Data Quality Comparison between Highly Integrated Single and Three Data Storage System Oriented Information Manufacturing System

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Abstract*—Sources of the information manufacturing system can be integrated with the data storage system in different degrees. Lowly integrated information manufacturing system uses multiple data storage system for storing data in the information manufacturing system. As a result, lowly integrated information manufacturing system was the cause of some data quality problems. Therefore, highly integrated information manufacturing system is installed in the organizations. Highly integrated information manufacturing system store data in one single data storage system. Refreshment and query function are to execute in the data storage system of information manufacturing system for making data available and for information support respectively. The tasks of the refreshment function (data loading, indexing) execute sequentially in the single data storage system oriented information manufacturing system. Further, a highly integrated information manufacturing system is developed for executing the tasks of refreshment and query function simultaneously in data storage system. This highly integrated information manufacturing system is the 3- data storage system oriented information manufacturing system. These highly integrated information manufacturing system could also cause the data quality problems regarding the completeness, accuracy and timeliness data quality dimensions. Therefore, the purpose of this paper is to show a comparative data quality scenario of both of these highly integrated information manufacturing system. As a result, simulated highly integrated single and 3-data storage system oriented information manufacturing system is developed for assessing the data quality of these two information manufacturing system.

Keywords—accuracy; completeness; timeliness; single data storage system; 3-data storage system.

I. INTRODUCTION

Multi channel or multi source information system, cooperative information system and web information system work as the information manufacturing system of an organization, inter-organizations and virtual organizations respectively. These information manufacturing systems work in both real time and non-real time environment. Data come from multiple channels or sources are to integrate to store data in the data storage system (DSS) of IMS of those organizations. These data have to be processed before storing the data in the DSS of IMS. Processing of data is done with the refreshment function of the system. Until refreshment function is finished, data will not be stored for being available in the IMS. Therefore, longer the duration of refreshment period, there is a possibility of poor quality data [4,6].

Lowly integrated DSS oriented IMS can cause for data quality problems in IMS. Therefore, a highly integrated DSS oriented IMS is used to solve the data quality problems in IMS [5]. This highly integrated DSS oriented IMS store data in single DSS and deliver a set of data for information support for query request. Henceforth, refreshment and query function are to execute in single DSS oriented IMS for making data available and for the information support respectively. Furthermore, the tasks of the refreshment function (data loading, indexing) execute sequentially in the single DSS oriented IMS. Therefore, duration of refreshment process can be longer. According to [4], frequency of refreshment is high, timeliness of data is high. On the other hand, frequency of refreshment is low, availability of data is low. Furthermore, there is a possibility of approximate or incomplete data delivery from the system if, availability is low [19]. It is discussed in [5] that there is a time related accuracy and completeness problems for the refresh period in IMS. Therefore, data quality problems may occur in IMS for the frequency of refreshment and the duration of the refreshment process for the down time of the system and the obsoleteness of data. Hence, if, it is possible to execute the tasks of the refreshment (data loading, indexing, and propagation of data) and query (query processing) function simultaneously, duration of refreshment could be shorter and refreshment could be continuous or frequent without affecting the availability and timeliness (obsoleteness) of data. Highly integrated 3-DSS oriented IMS is needed for the simultaneous execution of the task of refreshment and query function. Henceforth, the purpose of this paper is to show a comparison of data quality between highly integrated single and 3-DSS oriented information manufacturing system (IMS).

II. Related Research

Multi-channel information system is integrated to resist the redundant data in the operational data storage system in [5]. Multi channel integration is effective for the quality of stable or long-term changing data. Conversely, this integration is not suitable for frequently changing or time related data. In the IMS, it is difficult to maintain the quality of data for both timeliness and other objective data quality dimensions. Time related data integration for data warehouses are found in [20]. Continuous data integration is one of the important requirements for time related data storage system are discussed in this paper. According to Capiello and Helfert [4] analyzed the trade-off between availability and timeliness data quality dimension for synchronizing or refreshment frequency of DSS in IMS. Batini and Scannapieco [3] described the environment for the trade-off between the dimensions and the occurrence of trade-off between data quality dimensions. Basically, trade-off is done between the time-related data quality dimensions and objective data quality dimensions like completeness, accuracy and consistency. Theodoratos and Bouzeghoub [13] worked on the currency quality factors for data warehouse DSS. Data currency quality goal is expressed by currency constraint associated with every source relation in the definition of every input query. The upper bound in a currency constraint is set by the knowledge workers according to their needs. Mannino and Walter [10] showed in a survey that some organizations refresh data continuously, some organizations refresh data in every 5 minutes for updating data. Most organizations indicated that more frequent refresh during business hours would negatively impact on the system availability and the timeliness in IMS. The meaning of data warehouse updating is defined in [18]. According to this paper, data warehouse updating means a periodical data gathering, transformation and its addition into a data warehouse. Chaudhuri and Dayal [7] worked on the overview of the data warehouse DSS. According to them, Data warehouse DSS store the historical data or individual data record or consolidated data. This data is used for decision support. Considering the complexity of all the factors that are involved in the process of updating the data warehouse, Hanson and Willshire [9] model a faster data warehouse to make available the current data as soon as possible.

III. Highly Integrated Information Manufacturing System (IMS)

The information manufacturing system (IMS) is the information system that manufactures information from raw data [15]. The most important component of IMS is the data storage system (DSS). It is integrated with the multiple sources of the system. Therefore, it contains inbound raw data come from multiple sources. Data come from multiple sources are to be processed for the availability of data in the DSS of IMS. Available data in the DSS are then delivered by the processing of a query request as outbound data for information support.

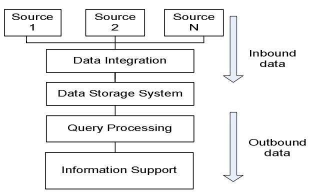


Figure 1. Information Manufacturing System

According to [10] [11] [21], refreshment and query function are to execute in the data storage system of IMS to make the data available and for the information support respectively.

Refreshment Function: It is a complex process comprising the tasks, such as data loading, indexing and propagation of data for synchronizing data in the information manufacturing system (IMS) [10] [11] [21].

Data loading: Storage of manipulating [insert, update] data are to extract from the sources; transformed data if the source data are in the different format. After that, extracted and transformed data are to integrate and to clean for loading data in the data storage system [10] [11] [21].

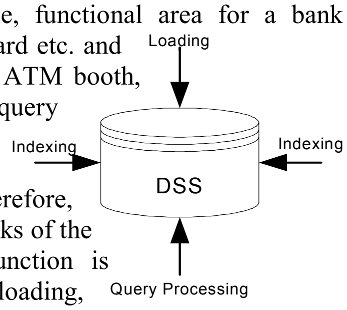
Indexing: Index is to update for newly loaded manipulated data or deleted data to align the data in the data storage system [11]. Indexing determines the effective usability of data collected and aggregated from the sources and increases the performance of the data storage system for information support [10] [11] [21].

Propagation of Data: Data is to propagate through the refreshment process for synchronizing the data of multiple DSSs of the system.

Query Function: This function of data storage system in IMS is done by the query processing task. The requested query of the user is processed in the data storage system for delivering the information to the user.

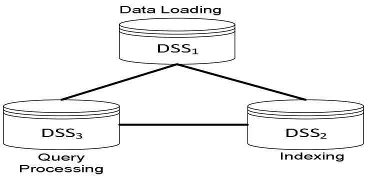
A. *Highly Integrated Single DSS Oriented IMS*

Single DSS is discussed in [6]. Data come from multiple sources are stored in highly integrated single DSS. Sources could be multiple functional areas or the multiple channels. Channels and functional areas are not same for all organizations. For example, functional area for a bank is trading, insurance, credit card etc. and channel could be internet, ATM booth, branches etc. Tasks of the query and refreshment function of data storage system run in single DSS. Therefore, execution process of the tasks of the refreshment and query function is sequential. It means that loading, indexing and query processing tasks work one after another and not simultaneously. Propagation of the data task does not need for the single DSS oriented IMS.



B. *Highly Integrated 3-DSS Oriented IMS*

In the 3-DSS, three individual DSS are mutually interconnected with each other. The tasks of the refreshment and the query function of data storage system work simultaneously in three individual DSS. Therefore, data loading and indexing with updated data propagation task of the refreshment function work in two individual DSS of 3-DSS and another DSS of 3-DSS executes the task of the query function at the same time. After each successive period, the tasks of the refreshment and the query function of data storage system will interchange with cyclic order. As, propagation of manipulated data in the DSS is done simultaneously at the working period of the task of the functionalities, there may not have propagation delay. Therefore, 3-DSS will hold exactly the same data.



Execution Process of 3-DSS

Suppose, DB1, DB2 and DB3 is three individual DSS for 3-DSS. These three DSS are mutually interconnected with each other. Now, if DB1 store some data from operational data sources, DB2 and DB3 must have the same data. The tasks of the query and refreshment function work simultaneously in these three data storage system. There must have a synchronization of starting and finishing time of the tasks of the query and refreshment function of these three data storage system. Manipulated data from operational data sources will load into one database. At the same time, another database will do the indexing and updated data propagation task for synchronizing data with other two DSS and the third one will be used for query processing. The indexed and query processing database lead the process. When the indexing with the propagation of updated data and the query processing are finished, the tasks of the refreshment and query function of data storage system will interchange with cyclic order. The rotation of the interchanging process is shown in the Figure 2.

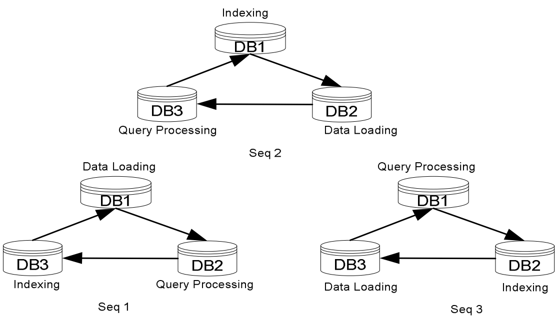


Figure 2. Rotation of the Tasks of Functionalities in 3-DSS

The algorithm for the rotation of function (Data Loading, Indexing and Query Processing) in data storage system is shown in Figure 3.

Rotation of Tasks of Functionalities in 3-DSS (Data Loading, Indexing with update propagation, Query Processing)

DB1 = Database 1, DB2 = Database 2, DB3 = Database 3

Step 1: DB1=>Data Loading, DB2=>Nothing, DB3=>Nothing

Step 2: DB1=>Indexing and send updated data to DB2, DB2=>Data Loading, DB3=>Nothing

Step 3: DB2=>Indexing and send updated data to DB3, DB3=>Data Loading, DB1=>Query Processing

Step 4: DB3=>Indexing and send updated data to DB1, DB1=>Data Loading, DB2=>Query Processing

Step 5: DB1=>Indexing and send updated data to DB2, DB2=>Data Loading, DB3=>Query Processing

Step 6: Repeat Step 3, 4 and 5.

Figure 3. Algorithm for Rotation of Tasks of Functionalities in 3-DSS

In the algorithm, Steps 1 and 2 indicate the initialization of the system. Data come from multiple sources are loaded into DB1 in Step 1. DB1 executes the indexing task and send the updated data to DB2 and DB2 loads the updated data and source data simultaneously in Step 2. Each task of the functionalities of data storage system works simultaneously in Steps 3, 4 and 5. As, data have been loaded into DB2 in Step 2, DB2 is indexed in Step 3 and send the updated data to DB3. At the same time, DB3 loads the manipulated data including the updated data of DB2. Further, DB1 provides the information by processing the query request of the system in Step 3. Steps 4 and 5 will follow the same process but interchange the roles of each DB of the system. Therefore, Step 3, 4 and 5 will continue repeatedly in the system.

Details of the execution process of the 3-DSS are discussed in [22].

IV. Most Usable Data Quality Dimension in IMS

According to researchers, most usable pertaining data quality dimensions are accuracy and completeness. On the other hand, time related data quality dimension is timeliness. The definition of these data quality dimensions is given below,

Completeness: Completeness of data in IMS is the ratio between the number of data stored in DSS and the number of data that should be stored in DSS [6]. Furthermore, if data is not available at the right time in IMS for the processing period, it cannot produce complete information [19].

Accuracy: Wang and Strong in [17] define the accuracy as the extent to which data are correct. Data stored in the DSS of IMS could be incorrect for the obsoleteness. Further, according to [5], Data duplication or inconsistency as well as non-current data is caused for the inaccuracy of time related data.

Timeliness: Timeliness is defined as the extent to which data are timely for use [17]. It is also defined as the property of information to arrive early or at the right time [2]. Therefore, timeliness of data in IMS depends on whether data are available in time or not. Obsoleteness of data can be measured by the timeliness of data. Obsolete data are useless for the inaccuracy of data.

V. Experiment for the Comparison of Data Quality between Single DSS and 3-DSS Oriented IMS

The following data quality assessment tool has been developed for measuring the data quality for both single and 3-DSS oriented IMS. This tool is used for manipulating data in the IMS and delivery of the query request sending by the user in IMS simultaneously. In 3-DSS oriented IMS, tasks of the refreshment (loading, indexing + propagation of data) and the query function executed in three individual DSS of the IMS. Therefore, three individual DSS of 3-DSS have a communication with each other for changing their tasks from one DSS to another DSS. This complex 3-DSS oriented IMS will also controlled by this tool for measuring the data quality.

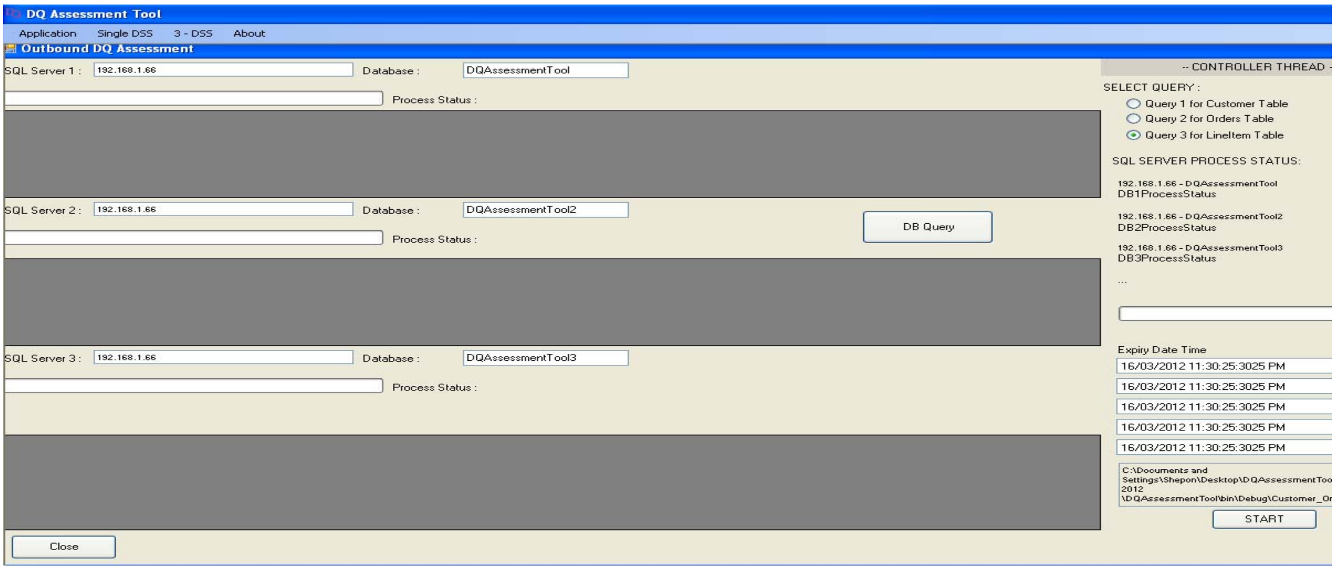


Figure 4. Data Quality Assessment Tool

A. *Assessment Functions for Measuring Data Quality in Highly Integrated IMS*

Data quality is measured in the IMS by completeness, accuracy and timeliness. Therefore, these data quality assessment functions are implemented in this tool for measuring the data quality of both highly integrated single DSS and 3-DSS oriented IMS. The developed assessment functions for measuring completeness and accuracy of the information are taken from [23].

Completeness: From the completeness function of [5], following function can be written for measuring the completeness data in highly integrated IMS.

$$Completeness\,(C_k) = 1 - \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} Incompleteness\,(d_{ij})}{M \times N} \quad \text{.......... (1)}$$

d_{ij} is the data for the particular location in DSS of IMS. i and j indicates the attribute (column) and tuple (row) respectively for measuring the completeness of data for a particular location of DSS. M and N are the total number of tuples (row) respectively. Therefore, M×N is the total number of data in the DSS.

Accuracy: Considering the accuracy assessment function of [5], following accuracy assessment function can be written for measuring the accuracy of data in highly integrated IMS.

$$Accuracy\,(A_k) = 1 - \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} Inaccuracy\,(d_{ij})}{M \times N} \quad \text{...........(2)}$$

Where, d_{ij} are the inaccurate elements of a particular location of IMS that does not contain the benchmark database or contain the benchmark database but obsolete for the time related issue or inaccurate for duplication issue. i, j indicates the attribute (column) and tuple (row) respectively for measuring the accuracy of the data for a particular location of DSS. M and N are the total number of attribute (column) and the total number of tuples (row) respectively. Therefore, M×N is the total number of data in the DSS.

B. *Timeliness of Data in IMS*

According to [3], Timeliness can be defined as currency and volatility dimensions. More specifically it can be written,

Max (0, 1 – currency/volatility) …………… (3)

This currency and volatility are to define for the DSS of IMS. The currency and volatility that are defined in [23,24] for the timeliness of data measurement is given in these papers.

Volatility of Data in IMS: As the definition of volatility we know that the length of time data remains valid is volatility [3]. Therefore, volatility of data depends on the expiry time of each individual data of DSS. Therefore, the formula for the volatility of data in the DSS of IMS is,

Volatility = Expiry Time – Start of Data Insertion Time ………………… (4)

Start of data insertion time means starting of insertion time of data from sources to the DSS of the information manufacturing system. Start of data insertion from the sources can be represented as SIT. On the other side, Expiry time can be represented as E_T. Expiry time indicates the limit of the validity of data.

Currency of Data in IMS: According to [3], currency is defined as,

Currency = Age + (Delivery Time – Input Time) ………. (5)

Where Age measures how old the data unit is when received, Delivery Time is the time information product is delivered to the user and Input Time is the time data unit is obtained. Therefore, the currency dimension of data in the data storage system (DSS) depends on the age, delivery time and input time. In the database data storage system (DSS), these parameters can be recognized as below,

TABLE I. Currency Parameters of IMS

General Currency Parameter	DSS Currency Parameter	Notation
Age	Waiting Period + Refreshment Processing Period	W (t) + Rpro (t)
Delivery Time	Query Response Time	QRT
Input Time	Insertion Time of Data in DSS	IT

Age A (t): It can be calculated in DSS by adding waiting period of data with the refreshment processing period of data. Waiting period means how long data is waiting in the source before the refreshment processing of data in IMS for the insertion of data in the DSS. Refreshment processing period is calculated by adding the following parameters.

TABLE II. Refreshment Processing Period Parameters

Refreshment Processing Time Parameters	Description	Notation
Loading Period	Time needs for loading data in the DSS	L (t)
Indexing Period	Time needs for indexing data in the DSS	Ix (t)
Propagation Delay	Time needs for propagating data from one DSS to another DSS.	P (t)

Therefore, refreshment processing time of data in DSS can be calculated in the following way,

Rpro (t) = L (t) + Ix (t) + P (t) ………………. (6)

Now, we can write the Age as,

A (t) = W (t) + (L (t) + Ix (t) + P (t)) ……………. (7)

Input Time: To make data available in the DSS, data have to be inserted in the DSS of IMS. Data insertion will be completed if refreshment processing of data in the DSS is done. Therefore, the end of the refreshment processing time for each individual data will be the input time of individual data.

Delivery Time: It is defined in DSS by query response time. This query response time of DSS means, what time query request of a user query is responded in DSS.

C. *Execution Process of Experiment*

This tool is used in a multi core 2.2 Ghz processors, 4 GB RAM, 5700 rpm hard disk based machine for doing the data quality experiment of both single and 3-DSS oriented IMS. SQL server was the database software for creating the data storage system. Same volume of data is stored in both types of DSS of IMS from the sources. Data come from the multiple sources of IMS was not 100% good quality. These data was 97% and 95% complete and accurate in the sources respectively. Data is extracted from the sources and stored in DSS with the refreshment function for delivering the data for the query request. In the real world, user can send the query request in the refreshment period. For this reason, query and refreshment function executed simultaneously in these experiments. A query result is delivered for each respective query request sending by the user. Therefore, these query results are measured by the data quality assessment function to get the data quality result for both single and 3-DSS oriented IMS. Timeliness value 0.3 is considered for measuring the obsoleteness of data. if timeliness of data is greater than 0.3, data is accurate otherwise inaccurate.

TABLE III. Outbound Data Quality (DQ) Assessment Result for Single DSS Oriented IMS

User	Age	Input Time	Delivery Time	Currency	Volatility	Timeliness	Completeness (%)	Accuracy (%)
1	0-240370	11:24:02	11:27:21	199437	633983	0.68	17.56	94.89
2	0-2385490	11:24:02	11:28:03	241989	633983	0.62	36.86	63.45
3	0-2931580	11:24:02	11:29:00	298972	633983	0.53	52.73	48.60
4	0-3312070	11:24:02	11:29:33	331872	633983	0.48	61.58	37.52
5	0-3904670	11:24:02	11:30:37	395069	633983	0.38	87.40	18.12

TABLE IV. Outbound Data Quality (DQ) Assessment Result for 3-DSS Oriented IMS

User	Age	Input Time	Delivery Time	Currency	Volatility	Timeliness	Completeness (%)	Accuracy (%)
1	0-130300	23:24:02	23:27:16	194535	633983	0.69	20.00	95.58
2	0-2263400	23:24:02	23:28:04	241914	633983	0.62	39.86	75.65
3	0-2901530	23:24:02	23:28:56	294972	633983	0.53	59.80	55.72
4	0-3312000	23:24:02	23:29:28	329671	633983	0.48	70.00	45.52
5	0-3862630	23:24:02	23:30:30	393069	633983	0.38	93.40	22.12

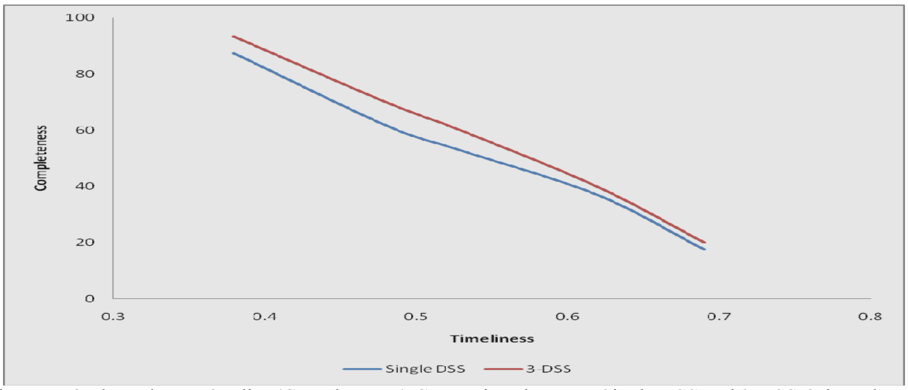


Figure 5. Outbound Data Quality (Completeness) Comparison between Single DSS and 3-DSS Oriented IMS

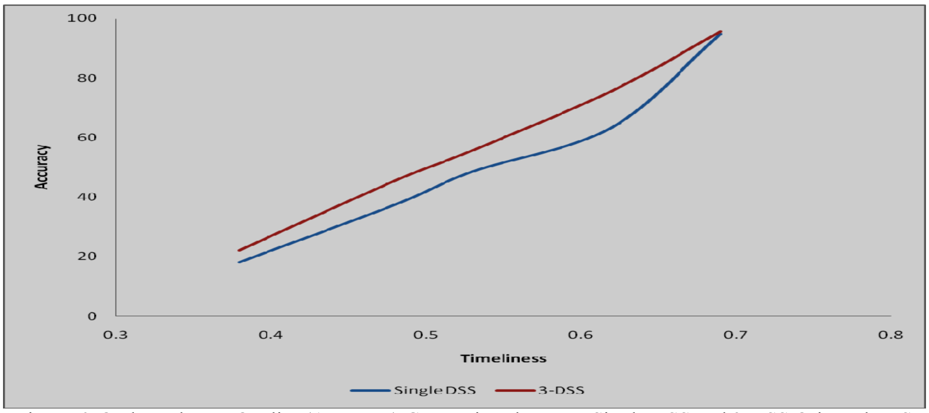


Figure 6. Outbound Data Quality (Accuracy) Comparison between Single DSS and 3-DSS Oriented IMS

D. Analysis

Table 3 and table 4 presents outbound data quality result for single and 3-DSS oriented IMS respectively. In these tables, 0 is the age of the first inserted data in DSS and input time is the time of the first inserted data. Therefore, timeliness of these tables is measured by the age and input time of the first inserted data and the delivery time of the set of data or information. Each individual data that is inserted in DSS has the age and input time. Delivery time varies in these tables. As a result timeliness of these tables varies for the delivery time. The set of data or information is coming at the right time or not depends on the delivery time. Completeness and accuracy comparison of single and 3-DSS oriented IMS are shown in the graph of figure 5 and figure 6 respectively. In the table 3 and table 4, it is found that volatility of data was indifferent for the experiment of both single and 3-DSS oriented IMS. Now, If we look at the distance between input time and the delivery time of each query request of both DSS oriented IMS, it will be seen that it is few seconds higher in single DSS oriented IMS than the 3-DSS oriented IMS for each query request. It means that query responding time for each query request of single DSS oriented IMS was few second late than the corresponding query request of 3-DSS oriented IMS. However, the data quality scenario of 3-DSS oriented IMS is better than the data quality scenario of single DSS oriented IMS.

The tasks of the refreshment and query function execute simultaneously using the multithreading process in 3-DSS oriented IMS. On the other hand, refreshment and query function execute sequentially in the single DSS oriented IMS for not defining the individual thread for each task. Therefore, the refreshment period of 3-DSS oriented IMS is shorter than the single DSS oriented IMS. For this reason, the age of the data of 3-DSS oriented IMS is lower than the age of the data of the single DSS oriented IMS. This age of the data affects on the accuracy data quality dimension with timeliness. Further, more data are inserted in 3-DSS oriented IMS than single DSS oriented IMS within the same duration of refreshment time. Completeness of the data with timeliness varies for the insertion of data within the refreshment period. As a result, accuracy and completeness with timeliness of 3-DSS oriented IMS is better than the accuracy and completeness with timeliness of single DSS oriented IMS

VI. CONCLUSION

This paper compares the data quality between single and 3-DSS oriented IMS. By Comparing the data quality result of both single and 3-DSS oriented IMS, it is found that 3- DSS oriented IMS can provide better quality information with timeliness than the single DSS oriented IMS. But, there is no existence of 3-DSS oriented IMS in the real world organization. Therefore, future work will be conducted for the implementation of 3-DSS oriented IMS.

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