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CORRELATION BETWEEN STORAGE DEVICE AND BACKUP AND RESTORE EFFICIENCY IN MS SQL SERVER

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Abstract. The importance of the process of restoring a database requires precise examination of all factors that affect it. Considering the decline of the price of SSD and its better read and write speeds, it seems that this is the logical choice when reducing downtime is a primary concern for the organisation. This paper categorizes storage devices in use as well as main backup types in MS SQL Server. Tests are conducted to evaluate the impact of the storage device on backup and restore efficiency. In this regard, the purpose of the research is to examine problems associated with selection of a storage device for efficient backup and restore in MS SQL Server. The conducted tests showed some surprising results regarding SSD's efficiency. The reason these findings are important is that they could be used as a guideline for choosing proper storage device for an organisation's needs.

1. Introduction. The volume of data worldwide is growing enormously, hence the need for storage capacity is increasing. Over five years, the generated data has more than tripled—from 12 ZB for 2014 to the

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expected 40 ZB by the end of 2019 [11]. Global data center IP traffic for 2018 is 952 EB and until the end of 2019 it is predicted it will be 997 EB only in traditional data centers but the traffic from the cloud data centers is over 10 times larger [12]. Especially considering the fact that more and more businesses are getting oriented towards online presence [4], the data is increasing rapidly, it is important to choose a storage data device for better performance of backup and restore processes and mainly because it can be used "to transmit real-time market information for real demand" [28]. "The storage of large volumes of raw data, in their original format, as for example text, video, hyperlinks, server log files is needed because then, by applying appropriate processing methods, the data can acquire an appearance suitable for processing and integration with other data" [24].

On the other hand, the energy efficiency of hardware when performing such operations, which require significant system resources, must also be taken into account. IT infrastructure consumes a significant amount of energy, which in turn leads to grid load and harmful emissions [25]. This is a prerequisite for choosing energy-efficient components of a computer system. „Power is a topic of great interest for industrial applications. On the one hand, the question is how stable is the power supply and, on the other hand, the effect of a sudden failure of the supply voltage" [26].

Software aimed at storing and retrieving user data is database management system (DBMS). It also implements security mechanisms designed to ensure the security of data from unauthorized access, transactions and concurrency, authorisation of access and update of data, data dictionary describing the metadata, backup and restore, etc. According to some statistics, top three DBMS are Oracle; MySQL and Microsoft SQL server [13]. Other surveys [2] state that MS SQL Server is the leader in field of operational DBMS, nevertheless [17] confirms the top 3 list as Oracle, followed by MySQL and Microsoft SQL server.

It is beyond doubt that MS SQL Server is one of the most popular commercial relational database management systems. It offers built-in backup and restore functionality, that can mitigate the risk of disastrous events. This functionality includes couple backup types that could be combined in many different strategies. The characteristics of each backup type are outlined by Microsoft regarding factors as database size and amount of changed data but there is no specific guidance on which storage device is to be chosen.

In this regard, the purpose of the research is to examine problems associated with selection of a storage device for efficient backup and restore in MS SQL Server. On this basis the paper could be used as a guideline for choosing proper storage device for organisation's needs. The tests are conducted using SOHO class equipment (digital data storage media, computer and operating system). They are performed using only one computer and results could be affected by its chipset, used drivers, operating system settings etc. The results can be considered only as a special case but the proposed approach could be applied to another computer architecture.

2. Comparision of digital data storage media. As an integral element of the information technology sector, the global demand and supply of data storages by the end of 2019 will be around 31,000 EB and 20,000 EB compared to a period of five years ago, when they were approximately 6 times smaller [9]. Worldwide spending on data storage has exceed 51 billion U.S. dollars in 2019 [3]. According to other statistics global data will grow by 61% to 175 ZB by 2025, with as much of the data residing in the cloud as in data centers [7]. This shows that the need for using storage devices is increasing, including for private users.

Data storage refers to the devices which are used for retaining and archiving digital data that will be used by a computer or another device. It can be divided into primary (main), secondary (auxiliary) and tertiary memory. The first type is random access memory (RAM) and its derivatives. The second type are the commonly used hard disk drives (HDDs) and solid-state drives (SSDs). The third type are networked or cloud storages. Other bearers of digital information include magnetic tapes, floppy disks, optical disks (CDs, DVDs, Blu-ray disks), flash drives and flash memory cards. Considering the purpose of this study and the capabilities of each of the digital data media, we are focusing on researching capabilities of secondary memory devices—HDDs and SSDs.

Currently, many computers (home or enterprise machines) use both main types of secondary memory media. Computer configurations equipped with both types of devices are often encountered, as home and corporate users prefer to take advantage of both technologies. Statistics show that around 360 million HDDs and 280 million SSDs are expected to sell by the end of 2019, compared to the previous three or four years, when SSDs sales were approximately 4 times less than HDDs [10].

No answer to the question “Which device is better?” can be given unequivocally because it depends mainly on the purposes for which each of them will be used. The main difference between them is the technology they are designed for—hard disk drives are magnetic data carriers and solid-state drives are based on flash technology. They store data in blocks, from which the device itself is called block devices. Data is also transmitted to RAM in block form.

One of the faster and more user-friendly flash technologies is NAND-Flash SSDs, which aims to reduce bit rates and increase cell unit capacity to compete with HDDs. The types of NAND flash storage include single-level cells (SLC), multi-level cells (MLC), triple-level cells (TLC), quad-level cells (QLC), and 3D NAND (stacks cells on top of one another), which are separated by the number of bits each cell uses. The more bits are stored in a cell, the higher the cost of the device.

In Table 1, we compare the characteristics of the two main media types —HDDs and SSDs.

In relation to the performance of the two storage devices, it can be noted that the benchmark tests take into account two main features – access (response) time and data transfer time (or rate). Still, the digital data storage capacity of SSDs is much smaller than HDDs'. However, the price ratio is inversely proportional—SSDs have a significantly higher price than HDDs. The flash based SSDs' technology, as seen in Table 1, enables faster reading and writing of data, faster access and a correspondingly lower annualized failure rate. CPU power consumption on SSDs is also less than on HDDs.

Table 1. Digital Data Storage Media[1]

Characteristic	**Hard Disk Drive**	**Solid-State Drive**
Cost	buying a cheap 4TB model—around €0.02/GB	buying a cheap 1TB model—around €0.09/GB
Capacity[2]	2 ÷ 10 TB	128 GB ÷ 4 TB
Power Consumption	7-Watt average	2-Watt average
Read Speed	approx. 150 MB/s	over 450 MB/s
Write Speed	approx. 100 MB/s	over 500 MB/s
Time to Access	approx. 2 sec. before it can read/write	read/write immediately
Annualized Failure Rate	1.7%	0.4%
Encryption	Full Disk Encryption	Full Disk Encryption
CPU Power	7%	0,7%

The performance of secondary storage media is not isolated from the overall computing performance. When assembling a machine, it is necessary to

[1] The data in Table 1 are averaged based on tests performed by [6, 8, 14, 15, 16]. The specifications vary from manufacturer to manufacturer.

[2] Depending on whether it is a laptop or desktop machine.

take into account the characteristics of the models of each of the computer components, since this is important for working together. Firstly, it can be noted that the performance and limitations of the motherboard affect the performance of the other components. They are located on it northbridge, southbridge, and Front Side Bus. Disk drives are communicated via southbridge.

On the other hand, it must also be taken into account whether the machine's processor is fast enough to process data and how many cores it consists of. For example, the number of kernels is relevant to the number of tasks processed per unit of time. Also, data transmitted from the secondary memory for processing by the processor is loaded into a buffer in the main memory (RAM), which in turn also influences the performance of various data operations and to "determine optimal speed of data processing and define critical points" [23].

System resources do not exist in isolation from each other. They are managed by the operating system, which also contributes to the overall performance of the computer system. Observing it can help identify and troubleshoot issues timely before reaching critical levels in database operations. [27] suggests the following operating system performance metrics which should be observed in consideration of database performance:

- memory usage metrics in MBs;
- average percentages for CPU utilization metrics;
- amount of work that a computer system performs;
- growth or reduction in the amount of available disk space used;
- percentage of disk space that is being used by DBMS at a given time;
- average disk throughput for read and write operations, measured in megabytes per second;
- averaged disk speed for read and write operations;
- average time consumed by disk seeks in milliseconds;
- average size in sectors of requests issued to the disk;
- average number of requests queued due to disk latency issues;
- percentage of CPU time consumed by disk I/O.

The metrics depend on the operating system—Linux, Windows or MacOS.

All these issues lead to the conclusion that operations such as database backup and restore depend not only on the performance of different storage media with the database management system, but also on the overall computer performance. Therefore, this study draws attention to a backup and restore approach in a specific DBMS (MS SQL Server) that has been tested in a specific hardware configuration.

3. Backup and restore in MS SQL Server. MS SQL Server is one of the most used commercial databases systems up to date. It offers a wide variety of options for continuity. To keep the business processes running, the organisation can implement solutions such as a clustering, replication, mirroring the database, and log file transfer, so that even if the main server stops working, the requests are sent to failover server [5]. The main issue with these strategies is that they require extra financing, including software, hardware and professionals with high level of expertise in the area. This factor is more than enough for majority of the organisations to look for cheaper alternatives, one of which is using the built-in backup and restore functionality in MS SQL Server Express.

Main database backup types can be considered depending on whether clients have access to the data during the process. With offline (cold) backup, the database management system suspends access to the archived object and all applications that use it must wait for the process to complete. Online (hot) backup enables the database to remain operational and allow clients to perform the necessary operations without knowing that backup is currently underway. Considering the fact that organisations prefer to keep systems running, hot backup types are examined in the following tests.

Since MS SQL Server version 7 there are four primary database backup types [1]:

- Full Backup—backs up all data and objects part of the database.
- Differential Backup—only backs up database changes that have occurred since the last full backup to date, and therefore runs in less time than a full backup would run at the same point in time.
- Log Backup—copies all operations recorded in the transaction log performed since the last log backup.
- Partial Backup—backs up file groups or individual files is used when the database is so large that the full backup goes beyond acceptable organisation timeframes. This option is added in MS SQL Server version 2005 and backups all file groups except marked as read-only.

According to the given definitions, full backup and differential backup are physical online archives, which means that they have relatively high speed of creation and restoration, and can't be viewed, edited or restored at a point in time. Microsoft solve this as part of the transaction log is also included in the full database backup [18]. This allows the recovery process to execute logged commands when point in time recovery is needed.

Differential backup does not include any part of the transaction log. After committed full backup SQL Server marks which extends are changed while users interact with the database. When differential backup is executed, only those extents that have been modified are copied [19]. This means that the more extents that have been modified, the slower this type of backup will be, until it reaches a point where it will take as much time as full backup.

Backup plan determines the intensity, sequence, and types of backup that apply to the database. It depends on various factors: what is the amount of information available, at what periods and how it enters the database, what part of it could be recovered from other sources, etc. Recovery plan depends on the backup strategy implemented. Time needed to execute a restore command is similar to time needed for corresponding backup type—fastest when using log backup and slowest with full backup.

Considering wide variety of backup types and strategies test should be conducted to measure their performance with different settings for used storage device.

4. Comparison of the performance of different storage media with MS SQL Server. To conduct the tests, we chose to use two of the fastest and most reliable storage devices examined in the first section – HDD and SSD. To properly compare their efficiency, we created a web-based application that executes commands to MS SQL Server instance and records the results of their execution. Database in use is a variant of AdventureWorks sample database. To observe if the characteristics of each backup and restore type is preserved with different size of the database, the application executes insert queries with every iteration. The algorithm in use is increasing number of execution of steps 2 and 3 at every iteration. This means that at the last step there are 10 log backups, containing database incremented 10 times. After the end of this the experiment is repeated using an HDD instead of SSD storage device. The program logic takes the following steps:

1. create full database backup;
2. increasing database size by adding 3 000 records in tables production.TransactionHistory, person.person and sales.SalesOrderDetail;
3. create log backup;
4. create differential backup;
5. create full backup;

6. restore full backup executed in step 1;
7. restore log backups executed in step 3;
8. restore full backup executed in step 1;
9. restore differential backup from step 4;
10. restore full backup executed in step 5.

For the purpose of this article there is a need to choose a tool, that should be able not only to register successful commands in MS SQL Server, but to reliably measure database backup and restore times at different sizes, and be able to be fully managed by an external program and not depend on the SQL Server version.

With these requirements in mind, it will be possible to build a highly portable aplication to compare the performance of backup and recovery processes across different platforms.

According to some authors [21], server performance metrics can be grouped into four categories (memory, processor, network, and hard disk I/O), and be monitored by the following tools: Performance Monitor, SQL Database Management Objects and Data Collector. After a thorough analysis of the capabilities of the listed tools, we come to the conclusion that none of them meets all four requirements mentioned above, because:

1. With SQL Server Management Objects some properties that use lots of memory are never retrieved, unless the property explicitly referenced. An example of this is the Size property of the Database object [20];
2. Performance Monitor is a built-in tool in Windows and is used to track system load, but cannot provide detailed information about the backup and restore processes.
3. MS SQL Server Data Collector provides the ability to collect information by predefined criteria, which can be aggregated into a single database and processed with graphical tools, but is only available to commercial editions – Enterprise and Standard – that are outside the scope of this paper.

SQL Server Profiler is not present in the list above, but provides the ability to track detailed data for the occurrence and execution of predefined events [22]. However, it is a graphical tool that does not provide an interface for accessing external applications and is also to be removed from future versions of SQL Server.

All this leads to the choice of one of the following two as an alternative approach:

- creating a program that measures the time to complete executed commands;
- use system views and tables in SQL Server.

The advantage of the first method is to achieve complete independence from the likelihood of functionality being dropped from future versions of SQL Server. However, with a larger volume of tests, the additional load from the measurement program could affect the overall time for testing. For this reason, we chose to add runtime markers only to measure runtime during database recovery, and to use the msdb.dbo.backupset system table, which contains information about all backups, in backup processes. server sets (including archive size and type, exact start time and end time).

Hardware testing environment can be considered as SOHO class equipment and is close to the one that a low budget organisation would be using: CPU AMD FX 6100 3.30GHz, RAM 4GB DD3-1333, Samsung SSD 850 EVO and SATA III Hard Disk. Software in use is as follows: Windows 10 64bit, PHP 5.4.7, Apache Server 2.4.3. The SSD uses the last flash technology V-NAND which advantage is lower production costs, power requirements and better speed.

Tests are performed using only one computer so results could be affected by its chipset, used drivers, OS settings etc., therefore they can be considered only as a special case. Below are the results.

Table 2. HDD Log Backup and Restore results

Iteration	**Log backup files**	**Log Backup**			**Log Restore**	
		Time (s)	**Backup Size**	**Speed (MB/s)**	**Time (s)**	**Speed (MB/s)**
1	1	0.70	63.37	62.76	4.43	9.94
2	2	1.06	89.72	83.36	5.19	16.95
3	3	1.81	133.25	73.03	6.97	18.94
4	4	2.30	170.79	76.67	8.63	20.39
5	5	3.02	212.70	72.93	9.84	22.35
6	6	3.29	254.74	80.32	11.47	23.02
7	7	3.89	298.29	79.20	13.35	23.07
8	8	4.39	348.46	80.12	15.32	22.98
9	9	5.55	425.52	71.38	18.06	21.93
10	10	5.91	469.55	74.47	20.43	21.54

Table 3. SSD Log Backup and Restore results

Iteration	Log backup files	Log Backup			Log Restore	
		Time (s)	Backup Size	Speed (MB/s)	Time (s)	Speed (MB/s)
1	1	0.55	63.06	80.62	4.37	10.06
2	2	0.78	89.80	112.45	5.10	17.25
3	3	1.18	131.97	111.96	6.68	19.77
4	4	1.48	170.51	119.30	8.62	20.43
5	5	2.54	212.93	86.55	10.32	21.31
6	6	3.09	254.75	85.45	12.59	20.97
7	7	3.43	297.22	89.91	14.67	20.99
8	8	4.26	347.56	82.65	17.02	20.68
9	9	5.05	424.55	78.49	20.19	19.62
10	10	5.61	468.91	78.49	22.92	19.19

Table 4. HDD Differential Backup and Restore results

Iteration	Differential Backup			Differential Backup Restore	
	Time (s)	Backup Size	Speed (MB/s)	Time (s)	Speed (MB/s)
1	1.55	140.13	13.53	1.84	11.42
2	1.61	164.75	26.03	2.16	19.46
3	2.01	195.82	31.30	2.32	27.20
4	2.35	224.38	35.81	2.65	31.70
5	2.63	254.82	39.88	2.91	36.08
6	3.01	287.63	41.84	3.25	38.74
7	3.28	324.88	44.81	3.60	40.84
8	3.56	365.82	47.19	4.30	39.06
9	4.35	420.00	43.47	4.54	41.64
10	4.84	467.25	43.39	5.40	38.90

Table 5. SSD Differential Backup and Restore results

Iteration	**Differential Backup**			**Differential Backup Restore**	
	Time (s)	**Backup Size**	**Speed (MB/s)**	**Time (s)**	**Speed (MB/s)**
1	1.43	139.04	14.68	1.73	12.14
2	1.54	164.23	27.36	1.98	21.24
3	1.82	196.17	34.54	2.20	28.58
4	1.97	223.04	42.59	2.48	33.92
5	3.13	254.04	33.50	2.73	38.43
6	3.49	287.29	36.07	3.53	35.71
7	3.81	323.92	38.61	4.28	34.35
8	3.82	365.23	43.94	4.74	35.44
9	4.61	419.98	41.04	5.07	37.26
10	5.61	466.10	37.41	6.22	33.78

Table 6. HDD Full Backup and Restore results

Iteration	**Full Database Backup from step 1**			**Full Database Backup Restore**	
	Time (s)	**Backup Size**	**Speed (MB/s)**	**Time (s)**	**Speed (MB/s)**
1	1.85	190.23	102.63	1.92	121.73
2	2.19	234.13	106.78	2.49	109.77
3	2.54	273.63	107.61	2.72	121.47
4	3.20	330.94	103.42	3.34	120.27
5	3.77	401.57	106.61	3.94	124.17
6	4.51	489.32	108.57	4.51	131.48
7	5.45	593.25	108.90	5.64	127.06
8	6.57	717.13	109.19	6.92	124.08
9	7.71	858.25	111.29	7.80	132.23
10	9.46	1031.69	109.02	9.56	127.73

Table 7. SSD Full Backup and Restore results

Iteration	Full Database Backup from step 1			Full Database Backup Restore	
	Time (s)	**Backup Size**	**Speed (MB/s)**	**Time (s)**	**Speed (MB/s)**
1	1.32	190.21	144.28	1.59	146.81
2	1.84	233.23	126.60	2.02	133.45
3	2.08	273.17	131.13	2.43	135.91
4	2.59	330.98	127.68	2.93	136.96
5	2.96	400.98	135.58	3.51	139.12
6	3.63	488.67	134.45	4.03	147.03
7	5.02	593.10	118.03	5.55	128.98
8	5.61	716.54	127.68	7.40	115.95
9	6.92	857.85	123.88	9.06	113.86
10	8.89	1031.23	115.94	10.82	112.72

Calculating average speeds leads to interesting results. Table 8 shows that surprisingly speed of differential backup and restore is better when HDD storage type is used. Speed of both full backup and restore is slightly better with SSD but once again log backup and restore speeds are not undeniably faster with the more expensive configuration.

Table 8. Average results

Data storage	**Operation Type**	**Log backup/ restore**	**Differential backup / restore**	**Full backup / restore**
HDD	Backup	75,424 MB/s	36,725 MB/s	107,402 MB/s
HDD	Restore	20,111 MB/s	32,504 MB/s	123,999 MB/s
SSD	Backup	92,587 MB/s	34,974 MB/s	128,525 MB/s
SSD	Restore	19,027 MB/s	31,085 MB/s	131,079 MB/s

4. Conclusions. The publication researches the different types of storage media and their combination with backup and restore in MS SQL Server. The analysis of the theoretical capabilities and qualities of the carriers shows that the SSDs has more advantages than HDDs. For example, better read, write and access performance, lower failure rate and CPU power consumption. On the other hand, we found that the actual speed of different backup types is not as better as it should be expected with SSD technology.

That is why HDD storage type should be used when the database is as large as several gigabytes or backup strategy relies on usage of differential backups. SSD should be used with databases as large of several thousand gigabytes with backup strategy using many full and log backups.

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