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Multiobjective System of Systems Architecting with Performance Improvement Funds

Hadi Farhangi[a], Dincer Konur[a]*, Cihan H. Dagli[a]

[a]Missouri University of Science and Technology, Engineering Management and Systems Engineering, 600 W. 14th Street, Rolla MO, 65409, USA

Abstract

A System of Systems architecting problem aims to determine a selection of systems, which are capable of providing a set of desired capabilities. A SoS architect usually has multiple objectives in generating efficient architectures such as minimization of the total cost and maximization the overall performance of the SoS. This study formulates a biobjective SoS architecting problem with these two objectives. Here, we consider that, by allocating funds to the systems, the SoS architect can improve the performance of the capabilities the systems can provide. The resulting architecting problem is a biobjective mixed-integer linear programming model. Specifically, the system selection decisions are binary while the fund allocation decisions are continuous. We first discuss the application of the adaptive epsilon-constraint method as an exact method for solving this model. Then, we propose an evolutionary method and compare its performance with the exact method. Finally, a numerical study demonstrates the benefits of fund allocation in the SoS architecting process.

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Keywords: System of Systems; Multiobjective optimization; Performance Improvement

1. Introduction and Literature Review

The system of systems (SoS) is a system, whose components are systems themselves[1]. SoS needs a set of capabilities and these capabilities come from systems that form the SoS[2]. It is worth mentioning the variety of

* Corresponding author. Tel.: +1-573-341-7256.
E-mail address: konurd@mst.edu

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applications of SoS in military, engineering, healthcare, and transportation[3,4,5]. During the construction of a SoS, the architect typically accounts for multiple objectives such as the minimization of the total cost and maximization of the overall performance of the constructed SoS[6]. This study assumes that the cost minimization and performance maximization are the SoS architect's objectives and accordingly formulates a biobjective SoS architecting problem. Here, we consider that the SoS architect can improve the performance of the capabilities that the selected systems can provide by allocating funds to them. A similar study of Konur and Dagli[6] investigates a related topic, where the systems negotiate with the SoS architect for fund allocation. In particular, Konur and Dagli[6] assume that the systems individually decide on how to utilize the allocated funds for achieving maximum performance improvements in their capabilities. Here, on the other hand, we consider that the SoS architect directs how the systems should use the allocated funds. Specifically, the SoS architect specifies how much of the allocated fund should be utilized in the improvements of the capabilities that a selected system can provide.

Note that it is possible to increase the overall performance of the SoS by allocating more funds to the systems; however, this will also increase the total cost of the SoS. We define the overall SoS performance as the sum of the performances of the capabilities provided by the selected systems. The total cost of the SoS is defined as the sum of the fixed capability costs charged by the systems, the funds allocated to the systems, and the cost of interfaces used to assure connectivity of the SoS architecture. The problem of interest in this study can be defined as follows: Which systems should be selected and how much funds should be allocated to each capability of the selected systems in order to minimize the total cost and maximize the overall performance of the SoS guaranteeing that the SoS is capable and connected? In Section 2, we give the formulation of this problem. Section 3 explains the solution analysis. The numerical studies are summarized in Section 4 and Section 5 concludes the paper.

2. Problem Formulation

The SoS architecting problem is to find a subset of the m available systems to provide the entire set of n capabilities such that the resulting SoS is connected and it shows high performance and low cost. In addition, a total fund amount of F is available to assign to the selected systems in order to improve their performances in providing capabilities. Therefore, in addition to which systems to select, SoS architect should also decide how to allocate this total fund among the selected systems. Particularly, let capabilities be indexed by i such that $i \in I$, where $I = \{1, \ldots, n\}$, and systems indexed by j such that $j \in J$, where $J = \{1, \ldots, m\}$. Let us define $x_j = 1$ if system j is included in the SoS and $x_j = 0$ otherwise, and let $\boldsymbol{X}$ be the $m \times 1$ −vector of x_j's. For SoS connectivity, a variable y_{qp} is defined such that $y_{qp} = 1$ if both systems p and q are included in the SoS, i.e. $x_p = 1$ and $x_q = 1$, and $y_{qp} = 0$ otherwise. Let $\boldsymbol{Y}$ be the $m \times m$ −matrix of y_{qp} values. For fund allocation decisions, we define continuous variables $f_{ij} \geq 0$ as the amount of funds that is being allocated to system j to improve its performance in providing capability i. Let $\boldsymbol{F}$ be the $n \times m$ −matrix of f_{ij} values.

A system can provide some or all of the capabilities required by the SoS. Let $A_{ij} = 1$ if system j can provide capability i and $A_{ij} = 0$ otherwise, and $\boldsymbol{A}$ be the $n \times m$ −matrix of A values. Moreover, we define c_{ij} and p_{ij} as the cost and the performance (without any additional improvement spending) of system j in providing capability i, respectively. Furthermore, to assure connectivity, interfaces should be used between any pair of selected systems. Let h_{pq} be the cost of connecting system p to system q with an interface. In this study, similar to Konur and Dagli[6], we assume that the performance of systems in providing capabilities can be improved linearly by the fund allocations. Specifically, let $\Delta p_{ij} = \alpha_{ij} f_{ij}$ be the increase over p_{ij} by allocating f_{ij} amount of funds to system j's capability i, where α_{ij} defines the rate of improvement in the performance of system j in providing capability i. Since, there should be a natural upper bound on the maximum performance achievable, we also define $\overline{f_{ij}}$ as the upper bound for the amount of funds that can be allocated to system j to improve capability i.

Based on the above discussion, the SoS problem of interest (**P-SoS**) can be formulated as follows:

$$\max \quad TP(\boldsymbol{X}, \boldsymbol{F}) = \sum_{i \in I} \sum_{j \in J} A_{ij} p_{ij} x_j + \sum_{i \in I} \sum_{j \in J} \alpha_{ij} f_{ij}$$

$$\min \quad TC(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{F}) = \sum_{i \in I} \sum_{j \in J} A_{ij} c_{ij} x_j + \sum_{p \in J} \sum_{q \in J, q > p} h_{pq} y_{pq} + \sum_{i \in I} \sum_{j \in J} f_{ij}$$

$$s.t. \quad \sum_{j \in J} A_{ij} x_j \geq 1 \qquad \forall i \in I \qquad (1)$$

$$y_{pq} + y_{qp} \geq x_p + x_q - 1 \qquad \forall p, q \in J, q > p \qquad (2)$$