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Parallel system utilization in weak link analysis

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ABSTRACT

Parallel subsystems within operational systems can improve system reliability, especially in areas of the system which are or may become weak links. The basic modes of operation of parallel systems include backup, operation under exceptional conditions, and functioning on a compare-for-equal basis to facilitate output quality. A parallel system classification scheme is presented as well as a description of a database which ties parallel subsystems to their corresponding operational systems. The database can assist the manager in identifying and analyzing weak links anywhere in the organization to determine where parallel subsystems can best improve overall system reliability.

INTRODUCTION

The purpose of parallel systems is to enhance the reliability of the overall system by serving as back ups, operating under exceptional circumstances, or being integrated into the quality assurance function. Parallel systems, if implemented in a cost-effective manner, can enhance overall organizational effectiveness by bolstering weak links, which are subsystems that would improve overall system reliability if they were supplemented.

Parallel systems abound in everyday life and occur when two or more subsystems are capable of performing a similar function. An automobile spare tire, for instance, functions as a parallel system for each of the four tires. Backing up computer files by copying them from a hard disk to media such as tape, diskette, or second hard disk is another example. This parallel system requires periodic updating because files are continuously being created and modified. A third example is an outboard motor on a sail boat. The motor can be used while the boat is under sail to maintain a certain speed, when the wind is insufficient, or to maintain greater control of the boat over short distances, such as in docking.

Production and operation systems have a plethora of parallel systems. A machine may serve on a standby basis in the event that other machines either unexpectedly break down or are receiving preventive maintenance. In other situations a parallel system might consist of personnel who are cross-trained in the event that the machine or individuals performing a given operation need to be replaced or supplemented. Parallel systems can also be used as part of a quality
assurance system. For example, two optical character recognition (OCR) machines might scan the same document on a compare-for-equal basis. If the two machines do not read the same character in a given row and column position, an error signal is generated and the character discrepancy is resolved by a person verifying the original input document. This quality check is based on the assumptions that there is a low probability that two machines will make the same error in a given row and column position and that the system resolving the discrepancies has a high reliability (Ribaric & Pavesic, 1988). Because of their versatile functions, parallel systems play a key role in Crisis Management. The extent of this role, of course, depends on obtaining an optimal balance between the cost of installing and maintaining the parallel system and the contribution of the parallel system to the overall system performance (Bodnar, 1993; Hughes, 1995; Rosander, 1992).

In order to explain the potential utilization of parallel systems, a parallel system will be explained in more detail. Following this, various parallel system applications will be presented according to a classification scheme along with a model for evaluating their potential application.

**DEFINITION OF PARALLEL SYSTEMS**

A parallel system can be defined as follows:

One or more subsystems serving in a supportive role to an operational system by producing or simulating the same output as its operational system under conditions other than continuous production of output.

The flow chart in Figure 1 on the following page illustrates a parallel system. This model distinguishes between operational subsystems connected in parallel and parallel subsystems within an operational system. This differentiation is necessary because it is common for a system to contain two or more operational subsystems connected in parallel in an effort to balance or expedite system throughput. In these situations the operational subsystems are not intended to serve in backup capacity to each other. Thus, to be defined as parallel, the subsystems do not function in a continuous operational manner to produce the output, but instead function as backups, are used operationally under exceptional conditions, are part of the quality assurance aspect of the system, or serve in a combination of these functions. Although the use of a parallel system in the quality assurance aspect could be interpreted as operational, it should be noted that only one output is created. In the above example of OCR machines, the actual operation of converting the characters on paper to a machine readable format is done by only one OCR. The second OCR serves in a verifier capacity because almost all of the output has been previously created.

A parallel system has a minimum of three sensors: a common input sensor and at least two independent output sensors. The common input sensor evaluates the quality and quantity of the input going into the system. Under some conditions the input sensor allows the parallel subsystem to be proactive. By evaluating selected characteristics of the input, the input sensor can instruct the input controller to perform a given operation, such as switching part or all of the input to a parallel component before the output becomes defective. An example of this would be a situation
Figure 1. Parallel System Model
in which a driver notices that it is about to snow. The driver then replaces one of the back tires with the spare tire because it happens to be more effective in snow, although it does not give as comfortable a ride. In a production situation, a change in the characteristics of the system input may result in switching or diverting the input to an alternative machine or system because of its superior performance when using that particular kind of input. For example, a food processing plant which freezes berries uses water jets from a series of pipes located above the berries on a conveyor washing screen to clean the fruit. If the berries are dirtier than usual, an inspector located near the dumping station diverts the flow of the berries to a special washing process composed of a shaker, a turbulent water bath containing a mild cleaning solution, and more powerful water jets above the conveyor washing screen. This cleansing process, however, is slower and tends to be more damaging to the fruit, and hence the parallel washing system is used only under exceptional circumstances.

The next unit of a parallel system, the input controller, is used to control the flow among the various operational subsystems. In some cases the controller operates as a toggle and merely switches input from one subsystem to another. In other cases the input controller sends the same input through each of the two operational subsystems. For example, in a data entry situation, one operator keys a document into a file. Later, another operator keys the same document against the file created by the first operator. In this case, the input controller consists of instructions given to the second operator to key the same document. When discrepancies are found between the two operators, as determined by the output sensors and fed back to the input controller, the character generated by the first operator can either stand as read, be changed to that keyed by the second operator, or be a character different from either of the two operators upon further scrutiny by someone examining the original input document (Rhodes, 1987).

The output sensors are used to evaluate the output of their systems and must be independent from each other. Information from these sensors can then be fed to the input controller, which controls the flow of the inputs based upon the information provided by the output sensors. Controlling the input as a result of information from the output sensors is often reactive and is triggered by defective output. Nevertheless, this need not be the case as the output can still be within specification, but according to the output sensors of the subsystem, may have a reasonable probability of going out of control. When this occurs, the parallel subsystem is activated. Such situations might take place when control charts are used. For example, when the weight of a product is recorded on a control chart during the manufacturing process in which containers are automatically loaded by filling machines, no corrective action is taken as long as the weight experiences random fluctuations within upper and lower control limits. If an upward trend occurs in the weight of the previous five samples, the input may then be diverted to another filling machine while the current filling machine is inspected. Thus, although the output is within the specified limits, a particular trend in the output may result in switching to the parallel system (Wadsworth et al., 1986).
CLASSIFICATION SCHEME OF PARALLEL SYSTEMS

The classification scheme for parallel systems presented here can help the manager analyze and evaluate operations to determine the need and extent of parallel system coverage. Because an organization consists of perhaps hundreds or even thousands of operational subsystems, it is necessary that an efficient method be used to monitor the parallel subsystem coverages of these operational systems. To do this, one might consider using a database in which each operational subsystem and its corresponding parallel subsystems, if any, are linked. Although the database used for this may ultimately entail more fields, a possible beginning is provided below:

- Operational System Identifier: <master database>
- Parallel System Identifier: <detail database>
- Input Controller Mode: Reactive or Proactive
- Input Controller Operation: Toggle or Variable
- Number of Operational Subsystems Covered:
- Intended Mode: Backup; Exception; Compare-for-equal;
- Time to convert from operational system to parallel system:
- Time to convert from parallel system to operational system:
- Reliability of Operational system:
- Reliability of Parallel system:

The Operational System Identifier field is linked to a database containing detailed information regarding a given operational system. The Parallel System Identifier field contains detailed information about the parallel system and is linked to the Operational System Identifier, and because of this, more than one parallel system may be associated with a given operational system. Each of the other fields is discussed in the sections below.

**Input Controller Mode**

The Input Controller Mode can be either reactive or proactive. In the reactive mode, input is switched to the parallel system after an output or input sensor has detected a problem. In the proactive mode, however, the input is switched to the parallel system after an unsatisfactory trend has been detected by either the output or input sensors.

**Input Controller Operation**

The Input Controller can operate as a toggle which directs discrete flows to the parallel system. Often the toggle operates in an ON-OFF mode in which the entire input goes to either the operational or parallel system. The other operational method of the Input Controller allows varying amounts of input to be shunted between the operational unit and the parallel system.
**Number of Operational Subsystems Covered**

A given parallel system may serve more than one operational system. This field can be quite important in conducting a weak link analysis because, in some situations, it may appear that a given system is sufficiently covered by a parallel subsystem. This coverage, however, could be deceptive because it may be that the same parallel system is covering numerous other operational systems.

**Intended Operational Mode**

There are three modes in which a parallel system can operate, depending on how it was designed and intended. In the Backup mode the parallel system is used as a substitute in situations where the operational system has shut down, either intentionally or through failure. In the Exception mode, the parallel system typically replaces the operational system only when the input or environment has certain characteristics. When those characteristics change to their original state, the input controller switches the input back to the operational system. In the quality assurance mode, the parallel system operates on a compare-for-equal basis, and discrepancies between the two subsystems are checked by the input controller to determine which operational system was in error.

**Input Conversion Time**

The Input Conversion Time is the time required for the input controller to switch input from the operational system to the parallel subsystem. Another field is used to indicate the time required to switch from the parallel system to the operational system. These two fields can provide important information for evaluating the effectiveness of the parallel system. A parallel system, although effective once it becomes operational, may have a long start-up time, thus impairing its overall effectiveness when this time is considered. In other situations, switching to the parallel system can be done rather quickly, but switching back to the operational system may be rather time-consuming.

**Reliability**

Reliability is defined as the probability that a given unit is functioning properly. Parallel systems are used to improve the reliability of operational systems. To illustrate, if a given operational system had a reliability of .80 and its standby unit has a reliability of .60, then the reliability of the parallel system would be .92 \[1 - (1 - .8)(1 - .6) = .92\] (Smith, 1972). Thus, the reliability of a parallel system is greater than the subsystem with the highest reliability. Unfortunately, these calculations are based on rather stringent Markov assumptions which can only be effective in rather limited situations - usually in isolated conditions in the physical world.
In using an example of a backup system, the above reliability calculations assume that when the parallel system comes on line, the same condition that made the operational system go down will not have the same effect on the parallel system. In many situations, this is not the case. Because of this and other violations of the Markov assumptions, the reliability of the parallel system often must be estimated using judgment in conjunction with past system performance (Stratton, 1994). The following conditions are assumed when evaluating the reliability of a parallel system according to the Markov assumptions:

1. Each series' subsystem is independent of the previous subsystem
2. The parallel-operational combinations are independent of each other such that a common cause does not impair both systems under the same conditions.
3. The occurrence of errors in the subsystems have a known distribution which can be manipulated mathematically or can be modelled by a simulation technique such as Monte Carlo.
4. The subsystems are in steady state (i.e., they are not transient).
5. The interface between the parallel subsystem to switch or resolve the output discrepancy from the subsystem in a defective mode has a known reliability (Kozlov & Ushakov, 1970; Smith, 1972).

Classification Scheme

In the above described database fields, those in bold print are used in the classification scheme. Imagine an operational subsystem with four machines each performing the same operation of stamping metal plates with standby machines used when the input is composed of material which is much harder than the material normally used. It requires 30 minutes to switch to the standby machine. This parallel system would then be classified as a PT4E:30M, which translates to a Proactive input controller operating as a Toggle switch for 4 operational subsystems in an Exception mode with a 30 Minute conversion time. It should be noted that if the hardness of the metal could not be determined until after it was stamped by the machines and was detected by the output sensors, then the parallel system would be classified as a RT4E:30M.

This classification scheme does not possess any particular dimensions, and the categories cannot be ascribed as having a set of qualitative characteristics. For example, it may be difficult to determine whether the above mentioned parallel system would have a specific advantage or disadvantage over another classification unless one were familiar with the characteristics of the operating system and the cost-benefit of a given parallel system.

WEAK LINK ANALYSIS

"A chain is no stronger than its weakest link" is unquestionably a familiar aphorism. An organization can be viewed as a chain of events, or sets of subsystems linked in various parallel
and series configurations. When considering the reliability of a series of subsystems, however, the chain is almost always weaker than its weakest link. For example, consider a system composed of three series-linked subsystems having reliabilities of .90, .95, and .85. Using Markov analysis, the reliability of the system would be \(.73 = (.90)(.95)(.85)\) (Smith, 1972). Obviously, if any of these links (subsystems) are impaired, the entire system suffers the consequences. Thus, at least implicitly, some operational systems need parallel subsystems to account for emergencies as well as planned events. Terms such as "Disaster Recovery," "Contingency Plan," "Back-up System" are common terms in the management field. The model presented here puts them under one paradigm: Parallel Systems. To illustrate, a manufacturing plant has an arrangement with a competitor who agrees to manufacture for them, given a week's notice, in the event that they receive orders beyond their capacity, and back ordering would have adverse consequences. The competitor would be considered as a backup parallel system classified as RVIB:1W. In another example, a company has one main supplier for a series of parts, with three other suppliers able to supply the same parts in the desired quantity upon two days notice. The main supplier must provide at least three days notice if they are unable to make a delivery. A given alternative supplier would be classified as PV1B:3D. It should be noted that the database would indicate that there were two other such suppliers (parallel systems) corresponding to this particular operational system because each operational system is tied to all of its parallel subsystems. In the situation in which an OCR serves as a compare-for-equal parallel system with the OCR actually producing the output, the classification would be RV1C:1D. In this case, the conversion time is assumed to be occurring on the same day.

The crucial part in weak link analysis is the level of detail used in analyzing the operational subsystems. There must be a careful balance between the micro and macro levels. If the analysis is conducted at too macro a level, one might end up with only the competitor backup factory situation cited above. This may not be too helpful, although it might delight the management of the competitor to receive such orders. On the other hand, a highly micro approach may result in an unwieldy and perhaps costly analysis, and in the process, management might get lost in a labyrinth of subsystems. Most likely, it would not be necessary to identify a unique parallel system for every light bulb in the organization!

The main advantage of parallel system analysis is that it places alternative sources of operations under the rubric of parallel subsystems, systematically identifies the important characteristics of the parallel systems, and ties them to their respective operational systems. Operational subsystems which do not have sufficient parallel coverage should be carefully evaluated for their effect on the total system should they become impaired or nonoperational. The database could then be instrumental in identifying weak links and conducting "what if" analysis regarding various scenarios. Conducting such analysis before difficulties occur could then have a proactive effect in coping with emergency situations.
COST EFFECTIVENESS

Unquestionably, cost is a crucial element in deciding whether to install parallel systems, and the cost of maintaining a parallel system should be weighed against the cost of the operational system being unavailable for a given period of time. Paramount in this analysis is that an alternative way of looking at some parallel systems is to consider them as an idle resource which should be minimized as much as possible. Some parallel systems can be viewed as a form of inventory. The critical difference, however, is that inventories are not processes; they are usually a physical object or something that functions as a physical object. Systems, as the term is used here, are processes consisting of combinations of mechanical and electrical parts which are subject to unpredictable wear and tear and subsequent dysfunction. Because of this, maintaining parallel systems can be justified in many circumstances.

In conducting a cost-benefit analysis, determining the cost of the parallel system is often easier than evaluating its benefit. For example, the cost of keeping a machine on standby can be calculated by amortizing the cost to the organization if output is impaired because standby machines were not available is likely to be more difficult because the nebulous concept of lost customers, imprecise determinations of reliability, and opportunity costs might cloud the analysis. Because of this, the decision to use parallel systems in many situations tends to be one of judgment coupled with acquiring "peace of mind" on the part of the manager.

REFERENCES


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