Man-Machine Project Management System For New Products Development

Susumu Tsuhara, Susumu Seki
Systems Development Laboratory, Hitachi Ltd.
Kanagawa, JAPAN

Koji Nakamura, Toshiro Namiki
Hitachi Ltd.

Abstract

Man-machine project management system for new products development has been developed. It possesses the following three functions. (1) Planning the optimum inspection project, (2) Project scheduling with limited resources and (3) Man-machine project prediction and evaluation. In this paper, the necessity of these functions is described. Authors will also refer to the realization methods.

1. INTRODUCTION

In developing new products, there are many uncertain factors such as trial and error due to many difficulties that have to be overcome. Therefore, activities such as design, test production and inspection are performed repeatedly under the severe restriction of due dates. What is worse, development plans of new products are frequently changed to meet shifts in market behaviour. In managing the development of new products under such conditions, unconventional and exceptional measures must often be taken. Consequently, computer processing alone cannot always cope with the situations that arise. Based on this point of view, the authors have developed the following man-machine project management system for the development of new products.

2. FUNCTIONS REQUIRED FOR MANAGING NEW PRODUCT DEVELOPMENT

In managing projects for the development of new products, the following three functions are required.

(1) Planning the optimum inspection project

In the development of new products, failure in one inspection affects other inspections. Therefore, it is possible that the following situation may occur depending upon the sequence of inspections. That is, the situation of being compelled to inspect test products again even though they passed in the inspection before. The frequency of such situations increases the time needed for development. Thus, it must be absolutely avoided from the standpoint of project management. It is necessary to decide the optimum project network which minimizes the number of additional inspections made necessary by inspection failures.

(2) Project scheduling with limited resources

The project determined by function (1) is performed under the condition of limited resources such as inspection rooms, test products and so on. So, it is necessary to decide the sequence of such inspections as they cannot be performed simultaneously under the limitation of restricted resources. This is why project scheduling with limited resources is required.

(3) Man-machine project prediction and evaluation

In managing projects for the development of new products, unconventional and exceptional measures are often necessitated by uncertain fluctuation factors such as inspection failures, changes in development plans and so on. In order to cope with them, it is necessary to combine the following two abilities.

(a) Human ability to make decisions
(b) Computer ability to process information

That is, the function of project prediction and evaluation by man and computer is indispensable.

The authors will describe these three functions below.

3. PLANNING THE OPTIMUM INSPECTION PROJECT

3.1 Basic model

Let us examine the case of two inspections. One of these inspections will be denoted by t_i and the other one by t_j. If the test products have failed in inspection t_i, it must be performed again after countermeasures for improvement such as design changes have been implemented. It is previously known whether these countermeasures affect the other inspection t_j or not. If they affect t_j, t_j must be performed. Therefore, in the worst case, inspection t_j must be conducted again even though the test products have passed in t_j before.

The problem is how the sequence of these two inspections t_i and t_j should be decided. First of all, let us assume that the countermeasures caused by the failure in t_i affect t_j and t_j does not affect t_i. There are three variations in the sequence of t_i and t_j as shown in Table 1. If it is previously known that the test products don't fail in both t_i and t_j, no additional inspection occurs in these variations (a) to (c). But this assumption is invalid. We should assume the worst case in which the test products fail both t_i and t_j. Additional inspections of each variation (a) to (c) under this assumption are shown in Table 1. In variation (a), there occurs no additional inspection. But in variation (b) and (c), inspection t_j is made necessary by the failure in t_i. Consequently, variation (a) should be adopted because the number of additional inspections is minimized. This conclusion shows that the relation whether t_i affects t_j or not is equivalent to the relation which describes the inspection sequence.

3.2 Expansion to N inspections and definition of the optimality

An example of matrix $f(t_i,t_j)$ $(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, n)$ which describes the relation whether t_i affects t_j or not is shown in Table 2. $f(t_i,t_j)$ is a binary matrix and if t_i affects t_j (if t_j is performed after passing t_i) let $f(t_i,t_j)$ be 1, and if it does not let it be 0. $f(t_i,t_j)$ can be transformed into the network shown in Figure 1. If the network does not contain cycles, we can derive the objective project network of inspections just by removing the redundant arcs from the network. And if each inspection is performed based upon this project network, there occurs no additional inspections. However, these networks generally contain cycles as shown in Figure 1. Therefore, it is necessary to derive the cycle-free network by removing some arcs from the network (1,2). The problem of which arcs should be removed is solved by the definition of the optimum project network.

Now, the optimum project network will be defined. If the arc $4 \rightarrow 5$ is removed from the network shown in Figure 1, it becomes a cycle-free network and the objective project network can be derived from it. When the inspections are performed based upon this project network, there occur three additional inspections- 5, 3 and 4. The number of these additional inspections should be minimized. Thus, the optimum project network can be obtained by the following four procedures.

(1) Obtain the optimum permutation $[t_1, t_2, \ldots, t_n]$ which is formulated as follows.

$$\min_{[t_1,t_2,\ldots,t_n]\in S_T} G \qquad \cdots\cdots\cdots\cdots (1)$$

Where,

T : the set of inspections
S_T: the permutation set of inspections

G denotes the number of the additional inspections and is defined in the following equation.

$$G = \sum_{k=1}^{n} \left[\bigcup_{i=2}^{n} \bigcup_{j=1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\} \right] \qquad \cdots\cdots\cdots\cdots (2)$$

Where,

$\tilde{f}(t_i,t_j)$: reachable matrix of $f(t_i,t_j)$
$\cup$ and $\cap$: Boolean sum and product

$\tilde{f}_1(t_j,t_k)$ is defined as follows.

$$\tilde{f}_1(t_j,t_k) = 0 \quad (2 \leqq j \leqq n;\ 1 \leqq k \leqq i-1)$$
$$\tilde{f}_1(t_j,t_k) = \tilde{f}(t_j,t_k) \quad (1 \leqq j \leqq n;\ j \leqq k \leqq n) \qquad \cdots\cdots (3)$$

(2) Change the order of t_i and t_j in matrix $\tilde{f}(t_i,t_j)$ into the optimum permutation $[t_1, t_2, \ldots, t_n]$. Thus, a new matrix can be obtained. Let it be $\tilde{f}_2(t_i,t_j)$.

(3) Obtain the triangular matrix $\tilde{f}_3(t_i,t_j)$ which is defined as follows.

$$\tilde{f}_3(t_i,t_j) = 0 \quad (2 \leqq i \leqq n;\ 1 \leqq j \leqq i-1)$$
$$\tilde{f}_3(t_i,t_j) = \tilde{f}_2(t_i,t_j) \quad (1 \leqq i \leqq n;\ i \leqq j \leqq n) \qquad \cdots\cdots (4)$$

(4) Remove the redundant "1" factors from $\tilde{f}_3(t_i,t_j)$. The obtained matrix will be denoted by $f_3(t_i,t_j)$. $f_3(t_i,t_j)$ can be transformed into the network. And this is precisely the optimum project network being sought.

3.3 Method of obtaining the optimum solution

The optimum permutation $[t_1, t_2, \ldots, t_n]$ which has been defined in 3.2 (1) can be obtained by the Branch and Bound Method (BBM).

(1) Division of permutation set

S_T consists of n! factors, since S consists of n factors. Subset in BBM is defined as one in which all permutations are equal from the 1st to the rth ($r = 0, 1, \ldots, n-1$). The number of factors in this subset is $(n-r)!$. If $r = 0$, then the subset is equal to S_T and if $r = n-1$, then the subset consists of only one factor.

The subset in which all permutations are equal from the 1st to the rth is divided into (n-r) subsets. And in each subset, all permutations are equal from the 1st to the (r+1)th. Let $\{t_1, t_2, \ldots, t_r\}$ denote the subset in which all permutations are equal to $[t_1, t_2, \ldots, t_r]$ from the 1st to the rth.

(2) Lower Bound

The objective function G for the arbitrary permutation $[t_1, t_2, \ldots, t_r, t_{r+1}, \ldots, t_n]$ of subset $\{t_1, t_2, \ldots, t_r\}$ can be written as follows.

$$G = \sum_{k=1}^{n} [\bigcup_{i=2}^{n} \bigcup_{j=1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\}]$$
$$= \sum_{k=1}^{n} [(\bigcup_{i=2}^{r} \bigcup_{j=1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\}) \cup (\bigcup_{i=r+1}^{n} \bigcup_{j=1}^{r} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\}) \cup (\bigcup_{i=r+2}^{n} \bigcup_{j=r+1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\})] \quad \ldots\ldots\ldots\ (5)$$

The first and second items inside [ ] in the right-hand expression don't depend upon the permutations of subset $\{t_1, t_2, \ldots, t_r\}$. But the third item does. However,

$$\bigcup_{i=r+2}^{n} \bigcup_{j=r+1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\} = 0 \text{ or } 1 \quad (k = 1, 2, \ldots, n) \ \ldots\ldots\ (6)$$

Hence

$$\sum_{k=1}^{n} [\bigcup_{i=2}^{n} \bigcup_{j=1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\}]$$
$$\geqq \sum_{k=1}^{n} [(\bigcup_{i=2}^{r} \bigcup_{j=1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\}) \cup (\bigcup_{i=r+1}^{n} \bigcup_{j=1}^{r} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\})] \quad \ldots\ldots\ldots\ (7)$$

Consequently the lower bound $LB\{t_1, t_2, \ldots, t_r\}$ is written as follows.

$$LB\{t_1, t_2, \ldots, t_r\} = \sum_{k=1}^{n} [(\bigcup_{i=2}^{r} \bigcup_{j=1}^{i-1} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\}) \cup (\bigcup_{i=r+1}^{n} \bigcup_{j=1}^{r} \{\tilde{f}(t_i,t_j) \cap \tilde{f}_1(t_j,t_k)\})] \quad \ldots\ldots\ldots\ (8)$$

3.4 Case study

The process of searching for the optimum solution is shown in Figure 2 when $f(t_i,t_j)$ is given as shown in Table 2. The optimum permutation is [6,2,1,4,5,3]. And the minimum number of additional inspections is three. The objective optimum project network is obtained by the procedures described in 3.2 (2) to (4). Thus, the original network shown in Figure 3 (a) can be transformed into the objective network shown in Figure 3 (b).

4. PROJECT SCHEDULING WITH LIMITED RESOURCES

To perform the project planned in chapter 3, resources such as test products, inspection rooms, etc. are necessary. But these are limited. So, the project contains inspections that cannot be performed at the same time (3). Here, the schedules which minimize the project term are made under the restrictions of the inspection sequence and limited resources. Schedules are made hierarchically by the following three steps as shown in Figure 4.

(a) Long range scheduling (term is one year)
(b) Medium range scheduling (term is one or two months)
(c) Short range scheduling (term is one week)

The outline of (b) is shown in Figure 5 as a typical example. The project network as the requirement is hierarchical and multiple. A detailed single project is made by comparing this requirement with the capacities of the inspection rooms as resources. The method of priority rule oriented digital simulation is adopted.

5. MAN-MACHINE PROJECT PREDICTION AND EVALUATION

In managing projects for the development of new products, there are many uncertain fluctuation factors in the fundamental data such as inspection times, capacities, etc., because of the frequency of the unconventional and exceptional measures employed. Under such conditions, a man-machine management system which supplies the analyzed information to support human decision making is desired rather than an automatic decision making is desired rather than an automatic decision making system. From this point of view, Hitachi has already developed a man-machine system (4). It is named PASS (Predictive Adaptive Simulation System). PASS is applicable to the management of projects for the development of new products.

The flow of project management in which PASS is applied is shown in Figure 6. This consists of the following three phases.

(1) Prediction of future problems and pursuit of their causes

Future progress of the project is simulated. The simulation results are summarized and displayed on CRT. This is called a glossary display. It shows the general progress and the amount of delay from due dates. For the pursuit of the causes which brought on these delays, the following two frames are provided.

(a) Progress display
(b) Load display

These frames clearly show the causes of the delays.

(2) Devising solutions to future problems

The following three frames are provided as the means of formulating solutions to the predicted future problems.

(a) Display for changing capacity
(b) Display for changing due date
(c) Display for changing priority

Project managers formulate solutions to the predicted problems and enter them using these frames.

(3) Evaluation of solutions

Future progress is simulated again based upon the changed model. The results are shown in a glossary display as described in (1). Thus, the effectiveness of these solutions can be confirmed easily.

6. CONCLUSION

A man-machine project management system for new products development has been perfected. The features of the system are as follows.

(1) The number of additional inspections made necessary by inspection failures is minimized by the planning of an optimum inspection project network.

(2) The flexibility for inspection failures and the changes in development plans is raised by the introduction of man-machine project prediction and evaluation.

The system developed is now being applied to progress management at an inspection department in a home appliance factory.

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Table 1 Three Variations on the Sequence of t_i and t_j

Variations	Inspection Sequences	Additional Inspections
(a)	$t_i \rightarrow t_j$	—
(b)	$t_j \rightarrow t_i$	t_j
(c)	t_i , t_j	t_j

Table 2 an Example of $f(t_i, t_j)$

t_i \ t_j	4	2	6	5	1	3
4	1	0	0	1	0	0
2	1	1	0	1	1	0
6	1	1	1	0	1	0
5	0	0	0	1	0	1
1	0	0	0	1	1	1
3	1	0	0	0	0	1

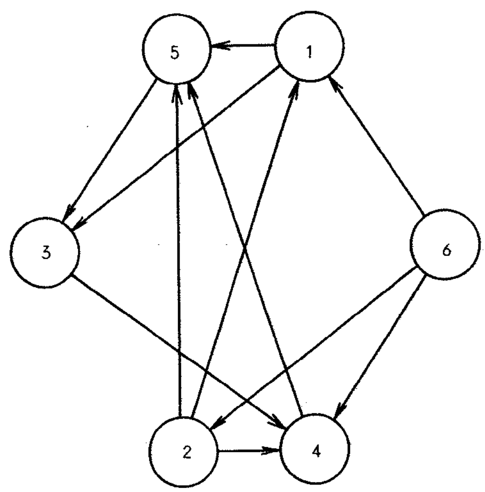

Figure 1 Network Expression of $f(t_i, t_j)$

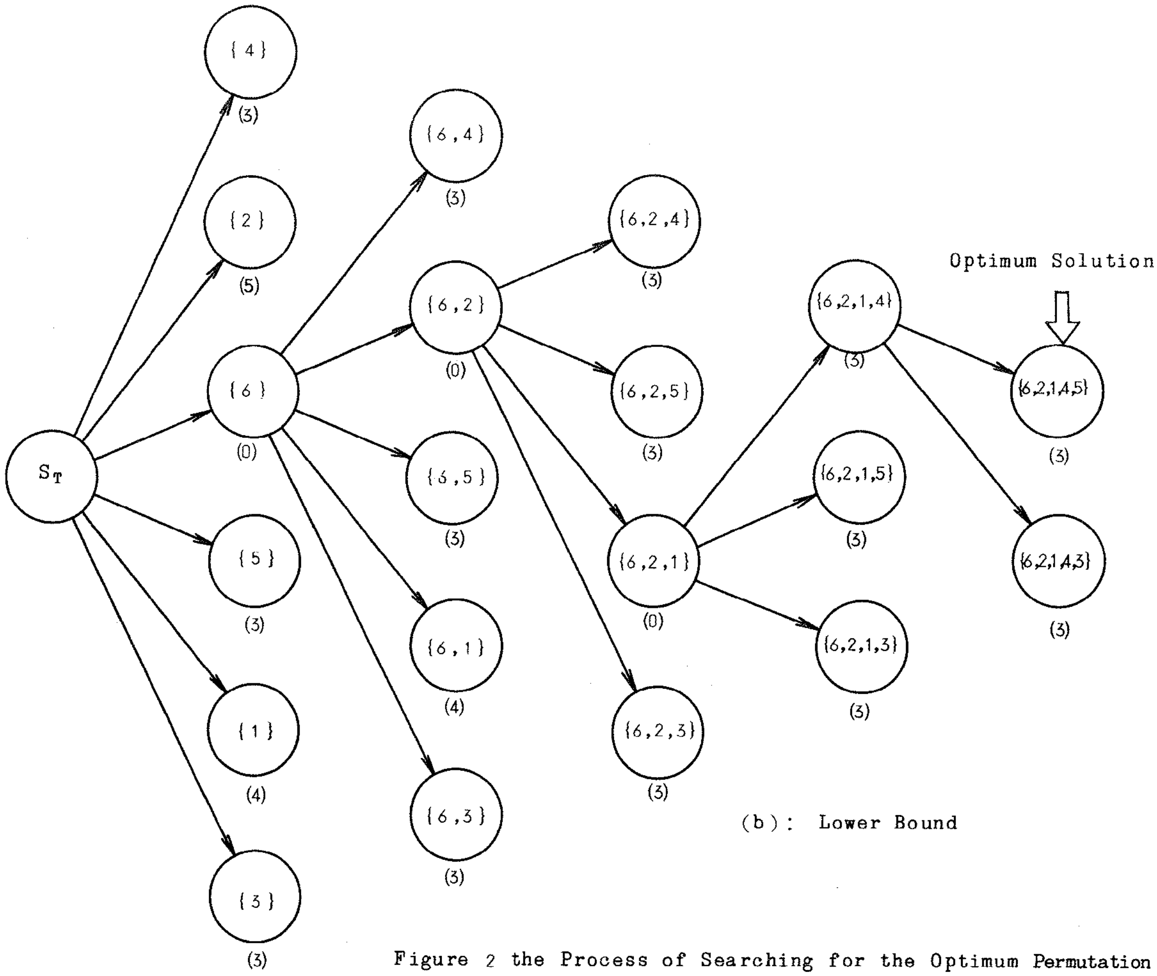

Figure 2 the Process of Searching for the Optimum Permutation

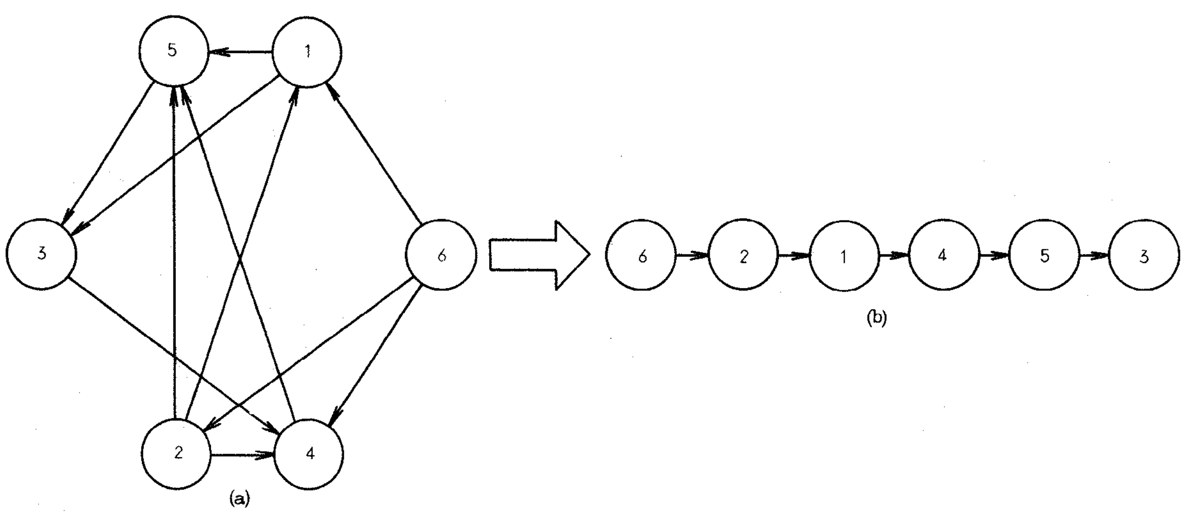

Figure 3 the Result of Optimization

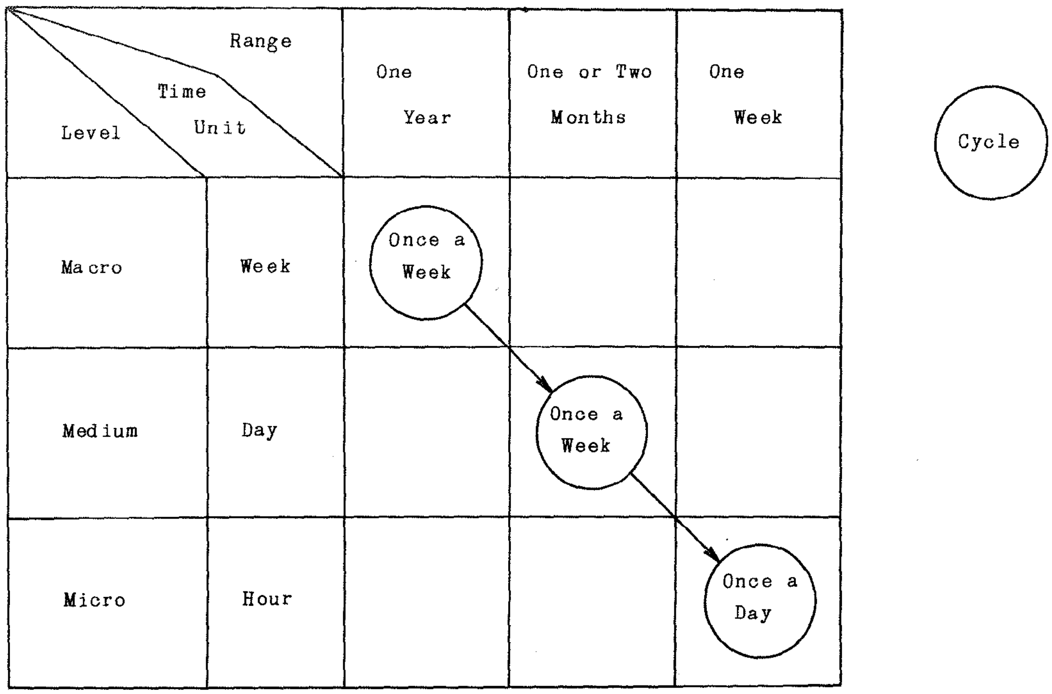

Figure 4 Method of Hierarchical Scheduling

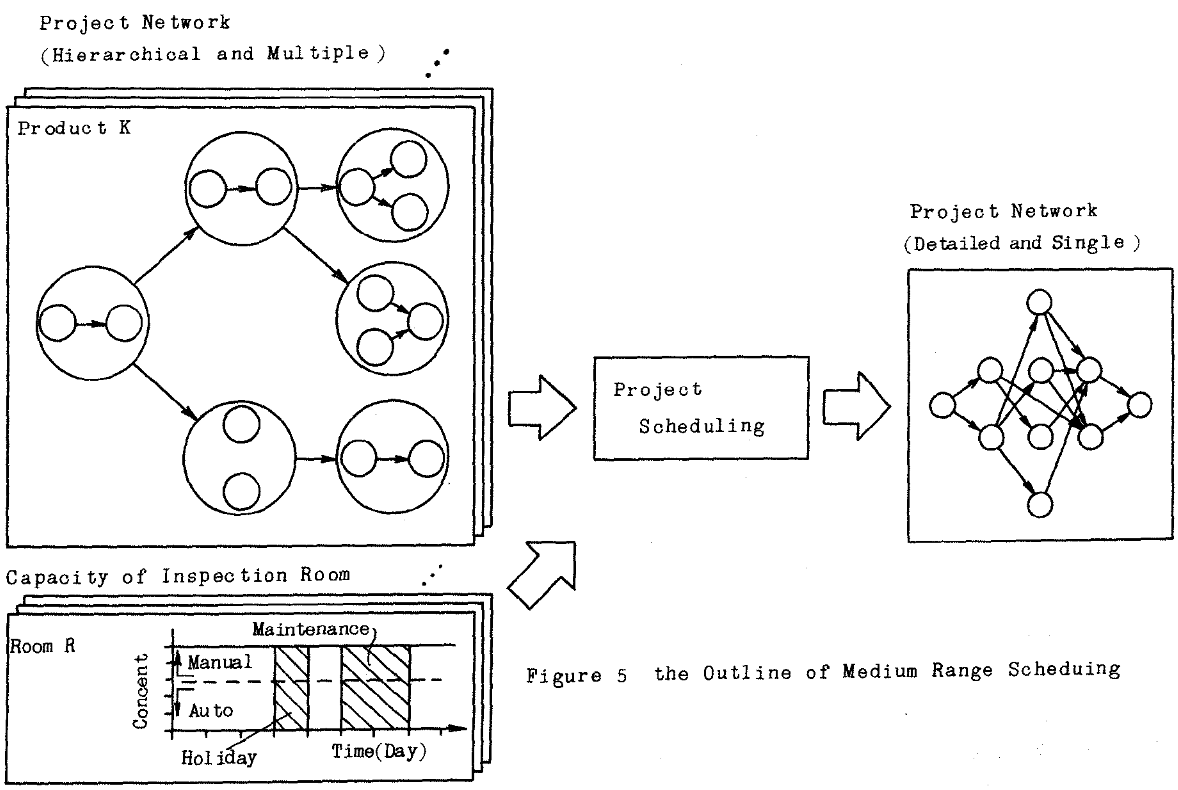

Figure 5 the Outline of Medium Range Scheduing

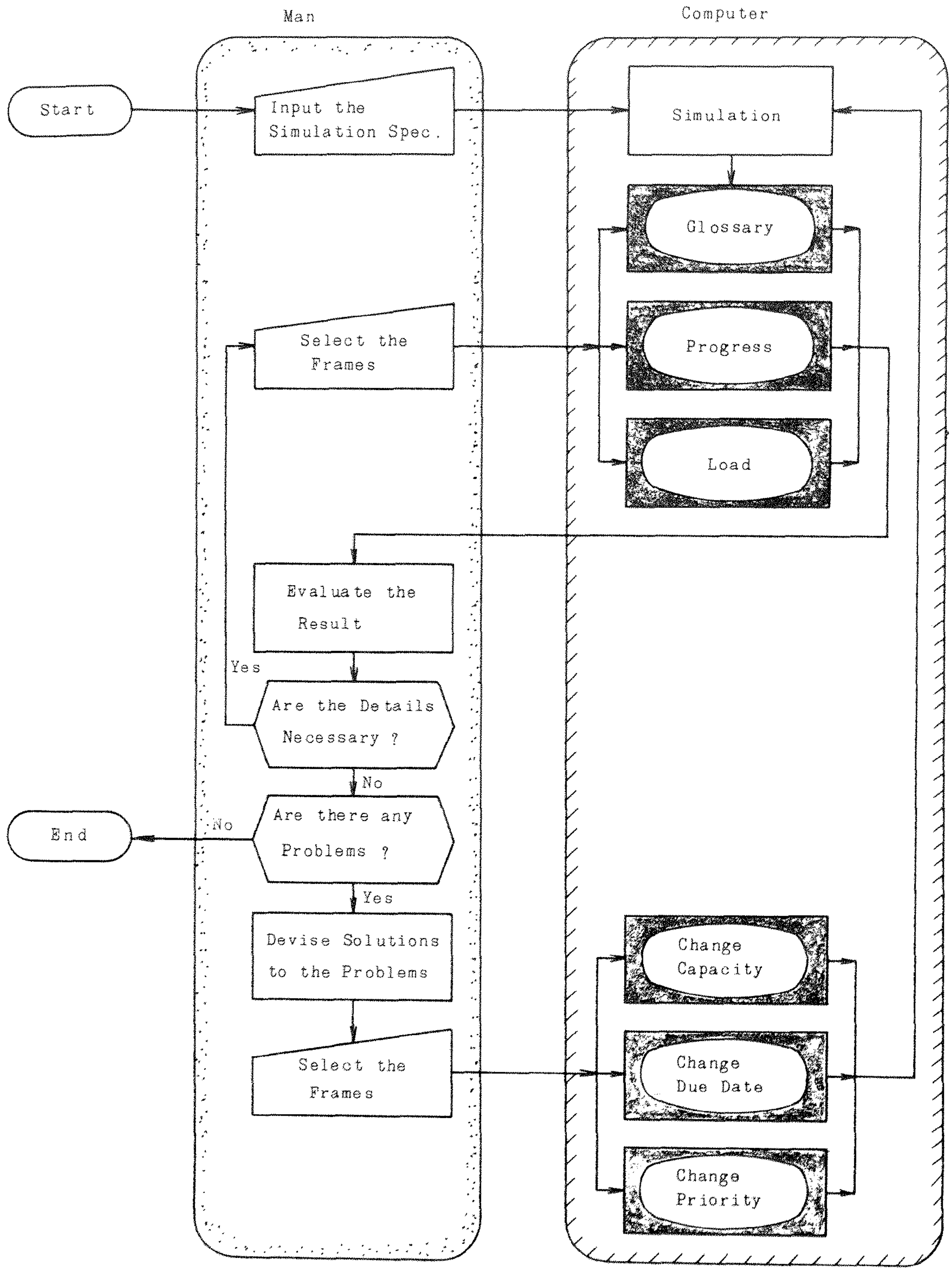

Figure 6 Man-machine Communication Flow in the Project Management System