Medical Workflow Transformation Method for Reliability Estimation

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Abstract

When we design a workflow system for medical care, it is very important to estimate the required time and its reliability. Even if the processing time of a system is short, but the reliability of the results is unfavorable, the total performance should be judged negative. By introducing and adapting the reliability engineering method to workflow models, an automatic estimation is readily achievable. In this paper, the authors introduce a method for the transformation of workflow models, that is to say, the transformation of Integrated computer-aided manufacturing DEFinition0 (IDEF0) models into reliability block diagrams [1]. The IDEF0 model discussed in this article is easy to handle even if users are not closely associated with workflow design. With this method, users can design and estimate the reliability of a workflow system automatically. We introduce the transformation algorithm and illustrate it by a simple example.

Keywords: workflow management, workflow design, IDEF0, reliability, simulation

Introduction

There are several researches about the reliability of medical care [2-6]. However, these researches are restricted to deal with specified diseases or wards and lack an unified and systematic view. We introduced the IDEF0 model to estimate the time required for “Triage” [7]. Triage is a sorting process by which the degree of injuries and order of priority for medical treatment are determined when there are massive casualties at the scene of a disaster [8]. Determinations are carried out in accordance with the staging protocol indicated in Table 1[8]. Surgeons and other medical practitioners involved in triage must be able to rapidly determine the condition of the victim, diagnose and then decide whether to treat or to transport. Injury victims are classified into four levels according to their condition and then are moved on to the next processing level. In that paper, we showed the validity of our model and simulation program to estimate and determine the demand time and disposition of staff. However, the simulation done gave only the required time and lacked the estimation of the quality of provided diagnosis. The reliability of the system is very important and an essential factor in system design [9]. Reliability represents a probability measure to evaluate the outcome of medical care designed as workflow. To improve workflow management, it is necessary to have a quantitative analysis method of evaluating its reliability. So we introduce an autonomous transformation method of the IDEF0 model to evaluate its reliability in this article. With this consolidation, we can carry out quantitative evaluations of the correctness in systems easily. This gives a guideline of designing and evaluating systems.

2. IDEF0 model and its application for medical care

2.1 Definition of IDEF0 model

IDEF0 represents a portion of IDEF, a modeling procedure for work analysis and system design that was developed through a U.S. Air Force project in the 1970’s [1]. It is also considered to be readily comprehensible to the average non-expert user. Basic descriptions in the IDEF0 model are composed of the five elements indicated in Fig. 1. Each task is expressed in the form of a box, within which is inserted a subject label that describes that task. The flow of the elements of work process is classified into four categories, all of which are expressed by arrows. The arrows are differentiated by their position in relation to the box that expresses the task. ‘Input’ refers to the flow of materials or other objects being treated or processed forwarded by the task. It is expressed by an arrow entering from the left side of the box. ‘Mechanism’ refers to the personnel who carry out the task, tools that are used in the task and so forth. It is expressed by an arrow entering from the bottom of the box. Relating to the task, ‘Control’ refers to control flow, including conditions, limitations and so forth. It is expressed by an arrow entering from the top of the box. ‘Output’ refers to all outputs from a task, including objects produced by output tasks, decisions that are made and so forth. It is expressed as an arrow exiting from the right side of the box, the tip of which then becomes either the above-described input, mechanism or control. Each of these boxes, together with the arrows that link them, forms one unit. That is, a workflow series is described by coupling these units. In addition, hierachical descriptions are also possible by providing further details regarding the activities in each box.

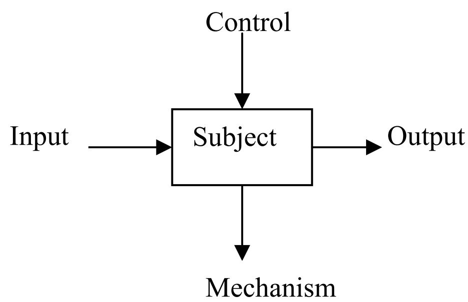


Figure 1- IDEF0 Model

2.2 Triage model described by IDEF0

We introduced a workflow model of triage as an example of medical application in our paper [10, 11]. Here, we show the triage model described by IDEF0 model in Fig. 2. In this model, Subject is triage, input is applied for casualties waiting for diagnosis. Output is assigned for the diagnosed casualties. Two surgeons are provided as mechanism. Assignment of multiple surgeons is intended to improve the correctness of diagnosis and to reduce the mental burden on each individual surgeon [12].

Surgeons involved in triage must be able to rapidly determine the condition of the victim, diagnose and then decide whether to treat or to transport. Injury victims are classified into four levels according to their condition and then are moved on to the next processing level. In medical care, the correctness of diagnosis is very important. What is required of this triage sorting process is the accurate sorting of large numbers of injured people within the shortest time possible. We calculated the required time in our article [11], however did not evaluate the correctness of diagnosis executed. So, we give a solution for this problem following chapters.

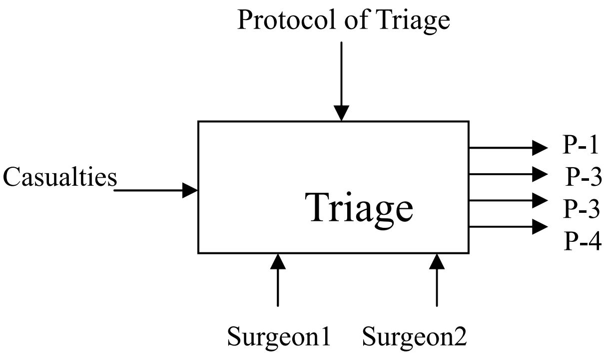


Fig 2 - Triage workflow

Table 1 - Protocol of triage

Rank	Management	Injury conditions
P-1	Top priority	Life or limbs in critical condition; Immediate treatment required
P-2	Standby	No determination of condition due to processing delay of 2-3 h
P-3	Pending	Slight trauma; treatable as outpatients
P-4	Death	No vital signs

3. Reliability block diagram

In reliability block diagrams, a system is described as a composite of subsystems or components. Individual subsystems are depicted as blocks or rectangles. The term "reliability" in this article follows the definition of the literature [9], i.e., it refers to the capability of a system to perform its function properly and presents a probability measure for the outcome of the designed system.

Reliability is intended to show therapeutic success rate, diagnostic sensitivity rate, and avoidance of complication or untoward effects of diagnosis and therapy in disease management or medical care. Reliability of each subsystem is independent. If a series of these block diagrams describes a medical management, calculating the overall reliability of combined subsystems provides the total reliability of medical management. Rules to determine the system are shown in Fig.3. Reliability is described as probability that the subsystem makes a proper operation. Block diagrams are classified into two systems, i.e., serial systems and parallel systems. In series system, if only one of the components fails, the whole system would fail. A parallel system is a redundant configuration. In such systems, only if all the subsystems fail at the same time, the whole system would fail.

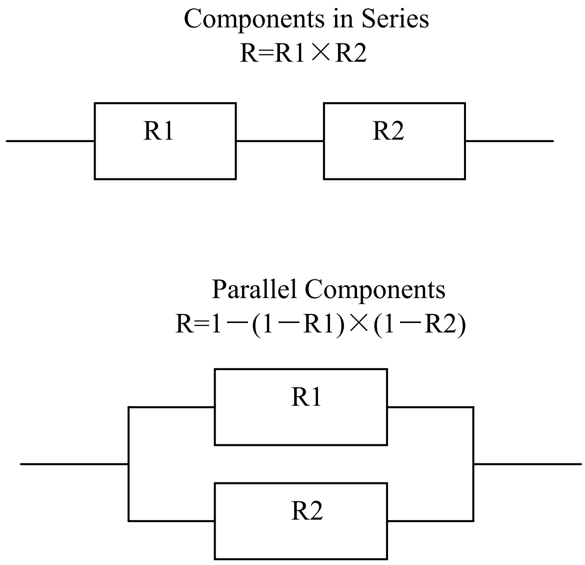


Figure 3 - Potential arrangement of two components in a system

4. Transformation of IDEF0 into a Reliability Block Diagram

4.1 Assumption of IDEF0

To estimate the reliability of a workflow described by IDEF0 model, we discuss one direction flow and assume there exists no feedback.

We introduce the following rules:

(1) An input arrow corresponds to the object processed by the components.
(2) An output arrow corresponds to the outcome produced by the components.
(3) A mechanism arrow is transformed into a subsystem in the reliability block diagram.
(4) A mechanism/subsystem has its reliability described in a mathematical way.
(5) The hierachical level of each subject in IDEF0 should be described explicitly.
(6) In the bottom level description of an IDEF0 model, if a subject has more than two mechanisms, these

mechanisms are transformed into parallel components in the reliability block diagram.

With the rule (5) and (6), we can decide the component configuration, serial or parallel.

(7) All the transformed components are active throughout the time of operation.
(8) A control arrow is not explicitly described after the transformation in the reliability block diagram.

However, the assumption that components are active throughout the time of operation is provided by the control arrow in the pre-transformed IDEF0 model.

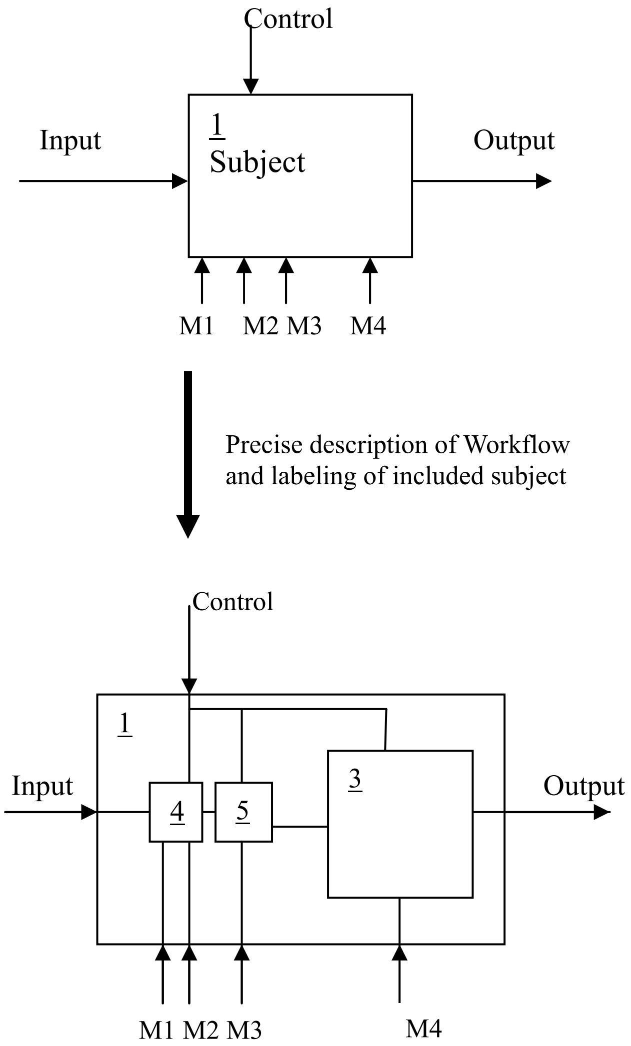


Figure 4 - Labeling of subjects

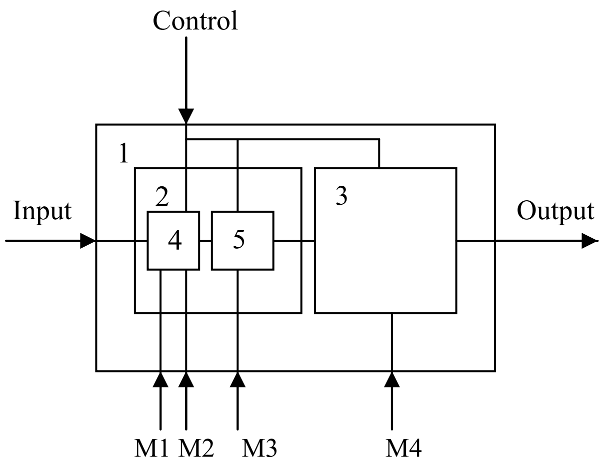
4.2 Estimation of Reliability

4.2.1 Block Level Value List

IDEF0 model in the bottom level of the description, all the subjects are delineated as boxes. We adopt a numbering rule of boxes in the IDEF0 model as follows:

(1) The top level box is numbered as 1.
(2) An upper level subject has a smaller number.
(3) In the same level of subjects, numbers are given in order.

Following these rules, each mechanism can have a list of numbers tracing its boxes as shown in Fig.4, 5. We name this "block level value list". Using these lists, we can transform the IDEF0 model into a reliability block diagram automatically.



M1 : (1, 2, 4)
M2 : (1, 2, 4)
M3 : (1, 2, 5)
M4 : (1, 3)

Figure 5 - Labeling of boxes and block level value list

4.2.2 Estimation of Total Reliability

The calculation of the total reliability is done as follows:

(1) Compare the max value of each list and separate between lists which have the same max value and others.

(2) Determination of components in series:

The lists which have different max values are the serial components.

Define the lists which have different max value in each list as S1, S1, … Sn. Reliabilities of these lists are described as: Rs1, Rs2, … Rsn.

(3) Determination of parallel components:

The mechanisms having lists holding same max values represent the parallel components. Define the sets of the lists which have the same max value as: P1, P2, … , Pm, and define the number of each set ,P1, P2, …, Pm as N1, N2, …, Nm.

In the set of P1, if the reliabilities of each element (mechanism) are described as: Rp11, Rp12, … Rp1n1, the reliability of the set P1: Rp1 is given as:

$$Rp1=1-(1-Rp11)(1-Rp12)\dots(1-Rp1n1).$$

(4) Calculation of total reliability:

Therefore the total reliability of the system is given as:

$$R\ total = (Rp1 \times Rp2 \times \dots \times Rpm) \times (Rs1 \times Rs \times \dots \times Rsn)$$

With these methods, if we have a chain of events described by IDEF0, we can evaluate the total reliability of the workflow quantitatively and automatically.

5. Example and Results

In medical care, the correctness of diagnosis is very important. What is required of this triage sorting process is the accurate sorting of large numbers of injured people within the shortest time possible. To exemplify our method described above, we deal with this triage workflow. We give a triage workflow described by the IDEF0 model and transformed into a reliability block diagram in Fig.5. There are multiple surgeons making decisions and the mental burden on each individual surgeon is alleviated [12]. We assume the accuracy of diagnosis of each surgeon with respect to time as function, $R(t) = \exp\{-(1/500) \times t\}$ [13]. Assumed accuracy of diagnosis is a reliability function described by an exponential distribution and takes into consideration of the weariness of doctors [12]. We calculate the reliabilities of two cases. One is that only one surgeon makes triage and the other is that two surgeons are engaged in, i.e., the parallel component shown in Fig.6. Results are shown in Fig.7. Compared with the result for one surgeon, the reliability of the parallel components is improved. Although measuring the mental burden of executing triage is not established, it is superior to do triage with two surgeons. This is an intuitive case showing the effectiveness of the reliability analysis.

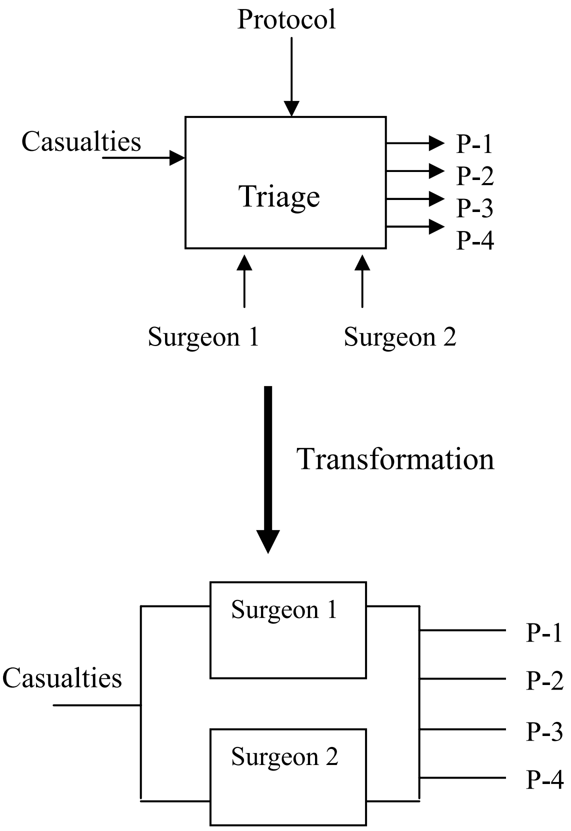


Figure 6 – Transformation of Triage Workflow

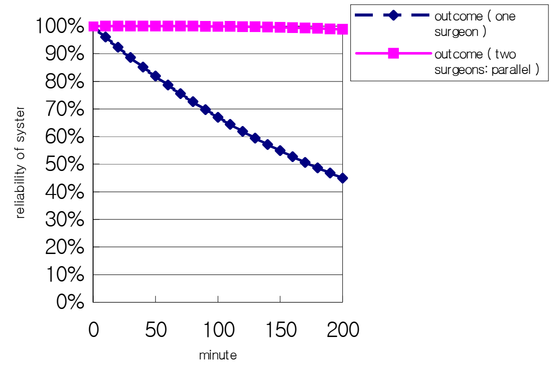


Fig.7 Reliability of components
(Probability of correct diagnosis)

Figure 7 – Reliability of Components (Probability of Correct Diagnosis)

6. Discussion

Supervision of workflow, from design to estimation, is not easy for all the people who need a tool to manage their task. There are many cases in which people having useful experience cannot contribute to design and manage their own profession due to the lack of the knowledge of workflow management. The IDEF0 model and the reliability block diagram simplify participation in system design by these people.

To combine these two models makes the prospect of workflow clearer and more predictable. However, the method we proposed cannot handle the monetary costs or management of resources. Reliability block diagrams assume probabilistic independence of the subsystems and have no defined equations to estimate cost-effectiveness for the system analysis. Measurement of the benefit gained by using this kind of system has not been established. Taking this matter into consideration, we should utilize the effectiveness of given methods. In order to proceed from model configuration to actual system implementation, it is important and necessary to develop a workflow evaluation system. The system being developed in future should have the following functions, (1) easy operation, (2) interactive design, (3) database management system, and (4) sensitivity analysis.

To implement the introduced transformation algorithm is not so difficult but to collect and assemble the data for reliability determination is very hard. Continuous accumulation of raw data is essential to implement this kind of system that has intimate associations with actual scenes.

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