WAREHOUSE LAYOUT DESIGN: MINIMIZING TRAVEL TIME WITH A GENETIC AND SIMULATIVE APPROACH - METHODOLOGY AND CASE STUDY

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ABSTRACT

This paper deals with the warehouse layout optimization problem with respect to the distance reduction and the travel time minimization. The authors also searched for a flexible tool in order to optimize layout functionally to the fluctuations in demand and inventory level. The addressed optimization problem is a constrained optimization problem on an integer domain and it is shown to be NP-hard. The wide applicability of evolutionary computation and its good performances on a variety of different optimization problems have led to a strong interest in this type of algorithm. A heuristic genetic algorithm have been developed and a system for the effective assignment of the storage area to the different class of items is presented. The system is based on the association of a genetic algorithm and a deterministic simulation model.
Computational experiments are conducted to verify the effectiveness of the algorithm. They were made by applying the proposed tool to a real industrial case concerning an Italian soft drinks company.
As a result, the authors intend to provide a tool for warehouse layout and operations optimization that could be attractive for operation management researchers and realistically applicable by practitioners.

INTRODUCTION

Warehousing can be defined by three functions: i) receiving goods from a source; ii) storing goods until they are needed by a customer (internal or external); iii) retrieving the goods when requested.
Storing material for an internal customer implies the need for work-in-process storage, whereas storing goods for an external customer may imply the need for finished products storage. However, the functions of warehousing remain the same and successful warehouse layouts must accomplish the following objectives, regardless of material being stored: maximize the use of space, maximize the use of equipment, maximize the use of labor, maximize accessibility to all items, maximize protection of all items.
Although the objectives of warehouse layout and operation are easily recognized, warehouse layout problems are often complicated by a large varieties of products needing storage, varying areas of required storage space and drastic fluctuations in product demand.
Optimal approaches to warehouse layout problems often consider a single objective (e.g. maximize floor space utilization) and/or provide a solution to a static problem.
Warehouse design problems are further complicated by alternative storage methods and equipment.

CA.RE. PROJECT

Frequently large companies, characterized by advanced production planning and control methodologies and an high technological level, are supported by small-medium enterprises (SMEs) which, in many cases, when not integrated in efficient industrial districts or linked to a consolidated network, can show remarkable structural limitations and low competitiveness. In this scenario, research activities devoted to improve ICT systems of SMEs are useful. This work has been developed within the CA.RE. project and it is just related to the whole re-organization of a SME, working in the large consume goods market, producing and selling soft drinks for the Italian and the French markets.

Importance of Finished Goods Warehouse Management

In several cases inventory management has a strong impact on the economics of a large-consume good company. Even if inventory management is primary related to demand forecasting and master scheduling, material handling is a critical issue of this process since the total lead time depend on it. Moreover it's a not value-added time-consuming activity. For this reason finished goods allocation within the storage areas is here addressed as a critical activity and it's deeply analyzed in order to reach an effective allocation of the finished goods. The reduction of the global storage cost through the minimization of the total travel time is the main goal of the proposed system, named Z-Sim.

THE INDUSTRIAL CASE

The studied company bottles mineral water and soft drinks in 8 different sizes and commercializes 15 types of soft drinks, producing 9 item classes. The structure of the warehouse is based on 11 blocks with a total number of storage cells equal to 4408; these cells have to be divided over the 9 commercialized items. Unit travel costs are item-dependent and different items cannot be mixed in a cell.

Physical constraints

Two different pallet formats are used inside the plant. The total length of each block binds the pallet number that can be inserted functionally to the specific assignment done. This last aspect plays a crucial role in the definition of an effective problem code and functionally to the constraints which make very difficult the research of an optimal solution: the constrained optimization problems are considered GA-hard [Chambers 1995].

Constraints related to the system performance

The execution time of the research algorithm is mainly used to evaluate the fitness of each member of the population. Thus it is necessary to optimize the computation avoiding this calculation whenever the configuration is characterized by an item place number less than the maximum allowed stock quantity. This approach introduces several typical limitations of constrained optimization problems (COPs).

Constrained Optimization Problems

A COP is defined on a free research space $D_1 \times \ldots \times D_n$, through a function F, which has to be optimized, and from several constraints $[c_{11}, \ldots, c_{kk}]$ which have to be satisfied. The constraints, characterizing the proposed industrial case, have a strong impact on the choice of the genetic operators: by increasing the number of constraints the probability to determine not-feasible configurations increases and the research process efficiency decreases. A critical aspect of this type of approach is to guarantee that the genetic operators maintain the constraints not considered in the fitness function.

In order to reach this target it is possible to apply three different approaches:

1. *filtering*: not acceptable descendants are eliminated;
2. *repairing*: not acceptable descendants are modified through a member post-processing operation;
3. *preserving*: starting from acceptable parents by using specific genetic operators the acceptable descendants creation is promoted.

Z-Sim implements specific genetic operators (*preserving*) supported by a *repairing* routine.

Z-SIM ARCHITECTURE

The development of the optimization process has been realized in order to achieve a rational and efficient assignment of pallet places with respect to the different item typologies. Starting from the demand forecasting and from the MPS (i.e. master production schedule, the movements foresee inside an annual planning horizon), Z-Sim has to determine a finished goods spatial allocation for which the travel time is minimum. The proposed approach adopts a genetic algorithm to explore the wide research space and to evaluate the fitness by using a deterministic simulator. The simulation plays a basic role inside the GAs research process. In fact the evolutionary computation requires the definition of a fitness function which, in many real cases, in not possible to explicit analytically. Therefore the simulation represents a suitable tool for candidate solutions' fitness evaluation.

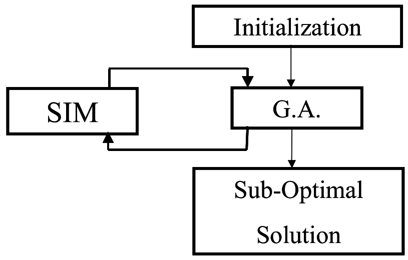

Figure 1: Main Units of Z-SIM Architecture

DESIGN OF A GENETIC ALGORITHM FOR COPs

Adopting a genetic approach, an import issue concerns the data structures able to code the problem. The adopted representation uses a chromosome matrix; the alphabet is composed by ten symbols: nine of those are referred to the existing items while a special char identifies not assigned places. Genetic search is generally based on three main genetic operators. They are selection, crossover and mutation [Mitchell 1998]. The adopted operators are partially derived from already applied heuristic approaches [Chambers 1995], modified and integrated whenever not satisfactory; moreover some new operators have been designed in order to improve the performances and the research process.

Crossover Operator

Scanning gene is the operator that are most frequently used to combine different members, reducing the generation of unfeasible (i.e. outside the research space) solutions. The idea on which the *scanning* is based proposes to position a marker on parents consecutive positions and then to choose one of the marked position values in order to derive the new descendant value. In the *uniform scanning* case the choice over marked genes is made through a casual mechanism according to a uniform distribution; in the *occurrence-based scanning* case the most occurring value is selected choosing among the marked ones. Two solutions have been adopted for the markers advance during the crossover process: the first one implies that all the markers related to the descendant's chosen value have to be updated (i.e. right shifted); the second one provides the updating of all the markers independently from the marked value.

Besides the two described solutions (*uniform* and *occurrence scanning*) a two-points standard crossover mechanism and a new operator, named *Holland schemes preserver,* have been implemented. This latter procedure implies the use of markers, like in the case of *occurrence scanning*, with the assignment of the most frequent value to the descendant only in the case in which that value occurs at least three times; if this is not true the value is chosen, from the adopted symbols dataset, in a random way.

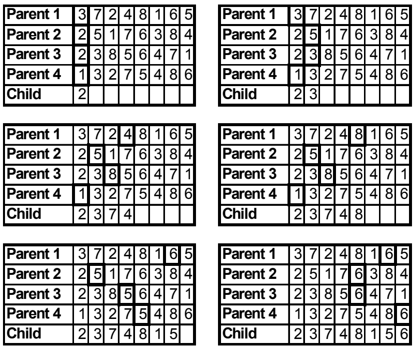

Figure 2: Basic Gene Scanning Operator in the Case of Sequences without Symbol Replications

Mutation Operators

By considering the mutation operators five new heuristics, especially studied with respect to the investigated problem, have been introduced; these heuristics are completely extendible to other COPs and are suitable to preserve the promising features of individuals. By realizing specific operators it needs to pay attention to two fundamental requirements:

1. it is necessary that the operator preserves promising solutions and in particular it is necessary to perform permutations of chromosome portions;
2. it is important to bound significantly the random substitution of the genes, that is typical of mutation operator. This type of mechanism, common for a larger part of free optimization GA applications, is fatal in the COP case.

SIMULATION FOR FITNESS EVALUATION

By looking at the minimization of the total travel time, the Authors decided to use a fitness function defined as the total time that trolley consume. The calculation of the fitness value of a specific warehouse configuration (i.e. the assignment of each storage cell to a specific item) is performed through a deterministic simulator.

The distance made by a trolley during a movement from a production line to a storage cell and from the storage cell to the distribution vehicle is identified by three paths:

- a constant path, which is equal to the distance between plants and block;
- a path perpendicular to the block section composed of two different routes:
  - the route to reach the border of the storage block;
  - the average route needed to pick a pallet inside the pile (B);
- a path, parallel to the block section, needed to arrive from the first pallet of the block to the place in which the pallet is picked-up (C).

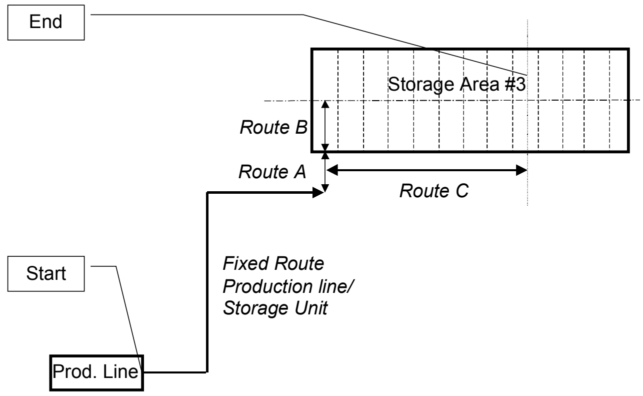

Figure 3: Description of the Path followed by a Trolley storing Finished Goods

During the research space exploration process 11 physical constraints and 9 constraints related to the system performance have been considered.

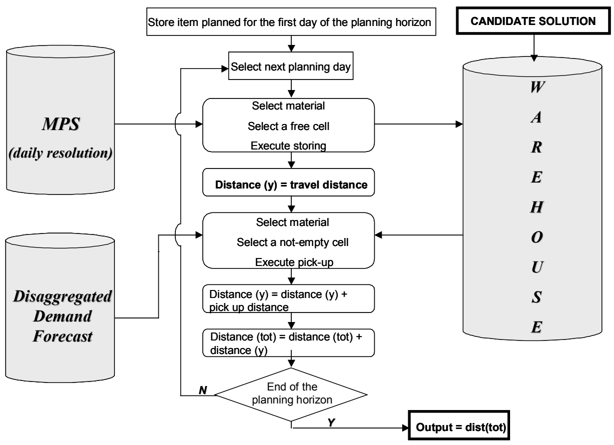

Figure 4: Block Diagram of the Fitness Evaluation Module

BONUS/ MALUS FITNESS COMPONENT

The described finished goods warehouse is managed in a non-automatic way. Therefore a pallet place assignment procedure, even if optimal from a performance viewpoint, implies management difficulties (i.e. the assignment of item-place is hard to memorize). It would imply the abandoning of the solution found by the GA in favor of a better usability. For this reason, in Z-SIM the fitness function is integrated by a component related to a bonus/malus function. This component is calculated as a measure of the real possibility to use the corresponding layout. This component is introduced at the termination of the traditional convergence process: at first an optimal solution is searched basing only on the total travel time; subsequently a local optimization is performed by addressing the research toward more realistic solutions.

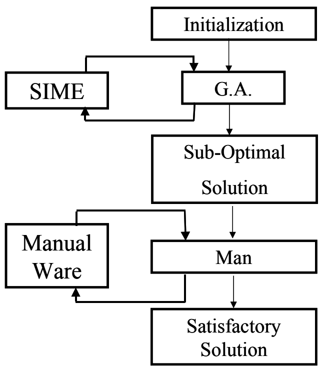

Figure 5: Integration of the Z-SIM Architecture with MANUALWARE

MANUAL FINE TUNING AND ACCREDITATION

Such a system allows to improve significantly the result from an applicability viewpoint. Nevertheless both referring to the GAs features themselves (oriented to determine sub-optimal solutions) and to facilitate the results sharing to the company management and production manager, a manual modification module has been developed in order to change the configuration determined by using the GA. This module, called MANUALWARE, represents a direct simulator interface. Thus, in this way, it is possible to make changes and to improve the obtained solution; moreover it is possible to perform solution robustness analysis and what-if inquires in order to evaluate the impact of variations directly depending from the products disposition inside the warehouse.

PERFORMANCE EVALUATION

The following figure shows the results obtained by the execution of a complete Z-Sim research process. It can be divided into two macro-phases: research with zero bonus and research with meaningful bonus values. Furthermore during the search process different crossover operators has been used in order to exploit the best features of each of them.

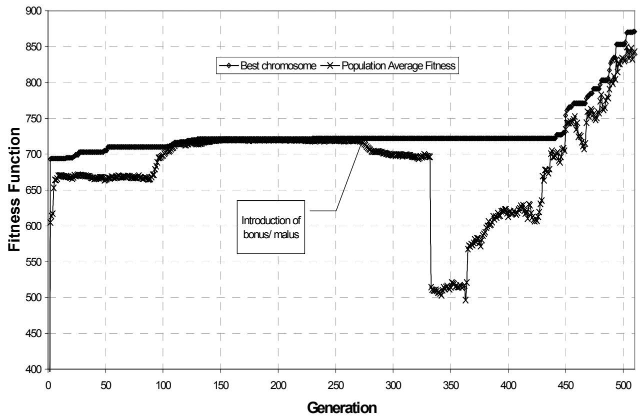

Figure 6: Z-SIM Evolution: Transient, Stabilization, Local Search and Determination of a Satisfactory Configuration

CONCLUSIONS

The authors approached a real industrial case concerning warehousing. The industrial problem has been modeled by a hybrid (genetic and simulative) approach. The GA showed good performance, efficiently determining an effective warehouse layout. Approaching COPs by using GAs, specific genetic operators should be designed and a sort of repairing procedure should be introduced, even if it reduces the performance of the whole system. By the introduction of MANUALWARE, the accreditation of the proposed approach has been reached and a critical issue of evolutionary computation (related to not optimal solution finding) has been successfully faced. Moreover MANUALWARE allows practitioners to consider all the qualitative constraints of the optimization problem; in fact its use led to the adoption of the suggested layout. The integration between GA and simulation greatly led to the analysis and results dissemination. In this way it was possible to analyze multiple scenarios and to share the obtained results with the production manager. Possible future work are related to the application of proposed techniques to a multi level warehouse optimization problem.

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