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Measuring Performance for Data Warehouses - A Balanced Scorecard Approach

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***Abstract*—Data warehouse is one of the key information technology (IT) infrastructures. Data warehouse involves a huge financial undertaking. It is important that data warehouse performance is measured in terms of some key aspects. A balanced scorecard (BSC) approach could be applied to measure the performance of data warehouse operations. This article discusses measurements of performance that provides a comprehensive view of data warehouse operations. These measures include user perspective, internal process perspective, financial perspective, and innovation and growth perspective. The motivation behind using a balanced scorecard is to make sure data warehouse environment is efficient and stable; data warehouse programmers do a great job in writing efficient code and continuously make progress in terms of innovation and learning; data warehouse project continuously helps IT department in adding business value and enable cost avoidance; and data warehouse team provides business executives quality information at the right time to support making strategic business decisions. We have highlighted the performance measurement criteria for data warehouses that academics, data warehouse architects and IT managers might find beneficial.**

***Index Terms*—Data Warehouse, Balanced Scorecard, Computing Resources, SQL, Query Performance**

I. INTRODUCTION

Traditionally, performance of business or an entity is measured from financial perspectives. Given the complexity of business operation, an organization needs to measure its performance in several areas. Due to global nature of business environment and competitiveness, data warehouse (DW) has become a very critical technology [47]. It is destined to provide up to date information. Hence, data warehouse refreshes need to happen several times a day [32]. Analytical users use data warehouse globally. In order to provide faster business information to different groups of users including business intelligence (BI) community a data warehouse needs to be stable and running. Data warehouse performance needs to be acceptable to the user community. Balance scorecard in data warehousing provides IT managers and top executives a fast and comprehensive view of data warehouse performance.

Balance scorecard allows data warehouse stakeholders to look at its performance from four important perspectives to provide answers to the following questions. How does the analytical community see the performance of the data warehouse (customer perspective)? Do we deliver quality information (customer perspective)? Are we successful with fulfilling service level agreements (SLA) with users (customer perspective)? How successful are we in providing user services beyond their expectations (customer perspective)? What must the data warehouse architects and ETL programmers excel at (internal perspective) and can they continue to improve and create value (innovation and growth)? How do we (data warehouse team) look to the chief technology office (CTO) and the company chief in relation to adding business value and achieving cost avoidance (financial perspective)? The answer to these questions addresses key areas of data warehouse performance and forces data warehouse managers, architects and technical leads to focus on the measures that are most critical for the success of a data warehouse.

Data warehouse stakeholders achieve several important goals with a balanced scorecard approach. These include availability of quality data in data warehouse, faster query response time, no missing SLA, decrease in data latency (operational source to the data warehouse), and efficient and stable data warehouse environment. Balanced scorecard approach helps with avoiding sub-optimization. For example, in order to provide report users a faster query performance (query with no joins) the reporting table could be made highly de-normalized. With high de-normalization the data model deviates from the 3NF and the load process is hindered. The consequence is data redundancy in the table and excessive consumption of computing resources in data warehouse refresh.

This article is organized as follows: Section 2 briefly discusses goal of proposed balanced scorecard of data warehouses and related work done in this area. Section 3 provides details of each area of balanced scorecard approach in data warehouses. Section 4 summarizes and concludes the article.

II. LITERATURE REVIEW

Kaplan and Norton [20], [21], [22] originally proposed the balance scorecard approach to provide executives and stakeholders a comprehensive view of how an organization is performing in relation to its business objectives. They argued that mere financial accounting measures were too narrow in scope. They proposed some additional measurement criteria which mainly come from operational perspectives of an organization. These perspectives have implications of vision and strategy of an organization [38]. Later their BSC approach was used by many organizations in different business scenarios. The literature analysis strategy and approach is rarely given much attention, with most papers elaborating more on the empirical data collection and analysis phases of the research [8]. Here we will make an

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attempt to review the existing literature to provide an account of work that has been done in improving performance and efficiency by using balanced scorecard approach. Balanced scorecard-based measurement technique has been used in different areas of business and technology to manage performance of business and technology [4], [48], [49] and [50].

Jordan and Mortensen [19] applied the balanced scorecard approach to measure performance of technology development programs. Rosemann and Wiese [37] used BSC in ERP and found that adopting balanced scorecard approach increased the completeness and the quality of enterprise resource planning implementation reports. They also point out that BSC raises the awareness of the factors considered for measurement. Grembergen [15] proposes BSC approach in IT governance. The author emphasizes that IT scorecard should consist of outcome measures and performance drivers and asserts that outcome measure must be driven by performance drivers. Borousan et al. [6] used balanced scorecard to measure performance of IT governance in healthcare organizations. Their evaluation criteria covered four aspects including corporate contribution, stakeholders, operational excellence, and future orientation. They suggested that IT should deliver business values and mitigate IT risks. Barclay [3] developed the project performance scorecard framework to improve understanding of information systems project management and evaluation approaches. The author developed this scorecard evaluation arguing that traditional IS project management assessment methods (time, cost, and specification) do not give enough clues to comprehend under what condition IS projects fail or succeed. The author devised a project performance scorecard consisting of six dimensions that include stakeholder, project process, quality, innovation and learning and benefit and use perspectives.

In our case, we make an attempt to implement scorecard approach in data warehousing projects. We propose that data warehouse team and other stakeholders look at the data warehouse performance from four important perspectives (4 P's). The goal is to ensure that they put a control on financial aspects in terms of adding business value and achieve cost avoidance while maintaining a data warehouse. The other prominent goal is to make sure data warehouse environment is efficient [28], stable, and provides quality information [30]. These perspectives are based upon sound metrics and are related to one another. They allow for increasing confidence of company executives that the company is not making its capital investment in a data warehousing that provides little or no return on investment [46].

III. DATAWAREHOSUE BALANCED SCORECARD APPROACH

A balanced scorecard means choosing such measures that are influential and balanced in providing performance results from both a financial and operational standpoint. It provides a balanced picture of the performance of an organization or entity that will satisfy executives and other stakeholders. Balance scorecard allows an organization to measure and evaluate its performance for continuous improvement [19].

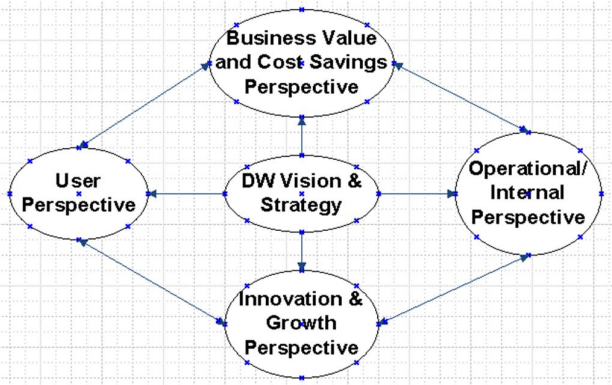

Fig. 1: The Data Warehouse Balanced Scorecard Model

The data warehouse balanced scorecard (Figure 1) includes four perspectives that are considered important to IT chief executive and other key sponsors of data warehouse. BI analytical community (user perspective) is the key user of a data warehouse. Their satisfaction in information delivery by the data warehouse is taken into consideration. Operational/ internal perspective is to make sure data warehouse is stable and running efficiently – with an acceptable query response time. This is needed to make the data warehouse available to the users on a 24/7 basis. Adding business value and cost savings are of special importance to company chief executive and chief financial officer. Innovation and growth perspective is important to IT executives and data warehouse architects. This is needed to maintain a state of the art data warehouse system on a continuous basis.

A. DW Balanced Scorecard: User Perspective

Data warehouse success depends on user (analytical community) satisfaction of data quality [44] and query performance. User satisfaction is considered as the most important measurement of data warehouse success [9]. The question arises that are the services provided by DW fulfilling the needs of the user community [3]. Key factors in assessing satisfaction include data quality, average query response time, data freshness (minimal latency between operational system and data warehouse), and timeliness of information per service level agreement (SLA) provided by the data warehouse. The data warehouse managers, architects and developers might want to maintain a good working relation with the analytical community for the success of a data warehouse. They need to fulfill all the requirements and features demanded by the users [14]. To understand users' information requirements and features a user-developer direct channel needs to be established. Keil and Carmel [23] assert that, "from a communication perspective, direct contact between a customer and developer is preferable to indirect contact because it decreases filtering or distortion that may occur." On the other hand, it is not always the case that a technical person has the knowledge to comprehend the details of business. In such situations a systems analyst (SA) help might be needed to fully understand the user requirements. This will help increase the ability of developers to deliver quality applications.

Measuring data warehouse implementation success depends on user satisfaction surveys to be conducted periodically among analytical community [4]. This will

provide performance metrics as to whether the data warehouse managers are able to increase user satisfaction over the years.

TABLE I: BALANCED SCORECARD – USER PERSPECTIVE

Goal	Measure
SQL Query Run	Average response time
Data Quality	% of defects reduced
Data Freshness	Average delay in hours between operational source and data warehouse
Service Level Agreement	Improvement in missing SLA per month
Data Warehouse downtime	Decrease of number of days in downtime per year

Table 1 shows some important services that might be provided to data warehouse user community. For users, query run time is critical, as they do not tolerate slowness in query response time. Data warehouse programmers need to make sure an efficient query is written, appropriate index is defined in the table, and statistics are collected on SQL joins and filters to help improve performance of queries run by reporting, BI and data mining tools. In order to ensure information quality and guard against data integrity issues, special attention needs to be given to data cleansing while processing data from heterogeneous sources and writing transformation logic.

There is a tendency with a data latency occurrence during data pull from different sources and load into data warehouse tables. Delay in data warehouse refresh impacts report generation at the right time for strategic business decisions. Data latency needs to be decreased between source and target. It is important to meet SLA's with customers in refreshing data warehouse subject areas. Missing SLA especially during monthly financial close period prevents analytical community in reporting financial results. This is true for other business areas including, sales and distribution. Data warehouse downtime occurs many times in a year. These downtimes happen as a result of software upgrades, patch installations, and other reasons. User community becomes frustrated with frequent downtimes. All possible care must be taken to reduce the number of downtimes in a year. Garvin [13] proposed eight critical dimensions of quality for strategic analysis: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. These eight categories of data quality contribute to ensuring user satisfaction of data warehouses as well.

B. *DW Balanced Scorecard: Business Value Perspective*

Data warehouse implementation requires a large amount of capital investment. A big amount of annual expense is also involved in its operation and maintenance of hardware, software and licenses. Company management and IT chief executive would want to know whether a data warehouse delivers business value to the company and continuously drives down costs. Data warehouse champions need to make sure they are accomplishing these goals. "Financial performance measures indicate whether the company's strategy, implementation, and execution are contributing to bottom-line improvement" [20].

TABLE II: BALANCED SCORECARD – BUSINESS VALUE & COST SAVINGS PERSPECTIVE

Goal	Measure
Hardware, Software, License	% decrease in cost
Expenditure per employee	% decrease in expense
Business Value delivery	% increase
Return in investments	% increase

Data warehouse architects need to evaluate if they are able to provide customer services to end user groups. If data warehouse cannot make data available at the right time they are not helping users with such items as marketing and sales departments including business intelligence in their effort to increase sales and revenues. If they cannot provide accurate data at the right time then they are not helping decision-makers in making strategic and tactical decisions [27]. Data warehouse architects needs to identify any bottleneck and inefficiencies in data warehouse operations. It is also important to make sure data warehouse workforce consists of the right people only. That would help in decreasing expense in this area. On annual maintenance-expenses side CTOs and data warehouse managers have to negotiate with suppliers of hardware, software and licenses in driving down total cost of ownership. They also need to consider level of risk aversion [12] in purchasing any hardware, software, tools (e.g., ETL and BI tools) that would involve significant amount of annual cost.

C. *DW Balanced Scorecard: Internal Process Perspective*

Balanced scorecard is designed to provide managers an internal perspective of an organization. "Managers need to focus on those critical internal operations that enable them to satisfy customer needs [20]." Data warehouse architects need to make sure that internal processes are effective and efficient in providing services to fulfill user satisfaction. As part of internal operation in data warehouses certain key factors needs to be taken into consideration. These include ETL code performance [34], batch cycles run-time [33], reporting and BI query runtime [39], agile development, testing and flawless deployment into production environment [35]. These factors are consistent with the IT success framework devised by Delone and McLean [10], [11]. Table 3 lists a couple of goals for which data warehouse architects and application developers must devise effective performance measures. These measures need to be revisited periodically to make sure continual improvement is achieved.

TABLE III: BALANCED SCORECARD – INTERNAL PROCESS PERSPECTIVE

Goal	Measure
DW Application Development	decrease in development time
Batch Cycle Runtime	average runtime of a particular cycle
SQL Query Performance	average query runtime
Application Test and Deployment	intensity of testing and flawlessness of deployment
DW Scalability and Stability	average availability and downtime
Data availability and quality	timeliness of data; number of defects

Data warehouse receives data from heterogeneous sources. Data warehouse job failure and data quality issue arise for many reason including bad data from source. Data cleansing, transforming, and maintaining of data integrity are critical. Software failure also happens due to lack of accurate dependencies between code blocks as well as gaps between

coordination requirements and the actual coordination activities carried on by the developers [7]. ETL code needs to be written in such a way that it can handle data issues during a cycle run and without compromising the load and result in a job failure. To ensure flawless cycle runs, the ETL programmers need to be creative and imaginative in writing programs that will allow them to cover all boundary conditions pertaining to issues with data demographics. This is very much needed to make sure that batch cycles are not in a failed state due to job failure. This has implications for SLA's with analytical community. Sen et al. [40] suggest using Capability Maturity Model (CMM) in building data warehouse applications. The CMM provides useful guidelines for software process management and improvement.

Data warehouse house architects need to consider whether they create, deliver, and maintain [3] applications efficiently. SQL query performance from both load and reporting standpoint is very critical. Data warehouse is a shared environment. No application should consume huge amount of computing resources as it slows down other application runs. Data warehouse architects and programmers should ensure ETL code (stored procedure, views, report SQL) go through review process and meet certain query performance criteria. We propose a SQL performance approach here (Table 4).

TABLE IV: DATA WAREHOUSE SQL QUERY PERFORMANCE EVALUATION

CPU Evaluation		I/O Evaluation		Spool Evaluation		EXPLAIN Evaluation		
Total CPU	CPU Parallel Efficiency (%)	Total I/O	I/O Parallel Efficiency (%)	Total Peak Spool	Spool Parallel Efficiency (%)	Statistics on all Joins & Filters?	Joins or Filters on Derived Attributes?	Overall Score ↓
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Table 4 shows that the performance of an SQL query could be measured in terms of computing resource consumption such as CPU, IO, database spool space and their respective parallel efficiency (PE). If an SQL query fails the performance criteria ETL programmers need to rewrite code to make it efficient. A data warehouse balanced scorecard approach must include SQL query performance evaluation as one of the measurement instruments. Data warehouse query performance and its stability are very much important to users. Technical factors positively influence information as well as system quality [16].

D. DW Balanced Scorecard: Innovation and Growth Perspective

Innovation-and-growth is the key to success in competitive global business environment. A balanced scorecard cannot condone this perspective as part of measurement criteria of a business. "A company's ability to innovate, improve and learn ties directly to the company's value [20]." In this research we take this into consideration to build, maintain and improve a data warehouse. Innovation and growth in a data warehouse must aim to provide data warehouse users with maximum reporting and business intelligence capability [17]. Nowadays ITs SLA is the lowest acceptable performance criterion. Data warehouse architects need to make all effort to anticipate business needs and ensure customer satisfaction by providing the services they need. Data warehouse architects need to come up with such products and services that go beyond users' expectation. Necessity is no longer the mother of invention [29].

Table 5 provides a few measures that need to be considered to foster innovation and growth in a data warehouse. In the computing field things change fast, new technologies emerge quite often and at the same time business also changes. To keep with the speed of business and satisfy technology needs of business, data warehouses need to show technology leadership. For example, recently big data and advanced analytics have come into picture. And for that a completely new set of hardware, software and tools have emerged. To deliver services in these areas data warehouse architects must adopt big data technologies to receive data into data warehouse and provide business value to the users. Most recent research findings suggest that the firms that have been continuing to develop new, valuable IT-enabled business process innovations are able to gain higher productivity [43]. There must be research, training and development programs in place so data warehouse developers can continuously improve their skill-set in current and emerging technologies.

In order to move at the speed of business data warehouse project life cycle (PLC) needs to be shortened through efficiencies that enable early production deployment, which pleases the users. Agile development methodology might be followed in data warehouse PLC [35].

Data quality [2] issue is one of the major concerns in data warehouses. Therefore, quality assessments are an essential element that needs to be take care of during project life cycle [3]. To ensure data quality an effective test-driven development methodology might be followed [36]. Test strategy must validate data for each individual columns and rows. Testing team must show accountability in their testing effort. Users cannot tolerate bad data even it is shown up in a single column. Experience shows that the more thorough software unit test and data validation is performed the less job failures encountered and less defects arise after production deployment. To be on the safe side, it is important that project release team (data analysts, developers and testers) continue data quality monitoring and validation for an additional period after the software product is released [18].

Data warehouse governance [45] is vital to safeguard data warehouse security, performance, stability, and data quality. There are multiple layers of check-points identified as part of governance. But governance process must not hinder timely production deployment. Process improvement must be adopted and processes revisited periodically to remove any bureaucracy. It is important to benchmark the time taken in each step of data warehouse governance processes.

One cannot over emphasize the importance of writing a very efficient query (Raman, 2013) for data warehouse load processes (e.g., stored procedures and macros), and reporting and BI tools. A data warehouse is meant for storing historical and current data. Most of the tables in data warehouse hold millions of rows. ETL programmers need to understand data demographics in tables and users' data retrieval needs. They need to be innovative and creative [42] in query writing so data load and retrieval response time is shorter and acceptable to users. In data warehouses many of the tasks are repetitive in nature and hence automation is needed. These tasks

include creating tables, views, stored procedures, test scripts, etc. For each of these tasks, metadata driven utility stored procedures and macros could be developed to make ETL development work less time-consuming. This is vital for process improvement as well.

TABLE V: BALANCED SCORECARD – INNOVATION AND GROWTH PERSPECTIVE

Goal	Measure
Technology Leadership	New capability at the speed of business
Shortened Project Life Cycle (PLC)	Maturity in development
Efficient Test-Driven Development	Defect reduction; Less job failure
Process Improvement	Reduction of time in process steps
Innovative Query Writing	Improved response time
Emerging Technology Learning	Research and Training effort
Increase Automation	Reduction of time for repetitive tasks

In data warehouses a lot of application projects along with hundreds of production releases occur in a year. Obviously, these application projects involve many unforeseen technical challenges [24]. The DW project managers need to have technical background to be successful. Otherwise, in many cases, they might not foresee the technical challenges and risks until it is imminent at which point they find it difficult to meet the deadline, manage resources and do a flawless production release. The data warehousing projects need data architects whose primary role is to provide an enterprise-worthy data model that ensures (soft) referential integrity [31] among related tables and also allows analytical tools to retrieve information efficiently and by ensuring data quality [1], [41]. As part of data warehouse project life cycle (PLC) the PM needs to make sure continuous improvement is adopted in development, testing, and deployment into production. While building a data model is good for reporting environment it is also important that the data model does not make tables refreshes skewed and computing resource-intensive. In this case, serving one or the other (i.e., if not both) would end up with sub-optimization and cannot be sustainable in a data warehouse which is shared. In a data warehouse, the data model for a subject area or an application must be consistent with the rest of the logical and physical data models to make sure the model is not sub-optimized. A sub-optimization "refers to situations in which optimizing a subsystem according to its local objectives leads to an inferior solution for the overall system [26]."

The data warehouse projects also need ETL Developers along with a senior developer as Technical Lead. Tech Lead's job is to provide an efficient ETL design and sustainable application. Leaders are not made by titles. Tech Lead must provide a blueprint of technical solutions. Tech Lead must have a solid technical background and significant experience to deal with technical challenges during project life cycle including development phase. They need to have adequate business knowledge [4] to communicate with users or include the systems analyst who can bridge the knowledge gap between themselves and the users to understand their business requirements. They need to translate user requirements into ETL design and then convey that to developers. Tech Lead must closely oversee and review the ETL work done by junior developers, contingent workers, and consultants that work under him/her. Tech Lead role in a data warehouse project is very critical because they are responsible for delivering efficient ETL code that will ensure flawless production release and efficient batch cycle runs in data warehouse environment. ETL Tech Lead also need to remember that he/she should not resort to any sort of sub-optimization in designing an application, building a batch cycle and writing ETL code for the sake of efficiency of an application but at the expense of inefficiency of the rest of the data warehousing environment.

Data warehouse is a shared environment; releasing inefficient code into production may cause disproportionate amount of computing resource consumption of database system. This slows down other critical applications run impacting many users. On the other hand, landing defective code in production has a severe consequence in terms of cost as well as bad or missing data in data warehouse. The cost of fixing defects grows in geometrical progression depending on which stage of project life cycle they have been discovered [25]. Boehm and Turner [5] report that the cost to fix a defect "in the fields" is 100 to 200 times more than it is to do so during the development process. Data warehouse architects and project Tech Leads must work diligently for continuous improvement of ETL code and SQL query performance.

IV. CONCLUDING REMARKS

In this article, we have proposed a balanced scorecard approach for measuring performance of data warehouse operations. We identified the key areas of data warehouse performance measurement based on practical experience in data warehouse implementation. The scorecard provides data warehouse managers and architects with crucial measures on business value creation, cost avoidance, innovation, user satisfaction, internal operations, efficiency, data warehouse performance and stability.

To make balanced scorecard effective senior IT executives need to patronize it. The balanced scorecard measures should enable data warehouse architects to deliver operational excellence in terms of quality, efficiency, velocity, and capacity to deliver services. Given computing industry is fast-moving and business conditions also change fast, the balance scorecard measures need to be revisited periodically and improved as needed. As part of future work, we will work on key performance metrics for data warehouse sustainability.

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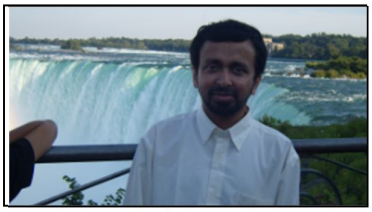

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