ARENA Coupling with Optimization Tools/Algorithms: Pattern Search

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1 Introduction and Motivation

Simulation and Simulation-based optimization are important for modeling and solving real problems that are generally more complex, of large size, dynamic and stochastic. Simulation-based optimization is widely used in a variety of applications including supply chain [1], manufacturing systems [2], project management [3], operations scheduling [4] and inventory systems [5]. Considering the mathematical limits of analytical resolution approaches [6], the development of empirical methods is necessary. For example, Gharbi et al. [7] combine a design of experiments, simulation modelling and response surface methodology to determine the optimal control policy parameters for an unreliable manufacturing cell with adjustable capacity. Versatile and powerful, Arena is the most used simulator in logistics; its popularity lies in its ability to handle very complex systems [8]. In the simulation-based optimization context, the simulation model should be fast, to allow many replications and evaluations. And the optimization tool should be robust enough to handle the randomness and uncertainty. Law [9] describes some Simulation-based optimization tools like: AutoStat, Extend Optimizer, OptQuest, SimRunner2, Witness Optimizer® and OptQuest. However, the literature of performance comparison of commercial simulation optimization packages is not so rich. In our literature review, we come across some of them [10, 11, 12]. This lack in the literature is one of the motivations of our present work plus the fact that OptQuest acts like a black box optimization. We were deceived by its performance for some problems like the one covered in this paper. Then we decided to build our own tool inside Arena. We started with the algorithm that fit, the most, for non-linear unconstrained optimization problem.

In the section two, of this paper, we define the benchmark problem. In section 3, we describe our approach. And in section 4, we present some results and conclude the present work in section 5.

2 Benchmark problems description

The benchmark's problem is based on the well-known problem of "Optimal Production Control of Unreliable Manufacturing System" (OPCUMS). It is the problem of serial production line with a single or many machines. The line produces one type of product and is composed of a sequence of *m* machines (M_i, $i=1 \ldots m$), which are separated by buffers of capacity Z_i. The machines are unreliable since they are subject to random breakdowns and repairs. The time to a failure state and the repair time follow an exponential distribution with means $MTTF_i$ and $MTTR_i$, respectively. When the machine breaks down the reparation is done perfectly. Each machine feeds the following buffer with a production rate u_i. The customers' demand is described by the constant rate *d*. Given U_{max} the maximum production rate of M_i and x_i the inventory level of buffer *i*, the production rate u_i of M_i, controlled through the hedging point policy (HPP) [18], is expressed as follow:

$$u = \begin{cases} U_{max} & if\ x_i < Z_i \ \&\ M_i\ UP \\ d & if\ x_i = Z_i \ \&\ M_i\ UP \\ 0 & if\ \ x_i > Z_i\ OR\ M_i\ DOWN \end{cases}$$

Because of unreliable state of the machines, shortage could happen and the backlogs occur. Therefore, the running of this production system incurs two costs: (1) the holding cost of the stock, $c\sum_{i=1}^{m-1} x_i + c^+ \max(x_m, 0)$, when $x_m > 0$; (2) the backlog cost, $c^- \max(-x_m, 0)$, when $x_m < 0$. Where c, c^+ and c^- are, respectively, holding cost for work-in-progress, holding cost for finished goods and backlog cost; these costs are expressed per units of product and unit of time. The objective of the model is to find the right buffers sizes Z_i that minimize the total cost, the holding cost and the backlog one.

3 Solving approach

Arena is a discrete event simulation and automation software by Rockwell Automation [8] based on SIMAN language. The Arena product family offers a set of tools, that help engineers, model and analyze their systems [13], among which we have an optimization tool, OptQuest.

For modelling the single machine, we use the model developed by Assid [14]. And for the production line, we use the model developed by Lavoie et al. [15]. These models are the most accurate and fast models. They are based on a combination of continuous and discrete approaches.

Once the model is build, the optimization could be done through OptQuest [16]. OptQuest employs three search heuristics, scatter search (SS), tabu search (TS) and neural networks (NN) [9]. Due to the lack of interaction with OptQuest and non-ability of tuning its embedded heuristics' parameters, we were obliged to build our own heuristic with the use of VBA language.

The algorithm used to test the ability of coupling Arena with a customized optimization tools is the classical "Pattern Search". We chose this algorithm, because the problem we are dealing with is a non-linear unconstrained optimization problem; in which the variables are continuous and the fitness function is not explicit so we could not assert that it is continuous or differentiable.

The implemented version of "Pattern Search" is an adaptation of the version in [17]. Initially, it starts with a given point in the search space and calls the simulation to evaluate it; and during the iterations, it samples points in a fixed pattern nearby the current point. It computes function values of these new points, through the simulation model, and tries to find a minimizer. If it finds a new minimum, it changes the center of pattern, initializes the pattern size and iterates. If all the values on the pattern fail to produce a decrease, then pattern size is reduced by half. This search continues until the search step gets sufficiently small, thus ensuring convergence to a local minimum.

4 EXPERIMENTS AND RESULTS

The tests were conducted on two production lines, one with a single machine and the second with a line of four identical machines. These tests aim to compare the accuracy of the optimization results and the solving time for the two approaches: OptQuest vs Pattern search. All tests were conducted on a Windows PC with Intel Core i7-6700 CPU@3.40 GHz and using Arena 14.7.

The parameters used in all tests are: mean time to failure *100*, mean time to repair *3*, demand rate *1* and maximum production rate *1.1*. We run the two cases with the same conditions: Simulations were run during *1 001 000* units of time with a warm-up period of *1 000* units; For both solvers, we use the same starting point and boundaries for the Zi values. Each evaluation uses 5 replications and stopping criteria: *500* simulations (*100* iterations).

Table (1) shows the results of running the optimization with the two approaches and for the two cases, single machine and 4 machines. The table displays the optimal buffer size (Z*), the minimum cost (Cost) and the performance of the solver in terms of: (1) number of simulation (Sim*) until the optimum and (2) computing time (time) in seconds. We notice that both approaches find a near optimal solution. Our approach is the fastest: *16* times faster for a single machine and *3* times faster for the line with 4 machines.

Approach	Case	*Opt. Z**	Opt. Cost	Sim*	time (s)
Arena / OptQuest	1 Machine	14,135	16,51	71x5	810,0
Arena / Pattern Search	1 Machine	14,00	16,48	13x5	48,4
Arena / OptQuest	4 Machines	[4,8; 9,4; 11; 18]	43,32	92x5	11 760,0
Arena / Pattern Search	4 Machines	[5; 8; 10,5; 21]	42,84	77x5	3 485,0

TAB. 1 – Optimization performance

5 Conclusions et perspectives

In this work we present the integration of the simulation in Arena with our optimization tool based on a Pattern Search algorithm. We also compare our performances with those of OptQuest on the classical problem of OPCUMS. The performances obtained are promising and exceed those obtained by OptQuest: Our approach is *16* times faster for a single machine and *3* times faster for the line with 4 machines.

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References

[1] Hlioui, R., Gharbi, A., and Hajji, A. (2015). Replenishment, production and quality control strategies in three-stage supply chain. International Journal of Production Economics, 166, 90-102.

[2] Rivera-Gómez, H., Gharbi, A., Kenné, J. P., Montaño-Arango, O., and Hernandez-Gress, E. S. (2016). Production control problem integrating overhaul and subcontracting strategies for a quality deteriorating manufacturing system. International Journal of Production Economics, 171, 134-150.

[3] April, J., M. Better, F. Glover, and P.J. Kelly. 2004. New advances and applications for marrying simulation and optimization. In Proceedings of the 2004 Winter Simulation Conference, edited by R. G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, 80-86. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

[4] Ait El Cadi, A., Benmansour, R., Serraj, F., and Artiba, A. (2015, October). A joint optimization-simulation model to minimize the makespan on a repairable machine. In Industrial Engineering and Systems Management (IESM), 2015 International Conference on (pp. 489-495). IEEE.

[5] Alferaei M.H., and A.H. Diabat. 2009. A Simulated Annealing Technique for multi-objective simulation optimization. Applied mathematics and computation 215: 3029-3035.

[6] Boukas, E.K., and Haurie, A. (1990). Manufacturing Flow Control and Preventive Maintenance: A Stochastic Control Approach. IEEE Transactions on Automatic Control, 35(9), p. 1024-1031.

[7] Gharbi, A., Hajji, A., and Dhouib, K., (2011). Production rate control of an unreliable manufacturing cell with adjustable capacity. International Journal of Production Research, 49(21), p. 6539-6557.

[8] Kelton, W. David, Randall P. Sadowski, and David T. Sturrock. 2007. Simulation with Arena. 4th edition. New York : The McGraw-Hill Companies, 630 p

[9] Law, A.M. 2007. Simulation Modeling and Analysis. 4rd Edition. McGraw-Hill, New York.

[10] Eskandari, H., Mahmoodi, E., Fallah, H., and Geiger, C. D. (2011, December). Performance analysis of comercial simulation-based optimization packages: OptQuest and Witness Optimizer. In Proceedings of the Winter Simulation Conference (pp. 2363-2373). Winter Simulation Conference.

[11] Jafferali, M., J. Venkateshwaran, and Y.J. Son. 2005. Performance Comparison of Search-Based Simulation Optimization Algorithms for Operations Scheduling. International Journal of Simulation and Process Modelling 1: 58–71.

[12] Ait El Cadi, A., Gharbi, A., and Artiba, A. (2016, August). Matlab/Simulink -vs- Arena/Optquest: Optimal production control of unreliable manufacturing systems. In International Conference on Modeling, Optimization and Simulation - MOSIM'16.

[13] Sadowski, D., and Bapat, V. (1999). The Arena product family: enterprise modeling solutions. In Simulation Conference Proceedings, 1999 Winter (Vol. 1, pp. 159-166). IEEE.

[14] Assid, M. (2013). Contrôle de la production et de la maintenance des systèmes industriels imparfaits (Doctoral dissertation, École de technologie supérieure).

[15] Lavoie, P., Kenné, J. P., and Gharbi, A. (2007). Production control and combined discrete / continuous simulation modeling in failure-prone transfer lines. International Journal of Production Research, 45(24), p. 5667-5685.

[16] Kleijnen, J. P., and Wan, J. (2007). Optimization of simulated systems: OptQuest and alternatives. Simulation Modelling Practice and Theory, 15(3), 354-362.

[17] DENNIS, J. and TORCZON, V. (1994). Derivative-free pattern search methods for multidisciplinary design problems, paper AIAA-94-4349 in Proceedings of the 5th AIAA/ USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Panamá City, FL, Sept. 7-9, (1994), pp. 922-932.

[18] Akella, R., Kumar, P.R., 1986. Optimal control of production rate in a failure-prone manufacturing system. IEEE Transactions on Automatic Control AC 31, 116–126