Development of tools for improving the data storage systems reliability as a part of digital transformation strategy

M V Bolsunovskaya¹, S V Shirokova², A V Loginova³ and M B Uspenskiy⁴

¹ Institute of Computer Science and Technology, Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya str., 29, St.Petersburg, 195251, Russia, marina.bolsunovskaya@spbpu.com
² Institute of Industrial Management, Economics and Trade, Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya str., 29, St.Petersburg, 195251, Russia, swchirokov@mail.ru
³ Institute of Computer Science and Technology, Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya str., 29, St.Petersburg, 195251, Russia, alexandra-lo@yandex.ru
⁴ Research Laboratory “Algorithms and systems for stream data processing” (ASPOD), Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya str., 29, St.Petersburg, 195251, Russia, mikhail.uspenskiy@spbpu.com

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Abstract. Information storage technologies play a vital role in the processes of enterprises digitalization. To ensure the necessary reliability of data storage, special technologies are being developed. The paper examines the market for such solutions and introduces tools to improve the reliability of data storage systems (DSS) as a part of the digital transformation strategy of the enterprise. The problem of developing and application of data storage systems and tools for managing such systems to predict failures and provide fault tolerance specifications are discussed. The results of the current data storage market state analysis are shown. Based on market analysis, the need for developing a software package for predicting data storage system failures is substantiated, and the project the purpose of which is to develop a hardware and software complex to predict failures in the storage system is presented. The functionality of the complex has been formed and the project of complex creation is underway.

1. Introduction

Nowadays in the practice of enterprise management data storage systems (DSSs) are widely used, and it could be said that the choice of DSSs and their implementation become a significant part of a corporate strategy (e.g., [1]). However, in general the scope of DSSs utilizing is very wide. Among the various DSS applications huge data warehouses that are used in Smart Home and Smart Cities management systems should be mentioned. When managing a “smart enterprise”, a “smart city” or “smart homes” it is essential to ensure successful coordination of the software and hardware complexes and to manage data for decision-making, including decisions that are made in real-time...
mode. This requirement, in its turn, leads to the need for high reliability of data storage devices [3, 4, 25].

Development of technologies, hardware and software systems for storing and processing information becomes an important component of the enterprise information strategy. Information strategy also assumes that there is the need for management DSSs continuous modernization and additional costs associated with it. Therefore, organizations that operate DSSs should not only build the storage infrastructure, but also reduce the costs of such upgrading, increasing the cost-effectiveness of owning the DSS, reducing its power consumption and service costs.

In the field of improving the DSSs reliability and prevention of critical situations by predicting failures in the operation of DSSs a comprehensive solution that meets all market requirements currently does not exist [5–7].

To solve the problem of increasing the DSSs reliability, a hardware and software complex has been developing aimed at solving the following tasks [21, 23]:

1. Data redundancy management
2. Integration with the data consumer security system
3. Ensuring a guaranteed level of consumer access to data
4. Reducing the amount of transmitted and stored data
5. Storage of data objects with preservation of their original security attributes
6. Irrevocable guaranteed data deletion
7. Management of long-term storage and disposal of data.

2. Materials and methods

2.1. Methodology for development a hardware and software complex for increasing the DSSs reliability

The proposed methodology for development a hardware and software complex for increasing the DSSs reliability could be represented in a form of the following algorithm (see Fig. 1).

Thus, the algorithm includes several steps, where the first step refers to the observing of the existing solutions in the DSS field. This step gives an opportunity to determine system requirements. The results of the DSSs market analysis are given in the section 2.3.

It is recommended to use methods of complex examinations to develop the ideas for building DSS’ structure. Complex examination methods can also help with assessment of the proposed DSS structures variants taking into account the effect of a DSS component on the management system and its purposes. For example, to answer the question whether a component of the system should be implemented two estimates from Denisov’s information approach could be used, namely the probability of achievement the appropriate goal when using the i-th component \( p_i \); and the probability (possibility) of the i-th component implementation \( q_i \) [22, 27]. A model for improving DSS reliability based on the information approach is discussed in the section 2.3.

The section 2.4 is devoted to the description of the decision support model for improving DSS reliability. The developed model also served as the basis for software creation.

2.2. Data storage market analysis and the technical characteristics of the developing complex for prediction DSS failures

Justification of the need to develop a hardware and software complex for predicting failures in DSSs and analysis of the research conducted by IDC Perspectives [2] showed that the world DSS market accounts for approximately 23-25% of all IT infrastructure costs, and has a continuous upward trend. According to The InfoPro, Wave 11, the increase in storage costs for medium-sized companies exceeds 50% per year [2, 4].

The main trends of the DSSs market are consolidated in the Table 1.
Fig. 1. Methodology for development a hardware and software complex for increasing the DSSs reliability

There are leading global storage developers on the market, among them are such companies as Dell (PowerVault, EqualLogic, Compellent); EMC (Celerra, CLARiiON, Centera, Iomega, Symmetrix VMAX/VMAXe, VNX, VPLEX); Fujitsu (ETERNUS, FibreCAT, Quantum); Hitachi (SMS, WMS, AMS, CAP, USP, VTL); HP (StorageWorks, EVA, 3PAR); IBM (Storwize, System Storage D, System Storage T, System Storage N, SONAS); NetApp (FAS, VTL, V, E) and Oracle (Sun ZFS Storage, Sun Flash, Pillar Axiom, StorageTek).

From manufacturers of storage systems represented in the Russian Federation, should be noted the companies that belong to the class of IT-integrators: AXUS, Buffalo, Cisco (Linksys), DLink, Dot Hill, Infortrend, Intransa, Maxtronic, Nexsan, Overland Storage, Plasmon, QNAP Systems, SGI and Thecus. The Russian DSSs market is developing very rapidly. For example, according to IDC Perspectives [2], in 2016 DSSs with a total capacity of up to 663,002 TB for a total of USD 382.77 million appeared and operate in the Russian market, that is, this market grew by 35.7% in capacity and 0.5% in tender terms compared to the previous year.
The top five largest suppliers of the Russian market include Dell Technologies, Hewlett Packard Enterprise, Hitachi Data Systems, IBM and NetApp. Many domestic manufacturers of DSSs (for e.g., DEPO Computers (DEPO Electronics)) build their systems based on components from foreign manufacturers, including Microsemi (formerly Adaptec), Chenbro, Falconstore, Intel, LSI Logic, Luster and others.

| Trend | Description and examples |
|-------|--------------------------|
| 1. The development of storages goes into the stage of deeply integrated nodes and perfect structures | Storages are integrated with processors, memory of different levels and ultra-fast interfaces (the delay time of signals’ propagation is calculated in units of picoseconds). Blade complexes, that are functionally complete “boxed” systems, of which storage and processing centres of any size can be created |
| 2. Steady growth of super-large databases and data storages | Volume of data storages is estimated in thousands of terabytes, that is a consequence of accumulation and storing of huge amounts of data. Moreover, the data amount is growing to meet the need for data safety and integrity by creating backups and redundancies |
| 3. Increasing complexity of data queries and complexity of data processing procedures | The data queries require analytical, operational and transactional loads, working with multiple data values, parallel processing of transactions. More than 20% of the analytical tasks are loaded in the last 15 minutes before the decision-making, therefore, they must be processed extremely fast. This circumstance reinforces the requirements for reactivity, i.e. temporal characteristics of data processing in storage |
| 4. Development of the need for strict accounting, auditing and monitoring of the expensive data storage systems usage | Corporate clients have need not only for the acquisition of storage, but also for auditing and monitoring the system. The owners of the expensive storage systems expect not only an abstract increase in potential performance and a reduction in the total cost of ownership, but also are looking for opportunities for simplifying the deployment and administration of systems despite of increasing load |
| 5. Creation of adaptable platforms for solving various analytical tasks | Such platforms include hardware component and DBMS. End users view the data warehouse as an information service (for e.g., banking systems, multimedia information storage systems, etc.) |
| 6. The trend of data migration to cloud resources | This tendency is directly related to the growth in scale and to the increased capacity in the storage systems’ segment |

Among domestic DSS developers and integrators, the following should be named: Kraftway; Yadro (KNS Group LLC, as part of the National Computer Corporation, NCC); MCST; INEUM named after I.S. Brooke; T-Platforms; National Center for Informatization (NCI); “National Technologies”. In general, Russian-made storage systems are supplied predominantly for Russian enterprises (e.g., [2], [8]). Nevertheless, large Russian storage manufacturers are now able to compete with foreign vendors. A national policy in Russia that is aimed at import substitution and changes in domestic legislation will also contribute to the gradual growth of domestic developments among Russian users.

It is important for Russian DSSs developers to maintain relations with the national scientific community, including creation of clusters with participation of academic institutions and industrial partners. It is a very common practice for Russian DSSs developers to have contracts with the state organizations, ministries and departments. The State provides legal and financial support to domestic DSSs developers. Another advantage of these companies is the low average age of the employees (about 30 years), but there are high requirements for personnel training and the lack of trained professionals.
However, in order to reduce the costs of owning an IT infrastructure, some companies are turning to new types of services when building DSSs. An important trend of the modern storage market is a massive transition to the use of cloud technologies, including such forms of service as SaaS (software as a service) and “software on demand”.

Software for storage management should support flexible organization of DSS, deduplication and data replication, dynamic memory allocation, file system snapshots.

Describing the storage management software market (including forecasting and evaluating their performance and reliability), it is important to note that the design of reliable drives has been solved for decades by large storage companies such as TDK Corporation, Seagate Technology, Hitachi Global Storage Technologies and others [4, 9]. Research groups in different countries around the world are working on the problems of predicting disk failures in large-scale data storage systems, and models of storage reliability have been proposed [10-13].

The most well-known solutions aimed at improving the reliability of storage are duplication (mirroring) of data, multi-level redundancy coding for digital data archives, deduplication systems for parallel data backup [4, 14, 15]. The nature of problems in storage systems is studied taking into account the age of the system [16]. The concept of “system survivability” in relation to storage systems is becoming popular [17]. At the same time, the issue of storage power management is being studied [18].

The software for the complex for prediction DSS failures was based on the concept of “system survivability” [17], and models of system dynamics in the developed of algorithms were used.

Technical characteristics of the developing complex are as follows:
1. Platform consists of a set of storage controllers, a PCI-express factory (PCIe-factory controllers), a disk chassis and disk drives. It is possible to create a system for storing and managing large (from 1 PB) and super-large data volumes (from 10 PB)
2. Scaling distributed storage
3. Providing adjustable redundancy on the client side; uninterrupted client access to storage is supported (hardware-software storage management system is designed to ensure availability of at least 99.99%).

2.3. Model for improving data storage systems reliability based on the information approach
For modeling the possible behavior of a DSS an expert methods were also used. However, “direct” expert assessments carries a strong subjective component, which do not disappear when processing the results of a survey. Therefore, to obtain more reliable estimates the models based on the information approach developed by A.A. Denisov were proposed [20, 22, 23, 25].

Methods of complex expert assessment organizing based on the information approach facilitate the calculation of a generalized assessment and provide the opportunity to take into account several criteria. Moreover, when using the information approach, it is possible to evaluate the project in time and taking into account the dynamics and progress of the project [14-16].

In accordance with the Denisov’s informational approach, for each evaluation criterion an expert evaluates the degree of satisfaction (i.e. the probability of achieving the goal) and the probability of using the criterion [27]. With these two probabilities the potential (i.e. significance) of the criterion can be calculated [22, 26, 27].

\[ H_i = - q_i \log (1 - p_i), \]

where \( H_i \) – information potential of the \( i \)-th criterion, bit, \( p_i \) – probability of achieving the goal when using the \( i \)-th criterion, \( q_i \) – probability of using the \( i \)-th evaluation criterion to achieve the appropriate goal.

For a DSS this analysis is possible within a certain period of time (system parameters) by comparing changes in information assessments over time. There are two ways to measure \( H_i \):
1) in terms of the probability of \( p_i \), that is, in our case, this is a probabilistic assessment of the forecast – “the problem is predicted”;
2) by means of deterministic characteristics of the perceived information, that is, on the basis of specific indicators – “the problem is detected”.

Using two methods for determining \( H_i \) (the potential, the possibilities of a given outcome; for example, contacting technical support) makes it possible to calculate \( n_i \):

\[
n_i = J_i / H_i, \tag{2}
\]

where \( n_i \) means the scope of the concept of the \( i \)-th object under study; information potential \( H_i \) is calculated through probability \( p_i \); and \( J_i \) is measured (\( J_i \) is information about the number of the \( i \)-th object under study, taking into account the significant step of changes in its value \( \Delta A_i : J_i = \Delta A_i / \Delta \).

By estimating the predictive \( p_i \) we can get an estimate (in terms of percentage) both on the basis of the forecast and on the basis of the found problems. A model of Complex examination for improving DSS reliability based on the information approach is presented in the work [23].

2.4. Decision support model for improving data storage systems reliability

A DSS consists of several subsystems, which can provide data path functions or/and control path functions. Key functional components of a DSS that can be analyzed during diagnostics are as follows: storage processors, disks and various network devices. The ideas of semantic networks, estimation method based on the Huygens theorem, the principles of simulation modeling and Markov chain theory elements were used to build a model for failures in DSSs management [23, 24].

From a diagnostics point of view the authors of this paper consider three general types of fault for any DSS’s component: a failure, when the component can no longer perform its functions and requires a repair; an error, when the component still operates, but lacks a full performance; and a predicted failure, when the component operates without explicit failure symptoms, but shows some signs of a future component failure.

It is expected that failures and errors can be diagnosed based on symptoms in actual data monitoring, while predicted failures can be detected using data science methods. As a result, a comprehensive decision process should take into account all available information, which can be grouped into four categories:

1. Features of the action that is being decided upon: a monetary cost, an expected efficiency in terms of system recovery or data availability, and risks in terms of the attainability of the expected result [9, 25].
2. Results of diagnostics: a severity level of estimated status of the system and its components, identified the root cause.
3. Data, that a diagnosis is based on: aggregated health and performance monitoring data, detected symptom, recognized fault, obtained prediction with a certain time frame, and confidence level.
4. Features of components that are considered problematic: its system functions and properties, current and average utilization, employment in redundancy scheme, etc.

The proposed types and groups of heterogeneous data, as well as types of external actions can be expected to be consistent for a wide range of DSSs.

The decision support model for improving data storage systems reliability is presented in the other works of the authors (e.g., [21], [23], [24]).

3. Results

3.1. The proposed software product and its competitive advantages

It was determined that the significant competitive advantages of the software products developed for Russian market are as follows: costs, reliability of the finished product, independence from the western markets, including spare parts markets and markets of analogous products.

It is an important fact that the hardware and software complex to predict failures in DSS presented in this paper is based on the new mathematical models of DSS reliability:

- a new estimation method based on the Huygens theorem;
- a mathematical model of scrabbing is proposed, taking into account unresolved bit errors and the process of continuous verification of checksums. Based on the principles of simulation modeling, a computational model of failures in an ultra-large distributed data repository was developed that takes into account hidden bit errors, data checking and recovery, designed to statistically describe the working properties of the repository, including the operation time before data loss.

- based on the Markov chain theory, a family of new analytical models was developed to assess the reliability of large data storage systems;

- a qualitative coordination of the reliability estimates calculated by the developed Markov chains analytical model with full-scale imitational calculations is shown, the following properties of the analytical model are confirmed: adequacy, versatility, accuracy, efficiency;

- developed practical recommendations in the development of methods, algorithms and technologies to improve the reliability and efficiency of storing large amounts of data.

The results of the project are designed to develop basic software technologies to improve the reliability of DSS and the subsequent commercialization of these technologies as part of innovative software solutions for managing storage and ensuring the reliability of storing large amounts of data.

The product being developed is a software package for predicting storage system failure (DSS). This software package is designed to diagnose and predict the status of storage systems and their components in real time.

3.2. Tools for improving a storage system reliability
The main result of the work in the decision support model for improving DSS reliability (a model for predicting failures in DSSs management). This model could be used to manager the DSS reliability in dynamic mode, and it is based on methods from the field of operations (operational) research and knowledge modelling.

The software package for predicting storage failures is designed for solving such storage management tasks as [19]:

1) transmission of telemetric information on the state of the storage system in real time;
2) detection of failures, failures and critical situations in storage based on the proposed classification algorithms for failures, failures and critical situations;
3) prediction of faults, failures and critical situations during storage operation;
4) decision support for the prevention of critical situations in the storage, implemented in real time;
5) provision of a wide range of health zones of the developed decision support system.

Potential similar software systems are:
1) enterprise-producers of storage systems and their components;
2) enterprises using storage systems of various architectures;
3) scientific and educational laboratories.

4. Discussion
Based on the competitive advantages of the products in the DSS market identified in the work, technical characteristics of the developing complex for DSS failures prediction were discussed and evaluated. The results of the market analysis were used to conduct theoretical and experimental research while development the diagnostic algorithm for DSS failures prediction and the stands for software testing.

The proposed solution will improve the reliability of data storage systems during the digital transformation of the enterprise.

The developed hardware and software complex for prediction DSS failures the concept of “system survivability” includes such components as:

1. Platform consists of a set of storage controllers, a PCI-express factory (PCIe-factory controllers), a disk chassis and disk drives
2. Program for collecting parameters of the data storage system
3. The model for failures in DSSs management based on the ideas of semantic networks, the Huygens theorem, the principles of simulation modeling and Markov chain theory.
4. The models for DSS status management based on the information approach.
5. The software package for predicting storage failures.

5. Conclusion
Comparative analysis of the basic technical and cost characteristics of storage systems of foreign vendors that are popular in the domestic market has been carried out. The cost of storage systems varies greatly depending on their functional capabilities, technical characteristics and scale of business for which these solutions may be suitable. In general, in Russia, the storage market behaves stably, but, as in the rest of the world, there is a decline in demand for traditional disk storages in favor of solutions on flash drives.

Among the competitive advantages of the created product (“Program for collecting parameters of the data storage system”) should be mentioned:
- The compliance of decisions with the requirements of modern Russian legislation;
- High reliability of solutions;
- Utilization of original data protection mechanisms;
- Independence from the western market of spare parts and analog products;
- The relatively low cost of solutions, and therefore their availability to a wide range of users.

The program complex for forecasting of data storage system failures has been developing by the scientific group from Peter the Great St. Petersburg Polytechnic University. The program complex was designed to diagnose and predict the state of DSSs and their components in real time [19]; the model of the complex was based on the idea of the system dynamics model [21, 24].

The program complex was initially designed for DSSs running on the platform “YADRO TATLIN” in various configurations. Structural scheme of the program complex for predicting DSSs failures and other characteristics of the complex are presented in the work [21].

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