Methods and Effects of Introduction of the Functional Component Grouping Process into Systematization*

Katsuhiro TANIGUCHI**

In this paper, systematization is divided into system design, system improvement, system development, and system analysis, and the methods and effects of introduction of the functional component grouping process into each type of systematization are discussed. That is, firstly, the functional component grouping process, which is a method of establishing multilayered functional component grouping structures according to the basic policy of each systematization case, is discussed. Then the relationship between the process and each type of systematization from which various kinds of effects are gained, is also discussed.

Key Words: System Engineering, Design Engineering, Layout Planning, Grouping, System Design, System Development, System Improvement, System Analysis, Systematization

1. Introduction

Systems normally consist of several functional components. The evaluation of the system is significantly influenced by the relationship between these functional components. It is possible that analysis starting from a particular structure of the functional components comprising a system, and the way in which they are grouped, may reveal new phenomena which cannot be analyzed by conventional methods. The functional component grouping process is one procedure for establishing a framework of functional components through multilayered grouping structures according to the relevant basic policy, and for analyzing grouping phenomena. In this paper, the former is divided into system design, system improvement, and system development, which together with system analysis are classified under the general term "systematization."

In this paper, I aim to clarify the concept of functional component grouping, and the functional component grouping process. Methods are then proposed for introducing this process into each type of systematization. Examples of the effects of the process are also given for each type of systematization.

2. Definition of Functional Component Grouping

According to Nadler and Chestnut, the attributes of each functional component are determined by the specifications of its system characteristic items*¹. Functional component grouping is the grouping of related functional components based on similarities of the specifications of system characteristic items ('specifications') and/or the level of correlation, bearing in mind their respective significance levels. An illustration of functional component grouping in human body is shown in Fig. 1 (see Ref. (4)). The grouping structure is different for each system; in some systems each group exists separately, while in other systems the groups are compounded in several

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** Development Dept, Urban and Regional Development Div., Taisei Corporation, 1-25-1 Nishi-Shinjuku, Shinjuku-ku, Tokyo 163-03, Japan

*¹ Input, output, function (objective), subfunctions, elements, systematization requirements.

Fig. 1 An illustration of functional component grouping in human body

layers. Regarding the levels of correlation, the rate dimensions differ for each case of systematization, but fundamentally the level of relationship corresponds to a standardized volume dimension based on input and output parameters.

This dimension may involve movement volumes of people, goods, data etc. between functional components, or quantifications of other specific relationships. The similarities of specifications and/or level of correlation are referred to as functional component grouping factors in this paper. And the composition of the factors varies depending on the objectives of systematization, while at the same time having a significant influence on the effects of functional component grouping.

3. Outline of the Functional Component Grouping Process

The details of each step in the process vary depending on the type and purpose of the systematization being carried out, but a basic model for the functional component grouping process is illustrated in Fig. 2.

In this paper, I consider only a qualitative outline common to all types of systematization. A quantitative case study relating to facility design is described in Ref. (1).

1) Organization of systematization requirements

The overall initial systematization requirements, and the individual systematization requirements relating to each functional component unit, are organized to form the basis for the following steps. Since the basic policy in particular has a considerable effect on determination of the weighting values during the preparation of affinity data in step 5, the basic policy should be clarified from a quantitative standpoint.

Naturally, both sets of systematization requirements (overall and individual) form part of the basis for the checking procedure described in step 11.

2) Organization of functional components subject to functional component grouping

The main aim of this step is to establish the functional components subject to functional component grouping, and organize the specifications of each functional component. Depending on the type of

Fig. 2 Basic model for functional component grouping process

systematization, establishing the functional components may involve setting up functional components not subjects to functional component grouping also.

3) Preparation of functional component-system characteristic item interaction data

These data are prepared in order to compare the specifications of functional components, which form one of the functional component grouping factors. Based on the findings from step 2, the functional components are arranged on the vertical axis and the system characteristic items thought to affect the functional component grouping are arranged on the horizontal axis. The presence or absence of a relationship between sample functional components for each item is marked with a 1 or a 0, providing a useful basis for the data processing described in step 5. It is assumed that the system characteristic items on the horizontal axis are independent.

4) Preparation of data on levels of correlation

This is the other set of data concerning functional component grouping factors. The techniques for preparing this data vary according to the type and objective of systematization, systematization requirements described in step 1 etc., but in any case it is desirable to create a set of categorized data in preparation for step 5. These data can be usefully organized using, for example, a relation chart, or a

from-to chart.

5) Preparation of affinity data

The aim of this step is to integrate the data from steps 3 and 4 converted to a single dimension, in preparation for input data in the following steps. The most suitable preparation technique for this affinity data depends on the type, requirements and objective of systematization. For systems involving physical space, for example, a number of distance coefficients^{*2} and affinity indices derived from 2×2 contingency tables^{*3} have been published, but these must be applied carefully to the preparation of affinity data, bearing in mind the significance of each coefficient or index.

6) Establishment of functional component groups

A number of mathematical techniques have been developed for grouping^{*4}. In some cases, however, the technique must be selected carefully, depending on the nature of the data from step 5 and the objective of systematization. Ideally a technique should be selected which allows the internal grouping intensity within each functional component group, and the external affinities between groups, to be determined quantitatively. On the other hand, it should also allow evaluation of the attributes of each functional component group, and the relationship between them.

7) Secondary processing of establishment of functional component group composition

Functional component groups are set up in step 6, but in many cases it is not possible to link these directly to the presentation of functional component group structures in step 10. In this step, therefore, the functional component groups should be arranged or restructured for maximum feasibility.

8) Presentation of relationships between components subject to functional component grouping

As noted above, the aim of steps 8 and 9 is to assess the relationships and mutual influences between individual functional components. The principal aim of step 8 in particular is to present the relationships between components subject to functional component grouping by the most suitable means for the type and objective of the systematization being carried out. This procedure allows comprehensive investigation of individual relationships liable to be overlooked in the steps for functional component groups shown in Fig. 2,

in order to make the final functional component grouping structure as comprehensive as possible.

9) Investigation of influences on each functional component

While step 8 dealt only with components subject to functional component grouping, this step involves investigation of the influence on all components in the system for which systematization is being carried out, in preparation for step 10. In this step, the results from step 8 and those from step 6 are combined.

The main criteria for this investigation are the systematization requirements, both overall and individual.

10) Presentation of functional component grouping structure

In this step, a functional component grouping diagram is prepared in accordance with the objective of each systematization case, combining the results of the investigation of relationships between functional component groups in steps 6 and 7, and those of the investigation of the relationships between individual functional components in steps 8 and 9. This diagram at the present stage represents a tool to assist in decision making, which can be made more effective by using presentation media suited to its content.

11) Checking

The main aim of this step is final checking of the functional component grouping patterns in the diagram, the functional component grouping factors, and the significance of grouping intensity and relationships. Another important task is the final coordination of the relationships between the results of the steps for functional component groups and functional components in Fig. 2.

In cases where processing at this step is difficult, feedback to steps 6, 7, 8, and 9 may be considered.

4. Methods of Introduction of the Functional Component Grouping Process into Each Type of Systematization

Defining the basic framework ('conceptual planning') of a system is referred to in this paper as 'system development', while formulation of the specifications of overall system characteristic items in line with specific design requirements based on these results (following the framework) is referred to here as 'system design'. Both of these types of systematization are applied to new systems, whereas system improvement focuses on a partial solution of problems in existing systems.

System analysis in principle refers to clarification of functional component grouping structures according to the objectives of the analysis, which include classification (including checking) of the positioning

^{*2} Cattel & Coulter coefficient, Lance & Williams coefficient, Rhodes coefficient etc.

^{*3} Russel & Rao index, Jaccard index, Rogers & Tanimoto index, Yule index etc.

^{*4} Clustering analysis, principal component analysis, HIDECS, various quantification theories, the Tabor model etc.

of each functional component and functional component grouping conditions, and study of various related issues etc., from the viewpoint of functional component grouping. System analysis may therefore be applied as a preliminary stage to system improvement or as a method for studying existing related systems for the objective of development and design, as well as general analysis.

Methods of introduction of the functional component grouping process into each type of systematization are described below, based on the fundamental differences outlined.

4.1 Introduction of functional component grouping process into system design

In system design it is assumed that the basic framework for the system involved has been formulated at the development stage, and thus the functional component grouping framework is identified almost automatically. Systematization processes of this kind, therefore, merely require a functional component grouping structure to be set up according to the conceptual plan. Normally, betterment can be achieved simply by altering the system characteristic items, or their specifications, of each functional component. Feedback into major alterations of the conceptual plan would mean a return to the field of system

development (see Fig 3).

4.2 Introduction of functional component grouping process into system improvement

In the introduction of the functional component grouping process into system improvement, it is important to maintain an overall balance, since the establishment of functional components for problem solving is based on the concept of functional component grouping, and the process centers on a recursive loop of coordination between design (formulation of specifications) and specification changes to the existing and new functional components. In some cases, it may be necessary to return to the system development stage for some functional components (see Fig. 4)

4.3 Introduction of functional component grouping process into system development

In the introduction of functional component grouping process into system development, development objectives and requirements are frequently influenced by the motivation for development. In some cases a chain reaction of changes can result from variations in the functional component structure. The repetition of functional component grouping in the context of these variations may result in feedback affecting the development objectives and requirements, and in some cases even the motivation for development. At this stage, normally an initial check

Fig. 3 System design process applying functional component grouping

Fig. 4 System improvement process applying functional component grouping

Fig. 5 System development process applying functional component grouping

of basic feasibility is made, before moving to the next stage of system design (see Fig. 5).

4.4 Introduction of the functional component grouping process into system analysis

The functional component grouping process is generally used to analyze existing system, in order to achieve the analysis objectives described above, following more or less the same procedure as for system design. Feedback loops do not normally occur, although comparative studies may sometimes be made of analysis requirements and the results of previous stage. The functional component grouping process may be reintroduced at the 'Evaluation and Betterment' step shown in Fig. 2, and in some cases systems analysis may be applied in the course of design and development of new systems (see Fig. 6).

5. The Effects of Introduction of the Functional Component Grouping Process into Various Types of Systematization

As was noted in the definition of functional component grouping, similarities of specifications and/or the level of correlation constitute the factors for grouping. The effects of introduction of the functional component grouping process are discussed below under these two headings.

Fig. 6 System analysis process applying functional component grouping

5.1 Effects due to similarities of specifications

Six kinds of system characteristic were described in section 2, and the effects of functional component grouping according to similarities between these specifications are explained in terms of economy (E), safety (Sa), reliability (R), speed (Sp), amenity (A), utility (U) and maintainability (M). These categories will be referred to by the abbreviations in parentheses. The categories for which input and output can be treated together are combined under one heading.

1) Input and output

These are the system characteristics forming the parameters for the external relationships of the functional components under consideration. They are therefore set up in cases such as technical or other cooperative ventures (including complementary systems such as various types of symbiotic relationships and mergers), and petrochemical complexes and ecological infrastructures (closed system types: see Ref. (6)) where the needs(input) and seeds(output) are similar or identical, thus achieving E and Sa effects. In physical distribution systems, grouping of disparate items according to similarity of goods, point of departure, route, destination etc. could be expected to yield E, U and M effects. A good example of this can be seen in utility tunnels. With regard to input and output with special conditions attached (electrical noise, radioactive waste, data in certain fields),

treating the relevant functional component groups together yields E, R and Sa effects.

2) Function (objective)

This effect can be achieved either when similar functional components with a common objective, or differing functional components with a common objective are grouped together. One example of this is that of adult horses protecting their young from external threats by clustering around them in a circle with their hind legs facing outwards (social group). Another example is that of polyclinics and group practices in medicine, where medical treatment is provided by teams of experts in each field. Similar cases can be seen in other fields, for example in the structure of project teams. Examples in industry can be seen in joint ventures and joint advertising, and in Chinatowns and tourist facilities such as Las Vegas and Japanese spa towns, where related businesses group together for the common purpose of attracting large numbers of customers, aiming for a synergy which will increase the potential of each individual business.

In these example, significant Sa and E effects can be achieved with regard to phenomena which for each individual functional component would be risky or impossible.

3) Subfunctions

Even if no similarities can be identified at the function (objective) level, some effects may be achieved by grouping according to similarities at the subfunction level.

An example of this is a cash dispenser system shared by a number of banks. Each bank has various subfunctions, one of which is cash withdrawals, which is an important function common to all banks. Based on the similarity (commonality) of this subfunction, cash dispensers have been developed which can be used by customers of all banks. This represents a significant E effect for the banks, and also a significant U effect for their customers.

4) Elements

The 'elements' in a man-machine system, for example, would be people, equipment, tools etc. If related functional components including high-level elements are grouped together and hold in common, a significant E effect would be achieved. In the case of apartments for factories and incubator facilities, special facilities (sophisticated computers, pollution control equipment etc.) and even people with special qualifications, which are difficult for medium-sized and small companies to install individually, can be shared between a number of companies.

Other example include the composite structures in composite girder bridges and composite piles,

multiprocessors (computers with two or more separate processing units capable of operating simultaneously), and multilayer wiring (printed wiring on printed circuit boards with conducting layers on both sides of the board and in intermediate layers). In all of these examples, E, Sa and R effects are particularly marked. Many examples of this type can be found in biological organisms also (see Ref.(4)).

5) Systematization requirements

Of all the systematization requirements, restriction conditions have a particularly significant effect on functional component grouping. For example, in a hospital some functional components should ideally be clustered on the ground floor, allowing patients to enjoy Sa, U and A effects.

Considering functional components related to radiology in hospital, Sa effects can be achieved by grouping these in a single area under a unified management.

5.2 Effects due to level of correlation

The similarities between specifications discussed above involve study on the qualitative plane. The 'level of correlation' on the other hand is more concerned with the quantitative plane, that is, it concerns whether a quantitative relationship exists or can be set up between functional components. The matters defining the level of correlation are as follows.

1) Quantitative aspects: weight, volume etc.

These might be for example the weight and volume of material to be transferred between the functional components in question. In many cases, however, priority is given to one or the other depending on the means of transport adopted.

2) Correction coefficients

If requirements such as real-time processing, confidentiality, avoidance of damage (difficulty of transfer), and avoidance of loss are attached to the items for transfer referred to above, these must be considered as coefficients defining the level of correlation. In many vertebrates, for instance, many of the organs of perception are located close to the brain. We assume that this is for simplicity and proximity of the nerve routes linking these organs, and for protection by minimizing the risk of damage.

3) Other conceptual coefficients

In addition to the above, it may sometimes be necessary to consider coefficients which are impossible to measure with certainty, such as interpersonal relationships (psychological coefficients etc.) in man-machine systems.

Appraisal of levels of relationship allows evaluation of the distances between the functional components involved (Euclidean distance, conceptual distance etc.), and the most suitable means of grouping

them, thus affording E, Sa, R and Sp effects.

5.3 Effects on system analysis

The above discussion focused on the effects of functional component grouping in system design, system improvement and system development, among the various types of systematization. The significance of the results obtained from system analysis, however, is somewhat different. In a word, we can expect to make new discoveries and predictions by clarifying the functional component grouping structures of the system analyzed, through evaluation of its details from a perspective different from that of conventional analysis methods. However complicated the system, may be appraised in detail in a systematic and orderly fashion.

6. Conclusion

The primary purpose of this paper has been to establish methods for the introduction of the functional component grouping process into various types of systematization. The effects of introducing the functional component grouping process into various types of systematization have also been discussed. In both instances, system structures are built up from the perspective of the concept of functional component grouping. In the case of hospital interior layout, for instance, the major layout factor is the level of correlation between functional components. Therefore, the total movement volume might be minimized. However, it is impossible to obtain Sa effects for the patients in terms of clustering functional components on the ground floor and/or unified management of functional components related to radiology with conventional factors such as the level of correlation. Here we see the critical difference between this and

the conventional approach. Although this is still at the development stage, with only some of the steps quantified, it is hoped to develop the process further, through among other means case studies in various fields.

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