Research Article

What Determines the Behavior of a System and How to Design a Satisfactory System for an Expected Behavior

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Systems are everywhere around us, such as products, production lines, the Internet, companies, schools, hospitals, airports, communities, cities, countries, governments, and military forces. System researchers and engineers always strive to achieve their desired system behaviors. Thus, this paper aims to solve two fundamental problems of systems engineering: what determines the behavior of a system and how to design a satisfactory system for the expected behavior. First, we determine the dimensions of a relationship flow, such as information flow, material flow, and capital flow. Second, we develop new theorems and propositions to solve the first problem. For example, they show that, for a given behavior of a system, if the dominant subsystem of the behavior has the basic level for the behavior, the behavior is only determined by its input and relationship flows at or above the basic level, all of which are collectively referred to as total relationship flow (TRF). Third, we develop a relationship flow diagram which is of great significance to system design, just as a circuit diagram to circuit design, and a TRF-oriented system design framework to solve the second problem. In order to show how the framework works, we apply it step by step to the schematic design of an airport system for the required passenger departure procedure service behavior, and get a system example; using this framework to design a system will greatly simplify the complexity of development and improve the maintainability of the system. Therefore, our findings provide a new theory for systems engineering and improve its methods and tools systematically.

1. Introduction

Rousseau and Calvo-Amodio [1] remarked that the rise of complexity in engineering systems has radically increased the risks in complex systems engineering projects; this rise is a challenge for systems engineering, which is still based on heuristics and not yet grounded in a general theory of systems; and such a theory is needed if systems engineering is to improve its methods, processes, and tools systematically. Indeed, researchers need to devote greater effort to advance systems engineering research. To this end, given that the systems engineer’s focus is to make a system realize the behavior desired by the system users, we consider that the two fundamental problems of systems engineering research are (i) what determines the behavior of a system and (ii) how to design a satisfactory system for the desired behavior. By knowing the answers to the two problems, systems engineers can make a more effective effort to make the systems under their care have the desired behaviors. In this paper, we attempt to address the two problems based on the findings in the pertinent literature.

Zhu and Xiang [2] pointed out that systems in the real world are usually composed of a large number of components with various interactions between them. Wang and Xie [3] believe that networks have been widely used to represent the interaction between individual units in complex systems (such as the Internet of things). According to Lin and Cheng [4, 5], (i) a system is a whole composed of relevant parts, having its own behavior, called the system behavior, which is the behavior that the parts cannot possess while isolated; a system can have a variety of behaviors in an environment. For example, an enterprise system can have R&D behavior, production behavior,
service behavior, competition behavior, and profit behavior in an environment; and these behaviors can be measured by their output, for example, production behavior is measured by production output while profit behavior is measured by profit amount. Thus, behaviors are variables which can be measured and they usually change over time; (ii) the relation between two parts means that a change in the state of one part causes a change in the state of the other; (iii) a relationship is a factor, by which a part reacts to another part, thereby establishing a relation between them; (iv) the structure of a system is the set of its relationships; and (v) the basic/dominant level for a system behavior is defined as such a system level that possesses the following characteristics: for each part at or above the basic level, its behavior is determined only by its input, that is, the same input certainly generates the same behavior, especially the same output. On the basis of these definitions, they proved several theorems and propositions that reveal the relations among the behavior, the structure, and the environment of a system, for example, they showed that, for a given behavior of a system, if the system has the basic level for the behavior, the behavior is determined only by its input and structure at or above the basic level. Manfred and Gregor [6] remarked that Bertalanffy’s General Systems Theory was meant to become a unifying logic-mathematical approach [7, 8], and the works of Lin and Cheng [4, 5] are the elaborated development in this direction. In addition, Lin and Cheng [9] proved two lemmas, showing that, for a given behavior of a system, if the system does not have the basic level for the behavior, the behavior is determined by its input and structure at all levels.

Further, according to the definitions of relationship [4] and relationship flow [9, 10], they both are a factor, for example, force, electric current, information flow, material/ matter flow, energy flow, financial flow, personnel flow, by which a part reacts to another part, thereby establishing a relation between them, so later we replace the relationship with relationship flow. Therefore, the findings of Lin et al. [4, 5, 9] show that, for a given behavior of a system, if the system has the basic level for the behavior, the behavior is determined only by its input flow and relationship flows at or above the basic level, both of which are collectively called the total relationship flow (TRF) for the behavior, otherwise, by its input flow and relationship flows at all levels, both of which are collectively called the extreme TRF for the behavior. These findings have partially answered the problem of what determines the behavior of a system. Xu et al. [11] and Liu et al. [12] remarked that the findings can be regarded as a theory, a concept, a tool, and an approach for systemic analysis. However, these findings are not enough to fully address the problem of how to design a satisfactory system for the behavior desired by the system users.

Hence, we try to develop new theorems and propositions of the relations among the behavior, the TRF or the extreme TRF, and the input flow of a system, which may provide a theoretical foundation for systems engineering, especially system design. System design aims at facilitating systems engineers and users to realize the behavior of a system desired by the system users. According to Lin et al. [4, 5, 9], given a behavior of a system, if the system does not have the basic level for the behavior, the behavior is determined by the system’s extreme TRF for the behavior, so the behavior cannot be certainly obtained as desired because the extreme TRF includes the neural currents in human bodies and the electromagnetic, strong, and weak forces in atoms, all of which cannot be designed, established, and maintained as desired by systems engineers. This means that the desired behavior of a system can be certainly obtained only by designing, establishing, and maintaining a TRF for the behavior. Thus, the problem of how to design a satisfactory system for the desired behavior reduces to how to design a satisfactory TRF for the desired behavior of a system.

It is well known that, without the circuit diagram, the circuit design would be extremely difficult to make, and system design would be the same if there is no appropriate system diagram. Researchers have developed some very helpful diagrams to depict systems (see, e.g., [13–16]). Unfortunately, they cannot depict a TRF for the desired behavior of a system completely, especially all the dimensions of its relationship flows. Thus, we attempt to develop a new diagram, called a relationship flow diagram. It would be significant to system design just as a circuit diagram to circuit design, and its design is essentially a graphical system design.

In order to obtain a satisfactory TRF diagram for the desired behavior of a system, we develop a TRF-oriented system design framework according to the theorems and propositions obtained in this paper. It is intended to have the following characteristics:

(i) It is suitable for all systems, especially those involving a variety of relationship flows, whose dimensions cannot easily be determined through trial and error by the system users in practice, for example, industrial systems, business systems, economic systems, and social systems.

(ii) It is entirely based on logically derived theorems rather than experience, intuition, or heuristics, so its scientificity and effectiveness need not be tested.

(iii) Its inputs are only the behavior of a system desired by the system users and the system resources that they can allocate.

(iv) It is “graphical,” which means that the inputs and outputs of all its steps are presented in the relationship flow diagram.

(v) Its output is a satisfactory TRF diagram for the desired behavior that provides a practical blueprint for the systems engineers and system users to establish and maintain the TRF in practice so as to obtain the desired behavior.

Due to the characteristics above, our framework is different from the others (see, e.g., [17–20]), all of which are well developed and oriented towards their own pursuits.

In order to show how the framework works, we present an example in this article to demonstrate how to schematically design an airport system for the desired passenger departure procedure service behavior and obtain a system sample, that is, a satisfactory TRF diagram for the desired behavior. In this way, the problem of how to design a satisfactory system for the desired behavior is hopefully well approached.
2. Total Relationship Flow Management Theorems and Propositions

In this section, we seek to further address the problem of what determines system behavior based on the works of Lin et al. [4, 5, 9].

2.1. Concepts. First, we define or review several basic concepts, from which we derive new theorems and propositions to address the problem in more detail.

Definition 1. A system \( Z(n) \) is a whole made up of \( n \) related parts, \( n \geq 2 \), having its own behavior at time \( t \), called the system behavior \( H_Z(t) \), which is the behavior that the parts cannot possess while isolated in an environment.

The above definition of a system is widely used in the context of general systems theory. However, in order to address the problem of what determines the behavior of a system, it needs to be further developed without any loss of its generality. In particular, the \( n \) related parts mean that there are relations between them, so we define the relation between two parts of a system as follows.

Definition 2. The relation \( R_{ij} \) between two parts \( P(i) \) and \( P(j) \) of a system \( Z(n) \), \( 1 \leq i, j \leq n \), is equivalent to that a change in state \( s_i \) of part \( P(i) \) causes a change in state \( s_j \) of part \( P(j) \).

According to the above definition, a relation can be tested. Furthermore, in order to reveal how it is established, we define a relationship flow as follows.

Definition 3. A relationship flow \( R_{ij}(t) \) is a factor, such as force, electric current, information flow, material/matter flow, energy flow, financial flow, and personnel flow, by which part \( P(i) \) in state \( s_i(t) \) reacts to part \( P(j) \) in state \( s_j(t) \) at time \( t \), thereby establishing a relationship between parts \( P(i) \) and \( P(j) \), indicated by a directed line, as shown in Figure 1. Note that the relationship flows \( R_{ij}(t) \) and \( R_{ji}(t) \) are different.

According to the above definition, a relationship flow is a variable that can be measured and may change over time, and the relations between the different parts of a system and between the system and its environment are established by relationship flows.

Importantly, a relationship flow comprises TPLCAMD dimensions, that is, the time at which it is established, the pair of parts it connects, the level at which it occurs, the content and amount it contains, and the mode and time delay in which it is transferred, all of which are often related. Therefore, in order to understand, design, establish, and maintain a relationship flow, it is necessary to consider all its TPLCAMD dimensions.

A complex system usually has a large number of relationship flows, which appear at different system levels, as shown in Figure 2, where the red relationship flows are at the first level L1; the blue relationship flows are at the second level L2; the green relationship flows are at the third level L3; \( R(t) \) and \( H_Z(t) \) represent the input flow and the behavior of the system at time \( t \), respectively. As can be seen from the Figure, the system is composed of different parts at or above the different levels, that is, it is composed of four parts (red) at the level L1, seven parts (six blue and one red) at or above the level L2, and eleven parts (eight green, two blue, and one red) at or above the level L3.

Definition 4. A relationship flow cycle is the set of \( k \) relationship flows \( R_{1,2}(t), R_{2,3}(t), \ldots, R_{k-1,k}(t) \) that form a cycle, \( k \geq 2 \), as shown in Figure 3.

In a system, a relationship flow cycle often plays an important role in the evolution of a system.

Definition 5. The environment \( E(S(t)) \) of a system is the set of such parts outside the system that there exists the relation between each of them and the system at time \( t \), where \( S(t) \) indicates the state of the environment at time \( t \), and the relationship flow \( R(t) \) between the environment and the system is called the system’s input flow at time \( t \).

2.2. Theorems and Propositions. According to the definitions of a relationship [4] and a relationship flow, they both are a factor, by which a part reacts to another part, thereby establishing a relation between them, so according to the definition of the structure of a system [4], it is a set of the relationships or the relationship flows of the system. Thus, using Lemmas 1 and 2 [9], we obtain the following Lemma 1, and using Theorems 1 and 2 [4], we obtain the following Lemmas 2 and 3, respectively.

Lemma 1. Suppose under the influence of an environment \( E(S) \), \( S \in B \), where \( S \) and \( B \) indicate the state and state space of the environment, respectively, a system has \( m \) levels at time \( t \), \( m \geq 1 \), as shown in Figure 4. Then, its input flow \( R(t) \), relationship flow set \( R_Z(t)_c \) at level \( c \), \( c = 1, 2, \ldots, m-1 \), and behavior \( H_Z(t) \) satisfy the following simultaneous equations:

\[
f_1(S, R_Z(t)_1, H_Z(t)) = 0. \tag{1}
\]

\[
f_2(S, R(t), R_Z(t)_1) = 0. \tag{2}
\]

\[
f_3(R(t), R_Z(t)_1, H_Z(t)) = 0. \tag{3}
\]

\[
f_4(R(t), R_Z(t)_c, R_Z(t)_{c+1}) = 0. \tag{4}
\]

Lemma 2. Suppose under the influence of an environment \( E(S) \), \( S \in B \), a system \( Z(n) \) has the relationship flow set \( R_{Zb}(t) \) at or above a certain level \( b \), where \( R_{Zb}(t) = \{R_{Z1}(t), R_{Z2}(t), \ldots, R_{Zb}(t)\}_B \), input flow \( R(t) \), and behavior \( H_Z(t) \) at time \( t \), as shown in Figure 5. Then, there is the following equation:

\[
f_5(R(t), R_{Zb}(t), H_Z(t)) = 0, \tag{5}
\]
if and only if for each part $P(i)$ at or above the level $b$, $1 \leq i \leq n$, its state $s_i(t)$ or behavior $H_i(t)$ is a function only of its input flow $R_i(t)$, as shown in Figure 6, that is,

$$s_i(t) = f_6(R_i(t)),$$

or

$$H_i(t) = f_7(R_i(t)),$$

where $S$ and $B$ indicate the state and state space of the environment, respectively.

**Lemma 3.** Suppose under the influence of an environment $E(S(t))$, $S(t) \in B$, where $S(t)$ and $B$ indicate the state and state space of the environment, respectively, a system has the input flow $R(t)$, behavior $H_Z(t)$, and relationship flow set $R_{Zb}(t)$ at or above its basic level $b$ for the behavior at time $t$, and there is no relationship flow cycle in $R_{Zb}(t)$. Then, there are the following equations:

$$H_Z(t) = f_8(S(t)),\quad H_Z(t) = f_9(R(t)).$$

Using the lemmas above, we easily obtain the following theorems about the multibehaviors of a system.

**Theorem 1.** Suppose under the influence of an environment $E(S)$, $S \in B$, a system $Z(n)$ has the behavior $H_{Z1}(t)$ and its dominant subsystem $DZ_i(n_i)$ at time $t$, $i = 1, 2, \ldots, g$, $g \geq 1$, $2 \leq n_i \leq n$, which has $m_i$ levels, $m_i \geq 1$, as shown in Figure 7. Then, the total input flow $R_i(t)$, $R_i(t) = \{R_{SZ1}, DZ(t), R_{EDZ}(t)\}$, the relationship flow set $R_{Zb}(t)$ at level $c$ of the dominant subsystem, $c = 1, 2, \ldots, m_i-1$, and the behavior $H_{Z1}(t)$ satisfy the following simultaneous equations:

$$f_{10}(S, S^*, R_{DZ1}(t), H_{Z1}(t)) = 0, \quad (8)$$

$$f_{11}(S, S^*, R_i(t), R_{DZ1}(t)) = 0, \quad (9)$$

$$f_{12}(R_i(t), R_{DZ1}(t), H_{Z1}(t)) = 0, \quad (10)$$

$$f_{13}(R_i(t), R_{DZ1}(t), C, R_{DZ1}(t), C) = 0, \quad (11)$$

where $S$ and $B$ indicate the state and state space of the environment, respectively; $SZ_i(n-n_i)$ and $S^*$ indicate the support subsystem and its state of the behavior $H_{Z1}(t)$, respectively; $R_{SZ1-DZ}(t)$ indicates the relationship flow between the support subsystem and the dominant subsystem of the behavior, called the endogenous input flow of the dominant subsystem; $R_{EDZ}(t)$ indicates the relationship flow between the environment and the dominant subsystem of the behavior, called the exogenous input flow of the dominant subsystem.

**Theorem 2.** Suppose under the influence of an environment $E(S)$, $S \in B$, $S \in B$, a system $Z(n)$ has the behavior $H_{Z1}(t)$ and its dominant subsystem $DZ_i(n_i)$ and support subsystem $SD_i(n-n_i)$...
at time \( t, i = 1, 2, \ldots, g, g \geq 1, 2 \leq n_i \leq n \), and the dominant subsystem has the total input flow \( R_i(t), R_i(t) = [R_{Z_i}(t), R_{E-Z_i}(t)] \), and the relationship flow set \( R_{DZ_i}(t) \) at or above a certain level \( b \), where \( R_{DZ_i-b}(t) = [R_{DZ_i}(t), R_{DZ_i}(t), \ldots, R_{DZ_i}(t)] \), as shown in Figure 8. Then, there is the following equation:

\[
H_{Z_i}(t) = f_{19}(R_i(t), R_{DZ_i}(t)),
\]

and if for each part \( P(j) \in DZ_i(n_i) \) at or above the level \( b, 1 \leq j \leq n_i \), its state \( s_j(t) \) or behavior \( H_j(t) \) is a function only of its input flow \( R_i(t) \); that is,

\[
s_j(t) = f_{15}(R_j(t)),
\]

or

\[
H_j(t) = f_{16}(R_j(t)),
\]

where \( S \) and \( B \) indicate the state and space state of the environment, respectively.

We define the level \( b \) in Theorem 2 that satisfies (13) or (14) as the dominant system’s basic level or the basic level for the behavior \( H_{Z_i}(t) \), the set of the total input flow \( R_i(t) \) and the relationship flow set \( R_{DZ_i}(t) \) at or above the basic level as the total relationship flow (TRF) for the behavior, and the set of the total input flow and the relationship flows at all levels of the dominant subsystem as the extreme TRF for the behavior.

Theorem 3. Suppose under the influence of an environment \( E(S(t)) \), \( S(t) \in B \), where \( S(t) \) and \( B \) indicate the state and space state of the environment, respectively, a system \( Z(n) \) has the behavior \( H_{Z_i}(t) \) and its dominant subsystem \( DZ_i(n_i) \) at time \( t, i = 1, 2, \ldots, g, g \geq 1, 2 \leq n_i \leq n \), the dominant subsystem has the total input flow \( R_i(t) \), the basic level and the total relationship flow \( R_{DZ_i}(t) \) for the behavior, as shown in Figure 8, and there is no relationship flow cycle in \( R_{DZ_i}(t) \). Then, there are the following equations:

\[
H_{Z_i}(t) = f_{17}(S(t), S^*(t)),
\]

\[
H_{Z_i}(t) = f_{18}(R_i(t)),
\]

where \( S^*(t) \) indicates the state of the support subsystem of the behavior at time \( t \).

For all the equations in Theorems 1 and 2, in the case that their independent and dependent variables are defined, they all can be written as a function, for example, in the case that \( H_{Z_i}(t) \) and \( R_{Z_i}(t) \), are defined as dependent variables,
Proposition 5. The undesired behavior (problem) of a system can be certainly eliminated only by establishing and maintaining the TRF for the behavior to eliminate the undesired behavior.

Specifically, according to Proposition 1 and 2, we obtain Proposition 6 as follows.

Proposition 6. Any given resource of a system, while neither flowing as a relationship flow of the TRF or extreme TRF for a desired system behavior nor working for its transformation or transfer, makes no contribution to the behavior.

As the development of a system is a kind of a system behavior, so according to Theorem 3, we obtain Proposition 7 as follows.

Proposition 7. In a stable environment, the desired development of a system can be certainly made only by establishing and maintaining at least one relationship flow cycle in the TRF for the development, which is the “engine” to promote the development.

3. Relationship Flow Diagrams

In this section, we apply the theorems and propositions obtained in this paper to address the problem of how to design a satisfactory system for a desired behavior of the system.

It is well known that system design aims at constructing a model of the system concerned to facilitate the system users to better understand, establish, and maintain the system so as to obtain the system behavior that they desire. Thus, in system design, we first have to define the factors that determine the behavior of a system and then use them to build the system model. Propositions 1 and 2 show that, in order to understand and obtain the behavior of a system, it is necessary and sufficient to understand, establish, and maintain the TRF or extreme TRF for the behavior, and Proposition 4 shows that the desired behavior of a system can be certainly obtained only by establishing and maintaining the TRF for the behavior. Meanwhile, the TRF depends on the resources that the system users can allocate. Thus, the behavior, the TRF for the behavior, and the resources of a system are the necessary and sufficient factors for building the model of a system for the system behavior desired by the system users.

Now, we use them to develop the model of a system. Because the TRF is usually multiple levels, so is the model. In order to introduce it easily, we take an airport and its passenger departure procedure service behavior as an example of a system and its behavior because they are well known and present them in Tables 1–3, which show the models at or above the first, second, and basic level for the system behavior, called the relationship flow diagrams at or above the first, second, and basic level for the system behavior because they focus on the relationship flows and denoted as RF-D1, RF-D2, and RF-Dn respectively. In particular, we name the relationship flow diagram RF-D1 at or above the basic level for the system behavior as the TRF diagram for the system behavior.

About the relationship flow diagrams shown in Tables 1–3, we provide some explanations as follows:

1. The dominant subsystem $DZ(n-n^*)$ of the behavior is composed of related parts $P(1), P(2), \ldots, P(n)$, and $P(n-n^*)$, where $H_i(t)$ indicates the behavior of part $P(i)$, $R_i(t)$ indicates the resources that are allocated to part $P(i)$ at time $t$, for example, people, databases, networks, capital, machines, tools, materials, products, $t = 1, 2, \ldots, n-n^*$, and they may change over time.

2. The diagrams show one complete emergence of the passenger departure procedure service behavior of an airport from the starting time $t_1$ to the ending time $t_w$, called one behavior, which involves a set of subbehaviors $H_i(t)$, $1 \leq i \leq n-n^*$, $t_1 \leq t \leq t_w$, among which there is an evolutionary logic to make the behavior emerge and the time duration ($t_w-t_1$) is called the behavior cycle, denoted as $T_bc$, which is only dependent on the TD dimensions of the relationship flows.

3. For a given part, it may have different behaviors in different time intervals, but its behavior in any time interval is oriented towards establishing the relationship flows; otherwise, its behavior makes no contribution to the desired system behavior according to Proposition 6.

4. It always takes some time delay for a relationship flow to be transferred from a part to another part, and while the time delay is considered, the relationship flow is illustrated in a directed polyline, for example, it takes the time delay $(t_5-t_4)$ for the relationship flow $R_{2,3}(t_4,t_5)$ to be transferred from part $P(2)$ to part $P(3)$ and its time delay is indicated as $t_4-t_5$.

5. A directed line may indicate several different relationship flows that have the same TP dimensions, for example, $R_{2,3}(t_4,t_5)$ contains $R_{2,3}(t_4,t_5)$, $R_{2,3}(t_4,t_5)$, and $R_{2,3}(t_4,t_5)$, which indicate the passenger flow, the ID card/boarding card flow, and the hand-luggage flow, respectively.

6. $R_{E,i}(t)$ indicates the relationship flow between the environment $E(S)$ and part $P(i)$, that is, an exogenous input flow of the dominant subsystem, and $R_{E,i}(t)$ indicates the relationship flow between part $P(i)$ and the environment $E(S)$, called an output flow of the system, $1 \leq i \leq n-n^*$.

7. For a given behavior of a system, a set of the diagrams are specifically drawn level by level until the basic level for the behavior so that the TRF diagram for the behavior is obtained, as shown in Tables 1, 2, and 3.

8. The notes on the CAMD dimensions of the relationship flows are important. Specifically, for a material flow, its C dimension should contain its main characteristics, for example, size, colour, and power, and for a personnel flow, it should contain age, academic degree, and professional skill. Although both $R_{E,1}(t)$ and $R_{1,2}(t_2,t_3)$ are luggage
Table 1: The relationship flow diagram RF-D$_1$ at or above the first level for the desired PDPSB of an airport.

| The airport system $Z(n)$ | The desired behavior $H_D(t)$ and its evolutionary logic of the system |
|---------------------------|---------------------------------------------------------------------|
| $n - n^* = 4$             | $H_D(t)$: the passenger departure procedure service behavior (PDPSB) |
|                           | $C_{3C} = p_3^1$; $T_{3C} = p_3^2 = t_3 - t_1$; $F_{3C} = p_3^3$; $C_6 = p_4$ |

| $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | ...... | $t_8$ | $t$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|

$P(4): H_4(t)/ R_4(t)$: Boarding/Boarding pass scanner, corridor bridge/shuttle bus & passenger stairs etc.

Relationship flows (Level 2) $R_{3,4}(t_2)$; $R_{4,3}(t_3)$

$P(3): H_3(t)/ R_3(t)$: Safety inspection/ID card authenticity detector, X-ray machine, Safety inspector door etc.

Relationship flows (Level 2) $R_{2,3}(t_2)$; $R_{4,3}(t_3)$

$P(2): H_2(t)/ R_2(t)$: Check-in/Departure control system, luggage consignment machine etc.

Relationship flows (Level 2) $R_{1,2}(t_2)$; $R_{2,3}(t_2)$; $R_{4,2}(t_3)$

$P(1): H_1(t)/ R_1(t)$: Luggage packing/Packing machine, service counter etc.

Relationship flows (Level 1) $R_{3,2}(t_2)$; $R_{2,2}(t_2)$; $R_{3,3}(t_2)$; $R_{2,1}(t_1)$

Support subsystem $SZ(n^*)$

Input/output flows (Level 0) $R_{2,2}(t_2)$; $R_{3,3}(t_2)$

Environment $E(S)$: Passengers/s/Airlines/Aircrafts...

Notes on the relationship flows

| Content          | Amount  | Means/Manner | Delay |
|------------------|---------|--------------|-------|
| $R_{E,1}(t_1)$  | P: Passenger $p_{11}$ persons | By foot | -     |
| $R_{E,2}(t_2)$  | M: Luggage $m_{11}$ items | By passenger | -     |
| $R_{E,3}(t_3)$  | M: Luggage (packaged) $m_{12}$ items | By passenger | $t_3 - t_2$ |
| $R_{E,4}(t_2)$  | P: Passenger $p_{12}$ persons | By foot | -     |
| $R_{E,5}(t_2)$  | M: Luggage (packaged) $m_{13}$ items | By passenger | -     |
| $R_{E,6}(t_2)$  | P: Passenger $p_{13}$ persons | By foot | $t_3 - t_4$ |
| $R_{E,7}(t_2)$  | I: ID card/boarding card $i_{11}$ pieces | By passenger | $t_5 - t_4$ |
| $R_{E,8}(t_2)$  | M: Hand-luggage $m_{14}$ items | By passenger | $t_5 - t_4$ |
| $R_{E,9}(t_2)$  | M: Luggage (no prohibited article) $m_{15}$ items | By conveyor | $t_6 - t_4$ |
| $R_{E,10}(t_2)$ | P: Passenger (qualified) $p_{14}$ persons | By foot | -     |
| $R_{E,11}(t_2)$ | P: Boarding card $i_{12}$ pieces | By passenger | -     |
| $R_{E,12}(t_2)$ | P: Passenger (unqualified) $p_{15}$ persons | By foot | -     |
| $R_{E,13}(t_3)$ | I: Dissatisfaction survey report $i_{13}$ pieces | By IS | -     |
| $R_{E,14}(t_2)$ | P: Passenger (qualified) $p_{16}$ persons | By foot | -     |

Notes

I: Information; M: Material; P: Personnel
Table 2: The relationship flow diagram RF-D2 at or above the second level for the desired PDPSB of an airport.

| The airport system $Z(n)$ | The desired behavior $H_2(t)$ and its evolutionary logic of the system |
|----------------------------|---------------------------------------------------------------------|
| $n - n^* = 5$              | $H_2(t)$: the passenger departure procedure service behavior (PDPSB) |
|                            | $C_{ik} = p_1; \quad T_{ik} = p_2 = t_k - t_i; \quad F_{ik} = p_3; \quad C_0 = p_4$ |
| $t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5 \quad t_6 \quad t_7 \quad \ldots \quad t_w \quad t$ |

- **P(4):** $H_2(t) / R_d(t)$  
  Boarding/ Boarding pass scanner, corridor bridge/shuttle bus & passenger stairs etc.

- **P(3-2):** $H_3(t) / R_2(t)$  
  Body search and prohibited article inspecting/ X-ray machine, Safety inspector door etc.

- **P(3-1):** $H_3(t) / R_3(t)$  
  Passenger identity validating/ ID card authenticity detector, face recognition system etc.

- **P(2):** $H_2(t) / R_2(t)$  
  Check-in/ Departure control system, luggage consignment machine etc.

- **P(1):** $H_1(t) / R_1(t)$  
  Luggage packing / Packing machine, service counter etc.

**Input/output flows**  
- **(Level 0)**  
  $R_{2,3}(t_6)$: $R_{3,4}(t_6)$

**Support subsystem $SZ(n^*)$**  

**Environment $E(S)$**  
Passengers/ Passengers/Airlines/Aircrafts

| Notes on the relationship flows | The CAMD dimensions of the relationship flows |
|---------------------------------|---------------------------------------------|
| Content                        | Amount                                      | Means/Manner | Delay |
| $R_{2,3,1}(t_6)$: $t_1$       | P: Passenger                                | $p_{21}$ (persons) | By foot | $t_5 - t_4$ |
| $R_{2,3,2}(t_6)$: $t_2$       | I: ID card/boarding card                    | $i_{21}$ (pieces) | By passenger | $t_5 - t_4$ |
| $R_{3,3,3}(t_6)$: $t_3$       | M: Hand-luggage                             | $m_{21}$ (items) | By passenger | $t_5 - t_4$ |
| $R_{3,3,3}(t_6)$: $t_4$       | P: Passenger                                | $p_{22}$ (persons) | By foot | - |
| $R_{3,3,2}(t_6)$: $t_5$       | I: ID card/boarding card                    | $i_{22}$ (pieces) | By passenger | - |
| $R_{3,3,2}(t_6)$: $t_6$       | M: Hand-luggage                             | $m_{22}$ (items) | By passenger | - |
| $R_{3,3,2}(t_6)$: $t_7$       | P: Passenger (unqualified)                  | $p_{22}$ (persons) | By foot | - |
| $R_{3,3,2}(t_6)$: $t_8$       | I: ID card (unqualified)                    | $i_{22}$ (pieces) | By foot | - |
| $R_{3,3,2}(t_6)$: $t_9$       | M: Hand-luggage (prohibited article)        | $m_{23}$ (items) | By passenger | - |
| $R_{3,3,2}(t_6)$: $t_{10}$    | P: Passenger (qualified)                    | $p_{23}$ (persons) | By foot | - |
| $R_{3,3,2}(t_6)$: $t_{11}$    | I: boarding card                            | $i_{23}$ (pieces) | By passenger | - |
| $R_{3,3,2}(t_6)$: $t_{12}$    | I: Dissatisfaction survey report            | $i_{26}$ (pieces) | By IS | - |
| $R_{3,3,2}(t_6)$: $t_{13}$    | I: Dissatisfaction survey report            | $i_{26}$ (pieces) | By IS | - |

**Notes**  
I: Information; M: Material; P: Personnel;
Table 3: The relationship flow diagram RF-Dh at or above the basic level for the desired PDPSB of an airport.

| Relationship flows (Level 2) | Description                                                                 |
|------------------------------|-----------------------------------------------------------------------------|
| P(4): H_4(t)/ R_4(t)         | Boarding/ Boarding pass scanner, corridor bridge/shuttle bus & passenger stairs etc. |
| Relationship flows (Level 4) | Collecting article/ Security checkbox etc.                                  |
| P(3-2-3): H_{3,2,3}(t)/ R_{3,2,3}(t) |                                                                                   |
| Relationship flows (Level 3) | Body search/ Safety inspector door, hand-held security inspection instrument etc. |
| P(3-2-2): H_{3,2,2}(t)/ R_{3,2,2}(t) |                                                                                   |
| Relationship flows (Level 3) | Prohibited article inspecting/ X-ray machine, image recognition system etc.    |
| P(3-2-1): H_{3,2,1}(t)/ R_{3,2,1}(t) |                                                                                   |
| Relationship flows (Level 2) | Passenger identity validating/ ID card authenticity detector, face recognition system etc. |
| P(2): H_2(t)/ R_2(t)         | Check-in/ Departure control system, luggage consignment machine etc.             |
| Relationship flows (Level 2) |                                                                                   |
| P(1): H_1(t)/ R_1(t)         | Luggage packing/ Packing machine, service counter etc.                          |

Support Subsystem SZ(n*)

Input/output flows (Level 0)

Environment E(S)

Notes on the relationship flows

| The CAMD dimensions of the relationship flows |
|----------------------------------------------|
| Content | Amount | Means/Manner | Delay |
| R_{1,2,3,3}(t^*) | M: Hand-luggage | m_{31} (items) | By passenger | - |
| R_{3,1,2,2}(t^*) | P: Passenger | p_{31} (persons) | By foot | - |
| R_{3,2,1,2,3}(t^*) | M: Hand-luggage (no prohibited article) | m_{32} (items) | By passenger | - |
| R_{3,2,2,2,3}(t^*) | P: Passenger (qualified) | p_{32} (persons) | By foot | - |

............... | | |

| R_{3,2,1,2}(t) | M: Hand-luggage (prohibited article) | m_{33} (items) | By passenger | - |
| R_{3,2,2,2}(t) | P: Passenger (with prohibited article) | p_{33} (persons) | By foot | - |

Notes

M: Material; P: Personnel
flows, their C dimensions are different because the latter is packaged, and although both $R_{E,1}(t_1,1)$ and $R_{E,2}(t_w,1)$ are passenger flows, their C dimensions are different because the latter is verified to be qualified.

(9) There are inherent or designed relations among the TPLCAM dimensions of some relationship flows, for example, the A dimensions of the relationship flows $R_{1,2}(t_2,3)$, $R_{2,3}(t_3,3)$, and $R_{2,3}(t_4,3)$ satisfy the condition $m_{12} + m_{13} = m_{14} + m_{15}$. Note that "A" means the amount dimension of relationship flows.

(10) The behavior frequency is defined as the maximum time the behavior can repeatedly emerge in a behavior cycle, denoted as $F_{bc}$, and we obtain

$$F_{bc} = \frac{T_{bc}}{\Delta t_{bcmax}},$$

$$T_{bc} = t_w - t_1,$$

where $T_{bc}$ is the behavior cycle and $\Delta t_{bcmax}$ is the maximum of the working times of $n \cdot n^*$ parts of the dominant subsystem $DZ(n \cdot n^*)$ of the behavior in one behavior. Because $\Delta t_{bcmax} \geq T_{bc}/(n \cdot n^*)$, we obtain

$$1 \leq F_{bc} \leq n - n^*.$$

If $\Delta t_{bcmax} = T_{bc}/(n \cdot n^*)$, that is, the working times of the $n \cdot n^*$ parts are the same in one behavior, then $F_{bc} = n \cdot n^*$; and if $\Delta t_{bcmax} = T_{bc}$ or $n \cdot n^* = 1$, then $F_{bc} = 1$.

According to the definition, $F_{bc}$ is only dependent on the TD dimensions of the relationship flows for the behavior, and when the working time of each part of the dominant subsystem of the behavior in one behavior is the same, it reaches the maximum.

(11) The behavior competence of a system is defined as the maximum output of one behavior, denoted as $C_{bc}$, for example, the passenger departure procedure service (PDPS) behavior competence of an airport is defined as the maximum output of the passengers of one PDPS behavior, and the total behavior competence per unit time is the maximum output of the behavior per unit time, denoted as $C_b$, so we obtain

$$C_b = \text{inte}[(T + T_{bc}) \times F_{bc}] \times C_{bc},$$

where $C_{bc}$ is the behavior competence of the system, $T$ is the total operation time of the system per unit time, and $\text{inte}[(T + T_{bc}) \times F_{bc}]$ is/indicates the integral part of $(T + T_{bc}) \times F_{bc}$.

(12) In designing an actual system, we can try to find a satisfactory solution of the variables in RF-D$_b$ including the amount of each resource allocated to each part of the dominant subsystem, obtaining a satisfactory TRF diagram, that is, a satisfactory system model for the desired behavior.

4. TRF-Oriented System Design Framework

In order to facilitate systems engineers and users to design a satisfactory TRF diagram, that is, a satisfactory system model for the system behavior desired by the system users, we make an effort to develop its design framework according to the theorems and propositions obtained in this paper and obtain the design framework of a satisfactory TRF diagram for the desired behavior of a system, called a TRF-oriented system design framework, as shown in Figure 9. It provides a formal answer to the problem of how to design a satisfactory system for the behavior desired by the system users. As expected, it has the characteristics listed in the Introduction; especially, its inputs are only the behavior of a system desired by the system users and the system resources that they can allocate, and its output is a satisfactory TRF diagram for the desired behavior.

In order to show how the framework works to output a satisfactory TRF diagram for the behavior desired by the system users, we take an airport and its passenger departure procedure service behavior as an example of a system and its behavior and apply the framework step by step to schematically design a satisfactory TRF diagram for the desired behavior as follows:

Step 1. Define or design the behavior and its evolutionary logic (BEL) of a system desired by the system users. In particular, this step is to (i) define the desired behavior using the behavior competence $C_{bc}$, behavior cycle $T_{bc}$, behavior frequency $F_{bc}$, and total behavior competence $C_b$ desired by the system users, if applicable, obtaining $C_{bc} = p_1$, $T_{bc} = p_2 = t_w - t_1$, $F_{bc} = p_3$, and $C_b = p_4$, as shown in the upper right parts of Tables 1–3; (ii) design a set of subbehaviors of the desired behavior as desired, among which there is an evolutionary logic that can make the desired behavior emerge; (iii) categorize the subbehaviors into several kinds according to their correlations, obtaining $n \cdot n^*$ kinds of the subbehaviors, such as luggage packing, check-in, safety inspection, and boarding, denoted as $H_i(t)$ in Table 1, $1 \leq i \leq n \cdot n^*$, $t_1 \leq t \leq t_w$; and (iv) for each kind of the subbehaviors, define a part of the dominant subsystem $DZ(n \cdot n^*)$ of the behavior to realize it, so that all parts $P(1), P(2), \ldots, P(n \cdot n^*)$ of the dominant subsystem are designed, as shown in Table 1. At this time, the systems engineers can define or design the BEL of the system as the system users desire, and the framework would guide them to revise the designed BEL if no satisfactory TRF can be designed to realize the desired behavior.

Step 2. Initialize the level index $c$. The TRF for the desired behavior of a system involves the relationship flows at or above the dominant system’s basic level for the desired behavior, and they are designed level by level from the first level ($c = 1$) to the basic level ($c = b$). For the relationship flows at the same level, their designs are conducted in the reverse order in which they appear in practice, as illustrated in Figure 10; that is, first $R_{\Delta}(t)$, then $R_{p}(t)$, and finally $R_{b}(t)$ are designed.
Step 3. Design the appropriate relationship flow set $RDZ(t)_1$ at the first level of the dominant system that can logically achieve the defined or designed behavior $HZ(t)$ in a given environment $E(S)$ and support subsystem $SZ(n^s)$ of the behavior according to equation (8), as illustrated in Table 1, where $R_{k,E}(t_w)_1 = C_{kE} = p_1$. If it fails to design the relationship flow set, the design returns to Step 1 and the BEL is redesigned.

Note that an appropriate relationship flow set for a desired behavior is such a relationship flow set that can logically make the behavior emerge. As a relationship flow has the TPLCAMD dimensions, an appropriate relationship flow set means that each of its relationship flows has the appropriate TPLCAMD dimensions, that is, the appropriate time at which it is established, the appropriate parts it connects, the appropriate level at which it occurs, the appropriate content and amount it contains, and the appropriate mode and time delay in which it is transferred. Otherwise, an inappropriate relationship flow set for a desired behavior means that at least one of its relationship flows is inappropriate, and an inappropriate
relationship flow means that at least one of its TPLCAMD dimensions is inappropriate, so it cannot logically make the behavior emerge. For example, if the designed D dimension of a relationship flow requires its speed to exceed the speed of light, then the dimension is not appropriate.

**Step 4.** Design the appropriate total input flow $R(t)$ of the dominant subsystem that can logically achieve the relationship flow set $R_{D\Omega}(t_1)$ designed in Step 3 in the given environment $E(S)$ and support subsystem $SZ(n^*)$ according to equation (9) and achieve an appropriate relationship flow diagram at or above the first level of the dominant subsystem, denoted as RF-$D_1$, as illustrated in Table 1. If the total input flow cannot be designed, the design returns to Step 3 and the relationship flow set $R_{D\Omega}(t_1)$ is redesigned.

**Step 5.** Allocate the system resources to part $P(i)$ in the appropriate relationship flow diagram RF-$D_1$, denoted as $R_i(t)$ in Table 1, $1 \leq i \leq n-n^*$, $t_{i1} \leq t \leq t_{i2}$, for example, $R_i(t)$ includes packing machine and service counter; then evaluate whether the diagram is feasible, that is, whether a feasible RF-$D_1$ can be achieved, according to human, technical, economic, social, legal, and other feasibility considerations. If so, the design goes to Step 6; otherwise, it returns to Step 3 and the diagram RF-$D_1$ is redesigned.

**Step 6.** Judge whether all of the parts in the diagram RF-$D_2$ are basic parts, where RF-$D_2$ indicates the relationship flow diagram at or above the level $c$ of the dominant subsystem. According to equation (13) or (14), a basic part possesses the following characteristics: its state or behavior is determined only by its input flow, that is, the same input flow certainly generates the same state and behavior, especially the same output. In practice, the characteristics of a basic part mean that its behavior is relatively simple, and as long as the appropriate disposable resources are allocated to it and its appropriate input flow is established, it can autonomously realize its desired output flow without considering what may happen inside it. If so, RF-$D_2$ is a feasible TRF diagram for the desired behavior according to equation (12), and the design goes to Step 11; otherwise, the design goes to Step 7.

**Step 7.** Design and obtain an appropriate relationship flow diagram RF-$D_{c+1}$ that can logically achieve the feasible diagram RF-$D_c$, that is, for each part in RF-$D_c$, if it is not a basic part, design the appropriate relationship flow set at its first level that can logically achieve the related relationship flows in RF-$D_c$ according to equation (11). For example, suppose that, in the diagram RF-$D_1$ illustrated in Table 1, only part $P(3)$ is not a basic part that comprises two subparts $P(3-1)$ and $P(3-2)$ and then RF-$D_2$ is designed, as illustrated in Table 2, and that, in the diagram RF-$D_2$, only part $P(3-2)$ is not a basic part that comprises three subparts $P(3-2-1)$, $P(3-2-2)$, and $P(3-2-3)$ and then RF-$D_3$ is designed, as illustrated in Table 3. If RF-$D_{c+1}$ cannot be designed, that is, there is at least one part whose appropriate relationship flow set at its first level cannot be designed to logically realize the related relationship flows in RF-$D_c$, the design goes to Step 8, and RF-$D_c$ is redesigned; otherwise, it goes to Step 9.

**Step 8.** Decrease the level index $c$ by 1 and then judge whether or not $c = 0$. If so, the design returns to Step 2; otherwise, it returns to Step 7.

**Step 9.** Allocate the system resources to the parts in the appropriate relationship flow diagram RF-$D_{c+1}$ and then evaluate whether it is feasible, that is, whether a feasible RF-$D_{c+1}$ can be obtained, according to human, technical, economic, social, legal, and other feasibility considerations. If so, the design goes to Step 10; otherwise, it returns to Step 7, and the diagram RF-$D_{c+1}$ is redesigned.

**Step 10.** Increase the level index $c$ by 1, and the design returns to Step 6.

**Step 11.** Obtain a feasible TRF diagram and evaluate if it can satisfy the system users according to the resource utilization and the other indices concerned by the system users. If so, a satisfactory TRF diagram is obtained; otherwise, the design goes to Step 2 to redesign a satisfactory TRF diagram for the desired behavior.

### 5. Conclusion

The system is a whole formed by related parts, which can show its own behaviors in an environment, that is, the system behaviors that each part cannot have in the isolated state. The behaviors can be defined by behavior competence, behavior cycle, behavior frequency, and total behavior competence (if applicable). Therefore, they are measurable variables and may change over time.

For a given behavior of a system, if the dominant subsystem of the behavior has the basic level for the behavior, the behavior is determined only by the TRF for the behavior, otherwise, by the extreme TRF for the behavior. As the human is still not able to understand, design, establish, and maintain all relationship flows of the extreme TRF for the behavior of a system, in order to certainly obtain the desired behavior, it is the only way to design, establish, and maintain a satisfactory TRF for the desired behavior, especially which certainly involves at least a relationship flow cycle if the behavior is expected to be evolutionary in a stable environment.

For a given behavior of a complex system, a TRF for the behavior may involve a vast number of various relationship flows, and each of relationship flows comprises the TPLCAMD dimensions, so it is often difficult to design a satisfactory TRF for the behavior of a system desired by the system users. If system engineers want to provide satisfactory TRF for the system behavior expected by system users, they must seek satisfactory TRF through repeated experiments in practice, which is usually expensive and often full of failure. Therefore, based on the theorems and propositions obtained in this paper, we develop a TRF-oriented system.
design framework, which has the characteristics listed in the Introduction of this paper. Step by step according to the framework, the system engineer can design a satisfactory TRF diagram for the expected behavior of a system.

In designing a satisfactory TRF diagram, the notes on the relationship flows are closely related to their CAMD dimensions, as shown in Tables 1–3, and they are important and challenging to deal with. For a complex system, it usually involves various relationship flows such as force, electric current, information flow, financial flow, material flow, and personnel flow, and almost no one can undertake and complete the notes alone, so a group of systems engineers, users, and experts from multiple disciplines, each of whom is familiar with the relevant system resources and the relationship flows between the resources, are often required to work together for the notes, which shows that disciplinary collaboration is strongly required in systems engineering research and practice. The relationship flow diagrams provide a set of common templates for their work, and the TRF-oriented system design framework provides a systematic approach for them to coordinate their work.

Management practice aims to establish and maintain a system for the behaviors desired by managers, such as R&D behavior, production behavior, and profit behavior, so the value and vitality of a management theory lie in the extent to which it can help the managers better achieve their expected behaviors. Proposition 4 shows that the desired behavior of a system can be certainly obtained only by establishing and maintaining the TRF for the behavior. This means that the TRF management is sufficient and necessary for the behaviors desired by managers. Thus, a management theory should be oriented to TRF management, that is, it should link its related factors (such as process, structure, mechanism, assessment, motivation, rules, and regulations) with the TRF to realize them. When all management theories are oriented to the TRF management, the “jungle” of management theory will eventually evolve into a “big tree,” that is, a powerful management theory, which is sufficient and necessary for management education and practice guidance.

Human society is a system. So for any given behavior of human society, such as the social development behavior and the economic crisis behavior, the behavior is only determined by the TRF or extreme TRF for the behavior. As can be seen from the Industrial Revolution and the Information Revolution, they have greatly changed the transfer mode of information flows, material flows, energy flows, capital flows, and personnel flows, thus promoting the great development of human society. Therefore, it can be asserted that the next great development of human society will certainly start with the discovery of a new kind of relationship flow or a new transfer mode of relationship flow.

Data Availability
The data underlying the results presented in the study are included within the paper.

Conflicts of Interest
The authors declare that there are no conflicts of interest in this paper.

Authors’ Contributions
All authors have seen the manuscript and approved to submit to your journal.

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