is performed, consisting of the study of its internal information flows.

1. Introduction

This work presents an irregular cutting stock system. Cutting stock systems attempt to optimize the layout of a set of pieces on a raw- material plate, achieving minimum waste of material. The NP-complete nature of the underlying optimization problem makes it necessary to combine mathematical programming with heuristic search methods and human interaction. The proposed system belongs to the category of tandem systems, because it combines knowledge based methods with mathematical programming. The interaction with the user goes along the lines of the VIM (Visual Interactive Modelling) paradigm.

As a result of its main features the proposed system will be named DSS-VIM-cutting (Decision Support System based on Visual Interactive Modelling for cutting).

The proposed system will be analysed from a CIM viewpoint, meaning that its main relationships with other manufacturing systems will be analysed in terms of information flows.

The paper is structured as follows. In the second section, we present the cutting stock problem, its representation and a proposed heuristic algorithm. The third section presents the structure of the DSS-VIM-cutting system which is composed of three subsystems: *Language, Problem Processing* and *Knowledge*, each one is described in detail.

The fourth section shows the interaction with other CIM systems of the company (CAD, CAQC, PPC, NC), from a CIM perspective.

2. The Irregular Cutting Stock Problem

Problem Description and Applications

The irregular cutting problem is established when we want to cut a set of moulds from a stock piece with the objective of minimizing the loss of material involved in the process. We can identify the following approaches to the problem:

Manual: Using a CAD System the user is capable of manipulating (rotating, translating, etc.) pieces inside of the plate area to generate the layout [2], [3].

Automatic: The layout is constructed based on an heuristic procedure that generates a near optimum nesting of the pieces on the plate [1].

Semiautomatic: An initial solution is automatically generated by the system. Interactive improvements of the initial solution are allowed by a conversational display unit, using a special set of commands to operate on the solution process [4]. The treatment of the problem by exact algorithms is not feasible, considering that it is NP-complete and it has complex geometric characteristics.

Considering the broad application areas of the problem, a large number of heuristic procedures has been developed in the literature. In this article we emphasize the application of this problem to the textile and shoe industry.

In those situations the generation of a cutting model is performed by an expert that, although has specialized knowledge of the problem, usually spends a lot of time in generating a layout that does not even consider its optimization.

With regard to the shoe industry special attention must be paid to the analysis of the problem that considers the raw- material texture, the presence of defects, etc.

In case of a synthetic material the problem may be analysed assuming that the raw- material is a rectangular plate.

Another application of the problem appears in the shipbuilding industry, where a layout of regular or irregular shapes, appropriate for non-guilhotine type of cuts, is generated on a steel rectangular plate.

Problem Representation

To represent the problem, the following elements are assumed:

- The geometric shapes of the layout pieces are approximately represented by circumscribed polygons. Moreover, the rectangular stock plate has a relatively large area in such a way that it fulfills all the demands. In some complex instances of the problem, for example, in the leather cutting, the stock material is approximately represented by a place area delimited by a polygonal boundary.
- The overlap of the pieces is not accepted and rotations of the pieces in the layout should be allowed. In some situations, the positions of particular pieces in the layout are restricted to specific regions of the raw- material.
- The objective is to build a cutting model that meets the demand and minimizes the loss of material involved in the process.

We apply a production system to the problem representation that is characterized by a database, states and a set of rules, [6], [5]. In the database each piece j of the demand is characterized by a closed polygonal region. The manipulation of the individual pieces by the algorithm is performed by supplying the vertices (x_{ij},y_{ij}) of its associated polygon.

For a generic stage of the procedure, the information in the database relative to a specific layout pattern defines a state of the system. Consider a E_m generic state defined by the set of k polygons:

$$E_m = \{P_1, P_2, \dots, P_k\}$$

Inside the universe of feasible solutions, characterized by the problem constraints, the rules that are applicable to the E_m state allow the allocation of a new P_{k+1} polygon to the current layout, leading to a new feasible state E_{m+1} (a child state of E_m). Figure 1 illustrates the configuration of a generic state of the system.

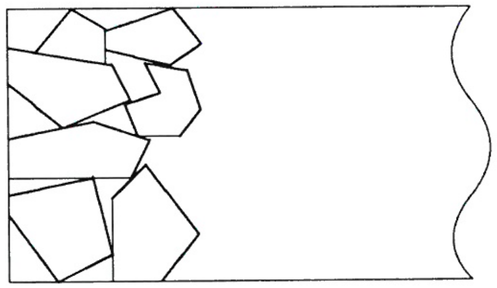

Figure 1. Configuration of a Generic State of the System

Considering the combinatorial characteristic of the problem, the layout process will be restricted to a bounded universe of possibilities, for example, only a specific set of orientations for the pieces on the plate will be analysed.

In this way, the problem to be solved is that of finding a minimal path on the state graph from the initial (empty plate) to its target state (exhaustion of the demand).

For a generic state E_n we associate a labelled element E^i (n, c, p) where:

n: the terminal node on the path from the root.

c: production cost of the layout associated with E_n.

p: pointer to another labelled element E^p(n', c', p').

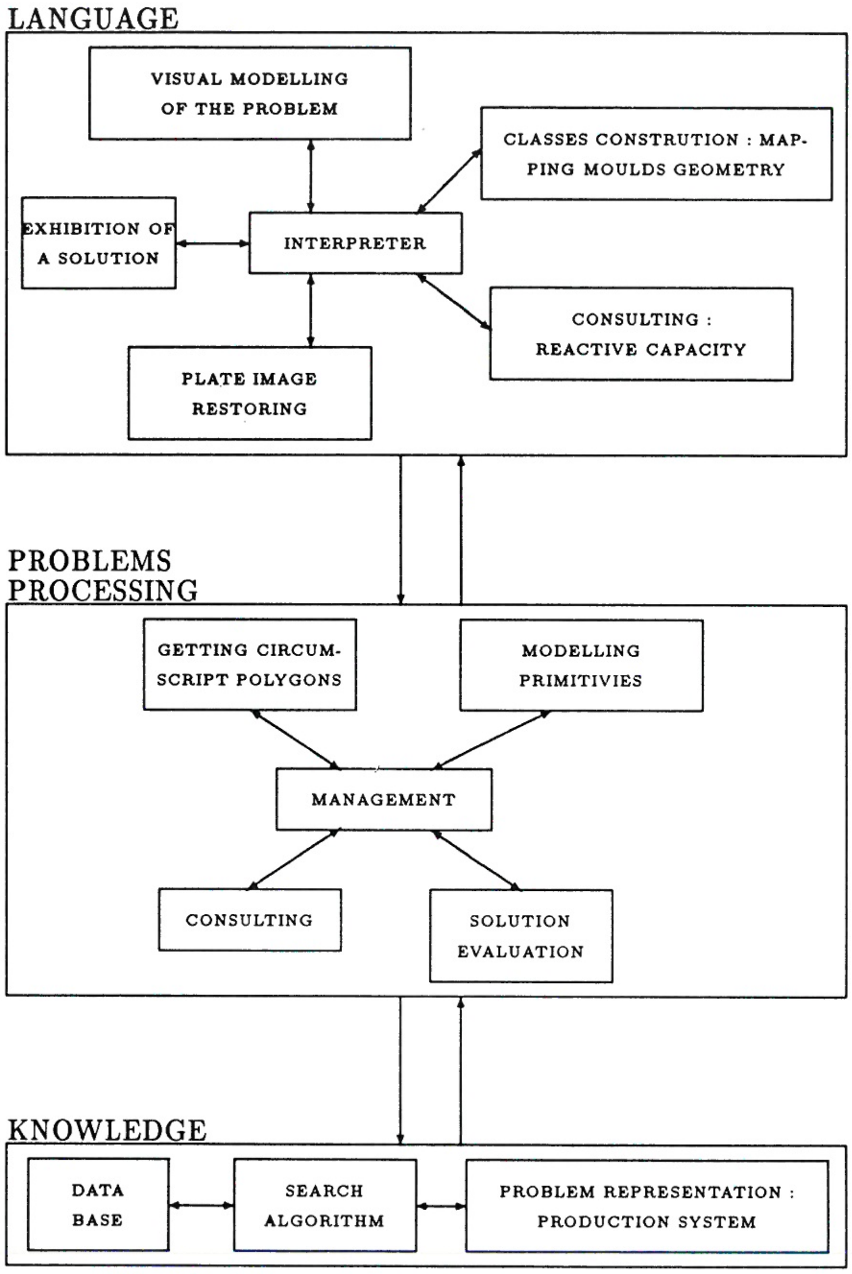

Figure 2. DSS – VIM – cutting

In this structure the initial state (empty plate) is represented by the element $E^0(s, 0, -)$, where s is the root of the graph. All the information related to a generic state E_n is represented by the node n of the structure.

Pattern Generation

Related to node n of the state graph we associate the evaluation function:

$f(n) = g(n) + h(n)$, where

$g(n)$: represents the cost for reaching the node n.

$h(n)$: an estimate of the cost to reach a solution from node n.

To describe the algorithm, a set, S, and two lists are necessary:

A: stores the nodes not yet analysed by the algorithm.

F: stores the nodes already explored.

In the algorithm below, the function *GERA(n)* generates child nodes of a generic node n.

Algorithm

```
Begin
  Insert the initial state in A (representation of the
  empty plate);
  F ← S ← ∅;
  Delete the initial state from A and insert it in F;
  Generate all child states from the initial state
  and insert them in A;
  Evaluate f(n), ∀n ∈ A;
  Stop ← False;
  While (Stop = False) and (A ≠ ∅) do
      Find n such that f(n) = min {f(m); m ∈ A}
      Delete n from A and insert it in F;
      If n is a final state then
        Stop ← True;
      Else
        S ← GERA(n)
        Evaluate f(j), ∀j ∈ S;
          Delete all nodes j ∈ S and insert them
          in A, updating the pointers if necessary;
        End-If;
  End-While;
  If Stop = True then
        "Solution Found";
  Else
          "Solution not Found";
  End-If;
End.
```

3. Functional Decomposition of the System

In this section, we describe the Decision Support System - DSS with respect to the problem of allocating pieces to be cut over a leather plate. The system encourages a strong user interaction through Visual Interactive Modelling - VIM [8]. Functionally, the system is composed of three subsystems: *Language, Problem Processing* and *Knowledge* systems. Figure 2 shows a detailed diagram of DSS-VIM-Cutting system.

Language

This subsystem performs the interaction with the user, which is based on the VIM (Visual Interactive Modelling) paradigm. It has the following functions:

Problem Visual Modelling: consists in modelling the problem by the visual aspect, i.e. constraints set up, stock plate(s) selection and moulds selection, which will participate in the layout. These are treated in the form of images. For example, in order to inform the system that such a mould cannot be alllocated on a certain region of the plate, this is done based on the plate and the mould set visualisation, i.e. the geometric configuration of the considered instance is shown on the screen.

Classes Construction: consists in mapping the moulds geometry using appropriate devices (camera, scanner, etc.), with the objective of supplying images to the database.

Exhibition of a Solution: at interface level, the task of this module is to exhibit on the screen the solution built by the user or computed by the system, so that the user should set up new guidelines to improve it.

Consulting: Beside allowing a systematic consulting of the database (moulds, plates, relation among objects, etc.), the system provides detailed justifications concerning any user intervention (reactive capacity).

Plate Image Restoring: In specific applications, this module has the function of getting the plate geometry and other features (texture, defects, etc.).

Interpreter: this module has the responsibility of the language subsystem management level and of setting the linkage between it and the other modules of the system.

Problems Processing

This subsystem exerts the central control on the solution search process, getting the basic algorithms from the Knowledge module and coupling it with interactive requirements of the user. Besides , it acts as mediator between the visual information format of the Language module and the database information format of the Knowledge module. It has the following functions:

Getting Circumscribed Polygons: the moulds manipulation by the fitting algorithm is possible through polygons. In this way, this module accomplishes the surrounding pieces to get the respective polygons.

Modelling Primitives: this DSS-VIM uses three basic building elements for model building:

- **Objects**: concrete or abstract entities (plate, pieces, etc.) with a set of attributes (type, area, shape, direction, location, etc.).
- **Relations**: objects describing functional or structural dependencies among other objects (neighbourhood, cutting areas, etc.).
- **Constraints**: constraints on object attributes values (e.g. piece 1 cannot be cut in area B).

Solution Evaluation: the language subsystem provides the user with choice of problem treatment re-direction based on the solution computed by the system. This module processes and provides justification to the criticism made by the user on the current solution.

Consulting: this module provides the user with information about moulds, plates, relation among objects, etc.

Management: this module makes the linkage of the problems processing subsystem with other subsystems. It also sets the data, model and knowledge management.

Knowledge

This subsystem contains the knowledge to perform the heuristic search, and the production system to represent the problem. It also contains the database that stores the main information shared by different functions of the system (pieces, plates, constraints, etc.). It has the following functions:

Database: information concerning:

- **Moulds**: their geometry and specific features according to their class.
- **Raw-Material**: in the synthetic material case there will be stored the length and width of the plate. When the raw-material is an animal skin, it is subregions geometry and some features with respect to texture and defect areas, that are stored.

Problem Representation: the problem is mainly represented by a production system. In this way, this module characterizes the system by defining:

- **States**: for any generic stage in the fitting process, a state is characterized by the plate layout and the set of pieces presented in the layout at that instant.
- **Rules**: set the strategy to generate a new state from the current one. This is done through the fitting of each piece along the profile associated with the current state.
- **Goal**: in the state graph, this represents the problem solution state which, in this specific case, represents the fulfilled plate or demand meeting.

Search Algorithm: the basic function of this module actually computes problem solution via a heuristic algorithm which performs a search in the state graph generated by the problem representation through a production system.

4. Integration with other CIM Systems

In this section, we approach the interaction of the DSS-VIM- cutting with other systems of the manufacturing environment from a CIM perspective [7]. Figure 3 depicts those other systems; the arrows indicate the direction of the information flows.

As shown in Figure 3, DSS-VIM-cutting interacts with the following manufacturing systems:

- *CAD*: Computer-Aided Design.
- *CAQC*: Computer-Aided Quality Control.
- *PPC*: Production Planning and Control.
- *NC*: Numerical Control of cutting machine.

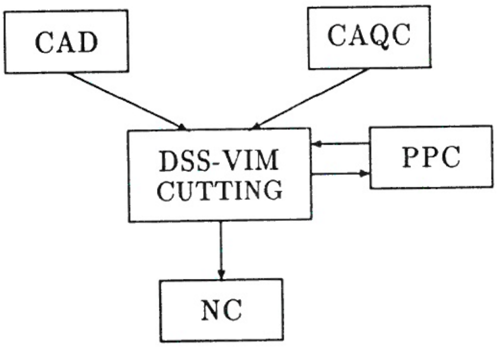

Figure 3. Manufacturing Systems Interacting with DSS – VIM – cutting

The interactions with those systems are as follows:

CAD: it supports the design of the product (e.g. shoe). It provides the DSS-VIM-cutting system with information about the parts (leather pieces), i.e. the shape, dimensions, tolerances, etc.

CAQC: quality control inspects raw- materials (leather plates) and finished products (shoes). Inspection of the leather plates can take place with an automatic vision system. The main features analysed and transferred to the DSS-VIM-cutting system are: shapes, dimensions, texture and defects.

PPC: it keeps records of actual customer orders and sales forecasts, and decides on what and when has to be produced or bought considering the inventory and the manufacturing capacity available.

This system provides the DSS-VIM-cutting with information about the type (size, colour) and volume of leather parts, as well as the due date. The existence of some slack in the schedule that the DSS-VIM-cutting receives from PPC is interesting, as it may offer better opportunities to optimize the layout of the parts, and produce less waste.

One important aspect of PPC is the raw- materials inventory control and the guarantee of the availability of leather plates. The DSS-VIM-cutting informs the PPC on the requirements of the cutting plan in terms of leather plates requiremets, in order that they are procured or reserved (if already in store).

The PPC may also provide the DSS-VIM-cutting with the information about the state of the cutting section of the shopfloor, detailing the state and work schedule of different work centers, as this information could influence the way DSS-VIM-cutting is operated (suppose one machine is down and another one has to be used which has a lower width, then a smaller plate would have to be used).

NC: the DSS-VIM-cutting generates a cutting plan in the form of a numerical control program which can be processed by an NC-machine to actually execute the cutting.

5. Conclusions

In this paper an Irregular Cutting System is described. The system, which is intended to be implemented and industrially applied, is currently in the design phase.The main application areas considered are the footwear and textile industries.

An effort has been made to combine three promising methodologies which are: knowledge based systems, mathematical programming and VIM.

The main interactions of the DSS-VIM-cutting system with other CIM systems (CAD, CAQC, PPC, NC) have been considered, in terms of the main information flows. Those information flows will, in future work, be made precise by creating a conceptual data model. An architecture has to be chosen for the information considering such issues as persistency and the desired sharing capability. Openness is viewed as an important requirement of the mentioned information system design. The main standards in the field (STEP, etc.) will be considered in terms of both data models and integration architectures.

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