ASGA: Genetic Algorithm for Assembly Sequencing

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Abstract. In this paper a new objective function to measure the kindness of the sequences of products for a mixed ORV-LRV problem is presented. This objective function is based on a model of repulsion of components that allows to consider interactions (so much of repulsion as of attraction) not only among components of the same type, but among components of different types. To put into practice this objective function we propose the use of a meta-heuristic - a genetic algorithm (Davis 1991 Goldberg 1989) - in which a novel concept is introduced with the purpose of avoiding a quick convergence towards local solutions. This algorithm is used to compare the results offered with those of the Monden heuristic for the ORV Problem using a simplification of the outlined objective function.

Key words: Sequencing, Repulsion Model, Genetic Algorithm, Automotive

1. Introduction

Sequencing Problems are important for an efficient use of mixed model assembly lines (Bard 1992) since they are being more frequently used in the industry due to the requirements of product diversification. In this type of lines a variety of products with similar basic characteristic are assembled. Different components being assembled onto the basic product require different assembly tasks, different operations and different times.

The objectives pursued when solving this type of problems have been diverse: minimising total utility work (Yano 1991), keeping a constant rate of part usage (Milterburg 1989) (Monden 1991), minimising the overall line length (Bard 1992), minimising the total setup cost (Burns 1987) and so on.

The sequencing of products in a JIT assembly line outlines a very well-known and widely analysed problem. It can be approached as a PRV (Production Variation Problem), ORV (Output Variation Problem) or LRV (Load Variation Problem) problem.

In the Kanban system used by Toyota, those processes supplying various parts or materials to the assembly line receive a special attention. According to this system of “attraction”, the variation of production quantities or transportation times should be minimised for these particular processes (Monden 1994) . In other words, the main objective is to maintain a constant speed of consumption for each part in the assembly line.

Monden (1983) proposed a mathematical model that went to show how important the precedent processes are when supplying a line with a Kanban system is used. The existence of some ideal quantities to consume of the different materials, (component parts) in each production cycle or for a concrete quantity of assembled product units is considered. For a concrete number of manufactured end-product an ideal consumption of components versus a real consumption can be obtained. Monden does not outline an objective function, but a method that would allow to select the most appropriate product to be used in each time period.

This and other similar proposals consider all the components equally important. Miltenburg and Sinnamon (Milterburg 1989) presented a vision of the problem where the components are structured by levels: products, subassemblies, components and raw materials. In this case the importance of maintaining the regularity in each level is weighted. They propose two heuristics to solve the problem. The first one differs of the one proposed by Monden in some aspects: to begin with, a wide sequencing concept expanded at several levels in the list of materials is used by introducing a weight for each level. The second heuristic aims at eliminating the myopia of the former one by means of analysing two serial stages in each iteration.

Bautista (1993) proposes a general model to sequence units with components. With this meta-model a classification of ORV Problems according to the pursued objectives is presented. He proposes 7 out of 32 evaluated heuristics. They are compared with one another to establish their quality. Bautista also proposes an exact procedure based on the Enclosed Dynamic Programming.

2. The Analysed problem

The problem we approach in this paper is the daily sequencing of big quantities of products with the objective of getting a regular flow of the necessary resources. These resources may be quantities of components or the necessary work loads for their production, as well as the work loads for their assembly in a production line that maintains a constant speed of work.

According to different objectives, the problem can be formalised in different ways:

Objective 1: Getting a balance of loads -expressed in time of process- for all the workstations of the mixed assembly line. Consequently, sequences are pursued to avoid an excessive consumption of resources in a certain moment. In other words, the goal is to minimise the units deviation ratio in any part of the sequence.

Objective 2: Balancing the consumption of different resources and synchronising the production flows in mixed assembly lines or processes with multiple stages, avoiding fluctuations in the consumption of resources and maintaining acceptable levels of the necessary WIP. The goal is to minimise the deviation ratio of the outputs required in the different processes.

The traditional solution to this problem consists on the generation of sequences of products that minimise the variation of the consumption ratios versus a theoretic ratio for the whole sequence. That is to say, it tries to get balanced sequences in relation to the ratio of average consumption.

If the problem is analysed according to Monden, we can speak of *poor* products and *rich* products. Rich products are those that require a high consumption of resources and components for their configuration, over the ratio of average consumption; on the other hand, poor products require the use of few components, having a ratio of consumption under the average.

Section 4 outlines the definition of the objective function used in the modelling of this problem. Both a general and a simplified objective function are explained. The general objective function entirely modelises the different relationships between the considered components, while the simplified one has been used to compare the ASGA and the Goal Chasing Procedure solutions.

3. The Goal Chasing Procedure

In (Burns 1987) the problem was approached in the search of the regularity in the use of resources or in the consumption of components. By minimising the variability in the consumption of components along consecutive periods (regularity in the consumption), the quantity required for each component in the mixed assembly line per unit of time will be the most constant possible.

Monden proposed a voracious procedure (Goal Chasing). This procedure built the sequence progressively, adding in each step a new product to the already built sequence. This product is chosen out of all the available ones and in accordance with its contribution to the sequence value. At each step, an objective function is minimised; it is based on the distance between the representative point of the components real requirements and the consumption point or average ideal requirement.

This heuristic procedure presents several advantages thanks to which it has been used for the resolution of real problems; those are, for example, great speed of calculation and converging process.

However, it also reveals various disadvantages:

It uses a simple escalade method (steepest ascent hill climbing). The main disadvantage of this method is that it doesn't guarantee an optimal solution.

The algorithm shows an undesirable behaviour in some cases; the more comfortable units of product run out very quickly while the less tempting ones are left for the end. Consequently, the final segment of the sequence can be comparatively worse that the average.

The myopia of the heuristic procedure is reflected in the fact that it does not carry out a search in depth, neither it evaluates the final solution as a whole.

4. Which is the problem to be solved?

In our problem, each component is assembled to the final products in different workstations of the assembly line. Therefore, the existence of a certain component reflects the necessity of a certain service or resource of production.

If we analyse the sequence from this point of view, we can reach the conclusion that a balanced sequence is the one that uses each one of the components at regular intervals, while regulating and trying to avoid overloads in the requirement or use of a service or work station.

When the resulting sequences obtained by the Goal Chasing Procedure are analysed, according to this particular point of view, it can be easily seen that the objective is not always achieved; it sometimes provides sequences with overloads in some of their components that can be easily improved.

Some of these inaccuracies are derived from: the above-mentioned myopia, the zero error in the calculation of their objective function, and also from the interference that the objective function introduces in the results when not only the elected elements are included, but also the non-elected ones.

5. The Repulsion Model

In the definition of the Goal Chasing Procedure, the algorithm was first and the objective function to be optimised followed. This procedure is logical if we take into account that an objective function that cannot provide an heuristic, is of no use for sequencing, only for measuring.

However, let’s consider the definition of the objective function before thinking of the resolution procedure. This objective function should keep focused on the analysed problem and, more importantly, should allow the consideration of different degrees of importance on the different components that are being used.

The objective function proposed is based on a repulsion model, and its general formulation is the following:

$$\min Z = \sum_{i=1}^{b} \sum_{j=i}^{b} \left(\sum_{n=1}^{N_i} \sum_{m=1}^{N_j} \frac{x_{ij}}{\left| t_{in} - t_{jm} \right|^{a_{ij}}} \right); t_{in} \neq t_{jm}$$

Where:

b : total number of types of components..

N_i : total number of units of the type of component *i*.

t_{in} : position in which the *n*-unit of the type of component *i is* used

a_{ij} : weight of the distance factor between the types of component *i* and *j*.

x_{ij} : weight of the repulsion factor between the types of component *i* and *j*.

The use of a distance factor and a repulsion factor in the types of components offers the possibility, not only of characterising the different components from the point of view of consumption ratios and of work loads, but of considering the possible relationship between different components. This allows us to keep in mind that two different components are to be assembled in the same workstation.

For the use of this objective function, the definition of both matrix a_{ij} and matrix x_{ij} is required. Both will have the same number of non null components and they will probably be quite disperse, having special importance the elements on the diagonals.

The values of a_{ij} should be positive (the greater the value, the less important it is considered in the objective function in terms of distance). While the values of x_{ij} could take positive or negative values, using this last possibility to characterise the cases in those that vicinity is required among components.

Note that the evaluation of the proposed objective function requires a great quantity of calculations. Nevertheless, these can decrease notably if the simplified problem is considered; there, only the relationships among the same type of components are considered. The formulation would be as follows:

$$\min Z = \sum_{i=1}^{b}\left(\sum_{n=1}^{N_i}\sum_{m=1}^{N_i}\frac{x_i}{\left|t_{in}-t_{im}\right|^{a_i}}\right)\forall i / N_i \geq 2; n \neq m$$

Instead of matrices, in this expression two distance and repulsion vectors are considered. This simplified problem will be good to compare the results offered by the Goal Chasing Procedure for different analysed problems. Also, as a first approach, and to avoid the introduction of substantial differences in the type of problem, the values of $x_i = 1$ and $a_i = 2$ will be considered, which can be associated to a model of repulsion of unitary electric loads in which the objective is to reach the state of minimum energy.

Let us suppose the following example: we want to put into sequence 3 products (p1, p2, p3) with their respective quantities (6, 3, 3), using a maximum of three possible components (a1, a2, a3), according to the following distribution in which each product only needs one component:

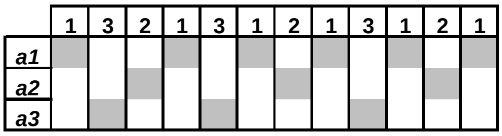
	a1	a2	a3	
p1	1	0	0	**6**
p2	0	1	0	**3**
p3	0	0	1	**3**

The Goal Chasing procedure will obtain the following solution:

	1	2	3	1	1	2	3	1	1	2	3	1
a1												
a2												
a3												

As we can see, component a1 is demanded twice in a row (in consecutive periods), so an overload in the assembly station dedicated to this component can occur.

Instead, a more balanced solution is the following one:



Which presents a smaller state of repulsion energy that the one offered by the Goal Chasing procedure.

6. A Genetic Algorithm for the Repulsion Model

We propose a genetic algorithm (ASGA) that uses the proposed objective function to evaluate the *fitness*; it will also use the solution of the Goal Chasing Procedure as the first starting point to obtain the initial population.

The next diagram shows the process of the implemented algorithm:

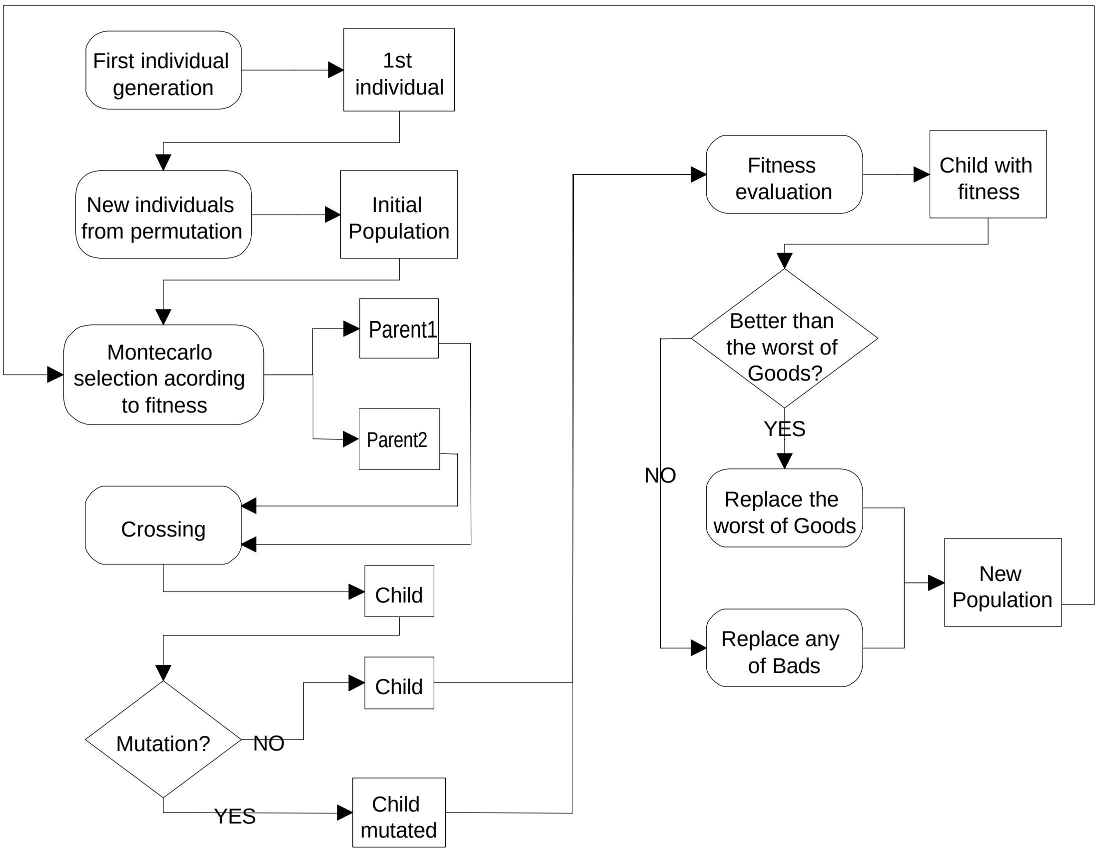


Figure 1: ASGA diagram

There are two special characteristics to be highlighted in the designed genetic algorithm: the *Zig-Zag* crossover and the constant storage of bad fitness solutions among the population.

The crossover being used eludes the problem of repetition of products that appears when using the traditional crossover methods of non-binary coded strings. It is a method of crossover quicker and simpler to implement than the PMX (Partially Matched CrossOver) or others.

The Zig-Zag crossover operates in this way: the child sequence will be formed by elements taken alternately from parent1 and from parent2; if the corresponding parent's taken element is already in the child sequence, the following element is selected. Next figure shows and example where the selected items are in grey, beginning with parent1.

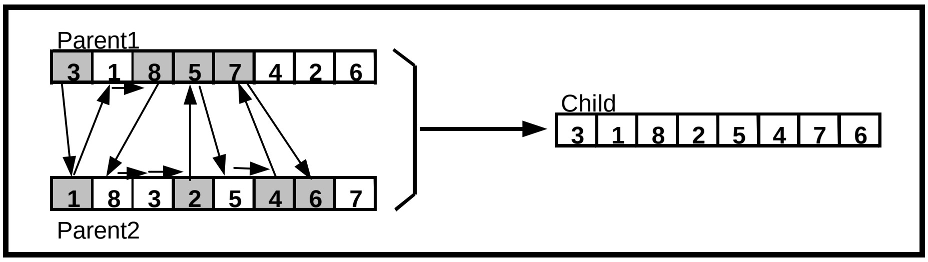


Figure 2: Zig-Zag crossover

The PMX crossover (Goldberg 1985) is only one of the numerous permutation crossover operators, and there exist very many crossover operators simpler than this one. For example the one point crossover 1X corresponding to OX crossover (a two point one) (Davis 1985).

The OX crossover is very good to keep the orders, but this and other crossover operators do not take into account the neighbours' relationships between the sequenced products. That is to say, this type of crossover operators get child sequences with bad fitness due to the effect of disorder when the vicinity relationships are ignored.

In case the child sequence suffers a mutation, and to favour the variability in the exploration of the search region, this mutation can be carried out in two different ways: in a traditional way, exchanging any two elements of the sequence, or using the *ends mutation*. The used mutation procedure exchanges two of the sequenced products with preference for the products located at the edges of the sequence, therefore affecting directly to the schemata of the child's search. This operation is achieved using a non uniform probability distribution.

By means of this special procedure of mutation, quantum jumps are obtained in the search regions of the genetic algorithm, favouring the variability and the exploration of new solutions. When the first elements of the sequence are affected, the rest of the elements will evolve towards solutions located in different search areas, trying to complete the vicinity relationships among products. In the carried out experiments the basic mutation does not produce significant variations for sequences of great size (1500 products).

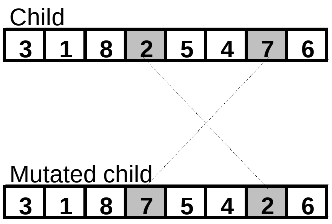


Figure 3: Basic mutation

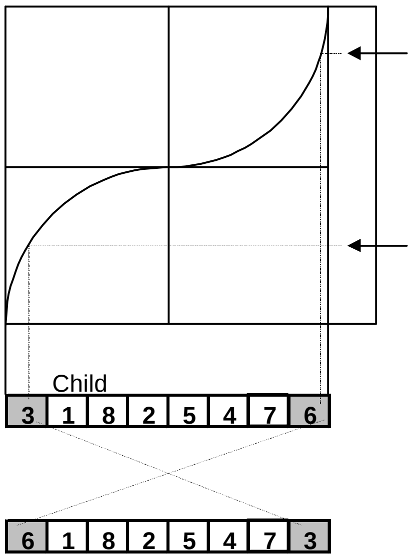


Figure 4: Ends mutation

As for the population, a proportion of bad solutions among the solutions with better fitness is maintained. Proceeding in this way, a new solution will become part of the population, substituting a good solution if it is better than this last one; otherwise it will substitute one of the bad solutions. The population's size and the percentage of good and bad solutions are parameters of the algorithm.

As a consequence, and with more probability, the good solutions will be selected for the crossover , but there is also a possibility of selecting bad solutions. This provides a variability to the algorithm that has proven to be more efficient than the mutation.

7. Experiments

The designed algorithm has been implemented to sequence 1500 vehicles in an automotive company. Experiments were carried out to validate the algorithm.

For problems in which only the relation between components of the same type were considered, and for the values of $x_i = 1$ and $a_i = 2$, under the condition that they were manageable for the Goal Chasing Procedure, ASGA overcame the GCP solution (measured in terms of the new objective function) in 87.96% of the generated problems (for a sample of more than 1000 different problems of diverse complexity).

The following picture shows two of the simplest problems analysed:

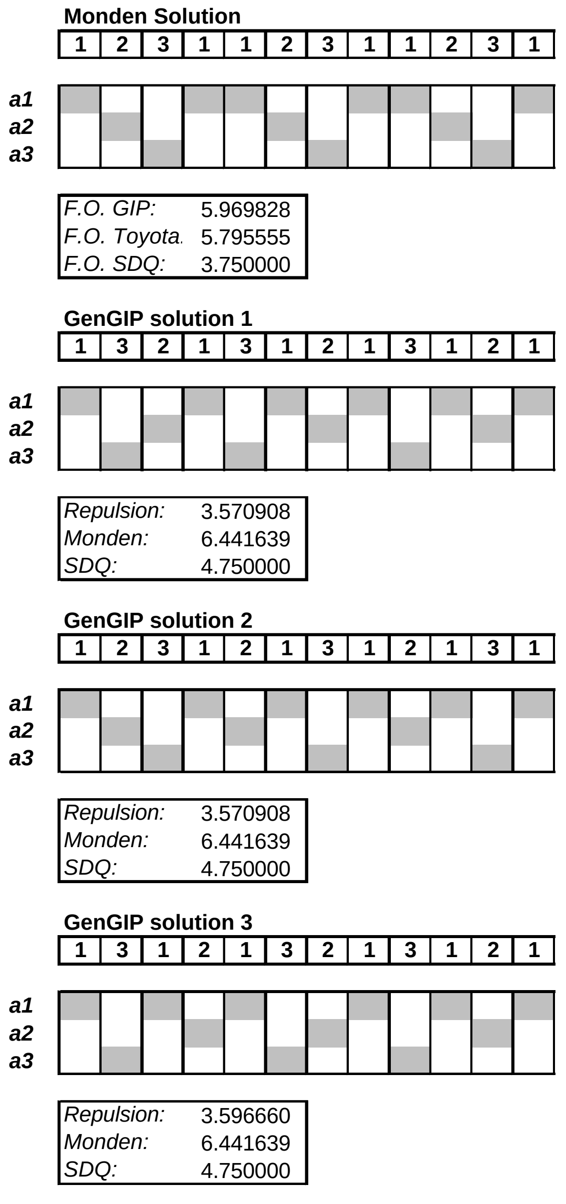


Figure 5: Goal Chasing vs Repulsion Model

8. Conclusions

The proposed genetic algorithm allows the evaluation of sequences in a global way, avoiding the myopia of the Goal Chasing Procedure in the exploration of possible solutions. Using the proposed objective function as a measure of the sequence kindness (repulsion model), and for manageable problems for the Goal Chasing procedure, ASGA has proven to be superior (in terms of the new objective function). However, the computational solving time is obviously, bigger.

The biggest contribution of ASGA is the possibility to correlate the use of different types of components, allowing, in this way, to solve the problem of loads at the same time. Also, the used repulsion model allows to use the attraction, since the grouping of certain components may be required.

One of the main problems of the heuristics for the solution of ORV problems are the draws that take place among different types of components when a progressive construction is used. With ASGA, the problem it is minimised by using a distance factor that differs among the components.

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