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Dynamical Safety Assessment of the Nuclear Power Plant Component using the Information Feedback oriented System Dynamics Method

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Abstract

A feedback oriented dynamical safety assessment in nuclear power plant is constructed. A commercial software for System Dynamics, Ventana Simulation Environment (Vensim), is used to develop a dynamics model for the Auxiliary Feed Water System (AFWS) of Pressurized Water Reactor (PWR). The 18-month refuel cycle is described for the real situation. The failure rate is higher when the plant is in zero power state like maintenance, test, and refueling, which is not well described in conventional Event/Fault Tree based safety assessment. This also means a human failure rate is high in the standby and shutdown states. Time Step is introduced for the different time weighted frequency of failure cases. The Common Cause Failure is affected by Time Step process. The simulation shows dynamically for the standby-running and shutdown-running of nuclear power plant. The modeling is easily made by a unique graphic designed method and understood by operator or reviewer well. The logical and systems thinking is simulated.

1. Introduction

The dynamical modeling of the Nuclear Power Plants (NPPs) is important for the reliability of systems. The advanced dynamic simulation, System Dynamics, is used for the advanced reliability assessment tool. The System Dynamics was introduced by professor J. Forrester [1][2][3] at the Sloan School of Management in MIT around the early of 1960s. This has been applied for the business and management fields to formulate a dynamical model for social systems successfully. This was also studied for the fields of Radiological Dispersion [4] and Human Factor study [5][7]. The Korean peninsula unification model was simulated in the public magazine [6]. The Auxiliary Feed Water System (AFWS) is frequently tested for the assessment methodology. The Oconee Unit 3 Nuclear Power Plant in the United States, YGN Unit 3 & 4, and Kori Unit 3 & 4 are modeled for this research.

The AFWS is used to remove heat released from plant systems, structures, and components in the closed system. The AFWS cools the safety-related and non-safety related reactor auxiliary loads. Heat transferred by these components to the AFWS is removed to the Condensate Storage Tank A and B. The refueling period is 6 weeks and the refueling cycle is 18 months. The dynamical concept is important for the operators who are working in the plant site. In this paper, more improved methodology is introduced for simulating of time dependent analysis.

2. Method

In this study, the system success of AFWS is quantified. The main model is incorporated with the state failures and the start failures in the subcomponents. The 'Time Step' is affecting to all components procedures. The state failures are composed of 7 models and the start failures are considered as 5 models.

The system success is a Boolean sum of the two run states of train A and B when it has the ½ success logic in Fig. 1. The pumps, steam generators, and valves are correlated for the AFWS success operating sequences. When the system is in a success condition, the condensate storage tank water goes to the steam generator.

The events are classified as 'State' situation and 'Start' situation. The 'State' means that the reactor is in the operating situation. Otherwise, the 'Start' situation means that the reactor is in the point of operating situation from maintenance, refueling, or any other kinds of stopping conditions. In this study, 'State' models are from Fig. 2 to Fig. 8 as 'Fails to Start', 'Failure State Train A', 'Failure State Train B', 'Pump State', 'Valve State', 'NPSH State', and 'Not Enough NPSH'. The 'Start' models are done from Fig. 9 to Fig. 13 as 'Pump A Start Failure', 'Pump B Start Failure', 'Pump Independent Failure', 'Valve Independent Failure', and 'Turbine Operated Pump Independent Failure'.

The 'Time Step' model in Fig. 14 affects to every model in the 'State' and 'Start' models. It is 0.02 in the case of refueling and 0.1 in the case of running. Namely, the refueling is considered for 'Start' modeling and the running is considered for the 'State' modeling. So, this concept is one of the advantage point in System Dynamics simulation in the NPPs, because the 'Time Step' makes the different analysis in the 'State' failures and 'Start' failures each.

3. Results

In Fig. 15, one example of Failure Rate is shown for the 'Pump A Operator Actuation Failure Rate'. In this graph, the 2 refueling periods are shown in 72^{nd} - 79^{th} week and 150^{th} - 157^{th} week. So, the 'Pump A Operator Actuation Failure Rate' is high when it is refueled. In the real situation, the failure rates are high in the periods of refueling due to the operator's fault. Therefore, the 'Time Step' is short (0.02) in the refueling period, which affects the higher failure rates in the events.

The Table 1 shows the several events unavailabilities in this model and Table 2 shows the top event capacity. In the System Dynamics simulation, the unavailability is calculated following the individual simulation. However, in the conventional method, the event quantification is based on the real basic data. This study makes the 2 cycles' simulation in each 18-month refueling cycle. Total period is 200 weeks, which is reasonable for the study's object period. As the result is seen in the Table 2, the system success is 0.975 (97.5%) during the simulation.

4. Conclusions

The comments for the conclusion of this simulation are as follows.

1. The ‘Time Step’ is a unique concept of System Dynamics. This ‘Time Step’ can change the failure frequency in each event. These events are sorted following the situation of nuclear power plants. That is to say, the ‘State’ and ‘Start’ situations are easily classified. So, the ‘Standby-Running’ and ‘Running-Shutdown’ cases are considered as ‘Start’ events. The higher failure frequency rates are shown in the ‘Refueling’ and ‘Trip’ cases are affected by ‘Time Step’.
2. The basic events are weighted by the feedback factor expressed by ‘Time Step’. Feedback operation is quantified continuously following the NPP’s situation. This is like a metabolism in the human body in order to keep the designed control condition.
3. The operator of this simulation shows easily the human factor [9] using operator’s time dependent situation.
4. The Common Cause Failure [10] is calculated by ‘Time Step’ quantified time variable.
5. The modeling is easily designed using the several commercialized softwares and understood by operator or reviewer.
6. The availability and capacity are made through the simulation. In conventional PSA, this work is just done by the operation data.

5. Acknowledgements

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6. References

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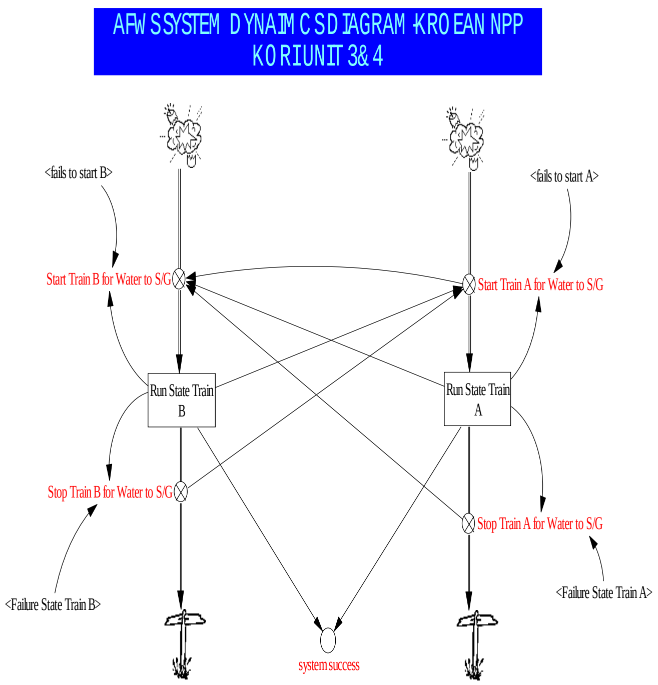


Fig.1 System Dynamics Main Model

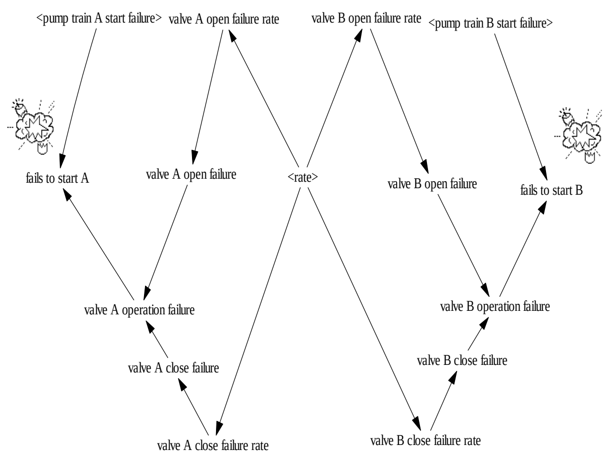


Fig.2 Fails to Start

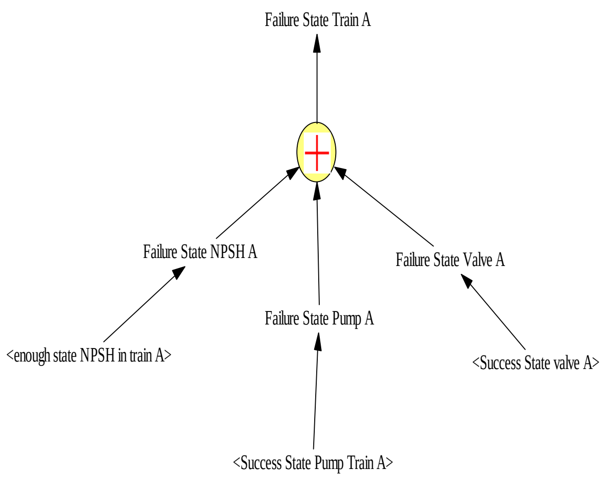


Fig.3 Failure State Train A

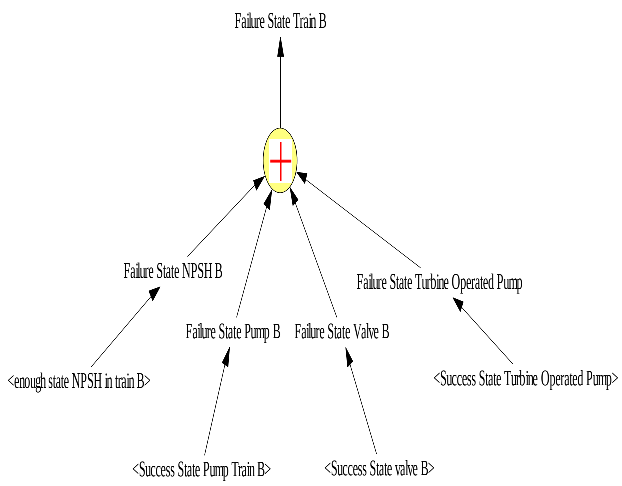


Fig.4 Failure State Train B

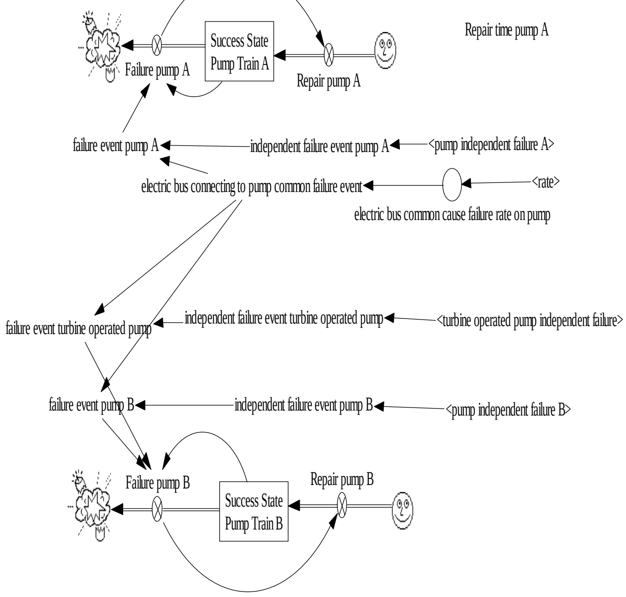


Fig.5 Pump State

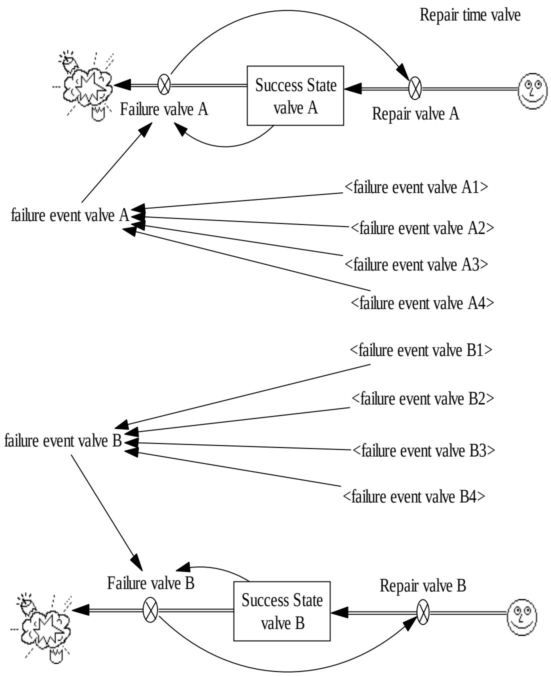


Fig.6 Valve State

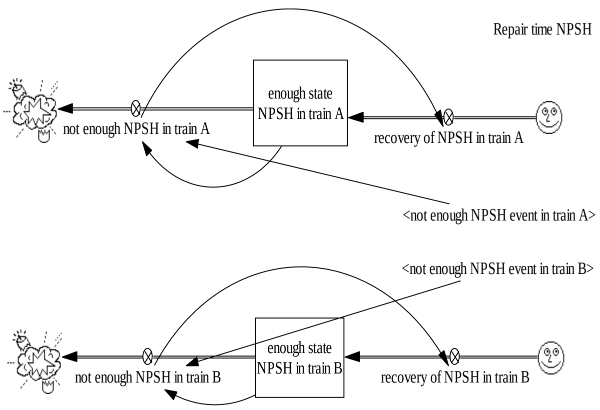


Fig.7 NPSH State

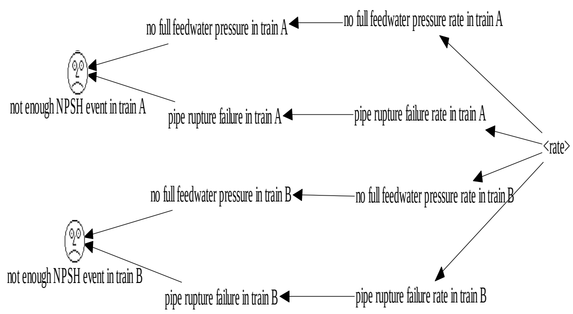


Fig.8 Not Enough NPSH

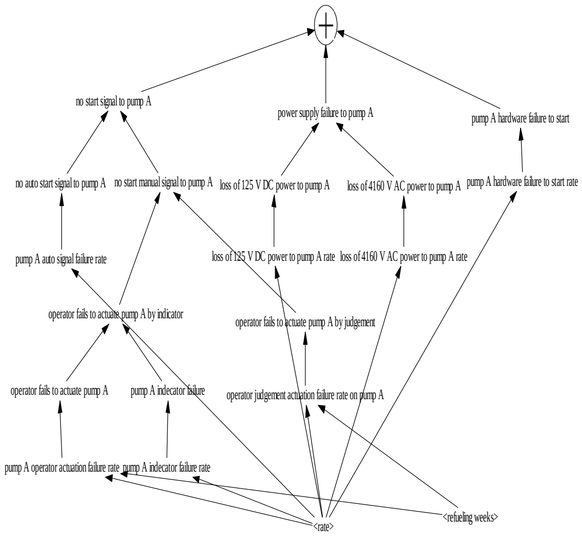


Fig.9 Pump A Start Failure

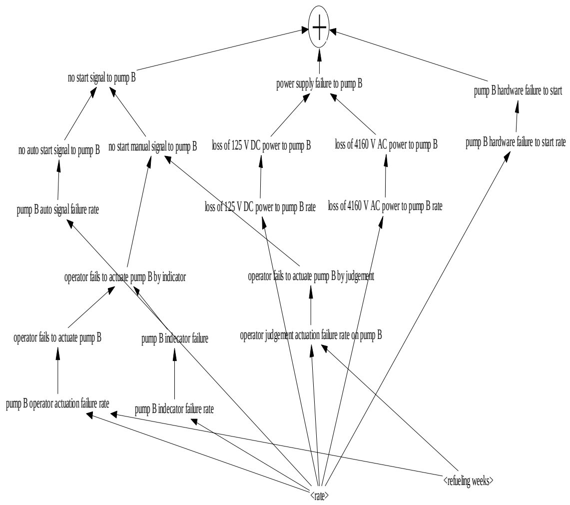


Fig.10 Pump B Start Failure

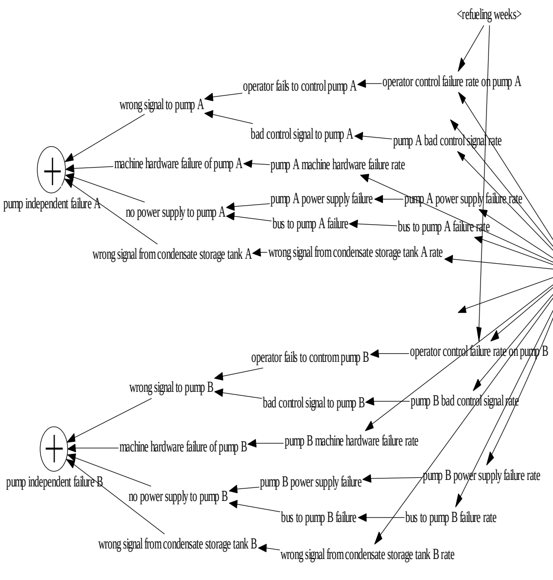
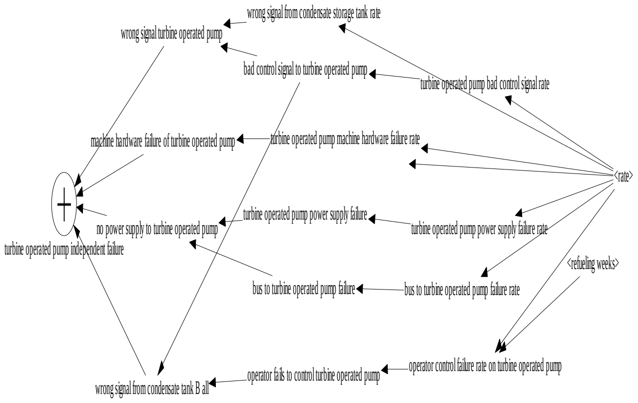


Fig.11 Pump Independent Failure

Fig.12 Valve Independent Failure



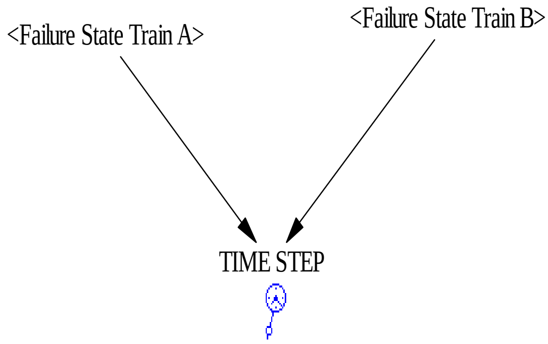


Fig.13 Turbine Operated Independent Failure

Fig.14 Time Step

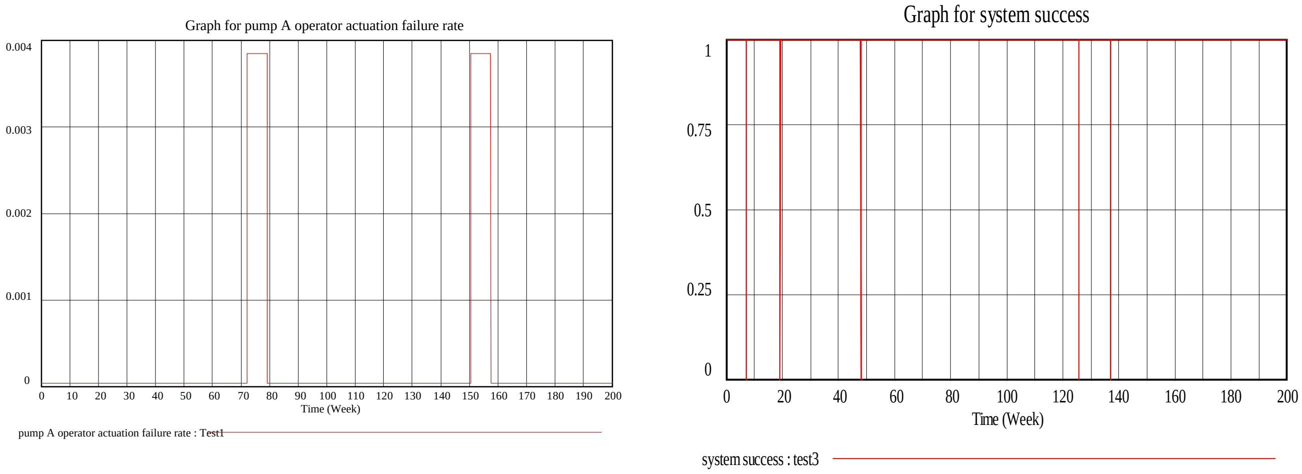


Fig.15 System Success and Failure Rate

Event	Freq-uency	**Each Events Unavailability (Frequency/Week)**
Fails to Start A	76	**76/200 = 0.380**
Failure State Train A	104	**104/200 = 0.640**
Failure Event Pump A	76	**76/200 = 0.380**
Failure Event Valve A	0	**0/200 = 0.000**
Not enough NPSH in Train A	0	**0/200 = 0.000**
Pump A Start Failure	66	**66/200 = 0.330**
Turbine Operated Pump Independent Failure	67	**67/200 = 0.335**

Table 1 Event Unavailabilities

Event	Freq-uency	**Top Event Capacity (Frequency/Week)**
System Success	195	**195/200 = 0.975**

Table 2 Top Event Capacity