Arkadiusz Gola[1]

GENETIC-BASED APPROACH TO PRODUCTION PLANNING WITH MANUFACTURING COST MINIMIZATION

The problem of production planning is oriented to the task of developing such a plan of production which takes into consideration specified marginal conditions and simultaneously generate the lowest cost of manufacturing. Such defined optimization task is a NP-hard problem and it makes impossible finding an optimal solution in multinomial time. Consequently, there is a need to apply the global optimization methods. This article presents the possibility of using genetic algorithms in the process of developing production plans for changeable market demands. Minimization of manufacturing costs is taken as a superior goal of optimization.

Keywords: *production planning; genetic algorithms; NP-hard problems; optimization; costs minimization.*

Аркадіуш Гола

ВИКОРИСТАННЯ ГЕНЕТИЧНИХ АЛГОРИТМІВ У ВИРОБНИЧОМУ ПЛАНУВАННІ ЗА МІНІМАЛЬНИХ ВИТРАТ НА ВИРОБНИЦТВО

У статті показано, що завдання планування зводиться до розробки такого плану, який враховуватиме певні граничні умови, генеруючи при цьому найнижчу собівартість виробництва. Сформульована таким чином оптимізаційна задача є НП-складною, що не дозволяє знайти оптимального розв'язку за номінальний час, і тому вимагає використання глобальних методів оптимізації. Для цього надано варіант застосування генетичних алгоритмів в процесі проектування виробничих планів в умовах змінного попиту. За головну функцію мети прийнято вартість виробництва.

Ключові слова: *планування виробництва; генетичні алгоритми; НП-складна задача; оптимізація; мінімізація витрат.*

Табл. 5. Рис. 3. Форм. 1. Літ. 21.

Аркадиуш Гола

ПРИМЕНЕНИЕ ГЕНЕТИЧЕСКИХ АЛГОРИТМОВ В ПРОИЗВОДСТВЕННОМ ПЛАНИРОВАНИИ ДЛЯ МИНИМИЗАЦИИ ЗАТРАТ ПРОИЗВОДСТВА

В статье показано, что задача планирования сводится к разработке такого плана, который учитывал бы определенные граничные условия при минимально возможной себестоимости производства. Сформулированная таким образом задача оптимизации является НП-трудной, что делает невозможным поиск оптимального решения за полиномиальное время, а значит, возникает необходимость применения глобальных методов оптимизации. Для этого представлено использование генетических алгоритмов при проектировании производственных планов в условиях переменного спроса. В качестве целевой функции принята стоимость производства.

Ключевые слова: *планирование производства; генетические алгоритмы; НП-трудная задача; оптимизация; минимизация затрат.*

Determination of the problem in its relation to the key scientific and practical tasks

Production planning under the conditions of changeable demand is actually one of the most important problems in manufacturing organization and management

[1] Ph.D., Eng., Assistant Professor, Institute of Technological Systems of Information, Lublin University of Technology, Poland.

© Arkadiusz Gola, 2014

(Nououzilame et al., 2013; Xue et al., 2011). It concerns both the existing production systems with a defined capacity level (Bocewicz et al., 2009; Swic et al., 2011) and the designing of new manufacturing systems, where the level of needed capacity is still a question (Gola et al., 2011, 2013; Swic et al., 2013). When sales vary significantly according to a season, the manufacturer makes special efforts to integrate the acquisition of raw materials and labor with an effective production schedule which satisfies customers' requirements. The recommended procedure is called the aggregate production planning (APP) which is a medium-term capacity planning, often from 3 to 18 months (Jamalnia et al., 2009).

Even though numerous and varied APP problem solution techniques are known, they are ignored by industry (Buxey, 1991). This is mainly due to unsuitability of the classical solution techniques under many circumstances. Depending upon the assumptions made and the modelling approach used, aggregate production planning (APP) problems can be quite complex and large scale. Therefore, there is a need to investigate the suitability of modern heuristics for their solution (Baykasoulu, 2006). This article presents the possibility of developing production plans using the Optima_AG optimization tool for MS Excel based on the theory of genetic algorithms (GA).

Review of the literature on the problem

The problem of optimal production planning was studied by many researchers during the last decade. A survey of models and methodologies for aggregate production planning was presented by Nam and Odendar (Nam et al., 1992). Some researchers have used a hierarchical approach for production planning that is called hierarchical production planning (HPP) (Ari et al., 1988; Bitran et al., 1982). Also, the multicriteria decision-making (MCDM) approach has been used for production planning (Foote et al., 1988; Tabucanon et al., 1989).

Nowadays, a meta-heuristic method is used to solve NP-hard problems and due to NP-hard class of aggregate production planning, this approach is applied to solving APP (Al-e-Hashem et al., 2013, 2011; Reay-Chen et al., 2001). Researchers have used fuzzy approach or other methods such as hybrid algorithms (Jamalnia et al., 2009; Kenne et al., 2011) and tabu search algorithm (Baykasoulu, 2006) to solve APP. But these presented methods are mostly concentrated on the solution algorithm but not on the general model. On the other hand, the consideration of all the parameters in an APP model makes it difficult. So researchers have not presented a comprehensive and general model for real production environments. The majority of models of APP and the tools used for it are not compatible to real production systems. In this paper a general and comprehensive aggregate production planning process using the simple computer optimization tool based on genetic algorithm is presented.

Definition of the target problem for the analysis

The research objective is to prepare an optimal one-year aggregate production plan characterized by minimum cost of production for the company which produces several different lines of kitchen and bathroom cabinets sold through major home retailers. The optimization problem was defined by Bozarth and Hanfield (Bozarth et al., 2006). The company's marketing department has come up with the following combined sales forecast for the next 12 months (Table 1).

Table 1. **One year sales forecast,** *devepoled by the author*

Month	Sales forecast (cabinet sets)
January	750
February	760
March	800
April	800
May	820
June	840
July	910
August	910
September	910
October	880
Nowember	860
December	840

In addition to the sales forecast, the company has also developed the planning values as shown in Table 2.

Table 2. **Planning values for the analyzed company,** *devepoled by the author*

Cabinet Set Planning Values	
Regular production cost:	2000 USD per cabinet set
Overtime production cost:	2062 USD per cabinet set
Average monthly inventory holding cost:	40 USD per cabinet set
Average labor hours	20 hours
Cabinet Set Planning Values	
Maximum regular production per month:	848 cabinet sets
Allowable overtime production per month:	1/10 of regular production
Workforce Planning Values	
Hours worked per month per employee:	160
Estimated cost to hire a worker:	1750 USD
Estimated cost to lay off a worker	1500 USD

The sales forecast shows an expected peak from July till September. As stated in planning values, the company can produce up to 848 cabinet sets a month using regular production time. Figure 1 shows the expected sales level against maximum regular production per month.

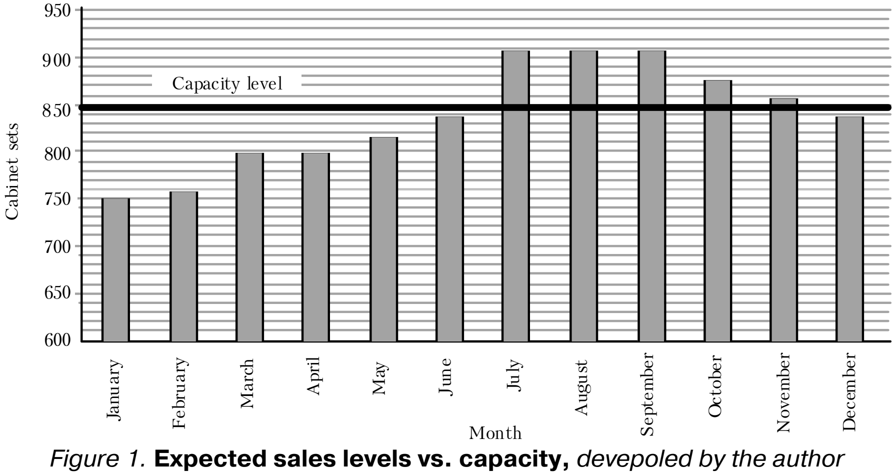

Figure 1. **Expected sales levels vs. capacity,** *devepoled by the author*

The implication of the presented is clear: the company won't be able to meet the expected demand in peak months with just regular production. So, the question is — how to develop an aggregate production plan to reach the minimal possible production costs?

When developing aggregate production plans there are 3 common approaches: level production, chase production and mixed production plan. Under the level production plan, production is constant, and inventory is used to absorb the differences between production and sales forecast. A chase production plan is just the opposite. Here production is changed in each time period to match the sales. The result is that production "chases" demand. A mixed production plan falls between these 2 extremes. Specifically, a mixed production plan will vary in both production and inventory levels in an effort to develop the most effective plan.

In case of the analyzed company both level and chase production plans were developed. The costs of manufacturing in each case are presented in Table 3.

Table 3. **Costs of level and chase production plans,** *USD, devepoled by the author*

	Level production plan	Chase production plan
Regular Production Costs	20160000	19712000
Overtime Production Costs	0	474260
Hiring and Layoff Costs	16250	39000
Inventory Holding Costs	114800	50240
TOTAL COST:	20291050	20275500

Under real manufacturing conditions, the best plan will probably be something other than a level or a chase plan. A mixed plan varies both production and inventory levels in an effort to develop the best plan. The aim of the presented research is to find an optimal mixed production plan for which the function of total cost of manufacturing (1) is minimized.

$$K_M = k_{rm}\sum_{i=1}^{i=12} n_{irm} + k_{ro}\sum_{i=1}^{i=12} n_{iom} + k_e\sum_{i=1}^{i=12} n_{ie} + k_d\sum_{i=1}^{i=12} n_{id} + k_s\sum_{i=1}^{i=12} n_{is} \rightarrow \min, \qquad (1)$$

where:

K_M — total manufacturing costs,

k_{rm} — unit regular production cost,

n_{irm} — number of cabinet sets manufactured in regular production in *i* period,

k_{ro} — unit overtime production cost,

n_{irm} — number of cabinet sets manufactured in overtime production in *i* period,

k_e — unit hiring cost,

n_{ie} — number of hired employees in *i* period,

k_d — unit lay-off cost,

n_{id} — number of laid-off employees in *i* period,

k_s — unit inventory holding cost,

n_{is} — number of inventory in *i* period.

Presentation of the research material, including methodology description and the key research findings

Because of the NP-hard character of the defined task, to solve the presented problem the genetic algorithm (GA) method was used.

Genetic algorithm is a universal tool for combinatorial optimization problems. It belongs to evolutionary algorithms and have been applied to a variety of function optimization problems. Many evolutionary algorithms have been developed in literature and implemented to solve manufacturing problems, due to the qualitative character of the variable and scale of the problem. In this article we used GA for the purpose of aggregate production planning. In particular we used a free software optimization tool for MS Excell called Optima_AG (Figure 2) (Gwiazda, 1999).

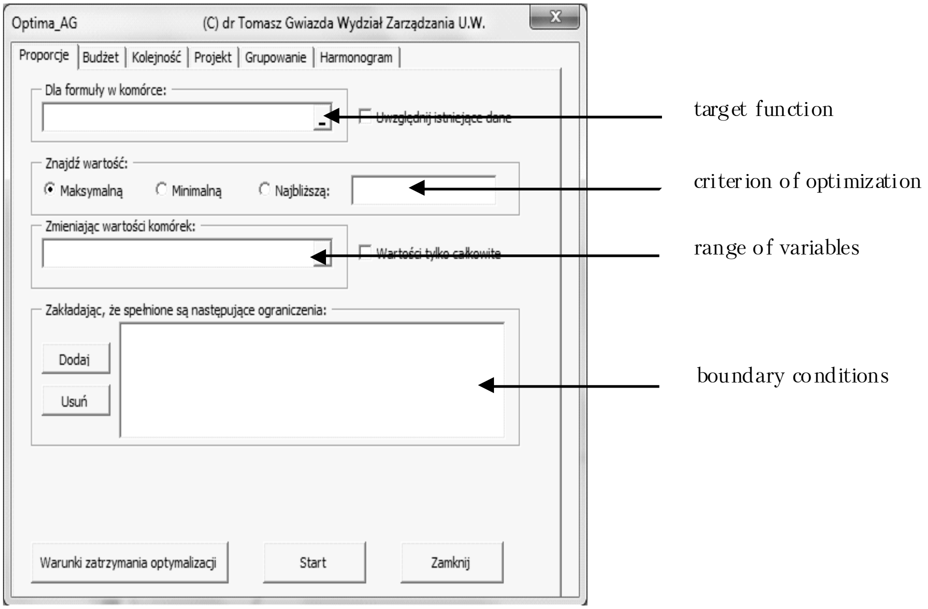

Figure 2. **An interface of Optima_AG – the tool used for optimization,** *devepoled by the author*

The key problem in developing an ideal production plan is to find the solution which catches both the criterion of total production costs minimization as defined in function (1) and takes into consideration the constraints characteristic for a manufacturing company. In the analyzed situation boundary conditions were taken as follows:

- the range of employed workers: 90–106 people;
- the range of monthly regular production: 770–848 cabinet sets;
- the range of inventory level: 40–150 cabinet sets;
- the maximum monthly overtime production: 8% of regular production.

The optimization experiment was conducted for times with different number of interactions and different time of optimization. The obtained results data are presented in Table 4. The best result was received in the fourth attempt, highlighted in grey. The obtained costs of production are shown in Table 5.

The obtained results demonstrate that the costs in the mixed (optimized) plan are lower by almost 60 ths USD when compared with the chase one and almost 75 ths USD when compared with the level production plan (Figure 3). It proves the effectiveness of the optimization process.

Table 4. **Results of 25 optimization experiments,** *devepoled by the author*

No	Regular production	Overtime production	Hirings	Layoffs	Inventory/ back orders	Regular production costs	Overtime production costs	Hiring and layoff costs	Inventory holding costs	Total costs	Number of interactions	Optimization time	Deviation from constraints, %
1	9984	96	6	6	834	19968000	197952	19500	33360	20218812	200	120	0,2059
2	**9984**	**96**	**6**	**6**	**767**	**19968000**	**197952**	**19500**	**30680**	**20216132**	**200**	**120**	**0,2059**
3	9984	96	6	6	853	19968000	197952	19500	34120	20219572	200	120	0,2059
4	9984	97	6	6	820	19968000	200014	19500	32800	20220314	200	120	0,2059
5	9984	96	6	6	903	19968000	197952	19500	36120	20221572	200	120	0,2059
6	9984	96	6	6	811	19968000	197952	19500	32440	20217892	100	60	0,2169
7	9984	96	6	6	898	19968000	197952	19500	35920	20221372	100	60	0,2059
8	9984	96	6	6	863	19968000	197952	19500	34520	20219972	100	60	0,2059
9	9984	96	6	6	921	19968000	197952	19500	36840	20222292	100	60	0,2059
10	9984	96	6	6	829	19968000	197952	19500	33160	20218612	100	60	0,2059
11	9768	312	15	16	1210	19536000	643344	50250	48400	20277994	75	60	0,1381
12	9984	96	6	6	869	19968000	197952	19500	34760	20220212	75	60	0,2059
13	9984	96	6	6	860	19968000	197952	19500	34400	20219852	75	60	0,2059
14	9984	98	6	6	803	19968000	202076	19500	32120	20221696	75	60	0,2059
15	9984	96	6	6	798	19968000	197952	19500	31920	20217372	75	60	0,2059
16	9984	96	6	6	803	19968000	197952	19500	32120	20217572	50	60	0,2059
17	9984	97	6	6	882	19968000	200014	19500	35280	20222794	50	60	0,2059
18	9984	97	6	6	800	19968000	200014	19500	32000	20219514	50	60	0,2059
19	9984	96	6	6	825	19968000	197952	19500	33000	20218452	50	60	0,2059
20	9984	96	6	6	964	19968000	197952	19500	38560	20224012	50	60	0,2059
21	9984	96	6	6	1138	19968000	197952	19500	45520	20230972	36	30	0,2059
22	9984	97	6	6	826	19968000	200014	19500	33040	20220554	33	30	0,2059
23	9984	96	6	6	859	19968000	197952	19500	34360	20219812	36	30	0,2059
24	9744	336	12	12	1226	19488000	692832	39000	49040	20268872	35	30	0,2748
25	9984	97	6	6	966	19968000	200014	19500	38640	20226154	34	30	0,2059

Table 5. **Costs of optimized (mixed) production plan,** *devepoled by the author*

	Mixed production plan, USD
Regular Production Costs	19968000
Overtime Production Costs	197952
Hiring and Layoff Costs	19500
Inventory Holding Costs	30680
TOTAL COST:	20216132

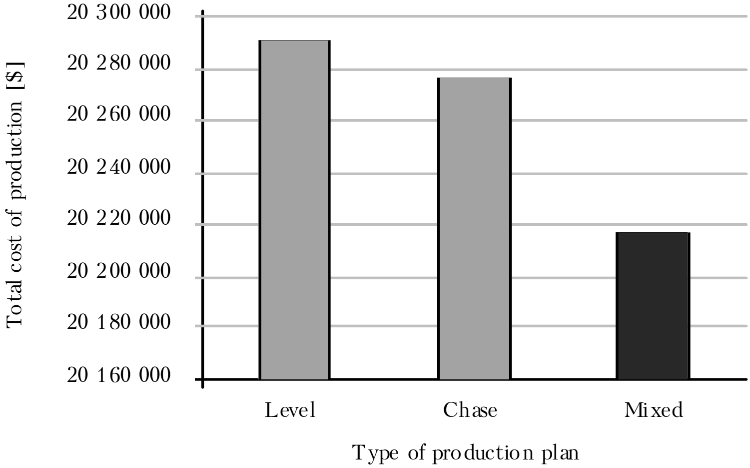

Figure 3. **Comparison of the total costs of production for different types of production plans,** *devepoled by the author*

Conclusions and for prospectives further studies

The purpose of this paper is to formulate and solve the aggregate production planning model using the genetic algorithm in which the objective function is to minimize the production costs over planning horizon. The experiment was conducted for specific manufacturing company producing cabinet sets where the demand is changeable. It shows that genetic algorithm can be a useful tool which allows preparing production plan with the lowest costs than in conventional level or chase production plans. However, this method assumes that demand data are known with certainty, what is simplification in some way. Therefore, further studies will be conducted to develop the method of designing production plans with the provision for forecast error to be incorporated.

References:

Al-e-Hashem, S.M.J.M., Baboli, A., Sazvar, Z. (2013). A stochastic aggregate production planning model in a green supply chain: Considering flexible lead times, nonlinear purchase and shortage cost functions. European Journal of Operational Research, 230(1): 26–41.

Ari, E.A., Axsater, S. (1988). Disaggregation under uncertainty in hierarchical production planning. European Journal of Operational Research, 35: 182–186.

Baykasoulu, A. (2006). MOAPPS 1.0: Aggregate production planning using the multiple-objective tabu search. International Journal of Production Research, 39(16): 3685–3702.

Bitran, G.R., Haas, E.A., Hax, A.C. (1982). Hierarchical production planning: A two stage system. Operations Research, 29: 232–251.

Bocewicz, G., Wojcik, R., Banaszak, Z. (2009). On Undecidability of Cyclic Scheduling Problems [in:] Mapping Relational Databases to the Semantic Web with Original Meaning, Lecture Notes in Computer Science, LNAI, Springer-Verlag, 5914, pp. 310–321.

Bozarth, C., Handfield, R.B. (2006). Introduction to Operations and Supply Chain Management, Prentice Hall PTR, New Jersey.

Buxey, G. (1991). Production planning and scheduling for seasonal demand. International Journal of Operations & Production Management, 13(7): 4–21.

Foote, B.L., Ravindran, A., Lashine, S. (1988). Computational Feasibility of Multi-Criteria Models of Production Planning and Scheduling. Computers & Industrial Engineering, 15: 129–138.

Gola, A., Swic, A. (2011). Computer-aided machine tool selection for focused flexibility manufacturing systems using economical criteria. Actual Problems of Economics, 10(124): 383–389.

Gola, A., Swic, A. (2013). Design of storage subsystem of flexible manufacturing system using the computer simulation method. Actual Problems of Economics, 142: 312–318.

Gwiazda, T. (1999). Optima_AG. Optimizator for Management and Business Problems for Microsoft Excel, Warsaw University Publisher, Warsaw (in Polish).

Jamalnia, A., Soukhakian, M.A. (2009). A hybrid fuzzy goal programming approach with different goal priorities to aggregate production planning. Computers & Industrial Engineering, 56(4): 1474–1486.

Kenne, J.-P., Dejax, P., Gharbi, A. (2011). Production planning of a hybrid manufacturing – remanufacturing system under uncertainty within a closed loop supply chain. International Journal of Production Economics, 135(1): 81–93.

Mirzapour, Al-e-hashe, S.M.J., Malekly, H., Aryanezhad, M.B. (2011). A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty. Journal of Production Economics, 134(1): 28–42.

Nam, S.J., Ogendar, N.R. (1992). Aggregate production planning – a survey of models and methodologies. European Journal od Operational Research, 61: 255–272.

Norouzilame, F., Jackson, M. (2013). On the application of Discrete-Event Simulation in Production, Advances in Sustainable and Competitive Manufacturing Systems, Lecture Notes in Mechanical Engineering, pp. 259–272.

Reay-Chen, W., Hsiao-Huo, F. (2001). Aggregate Production Planning with Multiple Objectives in a Fuzzy Environment. European Jorunal of Operational Research, 133(3): 521–536.

Swic, A., Gola, A. (2013). Economic analysis of the production of parts of casings in a flexible manufacturing system. Actual Problems of Economics, 3(141): 526–533.

Swic, A., Taranenko, W., Szabelski, J. (2011). Modeling dynamic systems of low-rigid shaft grinding. Eksploatacja i Niezawodnosc, 50(2): 13–25.

Tabucanon, M.T., Majumdar, S. (1989). Production planning in a ship repair company in Bangladesh. Proceedings of the International Conference on MCDM: Application in Industry and Service. Bangkok: Asian Institute Technology.

Xue, G.S., Offodile, O.F., Zhan, H., Troutt, M.D. (2011). Integrated production planning with sequence-dependent family setup times. International Journal of Production Economics, 131(2): 674–681.

Стаття надійшла до редакції 02.08.2013.