INDUSTRIAL SCOPE OF 2D PACKING PROBLEMS

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ABSTRACT

Packing problems are optimization problem encountered in many areas of business and industries and have wide applications. These problems look for good arrangement of multiple items in some larger containing regions with an objective to maximize the utilization of resource materials. 2D packing problem has wide industrial applications starting from small scale industries related to leather, furniture, glass, metal, and wood to large scale industries dealing with textile, garments, paper, shipbuilding, automobiles and VLSI design. It has been observed that using automated nesting solutions based on heuristics prove to be better over conventional methods where very few intuitive arrangements were tried by experienced craftsmen and in that case final layouts were dependent on the dexterity of skilled craftsperson. In this paper authors have summarized the different approaches used to solve 2D packing problem along with their industrial applications. Accordingly, this study is an academic review of the industrial applications of 2D packing problem.

Keywords: Packing problem, Trim Loss problem, Rectangle Packing, Bin Packing, Cutting and Packing.

1. INTRODUCTION

In the shipbuilding, electronics, metal, glass, paper, garment industries the problem of cutting/ laying rectangular pieces from stock sheets is a frequent feature. High material utilization is of particular interest to mass production industries since small improvements in the layout can result in large savings of material and considerably reduction in production cost. Among the wide-ranging objectives, all stock layout problems follow a common goal, which is to lay parts on the stock sheet so as to maximize sheet utilization or minimize trim losses. Knowledge about physical phenomenon, together with the appropriate selection and pursuit of objectives through organized activity, have always motivated researchers to suggest different heuristics to find optimal layouts. Using automated nesting solutions based on heuristics prove to be better over conventional methods where very few intuitive arrangements were tried by experienced craftsmen and in that case final layouts were dependent on the dexterity of skilled craftsperson. Ever increasing performance to price ratio of desktops has made these a popular tool among researchers to try various intuitive heuristics. The manual generation of layouts is costly in terms of man-power hence methods for the automation of packing are being sought (Singh and Jain, 2008, 2009a-b).

2. SCOPE OF 2D PACKING

Paper industry

The first work into cutting and packing was conducted in the 1950-1960s and addressed problems were from within the paper industry. Fig.1. shows an example of six boxes that drawn from a standard paper sheet as example of C&P problem of paper industry.

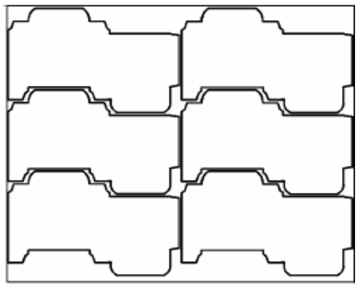

Fig. 1. Arrangement of six packages in a paper sheet (Selow et al. 2007)

Different methods have been suggested by many researchers to solve the paper cutting problem. The following section summarized the work reported of this problem:

Eisemann (1957) and Vajda (1958) first time reported the use of linear programming techniques for cutting of roll of paper into desired pieces on a restricted guillotine variant of the orthogonal packing problem. Hahn (1968) developed the methods for cutting up sheets with defective areas into given pieces while minimizing waste. Author used dynamic programming technique, which requires a value to be attached to each size. The computer program senses the defects and fits pieces into the clear portion of the sheet in such a way that it results in maximum sheet utilization. In order to shorten machine time, some simplifying shortcuts were reported.

Johnson and Rennick (1997) in their study used Skiving process (process of joining smaller rolls to form larger rolls) for solving the C & P problem of paper industries. When this process combined with traditional roll-cutting technology, profitable solutions to once hopeless one-dimensional cutting stock problems was found.

Harjunkoski et al. (1998) presented the paper on trim-loss problems, often named as cutting stock problem. The problem was non-convex due to certain bilinear constraints. Authors transformed this problem into linear or convex form. The resulting transformed problems, thereafter, be solved as mixed-integer linear programming problems or convex mixed-integer non-linear programming problems.

Aboudi and Barcia (1998) used linear programming methods for the paper cutting industry that also dealt with defective areas that can appear through manufacturing glitches. A defective area cannot be used when cutting out product rolls.

Giannelos and Georgiadis (2001) presented a new mathematical formulation for the short-term scheduling of cutting-stock processes on multiple parallel machines. A Mixed-Integer Linear Programming (MILP) model was proposed, solved to optimality using standard techniques A salient feature of the model was the explicit treatment of change-over times as integral part of a comprehensive multiple objective cost function, which can be adapted to minimize makespan, total flow time, or any combination of the two. An industrial case study from Macedonian Paper Mills, Greece has been used to illustrate the applicability of the developed algorithmic approach in a daily cutting schedule.

Menon and Schrage (2002) developed a procedure, based on the construction of tight sub problem bounds, for solving dual-angular integer programs. The method was illustrated by solving actual problems from the paper industry. This approach significantly reduces the effect of symmetry and hence is of particular interest.

Selow et. al (2007) proposed methodology for obtaining optimized packing arrangements layout in a sheet of paper using Genetic algorithms (GA) and heuristic approach. These methods consist of a sequence of steps: the packing representation, the packing operations, the heuristic search, the search space encoding schemes and the formulation of the cost function.

Wood industry

Wood used to be the most common material for packaging, workbenches, shelves, tools, buildings and interiors design. The wood cutting industry has also been the subject of stock cutting research. Different methodologies reported in wood industries are summarized in following section.

Morabito and Garcia (1997) reported the problem of cutting rectangular plates into smaller ones in Brazilian hardboard industry. The problem was to determine the best patterns to be cut by an automated machine composed of a set of circular saws, device to move and hold the plates and loading and unloading stations. A particular two-phase column generation procedure was described for the cutting stock formulation of the hardboard industry. Each phase of the procedure was modeled as an integer program and solved by two alternative methods. The first was a dynamic programming based integer program and the second was a simple extension of the algorithm presented in Gilmore and Gomory (1963). In continuation Hopper and Turton (1999) studied the problem consisting of packing rectangular items onto a rectangular object while minimising the used object space. The packing process has to ensure that there is no overlap between the items, which are allowed to rotate by 90°. Authors applied two genetic algorithms (GAs) to solve this problem. Both GAs were hybridised with a heuristic placement algorithm, one of which is the well-known Bottom-Left routine. A second placement method has been developed which overcomes some of the disadvantages of the Bottom-Left rule. The two hybrid genetic algorithms were compared with heuristic placement algorithms.

Morabito and Arenales (2000) analyzed practical aspects of the application of a cutting stock model to a Brazilian company that manufactures furniture on a large scale with a high degree of standardization. The model was based on the classical approach of Gilmore and Gomory (1965), which combines a linear programming and a column generation procedure. Besides the two-stage and three-stage guillotine cutting patterns, authors also considered one-group guillotine patterns that improve the productivity of the cutting equipment. Examples derived from the furniture company was used to illustrate some of the trade-offs involved, in particular the trade-off between cutting simpler patterns and patterns that yield less waste material, but reduce the productivity of the cutting machine.

Reinaldo and Luciano (2007) described approaches to generate cutting patterns that minimize the cost or waste of material, considering different particular constraints associated with longitudinal (horizontal) and transversal (vertical) saws, head cuts (head cuts are the vertical guillotine cuts that divide the plate into two parts), book rotation (a complete turn of 180°) and item unloading stations of the cutting machine. The method was based on dynamic programming recursive formulas combined with greedy constructive heuristics and the primal simplex algorithm.

Glass industry

Glass cutting almost always involves the rectangular guillotine variant of the stock cutting problem. In the glass industry holding good stock sizes appears to have at least as big an impact on trim loss as cutting up the stock plates efficiently. Chambers and Dyson (1976) described two techniques heuristic method and integer programming algorithm for determining "optimal" stock sizes. Several actual applications within the glass industry were described and solved using these techniques. Illustrative results of the improvements in wastage that achieved were discussed by the authors.

Bisotto and Corno (1997) reported genetic algorithm based solution to an optimization problem arising in flat glass cutting. The algorithm, called Genetic Glass Optimization Algorithm (GGOAL), aims at reducing the glass loss while keeping constant the total cutting time. The implementation of the algorithm has been chosen so that it can run in parallel with the actual cutting of a glass sheet by using the same personal Computer embedded in the cutting machine. It is therefore possible, at no additional hardware or software cost, to allow even small and medium glassmakers, which formerly could not afford the software investment, to benefit from the cutting pattern optimization.

Puchinger et al. (2004) described a combined genetic algorithm/branch & bound approach for solving a real world glass-cutting problem. The GA (Genetic Algorithm) uses an order-based representation, which is decoded using a greedy heuristic. The B&B (Branch & Bound) algorithm was applied with a certain probability enhancing the decoding phase by generating locally optimal subpatterns. Reported results indicate that the approach of occasionally solving sub patterns to optimality may increase the overall solution quality.

Arbib and Marinelli (2007) reported the assortment and trim loss minimization problem arising in an Italian plant, operated by Pilkington, which produces glass parts for the automotive market. Glass cutting was organized in two phases: in phase I large rectangular sheets of the same type were obtained from a ribbon of flat glass and sent to warehouse and in Phase II sheets of various types were taken from warehouse and cut into smaller rectangular parts of various sizes in order to satisfy a given demand. In both phases, a trim loss occurs. In this study authors used heuristic algorithm based on a p-median model with additional constraints that take into account all the relevant shop floor requirements for solving the problem.

Yaodong and Yiping (2009) discussed a rectangular two-dimensional cutting stock problem in the steel bridge construction. It was the problem of cutting a set of rectangular items from plates with arbitrary sizes that lie in the supplier specified ranges, such that the necessary plate area was minimized. This paper presents a heuristic algorithm for two dimensional cutting stock problems in bridge construction. The heuristic algorithm used both recursive and dynamic programming techniques to generate patterns.

Textiles industry

In textiles industry the cutting of clothes from material rolls offers many difficulties that must be handled by any automated approach (Fig. 2). Such problems may include patterned rolls of materials and, hence, rotational constraints on the orientations in which clothing can be cut (when pieces are stitched together, patterns must be aligned). Further to this, highly irregular shapes are usually involved, requiring complex geometric handling, and defective areas may be present within the material rolls (which, in general, must be identified by human operators). Some literatures for solving this problem using C & P approach are given below:

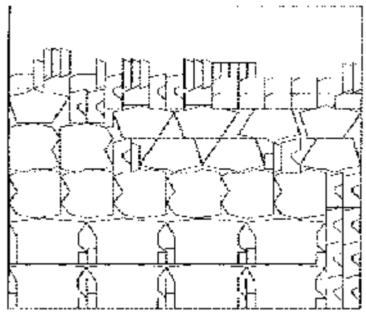

Fig. 2-Irregular packing problem from the textile industry (Hopper and Turton 2001)

Adamowicz and Albano (1976) first time described the use of cutting and packing concept in textile industries. They explained the need of complex modeling that is required by the high irregularities within shapes and sheets. Author described in this problem, one is given a number of rectangular sheets and an order for a specified number of each of certain types of two-dimensional regular and irregular shapes. The aim was to cut the shapes out of the sheets in such a way as to minimize the amount of waste produced. A two-stage solution was proposed in which the problem was converted from one of placing irregularly shaped pieces to one of allocating rectangular modules. The clustering algorithm used in the first stage to produce rectangular modules was presented and the results obtained when it was applied to some typical layout problems were described.

The cutting operation in the high fashion clothing industry essentially involves putting several layers of cloth on a long cutting table and fixing templates of the parts of several articles on top of the stack before the actual cutting can be initiated. This is a very time-consuming task giving raise to high set up costs in addition to waste production resulting from the cutting process. Total production costs can then be optimized by minimizing the number of these setups while at the same time producing little or no waste. In this paper a mixed integer programming model was proposed that searches for an optimal set of cutting patterns, each giving a combination of articles to be cut in one operation, and corresponding stack heights (Degraeve and Vandebroek, 1998).

Chryssolouris et al. (2000) presented a scheduling approach for the combined problem of production scheduling and nesting. The approach involves the generation of scheduling alternatives, their transformation through a rule base mechanism into nesting solutions and finally their evaluation using different criteria that reflect the overall production objectives such as meeting due dates, minimizing of the cost and maximizing the machines and stock sheet utilization. The proposed approach has been implemented in a software system for the purpose of solving a problem in the textile industry. Specifically, the scheduling of the carpet weaving process a problem of nesting rectangular patterns under complex production constraints-has been examined. The results showed that the proposed approach might be applied in real-life manufacturing processes under complex production constraints and multiple objectives.

Julia et al. (2001) introduced a new method for finding the nonfit polygon of two polygons. The nonfit polygon is a powerful and effective tool for handling the geometry required for a range of solution approaches to two-dimensional irregular cutting-stock problems. The primary purpose of this paper was to correct this misconception by introducing a new method of calculating the nonfit polygon. Although it was based on previous approaches which use the mathematical concept of Minkowski sums, this new method can be stated as a set of simple rules that can be implemented without an in depth understanding of the underlying mathematics.

Degraeve et al. (2002) proposed alternative integer programming models for solving the layout problem in the fashion industry. The problem consists of finding good combinations of templates and the associated height of the stack of cloth to satisfy demand while minimizing total excess production. Authors described two alternative formulations for a layout problem in the fashion industry. In 1st formulation the objective function was minimization of total production and the demand constraint is each size demand satisfied. In 2nd formulation objective function was as previous, i.e. minimizing total production, and the demand constraints, and additional constraints was modeling the maximal number of patterns to be selected and the maximal height of the stack and minimal number of stencils to be used for each size.

Yeung and Tang (2003) proposed a hybrid genetic approach for the cutting operation in the clothing industry. Garment cutting is a typical strip-packing problem, which is considered to be NP-complete. Authors proposed that with a combination of genetic algorithm (GA) and a novel heuristic algorithm, "lowest-fit-left-aligned," the cutting problem may transformed into a simple permutation problem, which can be effectively solved by the GA, and the searching domain will greatly reduced. From the simulation results, it was demonstrated that the optimal results can be obtained in a reasonably short period of time.

Martens (2004) built a pair of Genetic algorithms (GA) to solve a layout problem in the fashion industry. The GAs differed from each other, in that they were based on two alternative integer programming models. Author successfully built a GA that achieves high accuracy on small problem instances and that was capable of solving large, real life layout instances in an acceptable amount of time. GA was based on the Non Linear integer programming (NLIP) formulation.

Leather and footwear industry

In practical problems as found in the textile and leather shoe making industries the parts are irregularly shaped and in the case of shoe manufacture the surface shape is also irregular (Fig. 3). Consequently, the leather nesting problem involves placing a set of plane irregularly shaped parts on a plane irregularly shaped surface which is also characterized by further constraint requirements. The leather cutting industry has also been the focus of some of the latest work into cutting and packing, reported in the following section.

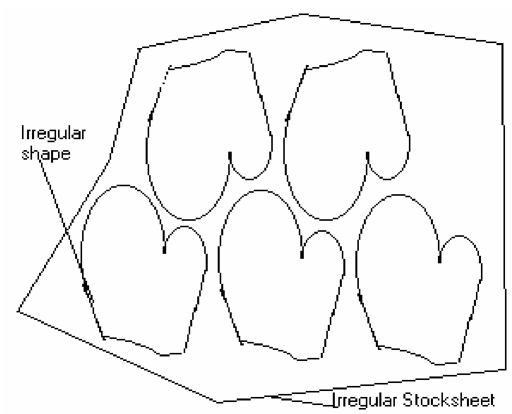

Fig. 3. Irregular shapes and irregular stock sheet (Singh, 2001; Singh & Lall, 2001)

Bounsaythip et al. (1995) carried out the study with objective fit in optimization of apparel shapes layout and mark all the shapes to be cut onto the sheet by minimizing unoccupied spaces using genetic algorithms. As genetic algorithm used alone was not found very efficient, so authors decided to hybridize GA with simulated annealing (SA) approach.

Crispin et al. (2003) addressed the problem of leather-lay planning for the footwear industry. Leather 'hides' have considerable variability in: i) the strength of the leather, ii) direction of this strength and iii) regions of differing quality. These factors often severely restrict potential placements of shapes and the variability in hides generally requires human operator input to either oversee the entire process or to define the areas of strength (unless X-ray techniques are used). The authors used an imaging technique to generate no-fit polygons of the sheet and the shapes and then used genetic algorithms to generate shape angles and nesting direction.

Crispin et al. (2005) described genetic algorithm coding methodologies for the leather-nesting problem, which involves cutting shoe upper components from hides so as to maximize material utilization. Authors develop a solution for leather nesting using two coding methodologies both based on no-fit polygon calculations. The first approach was based on a local packing paradigm and demonstrates how a window area was used to imitate the actions of a human lay-planner. The second approach was based on a graph connectivity strategy. Graph nodes were considered to have properties shape order, shape angle and placement angle.

Hsu-Hao and Chien-Li (2009) proposed a methodology that integrates in-house placement heuristics with genetic algorithms to solve the nesting problems of shoe making. The problems are classified as placing a set of irregular patterns on a regular area and limited to at most two different types of patterns on the area. Because of the intractability of the nesting problem, author's objective was to utilize genetic algorithms' fast convergence and solution quality to improve material utilization and reduce the calculation time of the pattern.

Sheet metal industry

Metal cutting is of interest because of the wide range of operational considerations that may occur. For example, the material costs can vary considerably, from thin aluminium to processed metals that can have thicknesses of several centimeters (or even meters in the case of power station reactor linings). This generally has an impact on the amount of computation time that one would be willing to allow an automated strategy. In the aluminium case the importance of generating the optimal layout is probably secondary to producing a quick solution as minimal cost savings can be achieved and it is important to keep the production line operating. However, thick processed metals have high unit cost and every improvement in material utilization can yield significant cost savings.

Tokuyama (1985) presents the characteristics of a cutting stock problem for large sections in the iron and steel industries. Author developed a two-phase algorithm using a heuristic method. This algorithm gives nearly optimal solutions in real time. It is applied to both batch-solving and on-line solving of one-dimensional cutting of large section.

In the steel industry, as hot steel products exit the producing facility, they are cut at primary saws (hot saws) into shorter pieces. After these pieces cool, they are inspected for defects and either applied directly to customer orders or further cut to ordered lengths at secondary saws (cold saws). In this case study, authors described the use of hierarchical algorithm, DYNACUT_CS that is a depth-first, branch-and bound, one-dimensional cutting stock algorithm and efficiently and effectively generates cutting patterns for material that is to be cut at cold saws. DYNACUT_CS strives to maximize yield over all the material cut and simultaneously tries to minimize overgrading (applying higher quality material than specified by the customer). This approach has been implemented for a variety of products at several different Bethlehem Steel Corporation facilities (Francis et al. 1999).

Nonas and Thorstenson (2000) attempted a stock cutting problem from a Norwegian off-road truck production company whereby the majority of the parts required for production of the trucks are made in-house. The authors presented three local searches and column generation approaches but restricted the problem such that only sheets with common dimensions were used. The solution algorithms considered are categorized as global or local algorithms. In the first category they reviewed the extreme point ranking method by Murty (1968), and suggested a linear under estimator for our concave objective function. The extreme point ranking method was then used with reasonably good results. In the second category of algorithms, three local search methods that operate among the local optima `around' the optimal cutting-stock solution were suggested.

Kos and Duhovnik (2002) reported a hybrid genetic algorithm that packs items into both available objects from the inventory and variable-sized objects from the stock. The algorithm tries to minimize waste. Large trim loss items were returned as remnants to the inventory for subsequent optimizations.

Yaodong and Xiaoxia (2008) described stainless steel rolls are often cut into circular items to make such common commodities as water jugs, buckets, pails, pots, cups and basins. The items are often cut with the shearing and punching process that consists of three stages. A guillotine shear cuts the roll into sheets at the first stage, and cuts the sheets into strips at the second stage. A stamping press punches out the items from the strips at the third stage. The sheets and the strips may be either rectangles or parallelograms. The height of the sheets is the same as the roll width. A strip contains one or more rows of items, and is parallel to a side of the sheet. This paper described an algorithm to generate optimal cutting patterns for the three-stage cutting process mentioned above. The algorithm used a knapsack procedure to generate optimal cutting patterns on the sheets, and uses a linear programming approach to determine the number of sheets cut according to each pattern. The computational results indicate that the algorithm is efficient in both computation time and material utilization.

3. CONCLUSIONS

Cutting and packing problems appear under various names in literature, e.g., cutting stock or trim loss problem, bin or strip packing problem, vehicle, pallet or container loading problem, nesting problem, knapsack problem etc. Many other industrial problems exist which possess a similar structure, e.g., capital budgeting, assembly line-balancing and processor scheduling. The paper is a pure academic activity that catalogues latest research in the area in addition to the earlier surveys made by Brown and Dyckhoff (and other patented surveys) that are easily accessible in the cyberspace. The basic purpose is to enumerate popular contemporary methodologies available in the literature for solving variety of these problems.

It is being inferred that during the past few years the subject of cutting and packing has fascinated the researchers all over the world. The reasons are but obvious:

i. There is a large scope of the applicability of the research as cutting and packing problems are being encountered in many industries e.g., paper, glass, plastic and foam, leather, sheet metal cutting, furniture, garments, ship-building, shoe-making, car production, building materials, packaging etc.

ii. Most of the standard problems in this area are known to be NP-complete. Obviously, the development of exact algorithms which are faster and produce near optimal solutions is still a major research issue in this area. Proliferation of sophisticated desktops and faith of researchers in metaheuristics have further allowed the researchers to look beyond the traditional optimization techniques to solve this hard problem. Genetic algorithms, graph partitioning, simulated annealing, ant colony optimization and many other techniques are being used to tackle the cutting and packing problem. It has been observed that there is an escalating trend in the use of computers in production process that allow better simulations and effective decision making. Sophisticated CAD/ CAM packages, easy to use front-end interfaces, sophisticated databases at backend and use of evolutionary approach to tackle these problems and above all easily affordable desktops that allows researchers to implement their solution strategies effectively, all these have really fascinated researchers to work on this real life application.

iii. It has been observed that even though commonality can be observed in the cutting and packing problems, these problems need so many manufacturing constraints to be woven in the solutions, which are peculiar to a particular type of industry. So there will always be a scope for reformulation and accordingly algorithms to be adjusted to the specific needs of a particular industry. The popularity of the problem can easily be imagined as now there is a special group of researchers, practitioners and academicians who are working on the problem domain of cutting and packing known as SICUP (Special Interest Group in Cutting and Packing).

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