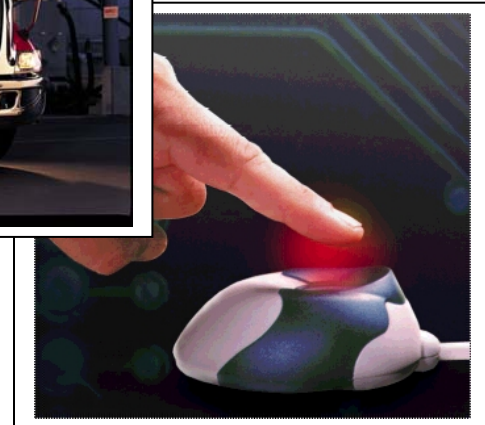
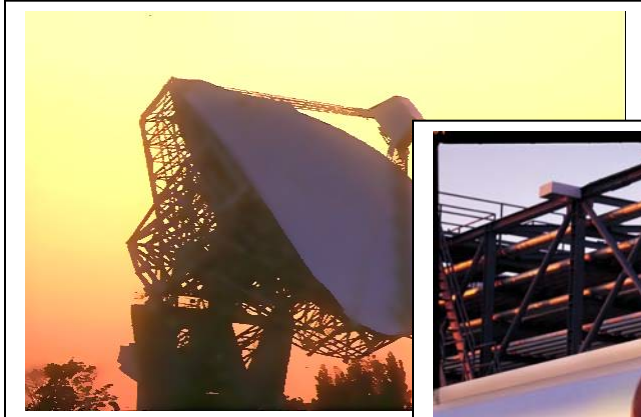


Freight Performance Measure Systems (FPMS) System Evaluation and Data Analysis



Final Report

Prepared by:

Chen-Fu Liao
University of Minnesota

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Prepared by:

Chen-Fu Liao

Senior Systems Engineer
500 Pillsbury Drive, S.E.
Minnesota Traffic Observatory, Room #790
Minneapolis, Minnesota 55455

Prepared for:

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Center for Transportation Studies
University of Minnesota

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TABLE OF CONTENTS

Introduction	1
Chapter One: Data Analysis	2
I. GIS-based FPM System (FPMS I)	2
II. SQL-based FPM System (FPMS II)	2
III. Analysis of Average Speed Differences	4
1. Segment size	4
2. Parameters of trip quality filters	4
3. Analysis of trip 108	4
4. Analysis of trip 115	5
5. Why different average speed?	5
IV. Conclusion of Data Analysis	6
Chapter Two: Analysis of Database Systems	7
I. GIS-based FPM System (FPMS I)	7
1. Data process flowchart	8
2. Functionality of <i>prjAvgSpeedCalc.dll</i> program	8
3. Database structure	8
II. SQL-based FPM System (FPMS II)	9
1. Data process flowchart	10
2. Functionality of <i>calcEvents.exe</i> program	10
3. Database structure	10
4. Issue of data expansion	11
5. SQL procedures	11
6. Summary of FPMS II analysis	11
Chapter Three: Ideal FPM System	13
I. Proposed FPM System	13
1. Two-tier system	13
2. Three-tier system	14
II. Requirements to migrate to ideal system	14
1. Software development needed	14
2. Potential hardware requirements	15
References	16

LIST OF FIGURES

Figure 1-1 Event counts of 1, 3, and 10-mile segmentation along I-5 southbound (FPMS II).....	3
Figure 1-2 Average speed comparison of 1, 3, and 10-mile segmentation along I-5 southbound.....	3
Figure 1-3 Event counts of 1, 3, and 10-mile segmentation along I-5 southbound (FPMS II).....	3
Figure 1-4 Segmentation illustration.....	4
Figure 1-5 Average speed comparison of trip108 from FPMS I & II	5
Figure 1-6 Average speed comparison of trip115 from FPMS I & II	5
Figure 2-1 Earlier generation of the FPM system (FPMS I).....	7
Figure 2-2(a) Raw truck AVL data	7
Figure 2-2(b) Snap raw data to a route	7
Figure 2-3 Data process flowchart of FPMS I system	8
Figure 2-4 Database structure of FPMS I system	9
Figure 2-5 Diagram of current ATRI FPM system (FPMS II)	9
Figure 2-6 Data process flowchart of FPMS II system	10
Figure 2-7 Database structure of FPMS II system	11
Figure 3-1 Block diagram of proposed 2-tier FPM system	13
Figure 3-2 Block diagram of proposed 3-tier FPM system	14

EXECUTIVE SUMMARY

One of the key measures of freight performance along interstate corridors in the United States is the average speed of travel. This report documents the findings and analysis of the ATRI Freight Performance Measure (FPM) database systems and investigates a potential FPM system design that can efficiently and effectively process more and larger Automatic Vehicle Location (AVL) datasets collected from various trucking companies. The current FPM system at ATRI was evolved from its previous system based on GIS software. The averaged speed calculations resulting from the data process of each FPM system are somewhat different. Analysis of the average speed calculation and investigation of speed differences are discussed in chapter one. FPM database system analysis and comparison are included in chapter two. The final chapter presents an ideal FPM system and requirements needed for migration.

Data analysis and average speed differences

In both FPM systems, the raw AVL data were first processed by projecting each data point to the nearest route. A route GIS map was used for reference during the calculation. The average speed was then calculated by taking the distance between the two projected points and dividing it by the difference of time between the two data points. Results from the current and previous ATRI FPM systems were analyzed to investigate the average speed differences. The previous GIS-based FPM system (*FPMS I*) allows average speed calculation at segment size from 10 miles up to 100 miles with 10-mile increments. The current SQL-based FPM system (*FPMS II*) initially has a predefined segment size of 1-mile for average speed calculation. However, ATRI recently changed the pre-defined segment size to 3-miles partially because of the size of the resulting speed data stored in SQL database. To compare the average speed calculation between the two systems, modifications to both systems were made to allow for processing AVL data at 1, 3, 10, or 50-mile segment sizes. Both FPM systems were configured and setup on a local computer at the University of Minnesota for data analysis and evaluation. Trip by trip analyses between both systems were also performed to investigate the speed discrepancy. Findings of the average speed differences between the two systems are summarized as follows.

- Segment size affects the average speed calculation. Average speed calculated with a smaller segment, resulting in larger data size in database, provides better accuracy as compared to calculated speed with larger segments.
- Both FPM systems use similar filtering parameters for removing outlier data. However, the *FPMS II* accepts a maximum speed up to 100 mph while *FPMS I* system allows a 75 mph maximum speed. *FPMS II* also introduces a parameter called *dMdT* ratio which was not found in *FPMS I*.
- Linear projection measures of raw AVL data generated in the *FPMS I* system are different from measures calculated by *FPMS II*. The differences may be caused by: (1) referring to different route map or different linear route references, (2) using different search radius in snapping algorithm, or (3) error in AVL projection calculation.

FPM system analysis

Raw truck AVL data obtained from trucking companies were imported into the GIS-based system through the geo-database interface. A Dynamic Link Library (DLL) was imported to the GIS running environment to process average speed. All truck AVL data were processed within the GIS environment through the *prjAvgSpeedCalc.dll* module. The DLL module was embedded in the GIS software so users could select different options prior to processing the truck AVL data with respect to the route Geographic Information System (GIS) database loaded in the GIS. After loaded, truck AVL data were sorted by truck ID and its

timestamp in order to generate trip data. Outlier trips were filtered and average speed was calculated for each trip. Calculated results were stored in the geo-database for later analysis. This GIS-based FPM system causes significant amount of processing time for a moderate size (200k AVL points) of dataset. This approach is not scalable due to the limitation of the employed database system (up to 2 GB per database). The GIS-based solution depends heavy on the GIS software for AVL data processes.

The current FPM system, evolving from the previous GIS-based system, introduces a SQL database to store and process raw AVL data outside the GIS environment. The SQL-based approach removes the direct dependency of GIS software.

Future FPM system

An ideal FPM system is proposed at the end of this report. The heart of an ideal FPM system is a SQL database server that allows external GIS applications to query processed results and to visualize performance measures. The linear references and segmentation of each route, based on a required minimum segment size of average speed calculation, can be pre-processed through the interface to the project's customized application or other open source GIS programs. The pre-processed GIS route data needs only to be segmented once. They will thereafter be stored in the SQL database. A truck data processing module will provide the capability to convert different formats of AVL data, perform AVL data snapping and calculate average speeds. Average speed of each segment will be referenced to the route segment that was already processed in the SQL database. The structure of current database tables needed to be optimized to exclude information that can be cross-referenced in other tables. The proposed truck data processor can either reside in the same computer as the SQL server or outside the database server. Single or multiple truck data processors can be connected to the central SQL server for simultaneous data processing. Several verification and validation tasks were recommended before migrating to future FPM system. Hardware requirements and necessary software developments for the future FPM system were finally discussed.

INTRODUCTION

This report documents the findings and analysis of the ATRI Freight Performance Measure (FPM) database systems and investigation of a potential FPM system design that can efficiently and effectively process larger amounts of Automatic Vehicle Location (AVL) datasets collected from various trucking industry sectors. The current FPM system at ATRI evolved from several previous project phases and was based on GIS software. Previously, questions were raised regarding the differences in the average speed calculated between the current and previous systems. Evaluation and investigation of the current FPM system were performed to seek potential improvements in data processing and enhancement in database system design. Chapter one includes the findings of the average speed calculation from both old (GIS-based, *FPMS I*) and current (SQL-based, *FPMS II*) FPM systems. Structured Query Language (SQL) is a standard computer language for accessing and manipulating databases. Chapter one mainly focused on the investigation of the average speed calculation and the causes of speed differences between the two systems. Detailed system analysis and evaluation of the FPM database systems will later be discussed in Chapter two. Finally, an ideal FPM system for processing AVL data is proposed in Chapter three which also includes the implication of migrating from current FPM system to the proposed system.

CHAPTER ONE: DATA ANALYSIS

The data analysis of the FPM system includes the old system (GIS-based) and the current system (Microsoft SQL-based). Two datasets were used in order to compare the average speed calculation for both systems. However, several errors occurred while processing the larger dataset with the FPMS I system. Both FPM systems will be discussed separately in section I and II. Section III includes the findings of the causes of average speed differences.

The major differences between the FPMS I and II systems are the database configurations, data structure and the dependency of the GIS environment. FPMS I processed the data in a GIS environment with AVL data initially imported to a database. FPMS II replaced the geo-database with an SQL database and processed AVL data through an external program that interfaces with the GIS software development platform and SQL procedures. The common procedures for processing raw AVL data for both FPM systems include the following procedures.

1. Import raw AVL data to database
2. Project AVL data to route references and remove outliers
3. Generate trip by sorting AVL data with truck ID and time
4. Calculate average speed for each trip and remove speed outliers
5. Perform segmentation per specified, or pre-defined, segment size

I. GIS-based FPM System (FPMS I)

The GIS-based system allows minimum segment size of 10-mile for average speed calculation. Additional modification to the source code was made and recompiled to allow 1-mile average speed segment size in order to compare with the results from the SQL-based system. Data processes with segment sizes of 1-mile, 10-mile and 50-mile were performed for this analysis.

The average speed calculation with a larger segmentation size results in less data accuracy which was mainly caused by data truncation during the calculation process. The AVL data were collected every 15-minutes. Average speed calculations with segment size larger than maximum travel distance between data collection periods may significantly reduce the speed accuracy and resolution.

II. SQL-based FPM System (FPMS II)

Initially, the SQL-based system has a pre-defined segment size of 1-mile for average speed calculation. It was recently changed to 3-mile segment due to the tremendous amount of data generated during the AVL data processing. Additional modifications to the SQL procedures were modified in order to execute the SQL Data Transformation Services (DTS) routine for different segment size for the comparison with FPMS I system. Figure 1-1 shows the event counts of each segmentation size. In northbound, the data segments of calculated average speed concentrate between 300 and 900 mileage post (Approximately between Portland, Oregon and Sacramento, California) with segment counts exceeding 400. The average speed comparison and the event count for each segmentation size in southbound is displayed in Figure 1-2 and 1-3. The data segments counts of calculated average speed concentrate between 400 and 850 mileage post with segment counts exceeding 400.

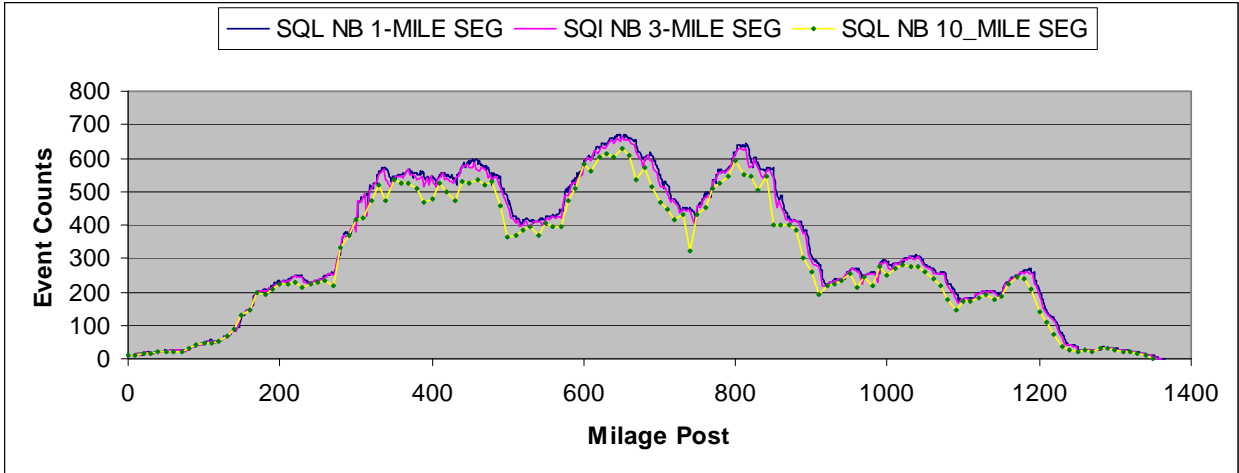


Figure 1-1 Event counts of 1, 3, and 10-mile segmentation along I-5 southbound (FPMS II)

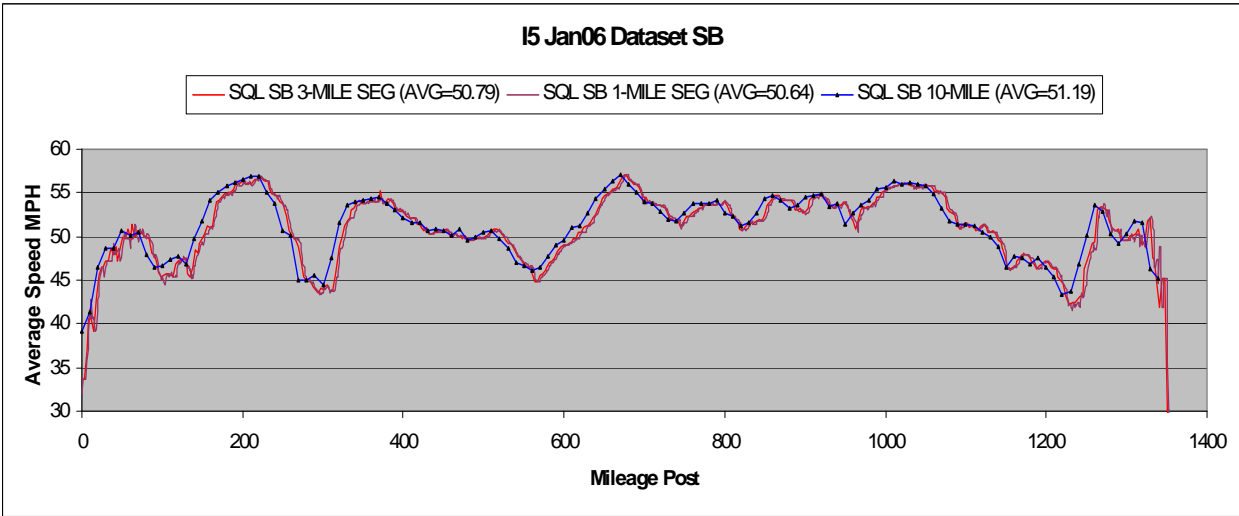


Figure 1-2 Average speed comparison of 1, 3, and 10-mile segmentation along I-5 southbound (FPMS II)

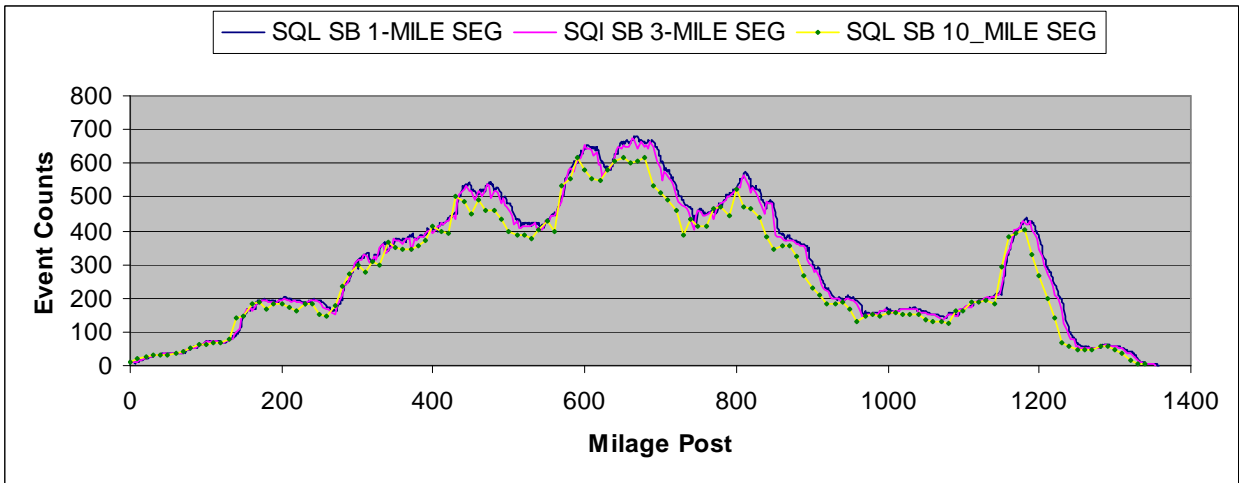


Figure 1-3 Event counts of 1, 3, and 10-mile segmentation along I-5 southbound (FPMS II)

III. Analysis of Average Speed Differences

After examining the average speed calculations, further analysis of the differences on average speed calculation was investigated for both FPMS I and II systems. Findings of the analysis were discussed as follows by comparing the segment size, trip quality filter parameters, and individual trip analysis.

1. Segment size

As illustrated in Figure 1-4 for a 1-mile segment example, the fraction segment at each end was truncated when assigning speed to each 1-mile segment for a particular trip. When segment size increases, larger amount of speed data at each end will be truncated which resulting in less accuracy as the 50-mile segment curve.

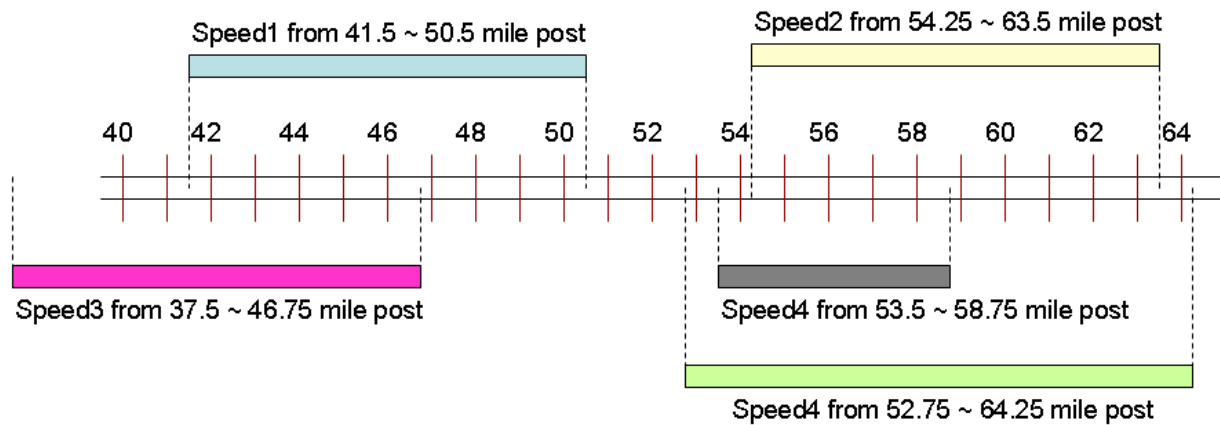


Figure 1-4 Segmentation illustration

2. Parameters of trip quality filters

When comparing results from both FPMS I & II systems, there can be relatively significant differences between the average speeds with same segment size calculation.

3. Analysis of trip 108

Trip108 travels over 100 miles. The results from both systems for trip108 were plotted in Figure 1-5. The red diamond mark indicates the average speed calculated from the SQL-based system and the blue triangle mark indicates the results from the FPMS I system. There are quite significant speed differences in some areas and some of the calculated results were shifted.

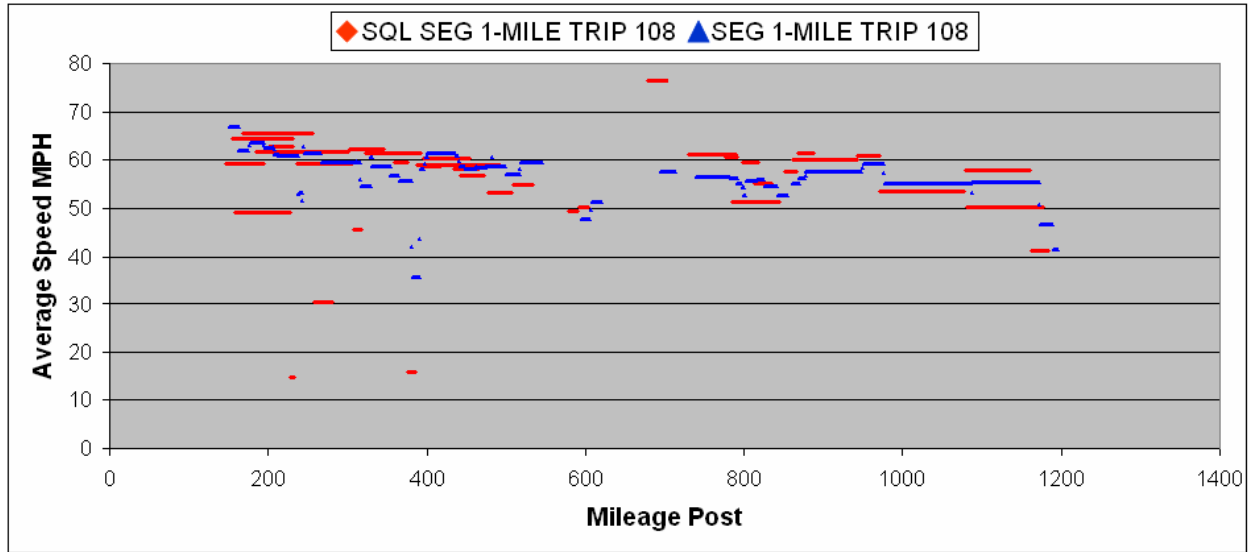


Figure 1-5 Average speed comparison of trip108 from FPMS I & II

4. Analysis of trip 115

With the interesting observation from trip108 data, another trip (trip115) was also analyzed to investigate the average speed differences. Similar results as discussed in trip108 section were found. Results were displayed in Figure 1-6.

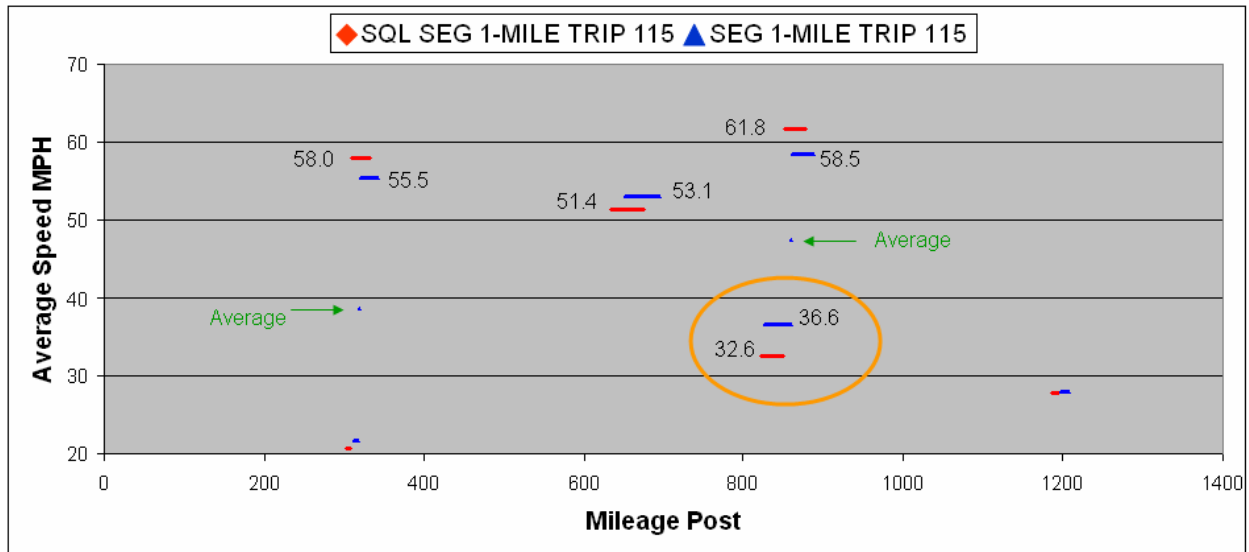


Figure 1-6 Average speed comparison of trip115 from FPMS I & II

5. Why different average speeds?

The AVL projection database was further examined to investigate the cause of speed differences. Obviously, the differences in AVL data projection cause the discrepancy of average speed calculation between the two FPM systems.

The following questions were listed as possible causes of linear projection discrepancy. It is difficult to determine the actual cause without further examination of the source code of the customized program developed for the FPM project.

- Is there an error in AVL projection calculation?
- Does FPMS use different search radius in AVL projection calculation?
- Does FPMS use different projection algorithm?
- Does FPMS refer to different route database (linear reference)?

IV. Conclusion of Data Analysis

The average speed differences could be caused by segment size, filtering parameters and the AVL projection results. In addition, the trip filtering parameters play an important role in the AVL data processing. FPMS I system uses a search radius of $\frac{1}{4}$ mile for AVL data projection. The search radius used in FPMS II snapping algorithm was hard coded inside the snapping algorithm program. FPMS I system limited maximum speed to 75 mph while the FPMS II allowed maximum speed up to 100 mph. Further investigation of the projection routine and the reference route database may be necessary to verify and validate the average speed calculations.

CHAPTER TWO: ANALYSIS OF DATABASE SYSTEMS

I. GIS-based FPM System (FPMS I)

The system configuration of the earlier generation of the freight performance measure (FPM) system developed by ATRI can be illustrated as shown in Figure 2-1. Raw truck AVL data obtained from trucking companies were imported into a GIS system through the geo-database interface. A Dynamic Link Library (DLL) was developed for FPM calculations. The DLL module was imported and embedded in the GIS software in order for users to select different options prior to processing the truck AVL data with respect to the routing database loaded in the FPM software. After loading from geo-database, truck AVL data were sorted by truck ID and its time-stamp to generate trip data. Outlier data were removed and truck average speeds was calculated with respect to the route maps that are loaded in GIS.

All truck AVL data were processed inside the GIS environment and the calculated results were stored back in the geo-database. This system configuration caused quite significant increases in processing time for a moderate size of dataset. The geo-database is limited up to 2 gigabytes of file size. Furthermore, the results stored in the geo-database have limited use because they can not be queried by external applications.

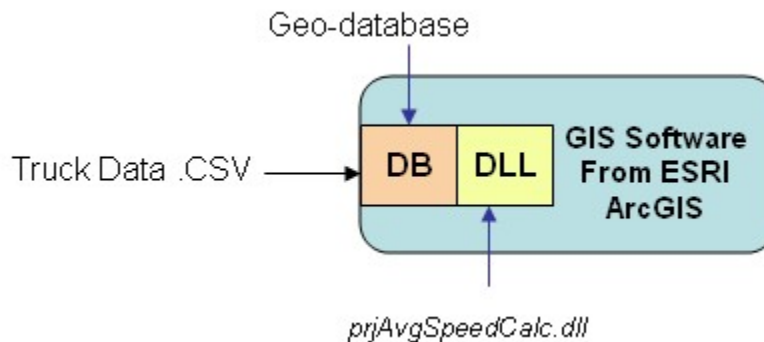


Figure 2-1 Earlier generation of the FPM system (FPMS I)

What is snapping?

Due to the GPS accuracy and uncertainty, the collected AVL data usually distribute nearby the traveling route as shown in Figure 2-2(a). Snapping is the process of moving a feature to coincide exactly with coordinates of another feature within a specified *snapping distance*, or tolerance [2]. It is an operation or process whereby the computer will move a point or line slightly so that it corresponds to a nearby point or closest point on a nearby line, Figure 2-2(b).

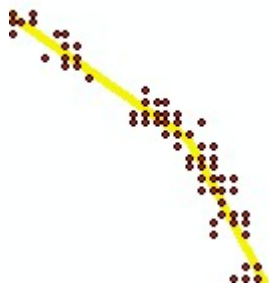


Figure 2-2(a) Raw truck AVL data

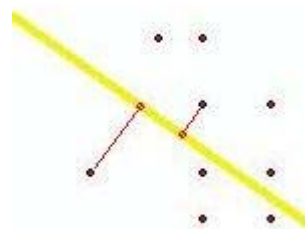


Figure 2-2(b) Snap raw data to a route

1. Data process flowchart:

The data process flowchart of FPMS I system is shown in Figure 2-3. The raw AVL data was loaded into a geo-database through a separate GIS application. A Dynamic Link Library (DLL) was embedded in the GIS application. The DLL program allows users to select which dataset to process and what segment size for average speed calculation with respect to a GIS route map loaded in the software. The program will project the AVL data to the nearest route and remove any disqualified data. It will then sort the qualified AVL data by truck ID and its timestamp to generate trip data. It will then iteratively go through each trip to calculate the average speed for each segment. Final results were stored in a table for data visualization and analysis in using a standard commercial-off-the-shelf (COTS) software program.

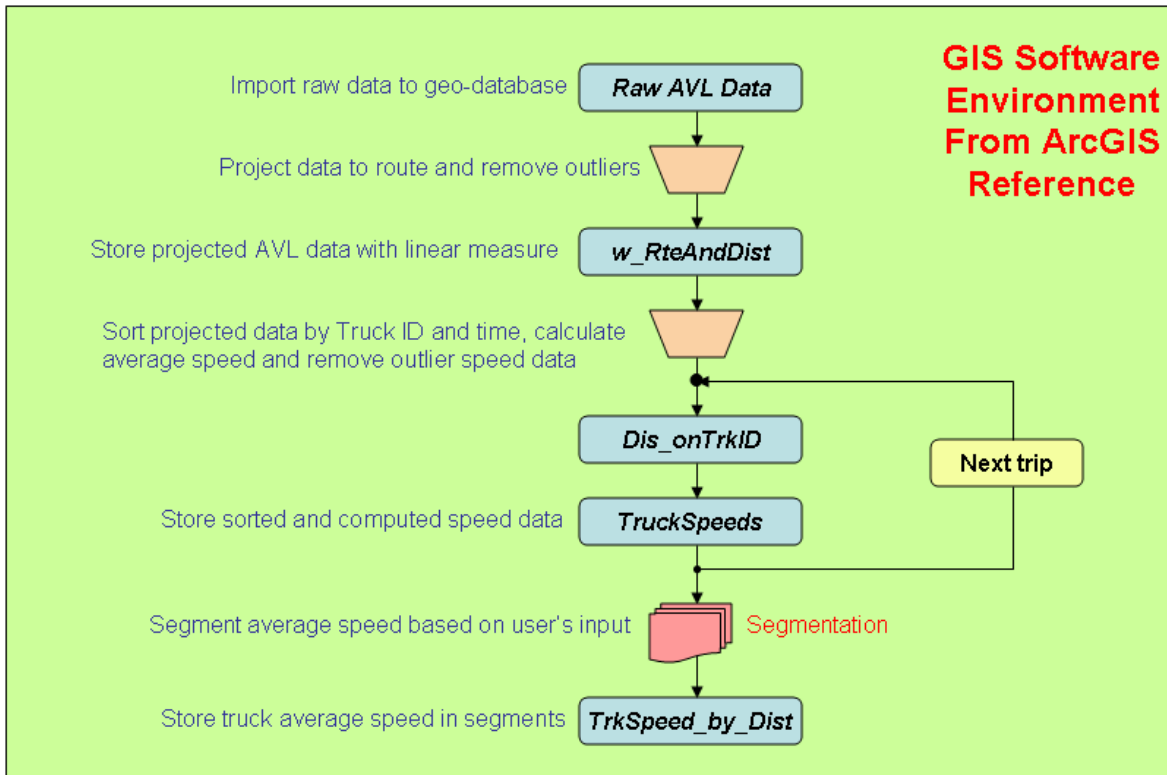


Figure 2-3 Data process flowchart of FPMS I system

2. Functionality of *prjAvgSpeedCalc.dll* program

The functionality of the customized DLL program is listed as follows.

- Interface with geo-database
- Project AVL data to a route
- Perform trip quality and average speed filtering
- Calculate average speed per segment size specified by user
- Store calculated data in geo-database

3. Database structure:

The geo-database of the FPMS I system consists of the following tables as shown in Figure 2-4. The raw AVL table contains the original AVL data. The *finename_w_RteAndDist* table contains the linear measures of each data point after projection. The TruckSpeeds table includes segments of calculated average speed records and traveling direction. The TrkSpeed_by_Dist table has the final speed calculation after segmentation. Major limitation of the database is its scalability (database limited to 2

gigabytes). Other limitations included, limited web applications, security issues, data integrity, backups, transaction logs and roll backs, network bandwidth, and limited user interface [3].

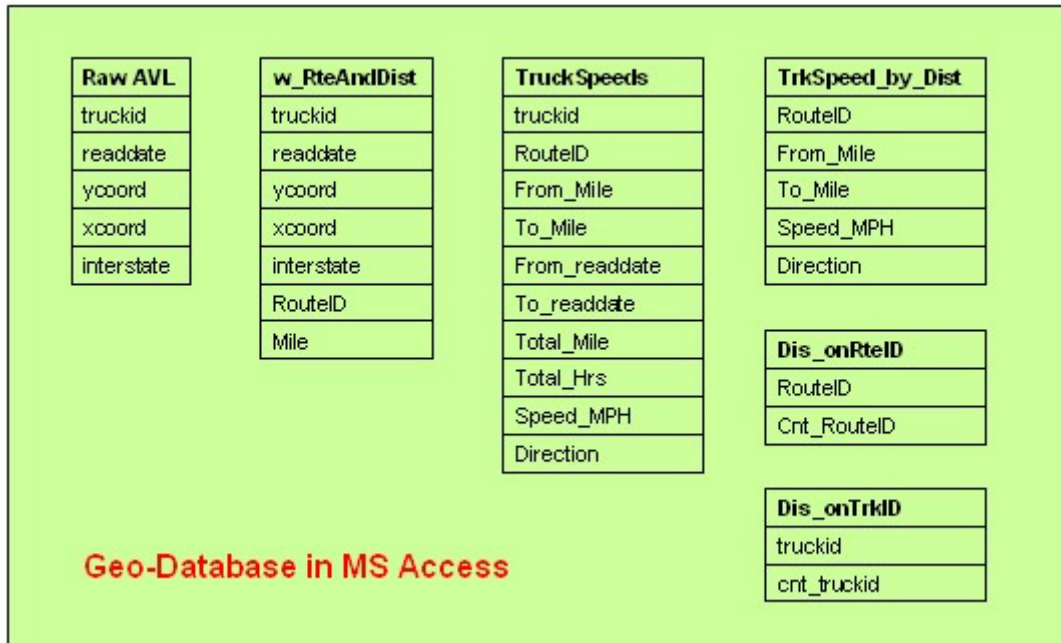


Figure 2-4 Database structure of FPMS I system

II. SQL-based FPM System (FPMS II)

The current FPM system (FPMS II), as shown in Figure 2-5, introduces a SQL server. A data transformation service (DTS) routine residing in the SQL server was used to streamline the truck GPS data processes. An external program (*calcEvents.exe*) was executed through DTS routine to calculate truck average speed with respect to a route GIS database. The *calcEvents* program interfaces with a GIS software development platform in order to determine the truck location with respect to the route GIS map. Calculated results were stored back to the SQL database which can be accessed either through the SQL analyzer or directly from the GIS software. The current FPMS system provides advantage over previous system by computing average truck travel speed outside the GIS environment. However, the *calcEvents* program was executed from the SQL server DTS package, the SQL manager will not respond to other service request when the *calcEvents* program was running. The *calcEvents* program can also communicate with the GIS software development platform and TruckData.dll in order to assign each truck AVL data with respect to the route GIS database stored in the ATRI.dll.

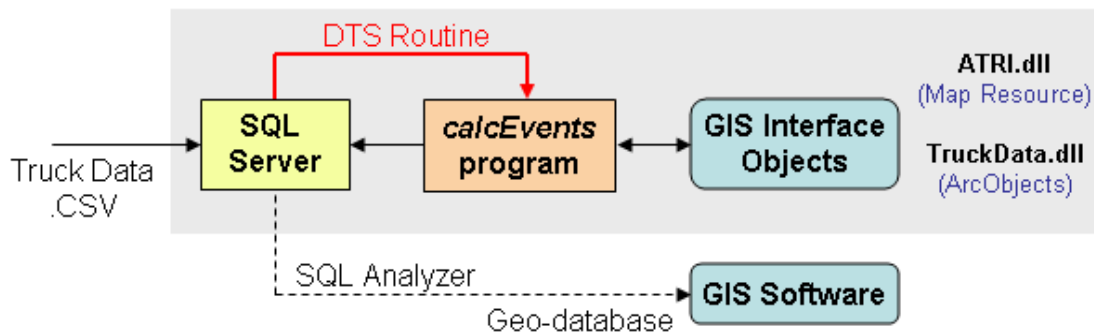


Figure 2-5 Diagram of current ATRI FPM system (FPMS II)

1. Data process flowchart:

The data process flowchart of FPMS II system is illustrated in Figure 2-6. The raw AVL data was loaded into the AVL table in SQL database. AVL data was sorted based on truck ID and its timestamp to generate trip event. An external program, *calcEvents*, was executed to interface with the GIS software development platform and to project the AVL data to nearest route and remove any disqualified AVL data. Each projected data with its corresponding linear measures were stored in the AVL_EVENT table. Average speed was then calculated based on the travel time and distance for each trip. Final segmentation of the speed data was performed in SQL by calling pre-stored SQL procedures. The final results were stored in the STD_LINE_EVENT table.

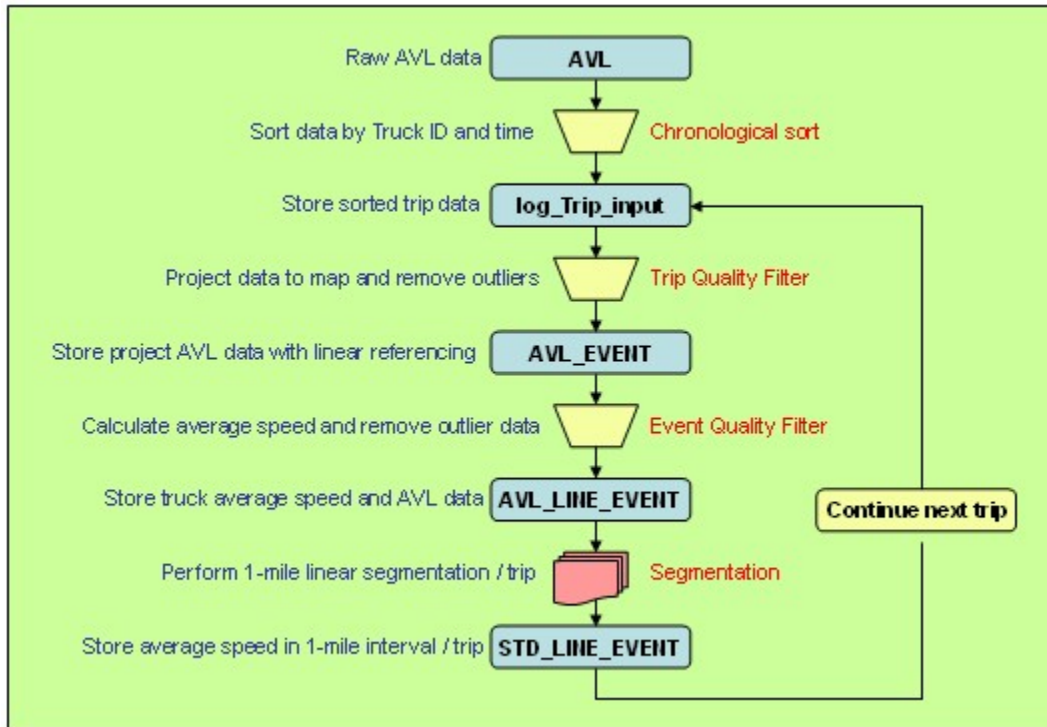


Figure 2-6 Data process flowchart of FPMS II system

2. Functionality of *CalcEvents.exe* program:

Major functionality of the *calcEvents* program is listed as follows.

- Interface with SQL Server
- Execute stored SQL procedure to perform trip quality filtering (in SQL database)
- Project AVL data to nearest route
- Execute stored SQL procedures to calculate average speed and perform segmentation (in SQL database)

3. Database structure:

The SQL database consists of the following tables as shown in Figure 2-7. The AVL table contains the original AVL data. The log_Trip_input table includes the trip information after filter by trip quality filters. The AVL_EVENT table contains the linear measures of each data point after projection and detail time information. The AVL_LINE_EVENT includes segments of calculated average speed records, traveling direction, state and border crossing information. The STD_LINE_EVENT table has the final speed calculation after segmentation. One observation from the current SQL database is that several duplicated data were identified in the AVL_EVENT, AVL_LINE_EVENT, and STD_LINE_EVENT

tables. (For example: *ReadYear*, *ReadQuarter*, *ReadMonth*, etc.) This type of duplication can be minimized or eliminated by using data joint in SQL database.

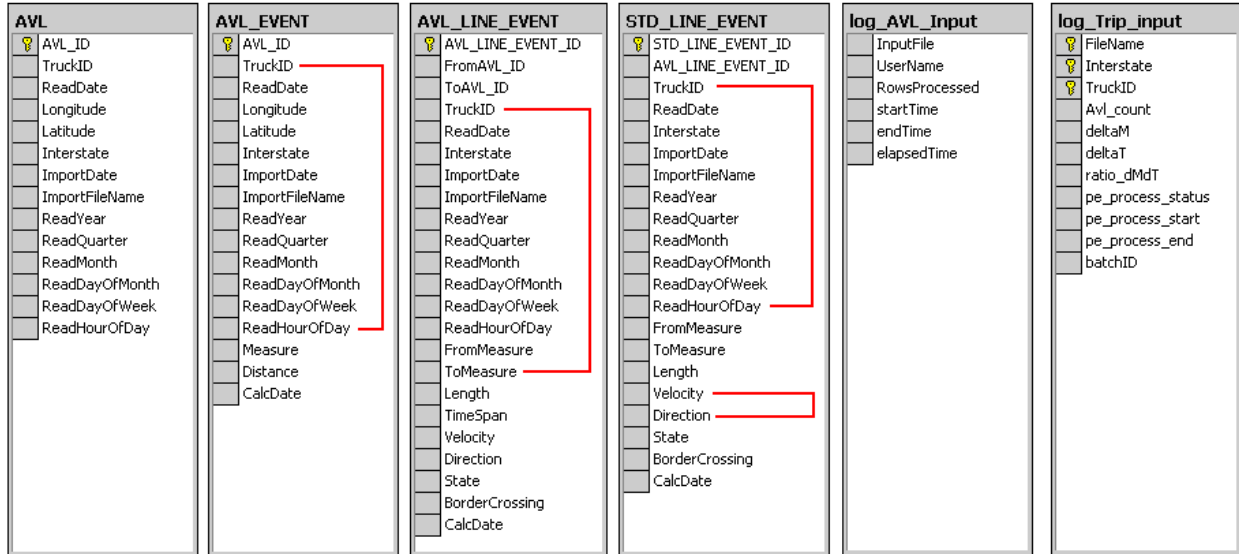


Figure 2-7 Database structure of FPMS II system

4. Issue of data expansion:

Another observation from the SQL database is the tremendous amount of data generated after processing a new dataset. The AVL_EVENT table consists of the acceptable AVL data points that passed the quality filtering test. The STD_LINE_EVENT contains the final speed data after segmentation. The final data size in STD_LINE_EVENT was about 6 times the size of AVL_EVENT for 1-mile segment calculation (about 2 times and 0.5 times for 3-mile and 10-mile segment, respectively).

5. SQL procedures

There are eleven SQL procedures pre-installed in the database server when initially configuring the truck database. The custom program (*calcevents.exe*) interfaces with these procedures in order to process raw truck data and insert calculated data in the database. They are briefly described as follows.

- ***get_line_event_qc***: Get trip quality filter parameters.
- ***get_new_trips***: Get trips with *pe_process_status* = 'New'.
- ***get_new_trips_by_batch***: Get trips by batch ID and with *pe_process_status* = 'New'.
- ***get_trip_avl_points***: Get sorted AVL data for a specified trip.
- ***getGroupStatistics***: Perform group statistics.
- ***getStatisticsAsSegmentEvents***: Calculate segment average speed statistics.
- ***getStatisticsAsSegmentEvents3***: Calculate segment average speed statistics.
- ***insert_line_and_segments***: Insert process trip data to AVL_LINE_EVENT.
- ***insert_point_event***: Inset filtered AVL data to AVL_EVENT table.
- ***set_pe_start***: Set trip data process start time in *log_Trip_input* table.
- ***set_pe_end***: Set trip data process end time in *log_Trip_input* table.

6. Summary of FPMS II analysis:

In evolving from the FPMS I system, the SQL-based FPMS II system processes the AVL data in SQL without the dependency of the GIS software. It allows users to query speed data at desired location and within specified period of time. The flexible DTS routine within SQL server also allows users to process raw AVL data with minimum user intervention. However, several issues were raised regarding the duplication of data in database structure and the growth of data after each process as described in

previous sections. Currently, the *calcEvents* program was executed from the DTS routine inside SQL server. This approach was somehow constrained due to the fact that all data has to be executed on the server. By executing the *calcEvents* program externally will improve the scalability of the FPM system, especially when expanding the system for future application.

Other notes for further consideration:

- GIS software Development Platform **Dependency** - As described in previous section “functionality of the *calcEvents* program”, the *calcEvents* interfaces with a GIS software development platform in the background while calculating AVL data projection. There are open source routines available for performing data projection. The researchers should investigate potential benefits associated with operating the FPMS II system independent from COTS products.
- **Customized Snapping Algorithm** – The ATRI researchers should investigate the accuracy and ease-of-use of the existing customized snapping algorithm in comparison to other applications.

CHAPTER THREE: IDEAL FPM SYSTEM

I. Proposed FPM System

Both 2-tier and 3-tier FPM systems could be considered for future freight performance measurement applications. The 3-tier system offers better system security while the 2-tier system is easier to implement.

1. Two-tier system

An ideal 2-tier FPM system was proposed as displayed in Figure 3-1. The heart of the system is the SQL database server which will allow external applications such as GIS to query processed results and to visualize the performance measures. The linear references and segmentation of each route, based on required minimum segment size of average speed calculation, will be pre-processed through the interface with the GIS software development platform or other open source programs. Segmentation of the GIS route map needs only to be processed once. And the pre-processed route GIS data will be stored in the SQL database for referencing. A truck data processing module will provide the capability to convert different format of truck AVL data, perform snapping and calculate average speed. Average speed of each segment will be calculated and referenced according to the route segment which was already processed and stored in the SQL database. Data structure of current database tables needed to be optimized to exclude information that can already be referenced from existing tables. The proposed truck data processor can either reside in the same computer as the database server resides or outside the SQL server. Multiple truck data processors can also be connected to the central SQL server for data stratification or simultaneous data processing when needed. The SQL database server will be independent of GIS software. Any custom programs, having the capability to interface with the SQL database, can query the data for their applications.

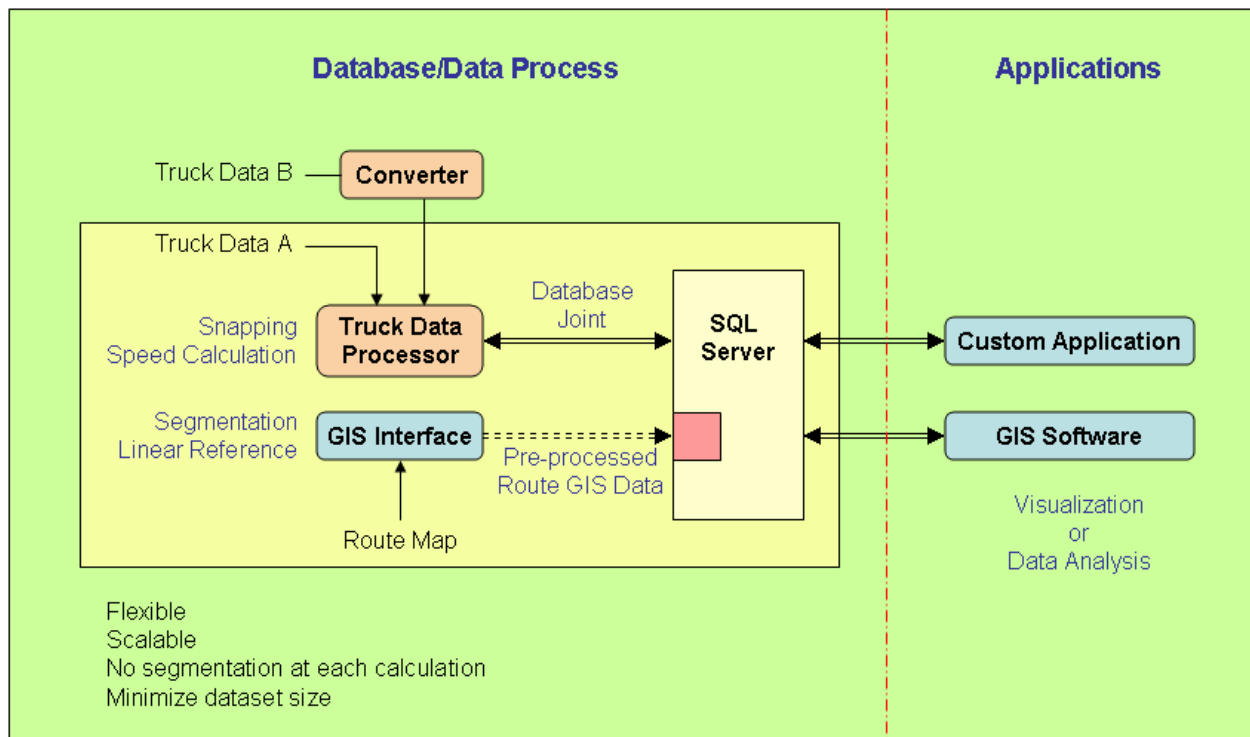


Figure 3-1 Block diagram of proposed 2-tier FPM system

2. Three-tier system

It is recommended that an additional middle tier be added to the system for data security and protection, when remote-access or web-based applications are required in the future. As shown in Figure 3-2, the middle-tier data manager will act as a middleman to handle requests and data transactions between the SQL database server and application clients. External applications can not directly access the database in the 3-tier configuration. The middle layer adds additional security protection to the database by making the SQL database server transparent to the external application clients.

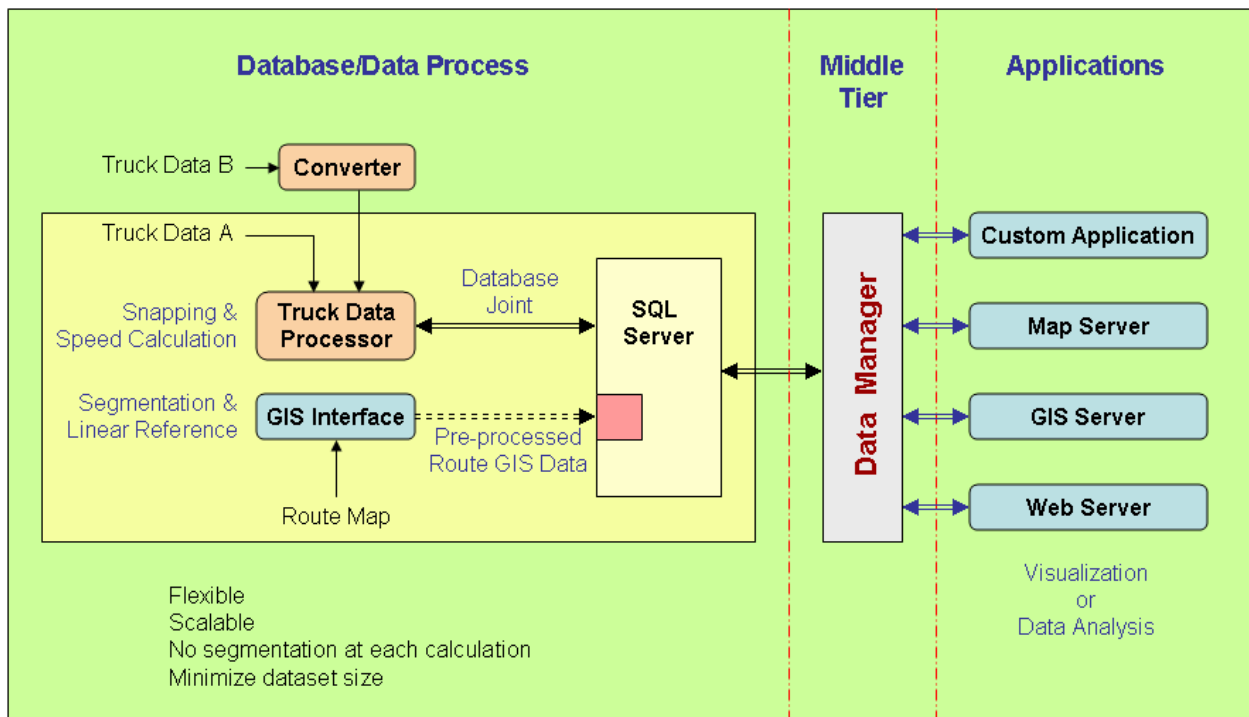


Figure 3-2 Block diagram of proposed 3-tier FPM system

II. Requirements for migration to ideal system

The following validation and verification steps are recommended before migrating to the proposed FPM system.

- Verify and validate GIS route map
- Verify AVL projection
- Determine appropriate segment size
- Modify database structure by using of database joint for minimum data storage

Potential hardware acquisition and software development needed to migrate to the proposed FPM system in the future as discussed a follows.

1. Software development needed

- Pre-process route map and store route data in SQL server
- Evaluate snapping algorithm and snap distance
- Truck data converter interface development
- Modify or include the *calcEvents* program in proposed truck data processing module

- May exclude the dependency on the specific GIS software development platform used for snapping, if considered
- Data manager interface development

2. Potential hardware requirements

- Consider setup multiple truck data processors
- Run SQL server on another multi-processor computer with sufficiently large disk space and memory
- Use current database PC (Dooley) as middle tier data manager for 3-tier configuration
- SQL server data backup & RAID configuration requirements

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