Multi-Criteria Scheduling Optimization With Genetic Algorithms

IGOR BERNIK, MOJCA BERNIK
Faculty of Organisational Science
University of Maribor
Kidriceva 55a, SI- 4000 Kranj
SLOVENIA

Abstract: Multi-criteria scheduling optimization with genetic algorithms is described. Scheduling optimization methodology provides the planner with a quick and efficient scheduling method and enables him/her to experiment and decide which of the suitable solutions will become the production plan. The scheduling system is composed of a business information system - a database, a discrete event simulation model and a scheduling algorithm. The purpose of the integrated system is to help operative management personnel with production scheduling and planning. By comparing various scheduling methods, we established that the system utilizing genetic algorithms and simulation yielded from 5% to 15% better scheduling within a shorter time compared to manual scheduling.

Key-Words: Production planning, scheduling, optimization, genetic algorithms

1 Introduction

How to schedule production in a way that would minimize production costs and evenly fill the production line schedule? Traditional methods prove unsuitable when dealing with a large assortment of products and complex production procedures since they are too time-consuming. Using genetic algorithms (GA) with discrete event simulation (DES) solves the complexity problem and enhances production transparency.

To maintain a large product assortment, a company needs to employ a large number of production operations and/or tools. Since the complexity of scheduling problems grows factorially with the number of jobs in a schedule, traditional methods consume too much time to find a suitable solution. Davis [1] and Goldberg [2] prove that GA is a search method with a good quality/speed ratio. The suitability and feasibility of GA derived solutions need to be verified against real world production line limitations. In some situations system behavior can be accepted as optimal, not just in the case of minimal make span, but also when the risk of a decision does not exceed a defined point, etc. In practice most decision-makers pay attention to specific limitations (law, social, performance) of the system, which in the future can lead to unstable system behavior. In [3] and [4] simulation is proposed as a verification tool, thus we have employed a DES model to verify the results produced by GA in our system. Although there is considerable work devoted to the study of combining GA and simulation methodology, there is a lack of its application in practice, especially in small and medium-sized companies. The reason probably lies in the lack of suitable methodologies for knowledge transfer to enterprises, and not in the methodology itself [5].

This paper presents a production scheduling system using a GA and DES model, resulting from the further development of integrated management information systems [5]. The scheduling system is composed of a business information system (IS) – a database, a DES model and a scheduling algorithm. The purpose of the integrated system is to aid operative management personnel in production scheduling and planning. The scheduling is done on two levels: the first level consists of approximate annual resource utilization planning using material stocks and delivery time for a known customer's data. The second level consists of the operative scheduling of a series of jobs without time limits and without constraints related to the identity of the customer (e.g. for any customer). In a later phase, this methodology is also used for raw material cutting in order to reduce raw material assortment and related material order complexity [6]. The main advantage of the presented system is to enhance man-machine interaction in production planning, since the computer is able to produce several acceptable schedules using the given data and a set of criteria. The planner then selects the most suitable schedule and modifies it, if necessary.

2 Methodology

The system presented was developed to schedule the production of a mid-size Millboard and Graphics Company where the type of production system is job-shop. There are four main universal machines, which are the basis for production scheduling. Currently the scheduling of a product series is done in two steps. In the first step a crude schedule is produced manually, and in the second step the production line workgroup leaders alter and finalize the schedule. A consequence of such an approach is that schedule quality varies significantly from day to day, depending on the planner and workgroup leader's experience. The DES and GA were used for multi-criteria scheduling optimization because of transparency and a holistic approach. Scheduling optimization with GA and visual simulation are just parts of an entire system, which should exist in conjunction with complete enterprise activity. Proposed integrated production scheduling system with the help of GA and a simulation connected with business IS was described in [7]. The system allows an automated scheduling process and offers superior control of the production process flow. According to the order of information, GA is used to generate product schedules, while a simulation model is used for schedule suitability and quality verification. The scheduling system utilizes the following order information:

- setup and production times for different products on the machines in the production process,
- work operations and necessary procedures,
- ordered amount, and
- production deadline.

A good schedule means good resource utilization while respecting deadlines and production line limitations. As previously mentioned, a manual schedule is produced weekly and then daily schedules are modified on the fly. This leads to highly variable resource utilization and miscoordination due to a time-consuming two-step scheduling process. Following this, it verifies plan feasibility and declares it operational. In the scheduling process the company uses an IS where the current state of orders, production procedures and resource availability are stored.

2.1. Genetic Algorithms

Of all the evolutionary techniques, the GA are best known and widely spread. They have been used successfully to solve continuous functional optimization problems [8]. GA use operators of selection, crossover and mutation. They combine survival of the fittest in a series of structures with structured, yet still random, information exchange in the form of search algorithms [9]. GA represents solutions to the problem in structures named chromosomes. In our case a chromosome is represented as a list of ordered products, whose production should be scheduled according to prescribed criteria and restrictions in the production process. As stated before, a simulation model was used for the fitness function, so each chromosome gets a fitness value.

Data for scheduling optimization are prepared from the database. A GA program based on extracted data prepares a starting population of chromosomes. Each population has a limited, fixed size and is called a generation. With the help of the fitness function, represented with a simulation model, chromosomes in each population are evaluated. A selection of chromosomes is used to choose which chromosome from the generation will survive to the next generation. The evolution of the surviving chromosomes is executed according to genetic operators such as crossover and mutation and therefore, a new generation of chromosomes evolves. The process of evolution is repeated as long as the stopping criteria are not satisfied. The last generation of chromosomes represents a number of suitable plans. Chromosomes with a better fitness value are then simulated on a visual simulation model. The planner can therefore choose the most appropriate – optimal plan. By using visual simulation and optimization integration in the system for production planning decision support, it is possible to decide more easily and quickly, which plan is the most appropriate based on the current data.

The process of GA scheduling and use of a simulation model are described in [10]. In the scheduling process, the missing product quantity represents production demands data as the starting (1^{st}) generation sorted according to the arrival time of orders. The chromosome presents one possible schedule, while the gene presents a customer order. The quality of an individual schedule in each generation is verified with the fitness function. The fitness function in the presented case is the minimum of production time of the entire schedule, and is represented with the DES model. It has the functions of each of the schedule's fitness evaluations to verify the schedule's feasibility. Fitness value selection is done according to the individual schedule. Selection has the function of selecting the fittest individuals and the elitist selection is used in the presented case.

Through GA evolution on the selected schedules, new schedules are produced with genetic operators. We tested different crossover and mutation recombination operators [11], but in the described system linear order crossover-LOX and gene swapping mutation were used, because they perform the best for the studied problem.

The evolution cycle of generating a new population is:

1. A starting population is formed from 60 randomly generated individuals
2. A simulation model is used as a fitness function and validates an individuals' quality – gives a fitness value to individuals
3. The selected individuals are used for generating new individuals with genetic operators

4. Non-selected individuals are replaced with new individuals made with genetic operators
5. Point 2 repeats if the stopping criteria is not satisfied

During the selection stage:

1. We selected a fixed number of chromosomes from the current population
2. Using genetic operators, evolution occurs in the selected population in order to obtain a new population

Newly produced schedules represent the new (n^{th}) generation and are evaluated with the simulation model as a fitness function. Evolution through GA runs until the stopping criteria is fulfilled. The rate of the result's progress towards a perceived optimum is used as a stopping criterion. If twenty successive generations bring no improvement, the evolution is halted. The last generation is a set of feasible schedules. Using GA, everyone should be aware that there is nearly always a better (closer to optimal) schedule available, but to find it may take too much time [12]. For each schedule produced by GA, the simulation model produces resource utilization statistics and material expenditure. Therefore the presented system, in addition to quality schedule production, also helps optimize material stocks and workforce placement, helps plan production utilization and determines due dates. After completion of the scheduling process, the most suitable production plans are simulated on the visual model of the system. With process animation, using chosen parameters and according to defined criteria, the decision-maker is motivated to search for results which will have the most advantageous influence on the whole production process. The schedule, which is selected after simulation on the visual simulation model, becomes the production plan and is written into the database. This production plan will be carried out completely if no urgent demands arise from the market during the process of production plan execution. In the case of urgent demands from the market, the scheduling process with visual simulation is repeated. The newly selected production plan should fulfill urgent demands, as less important tasks are scheduled at a later point in time. Programs for scheduling and a visual simulation model are integrated into the decision support system, so that the planner can quickly and efficiently search through possible schedules. Simulation and visualization of possible schedules on the simulation model also helps to better understand the process and in that way contributes to a quicker decision-maker response in the case of unpredictable events that influence the system.

3 Results and Discussion

The experiment was conducted in the case company with real world data for the duration of four workdays, where each day a new schedule was produced. Using order data, we used the GA and DES model in ProModel [13], which hides model complexity behind visual and animated representation to obtain the final GA generation of possible schedules. The planner therefore does not focus on process methodology but on searching for the most appropriate plan to fulfill the system requirement, leading to a better system operation. Visually representing the production process on the simulation model and graphically representating simulation results further simplify decision-making in the search for an “optimal” plan. In this way, better cognition of the studied system should lead to the optimal selection of a plan and the best operation of a production process.

Changes that warrant rescheduling are: order cancellations, new orders, machine breakdown and unexpected obstruction in the production process. If an order is cancelled or a new order arrives, the scheduling can be performed from scratch or from the existing schedule (with new orders appended and cancelled orders erased). The time needed for re-scheduling is much shorter than for scheduling from scratch, as has been confirmed through experiments. A similar problem was the subject of research by Fang et al. [14], with similar findings.

Figure 1 shows the difference between the two rescheduling methods. At first, the GA took about 25 minutes to prepare schedules for the four days. Before the production start, another three orders arrived and rescheduling was necessary. Starting from scratch with three new orders, approximately another 25 minutes were needed to produce the new schedule. However, when the GA started using the existing schedule, the new orders were simply appended and the new schedule was ready in only seven minutes. Both methods produced the same final schedule.

Table 1: Scheduling production methods comparison

Scheduling method	Day 1		Day 2		Day 3		Day 4	
	t (min)	result	t (min)	result	t (min)	result	t (min)	result
Manual (real data)	~120	491,2	~120	475,6	~120	512,6	~120	487,4
GA and sim. model	25	439,7	22	449,4	18	465,2	20	455,3
Rescheduling;GA and sim. model	7	436,8	5	446,3	4	463,3	4	455,3

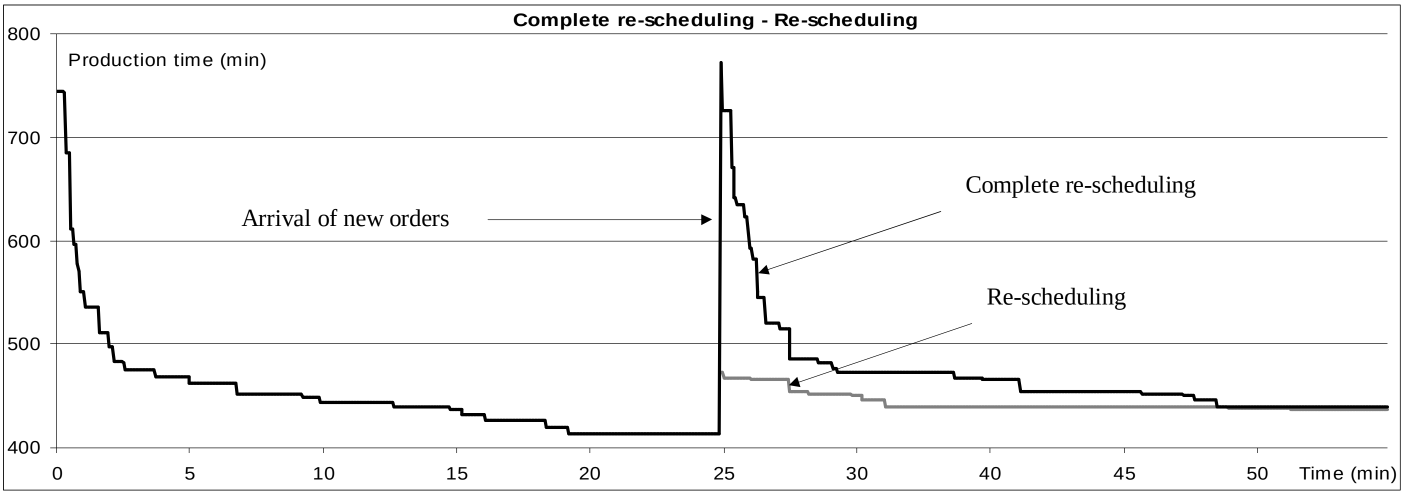

Fig. 1: Comparison of the times needed and result quality of the two rescheduling methods

A simulation model was used to verify and evaluate the historical schedules, and then new schedules were produced with GA for the same order data. Two schedules were produced for each series of orders: one starting from scratch and one from the historical schedule. Table 1 shows results for the four-day period. The results display that manual scheduling was the most time-consuming (~120 min). The shortest method was the rescheduling method with the GA and simulation model (~7 min). Manual scheduling consistently produced the poorest schedules according to criteria. The presented approach with the GA and simulation model and rescheduling using the GA and a simulation model system, produced similar final scheduling results except that the second was less time consuming.

In the studied example the type of production process is job-shop, where we have jobs that must be processed by a set of machines in a specific, predetermined order. It is not necessary that each job be processed on all machines. Figure 2 a non-optimized schedule containing five jobs (1-5) and a job order that has just arrived (new) are shown on the left. The schedule utilizes two (if necessary) workstations (ID1 and ID2). The available workstation time of each (8 hours) is represented by triangles. After the new job arrives it is placed on the non-optimized schedule, and the available time on workstation ID2 is exceeded. Figure 2 on the right shows an optimized schedule for the five scheduled jobs and one new job. The new order can be accepted, since none of the workstations' available time is exceeded.

After scheduling with GA, the scheduling program shows the most appropriate plans which have the smallest (minimum) simulated times, so parts of the final solutions (last GA generations) are shown in Table 2. The first three schedules (plans GA1-GA3) are very much alike in terms of production time. The fourth schedule (plan GA4) also does not exceed the maximum production time of 480 minutes in our case. All other plans exceed the maximum allowed schedule time. For comparison with GA scheduling, a manual schedule for the same data is also shown.

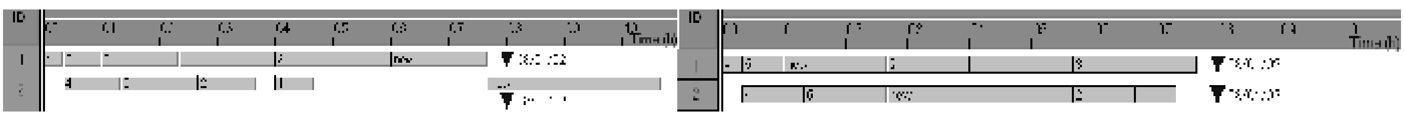

Fig. 2: Non-optimized schedule with new job added on previous schedule; available time is exceeded and optimized schedule with six jobs (five+new)

Table 2: Results of genetic algorithm and manual scheduling

Plan:	Sim. time (min):	Products order in each plan (ID no.)									
GA1	436,8	5	8	1	3	10	4	7	9	2	6
GA2	438,4	3	5	8	1	7	4	10	9	2	6
GA3	440,5	3	5	8	1	7	4	10	2	9	6
GA4	465,6	4	5	8	1	3	9	6	2	10	7
Manual	491,2	8	3	1	5	7	4	10	2	6	9

As can be seen, the manual schedule slightly exceeds the maximum available time and the business day must be prolonged. Which schedule will be used as the final schedule, depends on the planner. She/he is aware of vital information outside of the computer scheduling system, such as idle times, production and workstation blocking and wait states in the production process. The actual schedule is produced a day ahead, and is based on confirmed customer orders. Simulated times are the times from the simulated model, built into the optimization program. Simulation of plan GA1 from Table 2 in the ProModel is shown in Figure 3. A simulation model is used for animated simulation, which helps planners to determine the properties of each appropriate plan and helps them to find the best plan [15]. After conducting visual simulation on all suitable plans, planners can also compare the statistical simulation results of each plan.

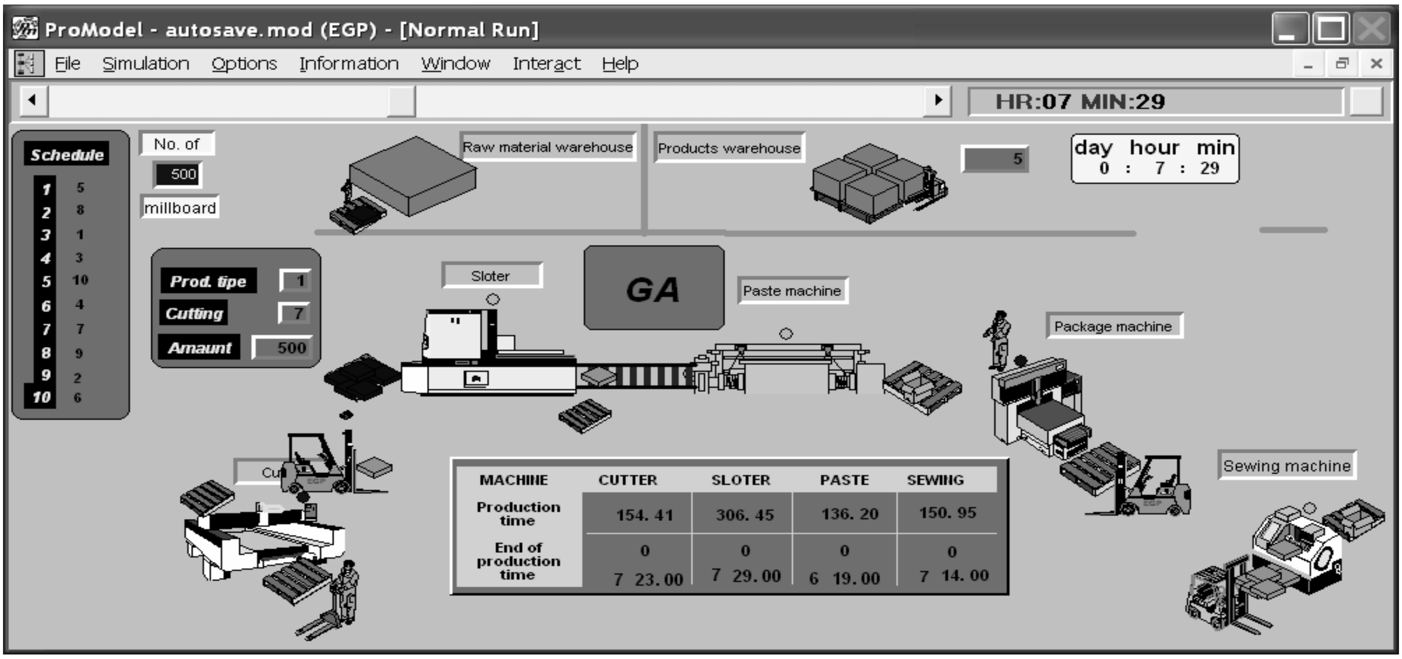

Fig. 3: Visual simulation of studied process after scheduling optimization

According to the observation of the visualized process (Figure 3) and graphical representation of simulation results, it is obvious that there are not major differences in the process when comparing the different plans. Regardless of the chosen schedule, the system functions well. In the case of bottlenecks or workstation over-utilization we chose a schedule that enables the system to operate more smoothly. Decision-makers select a suitable system for implementation based on schedules and animated visual simulation results. The schedule selected begins execution immediately and is followed through. In case of major changes in the system due to workstation failures, blocks or urgent orders, a part of the schedule is followed through, while a new schedule is developed with the new data. Depending on needs and demands, other criteria may be used to evaluate quality – e.g. station utilization, total production time, production costs, etc.

Using GA and simulation, the planner can produce schedules in less time, while being able to immediately verify schedules, compare them to existing schedules and possibly improve existing schedules using their experience and soft information. The benefits of the presented system are:

- real-time production resource utilization overview,
- aid in quality schedule development,
- greater flexibility (from weekly changes to daily changes),
- reduced impact of human factor on scheduling,
- fast rescheduling in case of order changes, seasonal deviations and machine downtime, and
- easier production tracking.

We can summarize that using GA and simulation yields 5-15% production timesaving, which translates to less resource utilization and larger production throughput of the existing production system.

4 Conclusion

Multi-criteria scheduling methodology with genetic algorithms (GA) and its evaluation with visual simulation are described. Different schedules – possible plans, generated by GA are tested on the visual simulation model. A system is connected to the corporate database, so the transfer of the presented system to the real process is simple. After scheduling optimization, a visual simulation model makes it possible to visually represent production process behavior according to different schedules.

The presented system can be quickly and easily implemented within a modern networked e-business information system. The basic quality of the described method is quick schedule development and consistent schedule quality and the main advantage is better schedule quality and resource utilization. Methodology supports the human thinking process, improving the limited rationality in the decision-making process. After comparing various scheduling methods we established that combinations of GA and simulation yield to better production results than manual scheduling, where the scheduling time is included. The presented rescheduling method using existing schedules proved to be very fast and effective. We believe that with minor modification to the model and optimization of GA, the time for GA evolution can be further reduced to about 2 to 3 minutes, which is an acceptable time for interactive business use.

The next phase of integrated system development is reducing material stock, enabling the development of a material carving optimization module. The module would be connected to order database and material stock database. Annual simulation of the production would produce valuable information for major material suppliers and help rationalize the production process and make scheduling easier, faster and better.

References:

[1] Davis L.: Genetic algorithms and simulated annealing, Pitman, 1987.

[2] Goldberg D. E.: Genetic algorithms in search, optimization & machine learning, Addison Wesley, 1997.

[3] Kljajić M., Bernik I., Leskovar R., Škraba A.: Simulation approach to decision assessment in enterprises, IASTED, Modelling and simulation, USA, 1998, 308-311.

[4] Dijk J. N. et. al.: Visual interactive modelling with SimView for organizational improvement, Simulation, 67(2), 1996, 106-120.

[5] Kljajić M., Bernik I. and Škraba A.: Simulation approach to decision assessment in enterprises, Simulation, 75 (4), 2000, 199-210.

[6] Sobotka A.: Inventory control: A simulation and decision support system, Simulation, 141(3), 1998, 141-153.

[7] Bernik I., Kljajić M., Bernik M.: Use of simulation and visualization in multi criteria scheduling optimization with genetic algorithms, WSEAS, Int. Conference on Evolutionary Computation, Switzerland, 2002.

[8] Azadivar F.: Simulation Optimization Methodologies, Proceedings of the 1999 Winter Simulation Conference, 1999.

[9] Ronald S.: Routing and Scheduling Problems, Practical Handbook of Genetic Algorithms vol. I, ed. Lance Chambers, CRC, 1995.

[10] Bernik I., Leskovar R., Bernik M., Kljajić M.: The importance of information system for optimization with genetic algorithms. WSEAS/IASME International Conferences, Italy, 2004.

[11] Bernik I., Kljajić M.: Uporaba simulacijskih modelov za večkriterijsko razporejanje z evolutivnim računanjem, Management and European Union, Portorož, 2002, 839-846.

[12] Kljajić M., Breskvar U., Bernik I.: Production Planning Using a Simulation Model and Genetic Algorithms, IASTED, Modelling and simulation, USA, 2002, 54-58.

[13] ProModel: ProModel 4 user's guide, ProModel Corporation, 1997.

[14] Fang H.L., Ross P. and Corne D.: A promising genetic algorithm approach to job-shop scheduling, rescheduling, and open-shop scheduling programs, Proc. of the Fifth International Conference on Genetic Algorithms, Urbana-Campaign, USA, 1993, 375-382.

[15] Kljajić M., Bernik I., Škraba A. and Leskovar R.: Integral simulation approach to decision assessment in enterprises, Shaping future with simulation: proceedings of the 4th International Eurosim 2001 Congress, Delft University of Technology, 2001.