Study on Merging and Optimization Method of Support Equipment Range in the Development Phase

Xiaoming Kang**,** Shihong Xiang

School of Automation Science and Electrical Engineering Beihang University, Beijing, China

Nanjing Glaway Software Co., LTD, China

x_kang@sohu.com, xiangshihong@glaway.com

Keywords: Support Equipment range; Dynamic Programming; Optimization

Abstract. Two support equipment range merging optimization methods, i.e. direct optimization method and dynamic programming optimization method, were proposed in this paper. Direct optimization method is more suitable for simple systems with only limited types of support equipment, while dynamic programming optimization method works better for complex systems with a large number of types of support equipment. We gave out a case study to validate the dynamic programming optimization method. This paper provides theoretical support for resolving problem of optimizing support equipment range in the system development phase.

Introduction

Support equipment is one of the most important factors that affects system support effectiveness and support footprint. During system development phase, reasonable determination of support equipment range and optimizing support equipment quantity are important to reduce support footprint and support cost.

There have been several methods, for calculating support equipment demands during system development phase, such as Chen Jun and Chen Yonglong [1-2] provide a method of calculating approximate support equipment demands based on similar system theory or neural network model; Reference [3-8] provide the calculation model based on support activity processes modeling or queuing theory; While there are few literatures focusing on support equipment types merging method. Also Reference [9] just gives the process for determining support equipment types through supportability analysis, without support equipment types merging method, which is premise and basis for support equipment quantity determination. This paper proposes support equipment range merging criterion based on support function equivalence relation. Furthermore, this paper gives a basic merging optimization method and a multi-step merging optimization method based on dynamic programming theory. The multi-step merging optimization method provides theoretical support for optimizing support equipment types of some complex systems.

Direct Optimization Method

If the system complexity is not high and the types of support equipment are few, direct optimization method could be used to merge the support equipment types. Firstly, the optimization goal and objective function should be defined, then judging whether the support equipment types can be merged through support functional equivalence relationship of the support equipments. Support functional equivalence relationship is defined as a case, in which, at given condition, different support equipments' functions can meet a given supporting task requirement.

The set named M need be established to represent support task requirements, the set named T need to be established to represent support equipment types. The mapping between R and P by support function equivalence relation should be established finally, see Fig.1.

Fig.1 Mapping Relationships Between Set T and M

According to the mapping relationship, matrix R is generated, with n rows (the number of support equipment types) and m columns (the number of support tasks) consistent of elements 0 and 1.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & r_{ij} & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}, \quad r_{ij} = \begin{cases} 1 & \text{Support Equipment i can meet support task j} \\ 0 & \text{Support Equipment i can not meet support task j} \end{cases}.$$

Given: Judgment matrix of merging is D, it is also a n rows m columns matrix consistent of elements 0 and 1.

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \cdots & \cdots & d_{ij} & \cdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix}, d_{ij} \text{ in matrix D can be calculated through Equation 1:}$$

$$d_{ij} = MAX(2 * r_{ij} - \sum_{k=1}^{m} r_{ik}, 0) \tag{1}$$

If there is any row full of value 0, the support equipment type represented by this row can be merged. After set optimization goal and objective function, the optimal support equipment range can be calculated through Equation 2.

The objective function is defined as:

$$\begin{cases} C_3 = MIN(f(L)|L \in S) \\ f(L) = \sum C_{pm_t} | t \in L \end{cases} \tag{2}$$

Where, C_3 is the optimization goal(such as the lowest usage cost); L is the subset of T that meets support tasks requirements; S is the collection of all L; $f(L)$ is the function for calculating the accumulated goal(such as usage cost) of all support equipments in L; C_{pm_t} is the objective value of support equipment t.

Dynamic Programming Optimization Method

Support tasks and support equipment types of complex system are various, so that it is very complicated to establish the support equipment equivalence relationship. The calculation amount of merging optimization through direct optimization method will be too huge. In this case, dynamic programming optimization method, which decomposes the optimization process into multiple steps, is more practicable.

The non-optimal support equipment combinations should be excluded before each step of optimization, then the remaining combinations can be directly optimized. The optimal construction can be achieved repeating the process. See Fig.2.

As Fig.2 shown, all support equipment types were divided into three groups:SE1, SE2 and SE3, then decision principles through multi-step merging optimization process should be decided. At each step, support equipment types are combined as a state of this step. The set of all state is called state set, named S. The state set of step 1 is named S1, which contains unique element -- the first group of support equipment types. The state set of step 2, named S2, is get by excluding the non-optimal combinations of support equipment types in step 2 based on S1 and a certain strategy. The state set of step 3, named S3, is get by excluding the non-optimal combinations of support equipment types at step 3 based on S2 and a certain strategy. Since the third step is the last step, each element in S3 represents

the possibly optimal combination of support equipment types. If the objective function is set to V, the optimal support equipment catalogue can be determined based on S3 and V.
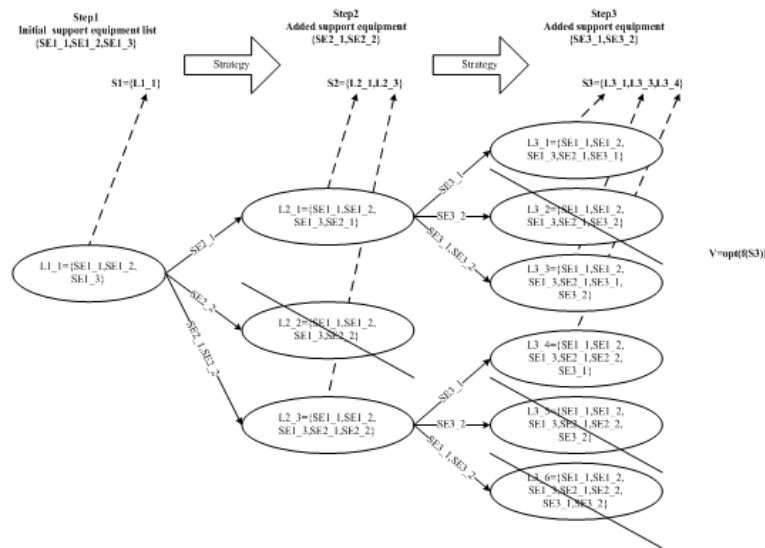

Fig.2 Multi-step merging optimization process

Dynamic Programming Optimization Process

The dynamic programming optimization process of support equipment catalogue contains 4 steps:
1.Determining the goal of support equipment range optimization;
2.Determining how many steps that the strategy of support equipment range optimization are devided into;
3.Establishing the strategy and determine the set of all possibly optimal combinations(state set) of support equipment types of each step；

4.Determining the optimal combination of support equipment types in the state set of last step through the optimal objective function.
The optimization process is shown in Fig.3.
Before using dynamic programming optimization method, the goal of optimizing support equipment range must have been determined. This paper chooses support equipment usage cost(SEUC) as the optimization goal. The accumulated usage cost of each combination of support equipment types should be calculated to drive the next step.
The amount of steps after determining the optimization goal should be determined, then the functions and the tasks that all support equipments can be completed in each support equipment group should be determined. Finally, the relationship between the tasks and function requirements should be mapping. See Fig.4.
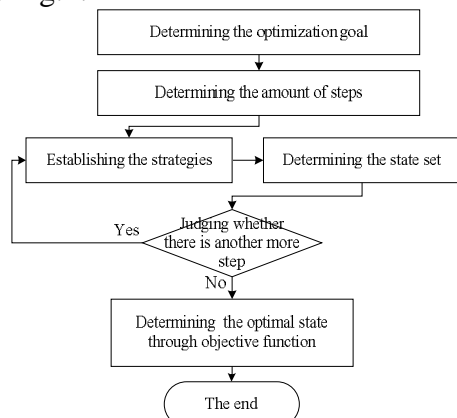

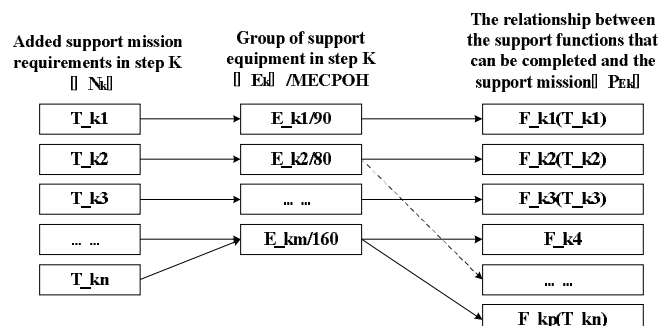Fig3. Dynamic programming optimization process

Fig.4 Mapping the relationship of support tasks, equipments and function requirements

At each step, the combinations of support equipment types (states) that impossibly be the optimal combinations should be excluded according to some strategy. The strategy of each step consists two constraint conditions: 1)All combinations of support equipment types must satisfy the support function requirements; 2)At this step, there is a combination of support equipment types that can complete more function and has lower accumulated usage cost than any other combinations. The determination of equivalent relation is the basis of comparing which combination can complete the most functions. The strategy of step k is named u_k, which is defined as:

$$s.t. \begin{cases} P(L) \supseteq R_k, L \in S_k \\ \exists L | P(L) \subseteq P(L') \wedge f(L) > f(L'), L \cdot L' \in S_k \end{cases} \tag{3}$$

Where, L is the combination of support equipment types, P(L) is the support function that L can complete; R_k is the support function requirements of the step k; S_k is the state set of the step k; $f(L)$ is the accumulated usage cost of L.

R_k is determined by:

$$\begin{cases} R_k = R_{k-1} \cup N_k & 1 < k < n \\ R_1 = N_1 & k = 1 \end{cases} \tag{4}$$

where, n is the amount of steps; N_k is the set of added support tasks.

The state is a combination of some support equipment types which satisfy the support mission requirements at current step. The state set is the set of all combinations and is defined as:

$$\begin{cases} S_k = T(S_{k-1}, u_k) & 1 < k < n \\ S_1 = \{L_1\} & k = 1 \end{cases} \tag{5}$$

where, n is the amount of steps; S_k is the state set after finishing the step k, and each element of S_k means a combination that satisfies the support task requirements of current step; S_1 is the combination of support equipment types at the first step and has only one element L_1; u_k is the strategy of step k.

The process of determining S_k is below:

Given $S_{k-1} = \{L_{k-1_1}, L_{k-1_2}, \cdots, L_{k-1_m}\}$, and the grouping of support equipment types at step k is E_k. The union of all elements of S_{k-1} and all subsets of E_k(with E_k itself) is the temporary state set of step k, named S_k'. Using u_k to make the decision of S_k', then get the state set of step k, named S_k.

The last step(step n) is to solve the optimal objective function and acquire the optimal support equipment catalogue. The objective function is defined as:

$$\begin{cases} V_s = MIN(f(L) | L \in S) \\ f(L) = \sum C_{pm_t} | t \in L \end{cases} \tag{6}$$

Where, V_s is the lowest accumulated SEUC; S is the state set of the last step; L is an any element of S; $f(L)$ is the function by which to calculate the SEUC of all support equipments; C_{pm_t} is the SEUC of support equipment t.

The state L, which satisfies the optimal objective function and has the lowest accumulated SEUC, is the final result of support equipment types optimization.

Case Study

Given: A system is composed of 3 functional systems. Fig 5~7 show the initial support equipment range, the list of support tasks, the list of support functions that the initial support equipments can be completed, and the relationship of these three aspects.
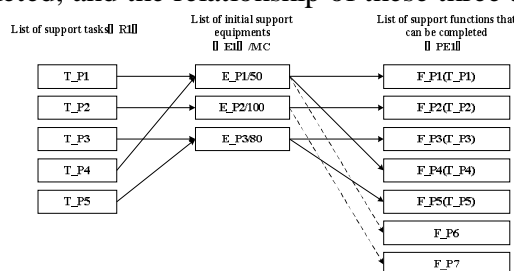

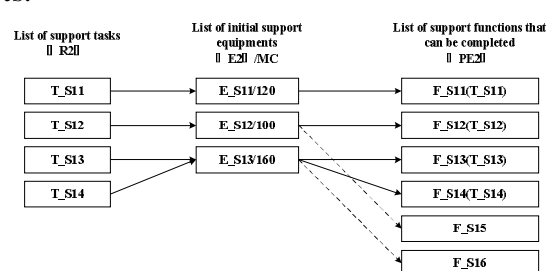Fig.5 Support relationship of System 1   Fig.6 Support relationship of System 2
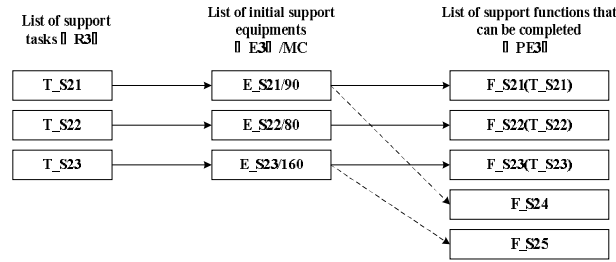
Fig.7 Support relationship of System 3

The list of equivalent relations is shown in Table 1.

Table.1 The List of The Equivalent Relation

Support Function	Equivalent Support Function
F_P1	F_S11
F_P6	F_S12
F_P7	F_S22
F_S15	F_S23

The optimization process should be divided into three steps to make decision, and each step decides the support equipments of one system.

The first step of making decision is using basic information about System 1 to determine state S_1、P、R_1 , there is:

$$S_1 = \{L_1\} = \{\{E\_P1, E\_P2, E\_P3\}\}$$
$$P_{11} = \{F\_P1, F\_P2, F\_P3, F\_P4, F\_P5, F\_P6, F\_P7\}$$
$$R_1 = \{T\_P1, T\_P2, T\_P3, T\_P4, T\_P5\}$$
$$= \{F\_P1, F\_P2, F\_P3, F\_P4, F\_P5\}$$

The second step of making decision is using result of the first step and the basic information about System 2 to determine R_2、S_2。

Firstly, calculate R_2:

$$R_2 = R_2 \cup N_2$$
$$= \{F\_P1, F\_P2, F\_P3, F\_P4, F\_P5\}$$
$$\cup \{F\_S11, F\_S12, F\_S13, F\_S14\}$$
$$= \{F\_P1, F\_P2, F\_P3, F\_P4, F\_P5, F\_S12, F\_S13, F\_S14\}$$

The subsets of E_2 are $\{E\_S11\}$, $\{E\_S12\}$, $\{E\_S13\}$, $\{E\_S11, E\_S12\}$, $\{E\_S11, E\_S13\}$, $\{E\_S12, E\_S13\}$ and $\{E\_S11, E\_S12, E\_S13\}$. The union of these subsets and L_1 is a new set. Judge the support functions(P) that the new set can be completed whether satisfy the requirements of R_2. There are four sets that satisfy R_2 : $\{E\_P1, E\_P2, E\_P3, E\_S13\}$, $\{E\_P1, E\_P2, E\_P3, E\_S11, E\_S13\}$, $\{E\_P1, E\_P2, E\_P3, E\_S12, E\_S13\}$ $\{E\_P1, E\_P2, E\_P3, E\_S11, E\_S12, E\_S13\}$. Made decision using the strategy u, then we can exclude $\{E\_P1, E\_P2, E\_P3, E\_S11, E\_S13\}$ and $\{E\_P1, E\_P2, E\_P3, E\_S11, E\_S12, E\_S13\}$ because they are impossible to be the optimal combinations. So S_2 contains two elements :

$$S_2 = \{L_{2_1}, L_{2_2}\}$$
$$L_{2_1} = \{E\_P1, E\_P2, E\_P3, E\_S13\}$$
$$L_{2_2} = \{E\_P1, E\_P2, E\_P3, E\_S12, E\_S13\}$$

The third step of making decision is using result of the second step and the basic information about System 3 to determine R_3、S_3. Then calculate V_{S3} and determine the optimal support equipment catalogue.

Firstly, calculate R_3:

$$R_3 = R_3 \cup N_3$$
$$= \{F\_P1, F\_P2, F\_P3, F\_P4, F\_P5, F\_S12, F\_S13, F\_S14\}$$
$$\cup \{F\_S21, F\_S22, F\_S23\} = \{F\_P1, F\_P2, F\_P3, F\_P4, F\_P5,$$
$$F\_S12, F\_S13, F\_S14, F\_S21, F\_S22, F\_S23\}$$

The subsets of E_3 are $\{E\_S21\}$, $\{E\_S22\}$, $\{E\_S23\}$, $\{E\_S21, E\_S22\}$, $\{E\_S21, E\_S23\}$, $\{E\_S22, E\_S23\}$ and $\{E\_S21, E\_S22, E\_S23\}$. The union of these subsets and the whole elements of S_2, that is(L_{z_1}, L_{z_2}), is a new set. Judge the support functions(P) that the new set can be completed whether satisfy the requirements of R_3. The sets that satisfy R_3 are:
$\{E\_P1, E\_P2, E\_P3, E\_S13, E\_S21, E\_S22, E\_S23\}$,
$\{E\_P1, E\_P2, E\_P3, E\_S12, E\_S13, E\_S21, E\_S22\}$, $\{E\_P1, E\_P2, E\_P3, E\_S12, E\_S13, E\_S21, E\_S22, E\_S23\}$. Since the third step is the last step, we came to the conclusion through equation (6).
Since $\{E\_P1, E\_P2, E\_P3, E\_S12, E\_S13, E\_S21, E\_S22\}$ has the lowest accumulated SEUC(MC=660), this set is the optimal support equipment catalogue.

Conclusion

This paper proposes direct optimization method and dynamic programming optimization method to solve the problem of merging support equipment catalogue. The direct optimization method fast solves the problem of optimizing the support equipment catalogue of simple system with fewer support equipment types; while dynamic programming method solves the optimization problem in the condition of complex system with various support equipment types. The dynamic programming optimization method is verified through an instance. The instance shows that, the dynamic programming optimization method proposed in this paper has an clear optimization target, simple calculation and reasonable optimization result and provides theoretical support for optimizing support equipment catalogue at development phase.

References

[1]   Chen Jun, Chen Yongge, Wang Cheng. Equipment Support Resources Evolution Based on Neural Network Model [J]. Academic Journal of MilitaryTraffic Institute, 2008, 10(4) : 46- 48.
[2]   Chen Yonglong, Wang Yuquan, Li Shiying. Study on Determining Operational Support Resources [J] . Academic Journal of Institute of Armored Forces Engineering, 2003, 17(3) : 59- 62.
[3]   Guo Caifen, Wang Ningsheng. Workstation Equipments Number Optimization Base on Queuing Theory [J] . Indutrial Technology economy, 2004, 23(3) : 101- 102.
[4]   Guo Hongfen, Liu Fusheng.Support Equipment Number Optmization Based on Queuing Theory [J]. Academic Journal of Institute of Armored Forces Engineering,.2005,19(1)29-31
[5]Wen Jia, Kang Rui, Liu Rui. Support Equipment Demands Calculation Moded Based on Support Activites[J]. Systems Engineer ing and Electronics, 2010(9):1903-1906.
[6]Wang NaiChao, Kang Rui, Wang Yu. Research on support equipment number determination model basing on item repair policy [J]. Systems Engineer ing and Electronics, 2009(5):1266-1269.
[7]Alfredsson, Patrik. Optimization of multi echelon repairable item inventory systems with simultaneous location of repair facilities[J] . European Journal of Operational Research, 1997, 99(3) : 584- 595.
[8]Green L, Kolesar P. The point wise stationary approximation for queues with non stationary arrivals [J] . Management Science, 1991, 37(1) : 84- 97.
[9]James V.Jones. Integrated Logistics Support Handbook[M]. SOLE LOGISTICS PRESS,2006:13.1-13.2;17.1-17.5
[10]Kang Rui, Kang Xiaoming, Wang Naichao, Study on Support Equipment Types Merging and Optimization