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# A Reliability Analysis of Man-Machine System (Holdup Tank System) by the GO-FLOW

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## Abstract

In order to evaluate the reliability of a plant, not only mechanical system and human factors but also their interactions should be analyzed properly. However, it is not easy to deal with their interactions by Event Tree (ET) and Fault Tree (FT), which have been used widely and conventionally in PSA. In this paper, a system, consists of holdup tank and operator, is analyzed as an example of man-machine system by a system reliability analysis methodology GO-FLOW. It is shown that the GO-FLOW methodology could be well applicable to the analysis of man-machine system.

## 1. Introduction

In order to evaluate the reliability of a plant, not only mechanical system and human factors but also their interactions should be analyzed properly. However, it is not easy to deal with their interactions by ET and FT, which have been used widely and conventionally in PSA. Though the GO-FLOW [1] has been applied to mechanical systems [2], authors have tried to apply this methodology to man-machine system [3]. In the present paper, a system, consists of holdup tank and operator, is analyzed as an example of man-machine system by the GO-FLOW.

If we try to apply ET and FT to man-machine systems, there are some difficulties as follows. (1) It is difficult to analyze the interaction between mechanical system and human factors precisely. (2) It is very troublesome to deal with the change of system state by time and time delay. (3) Since event sequences are made in the tree shape, it is hard to make clear the relation between its shape and system function/phenomenon. Therefore, creation, verification and modification of the “tree” are difficult. (4) Usually the number of sequences increases rapidly with the increase of events, and it is difficult to deal with it.

In this paper, it is shown that the GO-FLOW could overcome these difficulties in analyzing a man-machine system.

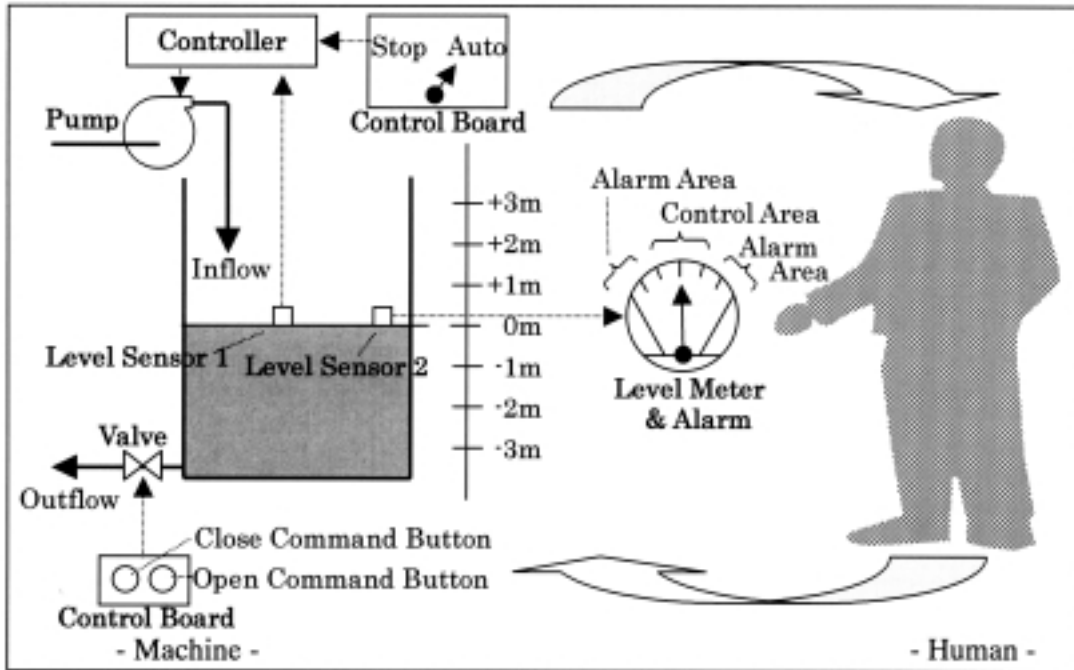


Fig. 1. Holdup Tank - Operator System

## 2. Holdup Tank System

As an example, a simple system, which consists of holdup tank and operator, is taken up as shown in Fig.1.

The holdup tank consists of a pump system, a level meter system and a valve system.

The pump system consists of a pump, a level sensor 1, a controller, and a control board. An operator can choose either the pump is operated automatically or is stopped. When it runs automatically the controller selects one inflow rate out of 0, 1 or 2m/tp (tp: time point) to adjust tank level within target range (from  $-1$  to  $1$ m) by signal from level sensor 1. The pump system has two failure modes of fails-max (2m/tp) and fails-stop (0m/tp). The operator can only stop the pump system when failure happens. The operator can read rough inflow rate with 3-series of propeller type flow meter through a small window on the pipe.

The level meter system consists of a level meter, level sensor 2, and an alarm. Its own level sensor is used for this level meter system. The level meter system has two failure modes of “fails-high & alarm” and “fails-low & alarm”. Tank level is expressed in seven stages from  $-3$  to  $+3$ m. When its level becomes less than  $-2$  or more than  $+2$ , an alarm sounds and the operator reads the level

meter whether the alarm is issued because of low or high.

The valve system consists of an electric valve and a control board. The operator can send an open command or a close command to the valve. The drainage capability of valve is 1m/tp (open) or 0m/tp (close). The valve system has a failure mode of fails-fix. When it fails, the operator cannot change the valve state. The operator can read rough outflow rate with equal device with pump system.

In the above system, it is analyzed how the system state changes according to time assuming that at time point 0 all the components are normal. Single failure of a pump system is considered as an initiating event.

### 3. Analysis by the GO-FLOW

A GO-FLOW chart is shown in Fig. 2. “A”, “B”, “C”, “D”, “E” and “F” models the state of a mechanical system, initiating event, human cognition, judgment, operation and the state of the whole system, respectively.

In “A”, No.3 models whole failure of a pump system (its probability is calculated by failure rate  $\lambda = 0.0008/\text{h}$ ) and signal line from No.3 represents the probability that the pump system is in normal state. No.5, a differential operator, generates increased amount of failure probability during the successive time points. No.6 models fails-stop of the pump (2/3 of all failure), and No.8 fails-max. No.10 models the failure of a level meter system ( $\lambda = 0.0004/\text{h}$ ). No.12 models failure of valve system ( $\lambda = 0.0003/\text{h}$ ) and No.13 models fails-fix.

In “B”, No.14 models an initiating event “pump fails-max & level meter normal” and No.15 “pump fails-stop & level meter normal”. No.16 and 17 model delay time for alarm generation. Their delay time is 2 time points.

“C”-“E” model human cognition, judgment and operation, respectively. An operator reads inflow rate, level meter and outflow rate, and he or she performs counter operation reasoning the state of a mechanical system. For example, No.36 is the case where an operator correctly reads inflow rate as 2m/tp, level meter high, and outflow rate 1m/tp. In this case, since the level meter reached alarm region but inflow rate is still 2m/tp, the pump is interpreted as fails-max. Because the continuation of system operation is impossible, the operator will try to shutdown the holdup tank system. Moreover, No.77 is the case where actually inflow rate is 0m/tp, level meter low, and outflow rate 1m/tp, but an operator reads inflow rate as 0m/tp, level meter high, and outflow rate 0m/tp. In this case, it will be judged that pump stops by omission of a valve opening, and the operator will try to open the valve and continue to run the system.

The delay operator of No.18 and 48 model the delay of human actions.

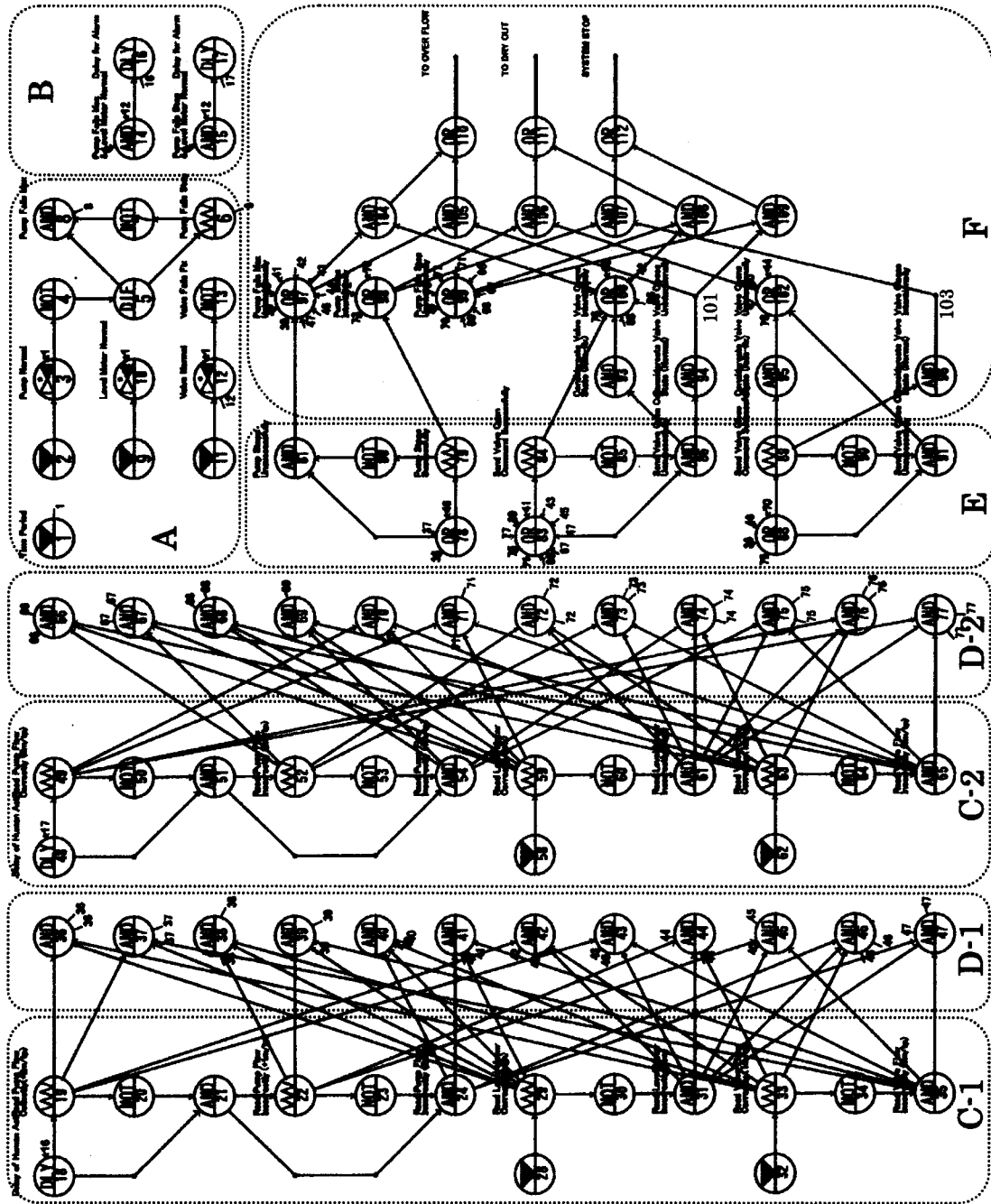


Fig. 2. GO-FLOW Chart

Their delay time is assumed to be 1 time point.

In "C", No.19-24 model reading of inflow rate. For example, No.19 models the probability of correct reading ( $p = 0.97$ ). No.22 and 24 model those of

incorrect reading ( $P = 0.015$ ) as 1m/tp and 0m/tp, respectively. No.29–31 model the reading of level meter when an alarm occurs. No.29 models the probability of correct reading ( $P = 0.98$ ) as “high” and No.31 models that of incorrect reading as “low”. No.33–35 model the reading of the outflow rate. No.33 models the probability of correct reading ( $P = 0.99$ ) as 0m/tp, and No.35 models that of incorrect reading as 1m/tp. C-2 models similarly.

“D” models operator’s judgment. An operator decides counter operations from the combination of reading.

“C-1”, “D-1” and “C-2”, “D-2” model the human cognition and judgment for two initiating events of “B”, that is “pump fails-max & level meter normal” and “pump fails-stop & level meter normal”, respectively.

“E” models operator’s action. In this area errors of operator’s actions are taken into account. For example, valve operation error is modeled in No.88–91. No.89 is the case where the valve stop command is sent correctly, and No.91 is the case where a wrong command is sent.

The result of the operation is modeled in No.97–103 with combination of mechanical failure. The GO-FLOW can take into account the interactions between human and machine like that mentioned above.

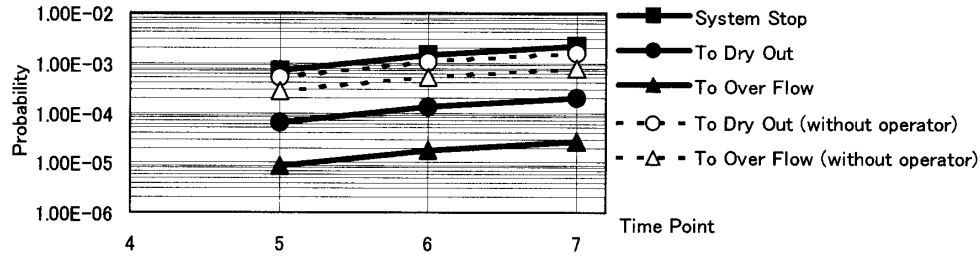
Next, system states are classified into No.104–109 from the combination of the operator’s intention and the state of a pump and a valve. Final state of the whole holdup tank - operator system is classified into the following 3 kinds, “To Over Flow”, “To Dry Out” and “System Stop”.

The GO-FLOW chart consists of many parts that represent fundamental function/phenomenon. Their independency of each part is high, and it is possible to make each part in detail individually at first, then dependencies are easily considered by connecting relating signal lines and GO-FLOW operators.

Moreover, because the GO-FLOW deals with plural number of situation events in one GO-FLOW operator and one signal line, so the number of GO-FLOW operators and signal lines do not increase so rapidly even if the factors to be dealt with in the model are increased.

The time points set up in this analysis is 7 from 0 to 6 hours. Once a chart is completed and time points are set in the GO-FLOW, it is possible to obtain analysis result for plural times in one computer run.

An analysis result is shown in Fig. 3. The probability of “System Stop” is the largest. “To Dry Out” and “To Over Flow” follow it. To know the effect of operator’s action, correspond data calculated without an operator’s participation is added with dotted lines in the graph. Because supposed valve failure mode is only “fails-fix”, there is no probability of “System Stop without operator”. In this paper, since the purpose of this analysis is to show the applicability of the



**Fig. 3.** Analysis Result

GO-FLOW to man-machine system, probability parameters are defined rather larger value than former study [4] so that a result may become easy to recognize. The calculation is done by Personal Computer, which has a Pentium II 400Mhz CPU and 3GB memory, and the calculation time is 229 seconds.

#### 4. Conclusion

Holdup tank and operator system is analyzed by the GO-FLOW, and the change of system state according to time is obtained. Through the analysis, the GO-FLOW illustrates that the following merits could be usable in man-machine system analysis. (1) It is capable to analyze the interaction between mechanical system and operator's action precisely. (2) Changes of system state according to time and time delay can be analyzed in one computer run. (3) Relations between the shape of the GO-FLOW chart and a system function/phenomenon are easy to understand. Therefore, creation, verification and modification of the chart can be done easily. (4) Though the number of sequences increases rapidly with the increase of event, the number of GO-FLOW operators and signal lines do not increase rapidly, so it is not difficult to deal with it.

In this analysis, the dependencies among different operator actions are not taking into consideration. It should be settled in the future.

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