Chapter 1
Reliability Allocation Problem in Series-Parallel Systems:
Ant Colony Optimization

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ABSTRACT

Reliability optimization is an important step in industrial systems design. In order to develop a reliable system, designers may introduce different redundant technologies with the same functionality in parallel. In this paper, each technology is assumed to be composed of series components. The obtained configuration belongs to the series-parallel systems. The presented tool is for the design or the improvement of such systems, in order to minimize the system cost with a reliability constraint. The aim is to find the reliability to allocate to each component in order to minimize the total cost, such that the global system reliability verifies a minimal level constraint. This problem is known to be NP-hard. In this paper, a metaheuristic approach, based on the Ant Colony Optimization technics (ACO), is used in order to improve an existing approach. The experimental results, based on randomly generated instances, outperform the one of previous method dedicated to this problem.

INTRODUCTION

Quality and safety management of production tools is a great challenge for industries. This leads them to develop cost management policies adapted to the encountered problems. For example, let consider the case of a hospital which must change its electrical power system. It is obvious that, in case of electricity breakdown, it must have one or two other reliable electricity systems. Its aim is to have electrical power systems (in redundancy, i.e., in parallel) which are reliable and not expensive. The hospital must study the reliability and the cost of the technological solutions in order to choose the less expensive combination which guarantees the minimum reliability level required for such

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system. Generally, this cost management approach arises at the system design step, for any system: a product, a production tool, a detection system or a safety one for example (Zeblah et al., 2009). A system is competitive if it answers to the requirements of its user and at the slightest expense. It means that at the design step, we have not only to answer to the functionalities requirements, but also to consider reliability and expense criteria.

The issue of this paper is a reliability allocation problem. A lot of authors as (Tzafesta, 1980), (Tillman et al., 1980; Misra, 1986; Kuo & Prasad, 2000; Kuo et al., 2001) have proposed classifications according to several criteria, as the system type (repairable, not repairable, series, parallel...) for example. The reliability optimization problems are *NP-hard* (Chern, 1992), which means we cannot compute the optimal solution in polynomial time. (Yalaoui et al., 2005b) compute the time complexity of the enumeration of all the solutions of such a problem and show that it is better to use an approximation method for real life problems.

In reliability allocation studies, two different approaches can be distinguished according to the values nature of components reliability (Yalaoui et al., 2004). In the continuous case, components reliability values may be any real value between 0 and 1 (Elegebede et al., 2003; Yalaoui et al., 2005a). In the discrete case, components reliability values may only take their value in a finite set of values between 0 and 1 (Yalaoui et al., 2005b; Aneja et al., 2004; Yalaoui et al., 2005c). In this paper, we are interested in the discrete case, which corresponds to the availability market constraint. As far as the use of ant colony optimization (ACO) for the design problem with reliability, (Nahas & Nourelfath, 2005) developed a specific method used for series systems. They studied this system, maximizing its reliability under cost constraints. They considered a system composed of several components in series. For each component, it exits different available technologies with different costs, weights, and reliabilities. The design problem studied in Nahas and Nourelfath (2005) is to choose the best components combination in order to maximize the reliability for a given cost.

As far as the parallel-series systems are concerned, Liang and Smith (2004) used Ant Colony optimization for redundancy allocation problems to maximize the system reliability. Meziane et al. (2005) adopted the UMGF approach (Universal Moment generating Function) with Ant Colony Algorithm for the reliability maximization. Nahas et al. (2007) presented Ant Colony Optimization for redundancy and reliability allocation in parallel-series systems, to maximize the system reliability. Their study consists in random choice of a redundancy level in each subsystem. Then, they assigned randomly among the available technologies, the type to each component. At each probabilistic choice, the ACO verified if it respects the cost constraint. Zhao et al. (2007) improved the work of (Liang and Smith, 2004). They used Ant System Colony to solve the allocation problem in parallel-series systems, maximizing the system reliability. The authors compared their results with Ant Colony Optimization - Redundancy Allocation Problem and Genetic Algorithm - Redundancy Allocation Problem (Liang & Smith, 2004). They improved the reliability with a smaller cost and less iterations. Let note that Ant Colony Optimization is also used for the minimization of preventive maintenance cost for example (Samrout et al., 2005).

Series-parallel systems have been less studied than the other types of systems. There are two studies for continuous and discrete reliabilities cases (Yalaoui et al., 2005a; Yalaoui et al., 2005c). For this second one, (Yalaoui et al., 2005c) developed a heuristic method called YCC-SP algorithm. Their two-stage approach used dynamic programming and the analogy between the reliability allocation problem and the knapsack one. As explained by (Yalaoui et al., 2005c), the performances (in terms of computation time and average gaps to the optimum) of YCC-SP are limited by the problem size, due to the use of dynamic programming which implies to use variable changes and to

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