Improving Reliability of Smart Transport Systems

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Abstract. The purpose of this article is to demonstrate the key improvement methods for smart transport system reliability and quality. The authors claim that the improvement of reliability and quality of information systems including smart transport systems is linked to the problem of improving the redundancy and structural complexity of systems. They suggest using the incomplete functional redundancy method to improve the reliability and quality of operation for multifunctional smart transport systems. This method is deemed promising because it facilitates the efficient use of the technical means of smart transport systems.

1. Introduction

There are two main ways to improve the quality of system operations. The first one stipulates the improvement of technologies used in the production of components and devices, the use of innovative physical principles and components, and the improvement of the operational conditions for the components. For the automated control systems in question, the first way stipulates a complete or partial replacement of unreliable control system elements with more reliable ones, sometimes these elements may include technical means.

The second way to improve reliability is the introduction and making use of redundancy. Additional devices (elements) introduced in the system structure to improve its quality are redundant. In this case, we can speak of structural redundancy. As the system structure becomes more complicated, we can construct an infinitely reliable system out of low-reliability elements using various methods of introducing technical system redundancy. Redundancy may also mean the additional information introduced in operational signals. This is informational redundancy. All of the existing methods of coding to fix or detect errors are connected to redundancy introduction.

Temporal redundancy is used to facilitate the required system reliability along with the structural and information redundancies.

2. Materials and methods

Temporal redundancy is based on the use of output signal generated at different times and received as a result of a specific transformation of data during the combined operation of different devices, the consecutive $n$ runs of one device, or when the output is delayed. Temporal redundancy can be
introduced if there are intervals during which the production of the solution can be delayed. We must note that the targeted use of information or temporal redundancy in reality generally requires hardware costs.

Combined redundancy methods are deemed more promising. A communications system with informational feedback can be an example of the combined use of information and temporal redundancy. The information at the transmitting device output is delayed and resent if error signals are generated in the receiving device. This system can provide a greater reliability of information compared to the system where only information redundancy is used.

The introduction of information, structural, and temporal redundancy helps compare and perform quantitative assessments of personnel parameters and various computing devices for smart transport systems.

Backup is a keystone concept for redundant systems. A system is backed up if it can maintain normal operation if one or more of its components fail. In this case, redundancy is created at the level of structural elements like machines, devices, and modules. To create multifunctional systems, redundancy should be introduced at the level of system function and problems solved (functional redundancy). In this case, the same system function can be performed by different devices in different ways. This can be seen in multimodal systems performing the same task in several different ways and through several efficiency indicators. The introduction of functional redundancy for the key functions only, rather than for all of the functions, helps construct resilient systems with limited functionalities in case of failures of specific elements. This type of redundancy is widely used in smart transport systems because it provides for the possibility of using various automation levels in the operation of control systems. This method is referred to as the incomplete functional backup [1-3].

Review the key parameters that are used to classify redundant systems and the established backup methods used to improve system reliability.

The elements of a system may have parallel, series, or mixed connections. Thus, we can identify majority circuits (voter circuits), branching structures, neural-like networks, bridge (series-parallel) structures, and feedback redundancy structures. These structures maintain their operability if some of their elements fail, i.e., they can provide a greater structure reliability than the reliability of its components. Systems can be classified depending on the level where the redundancy is introduced: elements, modules, devices, key functions, or the system level [4-7].

Depending on the efficiency of redundancy, backup systems can be classified as complete or incomplete. If a redundant system can continue normal operation and perform all of its functions in case one or more of its structural elements fail, this system is referred to as a complete redundancy system. In incomplete redundancy systems, some operating parameters may be reduced or some functions may become unavailable during the operation in the backup mode compared to the fully operable state of the system.

The calculation of backup system reliability is linked to the transformation of the structure using parallel connections (for reliability).

In particular, when the probability of fault-free operation of all of the system's elements are the same and equal $p(t)$, we get

$$P_r(t) = 1 - [1 - p(t)]^n,$$

where $m$ is the number of each group's bundles.

From this formula, we can see that the parallel connection of elements is an efficient way to improve the reliability of the system.

Total redundancy
Element-based redundancy

\[ P(t) = \{1 - [1 - p(t)]^{1/m}\}^{1/n} \]

If the backup has to provide the required fault-free system operation probability \( P(t) \), the required number \( m \) of equipment bundles for \( r \) backup groups must be

\[ m = \frac{\ln\{1 - [P(t)]^{1/r}\}}{\ln\{1 - [P(t)]^{n/r}\}} \]

For element-based backup \((r = n)\)

\[ m = \frac{\ln\{1 - [P(t)]^{1/r}\}}{\ln\{1 - [P(t)]^{n/r}\}} \]

For total backup \((r = 1)\)

\[ m = \frac{\ln\{1 - P(t)\}}{\ln\{1 - [P(t)]^{n}\}} \]

The redundancy methods developed within the scope of the reliability theory help increase the reliability of complex systems through the targeted transformation of their structure. Without focusing on all the redundancy methods described in detail in backup theory works [8-11], we will only present the most efficient backup method.

This method allows for an intensified use of reserve module resources through their loading between failures.

3. Results

Incomplete functional backups as a method to provide the reliability of smart transport systems.

For multifunctional recoverable systems [12-15] with several levels of efficient operations, we can set the requirement that in case of failure of one or several elements, their functions have to be performed by other modules, although partially rather than to the full extent. The experience of the development and introduction of smart transport systems shows that this approach is one of the promising ways to provide reliability.

The use and loading of redundant modules that partially back up the main modules require less backup equipment costs and can satisfy the requirements for the system over some permissible time \( T_{dk} \). If the main module can be recovered over this time, we can assume that the system maintains its operability and does not fail. Under this incomplete operation, system operation efficiency reduces for some time and then the original efficiency is recovered.

The incomplete functional redundancy method is a combined one. It uses temporal and structural redundancy.

This method is based on the assumption that the system can operate over some permissible time \( T_{dk} \) if some of its technical means or functional parts fail. The key functions must be implemented by switching to the module that was loaded with less important functions before the failure event. Redundancy can be introduced in the system at the level of functions and tasks or the level of devices and modules [16-20].

It is possible to create control system designs using series connections between functional modules.
with different requirements for reliability indicators with temporal and structural redundancy. Each of the system modules performs a function of importance \( i \) (reliability rank \( t \)). With temporal redundancy, the system can operate normally if the permissible downtime for any module is greater than the time required to recover any faulty module, i.e. \( T_d > T_v \). If this condition is unfulfilled, structural redundancy backup systems are used. In this case, redundant modules perform all the functions of the faulty modules, i.e. functional or complete redundancy takes place. It is also possible to use incomplete functional redundancy in such systems that are implemented either at the level of devices and modules or at the level of functions and tasks. During the recovery of a faulty module, another module is activated that performs only a required minimum of functions to maintain the operation of the entire system, rather than all of the faulty module functions. If a module fails, its functions are performed by a lower reliability rank module that will stop performing its functions during \( T_d < T_v \). Thus, the described solutions provide the incomplete operation of the system for a permissible time during device failures through the use of temporal and structural redundancy, fractional reserves, and reserve loading between failures.

4. Discussion
To implement the incomplete functional redundancy method, it is necessary to satisfy the following requirements:
- identify the functional devices and the possibility of system function implementation using various devices and various methods;
- set the requirements for the permissible delay times in the implementation of various functions.

The comparison of a system based on the incomplete functional redundancy (IFR) method and a conventional multifunctional system showed that the technical efficiency of the IFR system during failures was 2 times greater (for non-recoverable systems).

A feature of using incomplete functional redundancy methods in discrete smart transport systems is that managers can be used as the switching components of such systems as well as automated devices. We must note that the use of the incomplete functional redundancy method in smart transport systems is promising because it stipulates the use of the most efficient redundancy method (fractional redundancy) in terms of equipment costs and provides additional automation effects due to the expansion of automated system functions between failures.

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