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An improvement on "Integrated production strategy and reuse scenario: A CoFAQ model and case study of mail server system development"☆

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ABSTRACT

The authors (Tang et al. (2013) [1] developed a CoFAQ model to formulate a solution for the problem of production strategy decision and reuse scenario selection for a software product family. In the previous research, we stated that the CoFAQ model was a 0–1 mixed integer nonlinear program, where only a local optimal solution might be found. In a recent study, we found that the CoFAQ could be transformed into a 0–1 mixed integer linear programming model. By solving the model, a global optimal solution can be obtained. In this paper, we present the improved formulation and the optimal solution for the case study.

1. Introduction

One of the core problems in software product family (SPF) is the coordination of product building and core asset development. The authors [1] developed a model of Cost Optimization under Functional and Quality (CoFAQ) goal satisfaction constraints to formulate the combined problems of production strategy decision and reuse scenario selection. We initially tried applying certain well-known optimizers, e.g., IBM ILOG CPLEX (www.cplex.com), to solve the optimization problem. However, empirical studies showed that CPLEX failed in the context of CoFAQ. We further stated that the CoFAQ problem is a 0–1 mixed integer nonlinear programming, which is difficult to solve by traditional nonlinear programming techniques. Moreover, only a local optimal solution may be determined. Therefore, certain heuristics were developed to assist the decision makers in optimizing the SPF development process. However, the use of the heuristics may confront by two limitations. First, finding the global optimal solution is not guaranteed. Second, fixing the parameters of the heuristics techniques for a large-scale problem is challenging.

Upon further study, we determined that the global optimal solution may be obtained when the formulations of the original problem are slightly improved. The current paper is organized as follows. Section 2 briefly describes the original formulations. Then, we try to analyze the structure of the model and obtain some insights for improvement by mathematical manipulation. Section 3 gives the variants' relationship matrix to make the problems more tractable. A revised formulation (CoFAQ-1) expressed by an integer linear programming is discussed in Section 4. The conclusion is given in Section 5.

2. The original formulations and the insights for improvement

The notations in the previous paper are used throughout this paper. The basic parameters are cited in briefly:

θ_{fl} indicates the logic relation between a functional goal and a product; it is equal to 1 if the f-th functional goal is required by the l-th product and 0 otherwise;
M_j: the j-th group of functional goals, which correspond to a functional module;
A_{rt}: the t-th set of alternative goals group belongs to the market region r;
C_{rt}: the t-th set of the common goals group belongs to the market region r;
S_{jl} equals 1 when module j is included in the l-th product and 0 otherwise;
$Sat_{ij}(k)$: satisfaction level of module j implemented by using scenario i, regards to the quality goal k;

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χ_k: the weight of goal k;
w_j: the weight of module j.

Decision variables are showed as follows:

x_{ij}: Boolean variable, which is equal to 1 when module j is implemented by scenario i and 0 otherwise;
y_l: Boolean variable, which is equal to 1 when product l is selected in the production strategy and 0 otherwise;
w_j; integer decision variable, which represents the number of reuses of the module j.

In the previous study, the integrated decision on minimum total costs of product family can be determined by combining *production strategy decision* and *reuse scenario selection* using the following model (CoFAQ).

$$\textbf{min}\ F(x,y,w) = \sum_{j=1}^{J}\sum_{i=1}^{m_j}(a_{ij}+w_j b_{ij})x_{ij} + \sum_{l=1}^{L}\tau_l y_l \tag{1}$$

$$\textbf{s.t.}\ \sum_{j=1}^{J}\sum_{i=1}^{m_j}\omega_j Sat_{ij} x_{ij} \ge U,\ \text{ where } Sat_{ij} = \sum_{k=1}^{K}\chi_k Sat_{ij}(k) \tag{2}$$

$$\sum_{l=1}^{L}\theta_{fl} y_l \ge 1,\ \forall f \in M_j = \{M_j \mid M_j \in C_{rt}, \forall r, \forall t\} \tag{3}$$

$$\sum_{l=1}^{L}\theta_{fl} y_l = 1, \forall f \in M_j = \{M_j \mid M_j \in A_{rt}, \forall r, \exists t\} \tag{4}$$

$$\sum_{i=1}^{m_j} x_{ij} \le S_{jl} y_l,\ \forall j, \forall l \tag{5}$$

$$\sum_{l=1}^{L} S_{jl} y_l = \sum_{i=1}^{m_j} w_j, \forall j \tag{6}$$

Objective function (1) is formulated to represent the combined cost of reuse scenario implementation and product development (i.e., sum of the assembly cost τ) to be minimized simultaneously. The first term of the objective function, which is the total cost of reuse scenario implementation, gives the sum of the asset development costs (i.e., fixed costs a) and asset reusing costs (i.e., variable costs b) which depend on the number of reuses of the asset. Constraint (2) represent that the overall satisfaction of targeted software systems should meet an accepted threshold level. For common goals, the products selected in a product family a group of goal should be implemented compulsorily for each special market region, formulated as constraint (3). On the contrary, the only one alternative group of goal with an exclusive relationship can be chosen for each special market region, formulated as constraint (4). Eq. (5) indicates the logic relation between reuse scenario and a selected product with its module. Eq. (6) gives the number of assets reused in the SPF.

Separating the first term of Eq. (1), the product of the decision variables w_j and x_{ij} in the second double-sum becomes the source of nonlinearity in the original model. These formulations are expressed as either $w_j > 0$ if $x_{ij} = 1$ or $w_j = 0$ if $x_{ij} = 0$. In fact, it represents a combination of ***two contingent decisions*** that (1) if the module j is selected as an asset for software product family (i.e. $x_{ij} = 1$), certain number of reuses should be assigned on the module j (i.e. $w_j > 0$), (2) otherwise (i.e. $x_{ij} = 0$), the number of reuses of the module j should be set as zero (i.e. $w_j = 0$). A series of artificial variables may be introduced to describe the relationship between w and x in a linear procedure, which is discussed in Section 4. On the other hand, although the constraints (3) and (4) are linear expression, fixing the parameters of the real-world application on a large-scale is still a challenge. In the next section, we try to solve this problem by using the method of autocorrelation matrix.

3. The variants' relationship matrix

As mentioned in the previous paper, an SPF process should first involve the development of a production strategy in the product-building phase to determine which product variants are built from a given set of product variants to meet functional goal groups required by market segments. This decision is made by the organization in general when the domain market analysis is completed and the concept design of the SPF commences. Then, each selected product should meet one or several functional requirements. After this phase, the variants' relationship matrix $R_{ll'}$, can be directly obtained according to logical coherence. $R_{ll'}$ is equal to 1 when the product l and the product l' belong to the identical market region; otherwise, $R_{ll'}$ is 0. Taking our industrial case in [1] as an example, the variants' relationship matrix is formulated as

$$R_{9\times 9} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

The relationship matrix acts as a substitute of the discriminator that enables the identification of common and variant requirements for each market region. It effectively avoids the procedures of distinguishing the common goals from alternative goals, and it may be impossible to use for large-scale problems.

The parameter R is set, but it may be incompletely considered with the relationship's transitivity. It is likely to leak a related product that becomes transitive more than once, especially for large-scale problems. To satisfy the transitive relationship, a consistency check using Boolean calculation is introduced, as follows: Let $R^1 = (R+I)$, $R^2 = (R+I)^2$, …, $R^{r-1} = (R+I)^{r-1}$, where I is an identity matrix. If $R^1 \ne R^2 \ne \cdots \ne R^{r-1} = R^r$ $(r < L-1)$, then R^{r-1} is the determined autocorrelation matrix R.

4. Revised formulation

The CoFAQ can be rewritten as CoFAQ-1:

$$\textbf{min}\ F(x,y,w) = \sum_{j=1}^{J}\sum_{i=1}^{m_j} a_{ij}x_{ij} + \sum_{j=1}^{J}\sum_{i=1}^{mj} b_{ij}w_{ij} + \sum_{l=1}^{L}\tau_l y_l \tag{7}$$

$$\textbf{s.t.}\ \sum_{l=1}^{L}\sum_{l'=1}^{L}\theta_{fl} R_{ll'} y_l \ge 1, \forall f \tag{8}$$

$$\sum_{j=1}^{J}\sum_{i=1}^{m_j}\omega_j Sat_{ij} x_{ij} \ge U,\ \text{ where } Sat_{ij} = \sum_{k=1}^{K}\chi_k Sat_{ij}(k) \tag{9}$$

$$w_{ij} \le M x_{ij},\ \ \forall i,\ \ \forall j \tag{10}$$

$$\sum_{i=1}^{m_j} x_{ij} \le 1, \forall j \tag{11}$$

$$\sum_{l=1}^{L} S_{jl} y_l \le \sum_{i=1}^{m_j} w_{ij}, \forall j \quad (12)$$

To allow the decomposition of Eq. (1), first, the column vectors w_j are relaxed to the matrix w_{ij} by adding row vector in each column. Consistency constraints (10) and (11) are added to ensure that all copies attain equal values at the optimal point. Eq. (11) ensures that only one reuse scenario can be selected for each module. Eq. (10) indicates the logical relationship between the reuse time of core asset and that of a selected reuse scenario to its core asset. The parameter M indicates the largest number of reuse, and its value may be easily set as the total number of variant products. Now, let us prove that the new linear formulation satisfies the *two original contingent decisions*. **Proof.** (1) If $x_{ij}=0$ then the constraints $w_{ij} \le Mx_{ij}$ are active, which ensure $w_{ij}=0$; (2) If $x_{ij}=1$ then the constraints $w_{ij} \le Mx_{ij}$ have no effect on the feasible region, because the inequality $w_{ij} \le M$ is consistently satisfied. Minimizing the objective function can automatically determine the minimum number of reuses (i.e. w_{ij}). **End.**

Based on the autocorrelation matrix, constraint (8) ensures that the common goals are implemented compulsorily, and the alternative goals are chosen for each special market region by the products selected in a family. Eq. (12) gives the number of modular reused in the SPF. It can be noted that with the use of the optimization technology of CPLEX solver, less computation time might be obtained by using "the less than or equal constraints" instead of "the equality constraint". Since the objective function is a minimizing one and the model is an integer programming, identical optimal solutions were found under both of the two conditions. It should be noted that certain reuse scenarios do not count the core asset development costs (i.e., fixed cost a), such as the pure development (PD) and the opportunistic reuse (OR). Then, fixed costs should be set as any positive small numbers ε (not zero) for convenience of solving.

An integer programming (IP) model was formulated. Therefore, we try to investigate through the use of an IP solver. The optimization technology of CPLEX V9.0 solver (Concert Technology for.NET) is applied to solve the industrial case study presented in the previous paper [1].

The empirical studies showed that the global optimal solution, which was proved by exhausting all feasible production strategies in the previous paper, was exactly obtained by the solver. Four products (i.e., products 1, 3, 6, and 9) are selected for each market region, and eight employed modules (i.e., modules 1, 2, 3, 4, 5, 7, 8, and 12) are implemented using the scenarios OR, SRC, SRA, SRC, SRA, SRA, SRN, and SRC, respectively. We also recorded the run time on the test instance. The CPU time for obtaining the best solution is 271 (ms), which means CoFAQ-1 can be solved within a reasonable computation duration.

5. Conclusions

In this paper, we determined that the previous paper incorrectly declared that CoFAQ problem could not be expressed by an integer linear programming. We further propose a revised formulation to address this flaw. The revision has two contributions. First, finding the optimal solution can be guaranteed for any scale problems. Second, fixing the parameters of the real-world application on a large-scale can be convenient and efficient.

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