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Modular Organization of Product-service: An Approach Based on Extended Design Structure Matrix

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Abstract: A method to realize loose coupling, high flexibility and low iteration for product-service is proposed. Design Structure Matrix was extended to build a Function-Activity Design Structure Matrix (FADSM) to describe service function-structure unit. To reflect functional constraints synthetically, upper part of FADSM, which solves problem of consistency of service function with activities, is composed of service function, activity, function weightiness and function replaceability to meet requirements of service flexibility. Lower part of FADSM is constructed by service activities to simulate dependent degree between activities. Relationship between activities was defined as sequenced, uniting, branch and circulating modes to build relation matrix. Based on FADSM, process of service modular organization was given. A fuzzy similar matrix was firstly built and solved to form a fuzzy equivalent matrix. Service modules were divided by a value of partitioning granularity. Flexibility, coordination, scale and economy of service module could be adjusted by granularity. With dependent degree of activities, coupling activities could be sorted again to realize low iteration of service module. A case is given to demonstrate the validity of proposed method.

Key words: Modular organization, product-service, extended DSM, FADSM

INTRODUCTION

Recently, because of severe market competition, almost all manufacturing enterprises have to face rapid changing and more complicated customer's demand. Less and less profit forces manufacturing firms to find new way to broaden their profitable space. Product-service is deemed to a main effective approach to increase extra benefit and profit (Pappas and Sheehan, 1997). Some firms have already changed their strategic emphasis from providing mere product or service to offering a whole solution of product-service binding (Roy, 2001). Abundant demonstrations showed that design, development and implementation of service enhanced product were effective weapons for current manufacturing enterprises to extricate themselves from homogeneous competition, meet more and more complicated demand and get continuous profit increment. Practices indicate that, to occupy better market position, product manufacturers must combine product with necessary service to form "product-service binding" composed of product, technology, information and consideration (Meier and Roy, 2010).

Product-service has been widely studied by many different approaches. Lee and Abu Ali (2011) presented an operating system for innovation by offering a methodology for systematic innovative thinking and a toolbox of interconnected tools that can aid in the transformation of core product competencies into effective product-service amalgamations. Fourer *et al.* (2010) described a research project to design a distributed optimization environment in which solvers, modeling languages, registries, analyzers and simulation engines can be implemented as services and utilities under a unified framework. Former researches give an effective promotion for design framework or operating method of product service. However, research results involved less in service functions and their activities. Service functions and activities are most basic element of product service. Rational division of function and deployment of activity can ensure service provided efficiently and profitably. Sun *et al.* (2012) gave a method to find out the best part machining service provider combination and they didn't yet consider function design and activity optimization of service itself.

In product-service design, service module should be defined firstly and each module has some activities to support service function. The modules should meet requirements of loose coupling, high flexibility and low iteration. Focused on the centre-satellite system, Wang *et al.* (2009) proposed a collaborative product development framework with the technology of web

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services using service-oriented architecture. With method of Design Structure Matrix (DSM) normally used in product design, an attempt was done in this paper to build service function-structure unit to describe relationship between service functions, constraints and activities and a Function-Activity Design Structure Matrix (FADSM) was proposed to describe service function-structure unit. With FADSM, order of service activities in service modules can be adjusted to reduce iteration, ensuring service operation effective and economic.

DSM is generally used to analyze and optimize design process of product. In its application, there are some limitations for traditional Boolean DSM to adopt in design of product-service.

Low flexibility. Service procedure is affected by change of service function which results in change of service activities. Influence of service functions to activities need considered synthetically in definition of service module.

Simple expressive form. Because of unity of service function and process, configuration of service modules should consider not only corresponding relationship of function and process but also dependent type and degree between activities.

In this paper, DSM is extended through relationships of "function-activity" and "activity-activity" respectively to describe service function-structure unit. Modular change and optimization can be done through matrix analysis and calculation.

METHDOLOGIES

Extended DSM: Based on Design Structure Matrix and compound matrix, a Function-Activity Design Structure Matrix (FADSM) is proposed to describe service function-structure unit. Shown by Fig. 1, upper part of FADSM is a matrix composed of function S_i, activity a_j, function weightiness w_i and function replaceability u_i. Matrix element r_{ij} describes dependent relation of function element s_i with activity a_j:

$$r_{ij} = \lambda_{ij} w_i u_i \tag{1}$$

Function weightiness w_i represents influence degree of this service function on promotion of customer value. For w_i, the Fig. 9, 7, 5, 3 and 0 are used to denote the degree from great to zero. Generally, it is not exceptional that service functions with high w_i value are main factors driving customer value. Function replaceability u_i represents the function can be substituted by another function. On-site repair without resource influence, for example, can be substituted by remote service or self-service. λ_{ij} represents whether realization of function s_i depends on activity a_j or not:

$$\lambda_{ij} = \begin{cases} 1, & s_i \text{ depends on } a_j \\ 0, & s_i \text{ independs on } a_j \end{cases} \tag{2}$$

Constraints in function-structure unit are synthetically reflected by function weightiness, replaceability and relationship of service activities with service functions.

Lower part of FADSM is a Fuzzy DSM (FDSM) constructed by service activity a_i; dependent degree between activities is expressed by fuzzy relationship. Matrix element m_{ij} describes dependency between activities:

Function \ Activity	a_1	a_2	...	a_m	Weightiness	Replaceability
s_1	r_{11}	r_{12}	...	r_{1m}	w_1	u_1
s_2	r_{12}	r_{22}	...	r_{2m}	w_2	u_2
......	...	...	...	...	...	...
s_n	r_{n1}	r_{n2}	...	r_{nm}	w_n	u_n
Activity	a_1	a_2	...	a_m		
a_1			...			
a_2	m_{21}		...			
...	...	...	...	...		
a_m	m_{m1}	m_{m2}	...			

Fig. 1: Function-activity DSM

$$m_{ij} = \begin{cases} \beta \bullet D(a_i, a_j), i \neq j \\ 0, i = j \end{cases} \quad (3)$$

where, D (a_i, a_j) represents dependent degree between activity a_i and a_j; â is a weight of dependent relation.

FADSM presents a solution for limitation of existing DSM when adopted in product-service design.

Upper matrix reflects dependent relationship between service function and service activity, which solves the consistency problem of function with activity and meet requirements of service flexibility. When service planning need change a certain service function, activities directly relates to this module can be found through dependent relation r_{ij} in upper FADSM and service function relates to a activity can be also determined through m_{ij} in lower FADSM. This feature is propitious to design alteration and function search.

Lower matrix adopts FDSM. With membership grade of fuzzy set, dependency between service activities can be given quantificationally.

Service function-structure unit: For description of service function-structure unit, key tasks of FADSM construction are definition of relationship of functions with activities and dependent relation between activities. Concrete steps are as follows:

- Map every service function to a series of activities and put in FADSM at the first line after collation
- Describe weightiness w_{ij} and replaceability u_{ij} with Fig. 9 to 0 to express great, normal and small up to zero. The value can be determined through interviews, questionnaire, brain storm and etc. with service personnel, sales staff, engineers and customers. After dependent relation λ_{ij} between function and activity defined, upper matrix of FADSM could be built with Eq. (1)
- Convert relationship between activities to relation matrix according to sequenced, uniting, branch and circulating relationship shown by Fig. 2
- Define dependent type between activities. The dependent type can be described as follows

System resources dependence. It denotes that activity realization must depend on a certain system such as equipment management system, customer service management system or remote service system. System resources dependence can be known through investigation and interviews with system operator.

Equipment resources dependence. Strength of share dependency of equipment resources can be judged by two aspects of interactive level and resource importance.

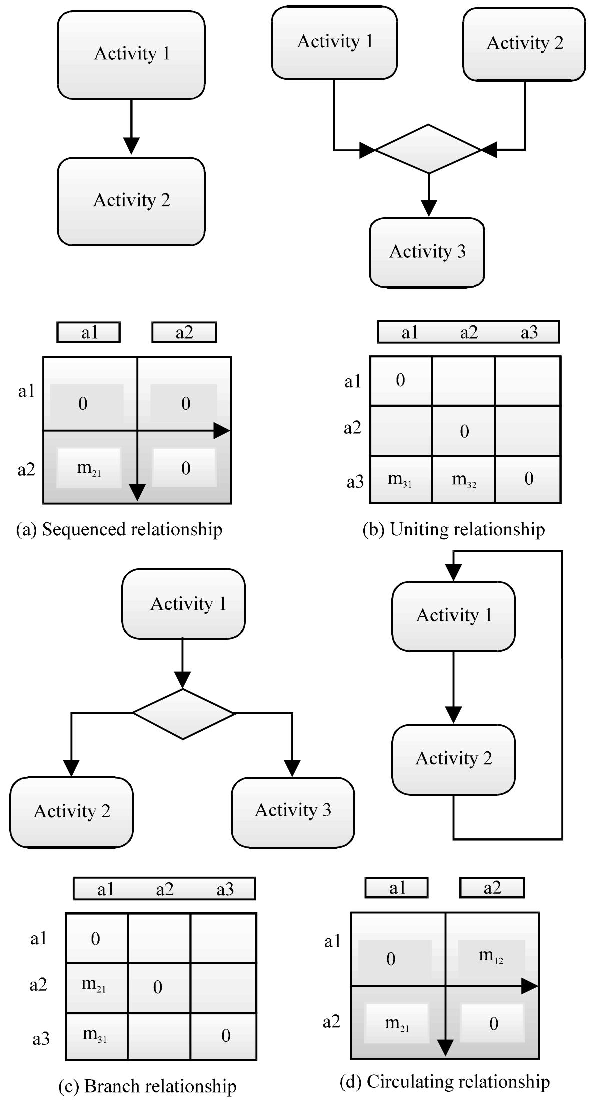

Fig. 2: Conversion of relationship into relation matrix

Interactive level denotes interactive frequency of resource for both activities. Resource importance denotes critical degree of resource to enterprise. For activities of scarcity resource, a closer integration mode should be adopted to avoiding high dealing cost.

Manpower dependence. Some service activities relate to dependence on latent resources such as knowledge, skills, experience and social relationship and etc. The extent of manpower dependence needs be judged subjectively by the way of visiting experts and deep review.

Information resources dependence. The dependent degree of information resources among service activities is different. Activities with coupling relation have more information dependence and should be arranged to one module.

- Define dependent degree and build lower matrix of FADSM. Dependent degree can be expressed with Fig. 9 to 0 to denote much stronger, normal up to zero. Dependent weight β can be given according to important degree of each dependent type. Lower matrix of FADSM can be built with Eq. (3)

FADSM based modular organization: Service modules could be formed through a clustering process of FADSM. Based on former-mentioned requirements of service module, loose coupling and high flexibility may be satisfied by clustering analysis of FADSM with fuzzy transitive closure method and feature of low iteration can be met through optimization of clustering analysis results. Namely, a tearing algorithm of matrix is used for service modules, which contain coupling activities, to organize interior activities of service module and reduce iterative times of activities.

Step 1: Building fuzzy similar matrix

Generally, there exists unequal dependent degree for two activities in service process, namely $m_{ij} \neq m_{ji}$. With utility theory, dependent relationship between two activities is defined through a transfer function $x_{ij} = (x_{ij}+x_{ji})/2$. Then similar coefficient between activities is calculated with cosine method,

$$l_{ij} = \sum_{k=1}^{n} \frac{x_{ik} x_{jk}}{(\sum_{k=1}^{n} x_{ik}^2 \sum_{k=1}^{n} x_{jk}^2)^{1/2}} \tag{4}$$

where, x_i is object set for clustering. x_i ($1<i<n$) contains m attributes and x_{ik} is k-dimensional attribute value. Fuzzy similar matrix L is derived by n similarity values l_{ij}:

$$L = \begin{bmatrix} l_{11} & l_{12} & \cdots & l_{1n} \\ l_{21} & l_{22} & \cdots & l_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ l_{n1} & l_{n2} & \cdots & l_{nn} \end{bmatrix} \tag{5}$$

Step 2: Solve fuzzy similar matrix to cluster

Fuzzy similar matrix L may not be transitive. For clustering analysis, a composing operation of L was done to form a fuzzy equivalent matrix L* with features of reflexivity, symmetry and transitivity. Transitive closure was calculated with Square Method:

$$L \to L^2 \to L^4 \to \cdots \to L^{2k} \to \cdots \tag{6}$$

where, After finite computations, there exists k making $L^{2k} = L^{2(k+1)}$. Let $L^* = L^{2k}$ and requested fuzzy equivalent matrix L* can be built. For L*, as long as a threshold is given, the matrix can be intercepted to a cutting matrix L_t at a proper level t. The elements more than t in matrix L* are regarded as a class to define service module.

$$l_t = \begin{cases} 1, & l_{ij}^* \geq t \\ 0, & l_{ij}^* < t \end{cases} \tag{7}$$

where, Eq. (7) shows that partitioning of service modules depends on partitioning granularity t or how many functions included in this module. Bigger t means fine divided result and less functions in service module. Therefore, the key to use fuzzy transitive closure is definition of clustering threshold t.

Service modules with coarse granularity includes more activities and provides more functions and vice versa. Granularity of service module has important relation to flexibility of transfer process. Service module with fine granularity has higher flexibility and alterability, with which transfer process can well adjust itself according to changes of internal and external environment. But at the same time more coordination cost is needed, reducing scale and economy of service module. On the contrary, Service module with coarse granularity needs less coordination cost and has higher scale and economy; and its transfer process has lower flexibility and alterability.

In practical application, partitioning granularity can be given according to influence degree of internal and external environment on service process (namely sensitivity of service module) and diversity of customer demand. Simple demand should adopt coarse granularity to get efficiency brought by economy and scale. For frequent changed market environment, fine granularity should be adopted to reply market change and different business mode.

Above analysis can only meet modular requirements of internal strong coupling, external weak coupling and high flexibility. But in product-service design, minimal iteration among service activities in module should be assured. Through calculation of dependent degree between activities, a concept, structural sensitivity, was introduced to determine initial iterative sequence of coupling activities to reduce repetition and iterative times in service execution.

Suppose C be the set of coupling activities, SI_i and SO_i be the dependent degree of input and output information of ith activity, structural sensitivity A_i can be calculated as:

$$A_i = {SI_i}/{SO_i} \tag{8}$$

Table 1: Upper matrix of FADSM

Activity function	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	w	u
S_1	3																					3	1
S_2		2	2	2	2	2	2															2	1
S_3								2	2	2	2											2	1
S_4												4	4	4	4	4	4	4				4	1
S_5																			3	3	3	3	1

where, Based on A_i, coupling activities were sorted again in ascending order, realizing low iteration of service module.

CASE STUDY: MODULAR DESIGN OF MAINTAINANCE SERVICE

In this section, modular design of maintenance service of a certain NC machine is discussed. A maintenance service FADSM model will be built and then FADSM based modular organization is done.

Upper matrix of FADSM: Service functions corresponding to maintenance service include: S_1-acquiring and treating of customer demand, S_2-contract signing, S_3-failure diagnosis, S_4-failure removal, S_5-database updating and task summarizing. Shown by Fig. 3, service flow is mapped according to these functions and then a series of activities and their flow relationship are given. With Eq. 1, upper matrix of FADSM is built as Table 1.

Lower matrix of FADSM: According to conversion method shown by Fig. 2, mutual dependency could be defined. Table 2 listed resources involved in maintenance service.

Suppose weightiness of system, equipment, manpower and information resource be 0.4, 0.1, 0.1 and 0.4 respectively. Dependency between activities could be determined according to Fig. 3 with Eq. (3), dependent type and degree can be found to convert to fuzzy similar matrix L:

$$
L=\begin{bmatrix}
1 & 0.6 & 0.6 & 0.3 & 0 & 0 & 0.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.8 & 0.4 \\
0 & 1 & 0.2 & 0.3 & 0.3 & 0.3 & 0.4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0.2 & 1 & 0.3 & 0.3 & 0.2 & 0.2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0 & 0 & 1 & 0.3 & 0.2 & 0.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0 & 0 & 0 & 1 & 0.7 & 0.6 & 0.6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.5 & 1 & 0.4 & 0.8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2 & 0.2 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0.5 & 1 & 0.6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.2 & 0.2 & 0.2 & 0.1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.4 & 0.5 & 0.4 & 0.3 & 0.1 & 0.1 & 0.1 & 0.2 & 0 & 0 & 0.2 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 1 & 0.2 & 0.4 & 0.2 & 0.1 & 0.1 & 0.1 & 0.2 & 0 & 0 & 0.2 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.4 & 0.2 & 1 & 0.5 & 0.5 & 0.2 & 0.2 & 0.2 & 0.3 & 0 & 0 & 0.2 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.7 & 0.4 & 0.5 & 0.6 & 0 & 0 & 0 & 0.6 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.8 & 0.8 & 0.8 & 0 & 0 & 0 & 0.8 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 1 & 0.2 & 0.3 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.5 & 0 & 0 & 0 & 0 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0.7 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7 & 0 & 0 & 0 & 0 & 1 & 0.8 & 0 & 0.5 & 0.1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0 & 0 & 0 & 1 & 0.7 & 0.2 & 0.4 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0.4 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
$$

Table 2: Resources involved in maintenance service

Item	Resource
System resources	PDM system, ERP system, service platform, inventory system for spare parts, logistics system
Equipment resources	Data acquisition instrument, failure diagnosis instrument, detection device, spare parts
Manpower	Service persounel, engineers and technicians, customer, flow control persounel, field service engineer, financial personnel
Information resources	Customer basic information, personnel planning, equipment basic information, service resource scheduling planning, case information, progressive information of service execution, service contract, service result information, changed parts information, customer feedback information

With utility theory, Fuzzy equivalent matrix L* is derived by transitive closure method. In studied case, for higher service efficiency and operability, value t was set to 0.9 to control granularity of service module created from clustering algorithm. Cutting matrix $L_{0.9}$ could be built:

$$
L_{0.9}=\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1
\end{bmatrix}
$$

Based on cutting matrix $L_{0.9}$, 21 service activities are divided to form service modules shown by Table 3.

For defined service modules, it is needed to organize service activities to minimize iteration between activities. Table 4 shows calculating results of sensitivity of activities in service module of failure information acquisition.

No	1	2	3	4	5	6	7	8	11	10	9	12	14	13	15	16	17	18	19	20	21
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0
3	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0
4	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0
5	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
6	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
7	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
8	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0
11	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
10	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
9	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
14	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
13	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
15	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
16	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
17	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0
18	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

Fig. 3: Organized lower matrix of FADSM

Table 3: Service Modules

Service module	Service activity	Service function
Analysis and treatment of customer's request	1	S_1
Task analysis	203,4	S_2
Task detailed planning	5,6,7,8	S_2
Failure information acquisition	9,10,11	S_3
Failure maintenance	12,13,14,15,16	S_4
Task execution feedback	17,18	s_4
Task summary	19,20,21	S_5

Table 4: Activity Sensitivity of Failure Information Acquisition

Activity	SI_i	SO_i	$A_i = Si/SO_i$
Running data collection α_9	5	5	1.00
Field information collection α_{10}	3	4	0.75
Field communication α_{11}	2	3	0.67

In service process, activity with minimal dependent strength to information input was firstly executed. From Table 4, executing sequence of every activity in module of failure information acquisition is $\alpha_{11} \rightarrow \alpha_{10} \rightarrow \alpha_9$. Adjustment of executing sequence can be realized through matrix conversion and other coupling modules are organized in like manner. Organized lower matrix of FADSM is shown as Fig. 3 and corresponding service modules is shown by Table 5.

Table 5: Organized Service Modules

Service module	Activities involved
Analysis and treatment of customer's request	α_1
Task analysis	$\alpha_2 \rightarrow \alpha_3 \rightarrow \alpha_4$
Task detailed plannin→	$\alpha_5 \rightarrow \alpha_6 \rightarrow \alpha_7 \rightarrow \alpha_8$
Failure information acquisition	$\alpha_{11} \rightarrow \alpha_{10} \rightarrow \alpha_9$
Failure maintenance	$\alpha_{12} \rightarrow \alpha_{14} \rightarrow \alpha_{13} \rightarrow \alpha_{15} \rightarrow \alpha_{16}$
Task execution feedback	$\alpha_{17} \rightarrow \alpha_{18}$
Task summary	$\alpha_{19} \rightarrow \alpha_{20} \rightarrow \alpha_{21}$

DISCUSSION

An organization method of service modules with extended Design Structure Matrix was introduced above. The kernel of this method is construction of upper and lower matrix of FADSM and following modular organization based on this matrix.

For upper FADSM matrix, an important work is to find function weightiness w_i and function replaceability u_i to define function constraints in service function-structure unit. These parameters will directly affect modular organization and executing sequence of activities. Suitable measurement, therefore, should be taken according to service environment to avoid subjective deviation in parameters definition.

To control flexibility and alterability of service activities, more attention should be paid to definition of service granularity. Granularity has important relation to flexibility of transfer process and affects coordination, scale and economy of service module directly. Based on service experiences and professional knowledge, granularity should be given by skilled engineers.

When building FADSM, the dependent relationship and degree between activities are considered. But in fact, the dependent strength for different dependent relationship changes dynamically. Further study should focus on how to build principle to classify service activities, give proper dependent regularity for each activity class and ensure stability of organized service module.

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