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Truck Cycle and Delay Automated Data Collection System (TCD-ADCS) for Surface Coal Mining

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Thesis submitted to the
Benjamin M. Statler College of Engineering and Mineral Resources
At West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Mining Engineering

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ABSTRACT

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Data management of production records has become a key element in surface coal mining operations. Information systems (IS) and information technologies (IT) can be used as valuable tools for the production monitoring and analysis of employee and equipment performances. This thesis presents the research results on the development and application of a custom-made Truck Cycle and Delay Automated Data Collection System (TCD-ADCS) for surface coal mining. The TCD-ADCS is capable of collecting trucks' production data, delay times, loading and dumping times, travel distance, and GPS coordinates of production events from a mine site. Also, it enables field data transfer through a wireless network to a server located in an office environment. Additionally, the system is compatible with the already developed Integrated Production Management System (IPMS). Data are locally stored in each truck and then synchronized and replicated into a centralized server containing database management system for analysis and reporting. The system relies on motion sensing and distance traveled in order to automatically define the cycle starting/ending points, cycle time, position, and delay time. Connectivity and communication between loading equipment and trucks have also been established. A user-friendly graphic interface has been developed for the communication between the equipment operators and TCD-ADCS system. The infrastructure used for the development of this system application consists in a rugged touch-screen personal computer, 2.4 GHz radio transmitter antenna, and a high-sensitivity commercial GPS receiver. The system was developed, tested, and deployed at a surface coal mines in the U.S.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Average Dump Cycle Time	*ADT*
Average Load Cycle Time	*ALT*
Delay Tolerance Time	*DTT*
Duration Time	*DT*
Employee	*EMP*
Equipment Database	*EDB*
Foreign Key	*FK*
GPS Point Interval	*GPI*
Graphic User Interface	*GUI*
Haul Location ID	*HAULid*
Horizon ID	*HRZid*
Inspection Time	*INSP*
Integrated Development Environment	*IED*
Integrated Production Monitoring System	*IPMS*
Last Update Difference Time	*LUDT*
Latitude	*LAT*
Local Database Cache	*LDBC*
Loader System Application	*LSA*
Loading Time	*LT*
Longitude	*LON*
Maximum Dump Cycle Time	*MDT*
Maximum Loading Cycle Time	*MLT*
Minimum Speed Limit	*MSLa*
Minimum Speed Limit	*MSLb*
Movement Tolerance Time	*MTT*
Point-to-Point Distance	*ppDistance*
Primary Key	*PK*
Production Equipment Environment	*PEE*

Surface Miner	*SM*
Temporary Database	*TDB*
Truck Cycle and Delay Automated Data Collection System	*TCD-ADCS*
Truck System Application	*TSA*

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Chapter 1

Introduction

1.1 Background

Data collection represents a significant endeavor in the mining industry. Most companies invest a considerable amount of time and money in order to obtain reliable and useful data from their operations. In the case of surface mining, operations need to collect different types of data, such as production rates, energy/fuel consumption, cycle times, delays, number of operating hours, and others. Raw data, or field data, need to be mined and filtered prior to the generation of daily, weekly, monthly, and yearly reports. Reporting such information can represent trends and patterns of operational behavior (Heersink and Wells, 2002). Such report analysis can easily display abnormalities in equipment and employee performance. Nevertheless, this field of investigation is still in its early stages of development, and reliable systems that are efficient and sufficiently flexible to be adopted by different operations must be created.

The mining industry is focused on implementations of computer hardware and software, as well as equipment to assist in production monitoring (Tenorio and Dessureault, 2011). Production data collection and transfer can be achieved using automated information systems (AIS) directly from the mine site. Application of information technologies (IT) provides the industry with computing technologies such as hardware, software, and networking components. In addition, the application of information systems (IS) enables mining operations to manage hardware and software to collect and process data. Both, IT and IS help the industry retrieve field data in real-time, and thereby eliminate paper-based reports. Constant, accurate, and on-time reporting places the industry one step ahead in detecting operational faults. Potentially, this approach can also decrease operating costs. Furthermore, MacMillan (1994) believes that reaching optimal levels of technology makes unmanned mining operations possible.

1.2 Problem Statement

Implementing information technologies (IT) and information systems (IS) in the mining industry can help increase productivity and reduce operating costs. Monroe (1992) states that productivity of mining equipment can easily be determined by field measurements. Morgan and Peterson (1968) agree that the productivity for truck and shovel operations can be calculated using average loading, hauling, dumping, return, and maneuvering times. Mkhatshwa (2009) states that equipment performance does not only depend on cycle times, but also on equipment matching, road conditions and gradients, rolling resistance, and operating costs. However, none of the mentioned authors suggest a specific approach of how field data should be collected.

In a prediction methods study for truck cycle time in open-pit mining, Chanda and Gardine (2010) indicate that the application of computer cycle simulation is often used. Simulation systems are capable of recreating haulage conditions and assigning some sort of randomness to loading, hauling, and dumping time, as well as to equipment wear and tear. All of these parameters can be used to estimate the performance and productivity of the equipment. Chanda and Gardine (2010) also believe that the cycle simulations have some inconsistency between actual and estimated results, since unexpected events, such as delays and breakdowns, can occur in the field and not in a simulation. This is certainly a problem because surface mines have constant physical changes over time. These changes have a significant effect on haul roads and, therefore, an impact on truck performance. Ideally, equipment performance monitoring can be achieved by the continuous collection of field measurements.

When it comes to data collection, there are different methods that can be used, including operator's daily production log, engineer field time study, and an automated information system (AIS). In some surface mines, the driver is required to write down the starting and ending times of every truck cycle. This is usually accomplished in an operator's journal, which can be very distracting and time-consuming to maintain. The second approach requires an engineer to constantly take time measurements from several cycles in a single shift in order to generate reliable data. This task is also highly time-consuming. Finally, the development and implementation of information systems (IS) and information technologies (IT) have made it possible to apply computerized systems capable of recording accurate and detailed data directly from the equipment.

There are several examples of computerized systems available that are used for truck cycle monitoring. The Australian company, APS, has developed a series of sophisticated information technologies (IT) capable of tracking and recording truck data such as equipment GPS locations, production cycle time, idle time, delay times, and production records (APS, 2011). This system's infrastructure consists of touch-screen displays connected to control boxes that monitor GPS antennas, radio communication, and multiple sensors located within the structure of the equipment. The entire system is capable of reporting to a centralized server in real-time (APS, 2011). Although this tool is highly sophisticated and useful, a significant amount of employee training must be required before it can be used, and it can be a large capital investment for smaller operations.

Wenco International Mining Systems Limited developed another automated information system (AIS). Wenco provides a FleetControl system that is capable of collecting activity, location, time, and production data directly from the field (Wenco, 2012a). It controls several mining activities, and connects directly to an on-site and off-site WencoDB system (Wenco, 2012b), which is a tool operated with a MS SQL Server database. Using database management systems (DBMS), the Wenco control system facilitates the generation of custom-made field reports. It is also versatile enough to connect to other reporting systems. Like APS, this monitoring system is well-suited for larger surface mines, and it also may require significant employee training.

Hawkes et al. (1995) also believe that the implementation of monitoring systems in mining operations can provide a significant improvement in productivity. When studying the productivity of machinery such as trucks and shovels, one must take measurements of cycle time, loading time, dumping time, idle time, breakdown time, delay time, shift changes, scheduled maintenance, and truck location. However, Hawkes et al. (1995) do not provide a description of a hypothetical infrastructure, or a methodology for collecting data from the field. Instead, they suggest using various information systems (IS) such as AMSKAN, DISPATCH, and PMCS 3000, all available on the market.

Many large-scale surface mining operations have implemented various automated data collection systems (ADCS). For instance, the Fimiston gold mine in Western Australia has developed and used its own surface mining reporting system since 1997 (Karunaratna and Mattiske, 2002). It consists of a combination of data collection tools that have been adapted to multiple development stages of the mine. The system is structured around a local Oracle database which connects to the different data collection tools through an Intranet network. However, it is not clear if the system can be linked directly to cycle and delay monitoring. Modern surface mine operations apply various database engines such as MS Access, Oracle, and MS SQL server to store incoming field data in a real-time or near-real time (Bogunovic, 2008). It is not uncommon for less technologically advanced mines to use spreadsheets and paper-based reports.

Today, systems like VIMS (Vital Information Management System), APS (Automated Positioning Systems), and FleetControl in combination with WencoDB are used for equipment data management. All three systems can be used to collect, mine, analyze, and report data. However, the application of available information technologies (IT) restricts the client to use the provided data analysis and reporting features, reducing the opportunity for further data analysis and customized reporting (Bogunovic, 2008). Customization of information systems (IS) for data collection, analysis, and reporting is an alternative approach the industry can take to integrate information technologies (IT) that best fit their needs.

The Integrated Production Management System (IPMS) developed by Bogunovic (2008) is capable of managing data from various sources in surface coal mining environment. It was initially designed to create a Database System (DBS) that handles production, energy consumption, and CO_2 emission data from multiple pieces of equipment. However, it uses sources such as spreadsheets and paper-based forms were data is inserted manually. The IPMS's purpose is to generate near real-time reports that will help to improve management decisions (Bogunovic, 2008). Yet, there is a need to develop customized technologies that will facilitate the automated data collection and transfer directly from the field while still being compatible with present data management systems (i.e., the IPMS). Mielli (2011) proposes a solution for the mistreatment of field data. Implementation of information technology (IT) solutions can handle dissimilarities between new and already existing information systems (IS). Customized data management systems help share common information in a more centralized and interchangeable form. Mielli also refers to this approach as an orchestration of information systems (IS). However, current systems need to be standardized for friendlier information accessibility (Mielli, 2011).

Development and integration of a custom-made automatic information system (AIS) for field data collection is generally more efficient than using available production monitoring systems. It allows the user to make changes and adjustments that best fit the company's business model to generate more effective results. Additionally, the development efforts are focused in developing a system that overcomes the current needs of the mine. Furthermore, it is not only a lower capital cost but it could also be user-friendly.

1.3 Scope of Work

The main goal of this research study is to develop and implement an automated information system (AIS) that will be able to collect production data from dump trucks, and to transfer field data in real-time through a wireless network (WLAN) to a centralized server located in an office environment. The data collection includes loading and dumping times, haul time, haul distance, equipment location, materials description, dump locations, load count, delay time, number of operating hours, and employee identification numbers. The information system (IS) must be compatible with the IPMS infrastructure in order to make data interchangeable.

The research objectives are as follows:

- To apply information technologies (IT) to establish communication between trucks, shovels, and a remote server, using a wireless network.
- To build a software application to collect truck cycle records such as loading time, dumping time, haul time, haul distance, load location, and dump location.
- To create a software application for delay time and delay category recognition during regular operating hours.
- To generate a user-friendly front-end interface for truck and shovel operators.
- To select and integrate computer hardware such as touch-screen displays, portable computers, GPS antennas, wireless modem PC-cards, and appropriate radio antennas. All hardware must be mounted in a secure form on trucks and shovels.

- To establish communication between an automated data collection system (ADCS) and the existing IPMS. The developed automated information systems (AIS) must be able to synchronize data in real-time.

Having reliable data transfer routes is essential for the industry, since this will avoid field data corruption. It is important to consider that instability of data routes can result in data loss. Interaction between the ADCS and DBMS depends on a reliable wireless network. Equipment must be able to communicate to a centralized server regardless of its location on the mine site. Unfortunately, network administrators do not have complete control over possible events that may disrupt the on-site network components. In a surface mine, wireless network components can be easily affected by weather conditions, power supply failure, or hardware damage. In the case of such events, the TCD-ADCS should also incorporate local data storing features.

This thesis does not include the integration of already existing technology on mining equipment such as built-in payload scale, safety warning systems, and tire pressure sensors. However, such considerations should be considered for further research in the field, and possible expansion of this study.

Chapter 2

Methodology

2.1 Introduction

The objective of this research project is to develop a Truck Cycle and Delay Automated Data Collection System (TCD-ADCS) for the surface coal mining industry, specifically for an operating coal mine in the southern part of the United States. The TCD-ADCS is a custom-made system that fulfills the company's business model. Data flow, naming conditions, variety of codes, and many other details used for day-to-day process are integrated in this system. In addition, the system has been built within the company, and all maintenance and upgrades will be provided by the mine IT personnel. Since the TCD-ADCS has been designed around the company's business model, it can be applied to other mining operations within the same company.

2.2 Proposed Technical Approach

The methodology for the TCD-ADCS is inspired by the successful development and deployment of the IPMS in a particular surface mine environment. The expansion of the IPMS makes paperless truck production reporting a reality. Data collection and database synchronization is accomplished real-time using on-site wireless networking (Heersink and Wells, 2002). Data compilation, data management and analysis remain the IPMS's main task. The reporting of applicable information is performed by the tools within the IPMS. The integration of both information systems, the TCD-ADCS and the IPMS, generates accurate and up-to-date production and performance information for equipment operators. The data gathered is transformed into valid information for improved management-decision making. Figure 2.1 shows a representation of data transformation from raw field data to applicable actions.

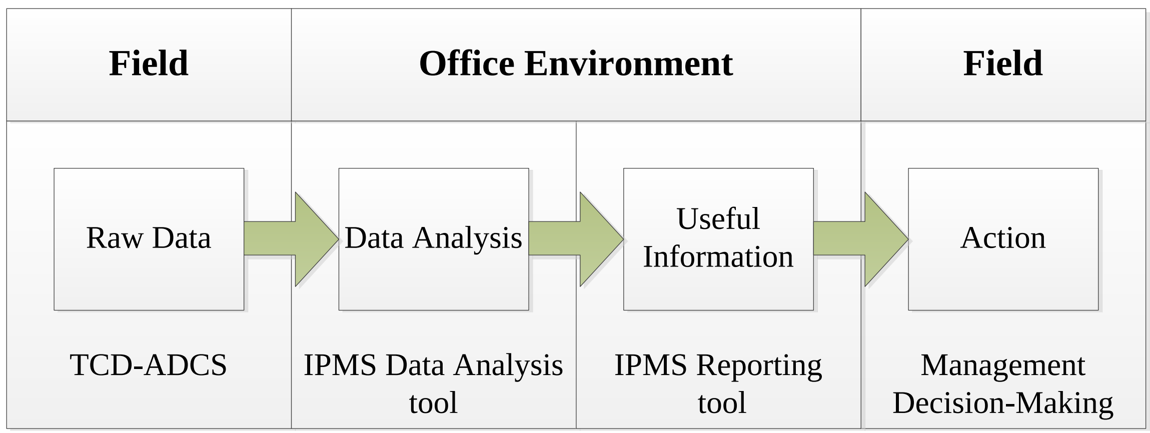


Figure 2.1 Raw data transformation

There were four major phases in the development of the TDC-ADCS: (1) Design, (2) Development, (3) Testing, and (4) Integration. All phases addressed multiple tasks for the completion of this research (Figure 2.2).

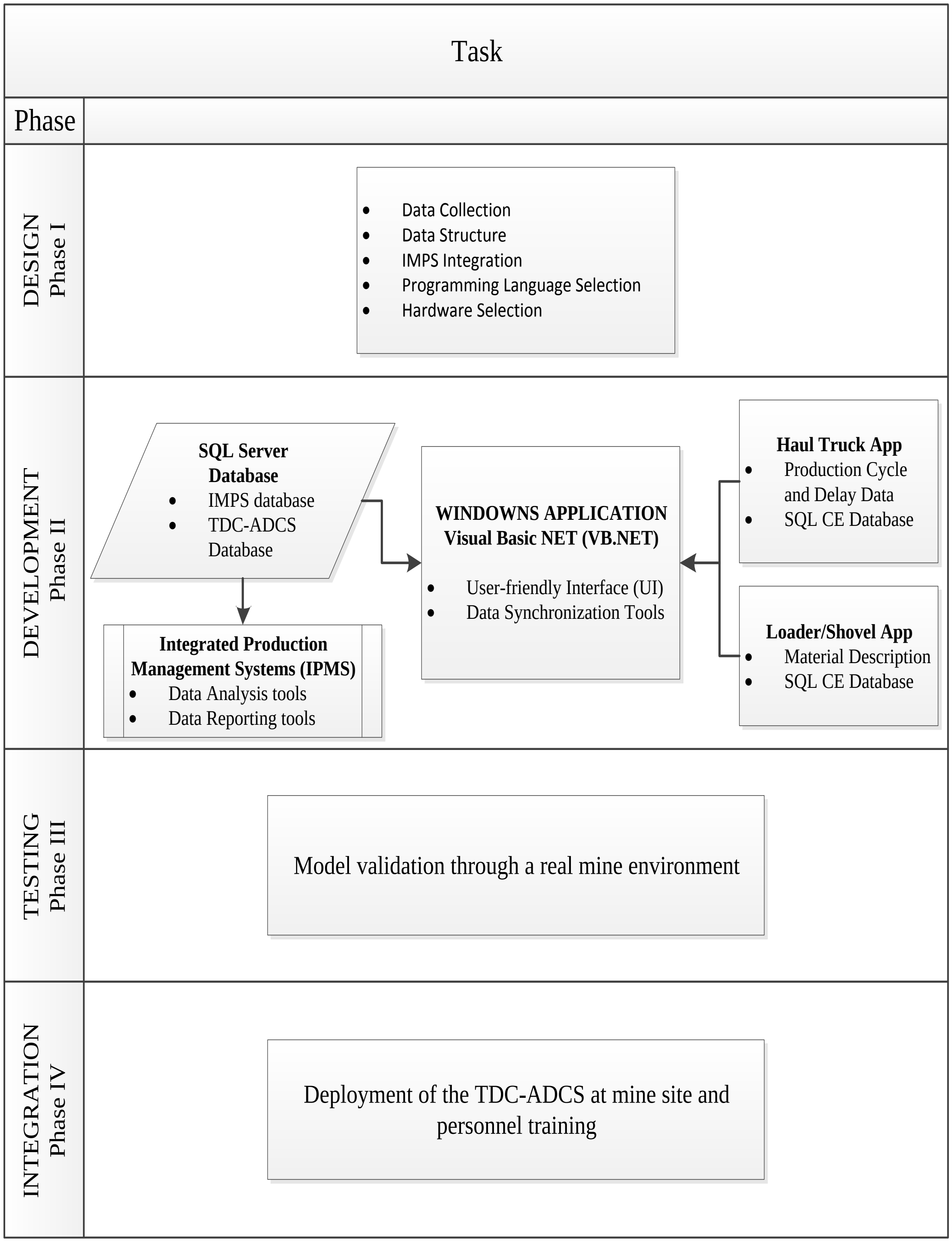


Figure 2.2 Methodology for TCD-ADCS development

2.3 Implementation Requirements

Data compatibility is always a major concern when integrating existent and new information systems (IS). As a requirement, the main data structure of the TCD-ADCS should be identical to the one found in the IPMS environment. The IPMS is structured over a MS SQL Server database engine, so the automated data collection system (ADCS) must also use a MS SQL Server database. If incompatible technologies are implemented, data can be segregated in isolated and duplicate databases (Mielli, 2011). In order to make data interchangeable between the TCD-ADCS and IPMS, both data models must share equal table names, Primary Keys (PK), Foreign Keys (FK), and data types. In order to avoid the accumulation of dissimilar and meaningless data, the information system (IS) implementation should treat raw data, filtering, and active integration carefully.

2.4 Hardware Requirements

The hardware for the implementation of an ADCS must be selected based on purpose, size, flexibility, and durability. During the integration between the TCD-ADCS and the IPMS, hardware components are divided into two categories: Equipment hardware and Non-equipment hardware.

Non-equipment hardware refers to information technologies (IT) that establish the Local Area Network (LAN), Wireless Network (WLAN), servers, modems, routers, and other passive and active network components (Bogunovic, 2008). Most network components are located in an office environment (Figure 2.3). Some of them, like wide range wireless receivers and repeaters, are located throughout the mine site. The TCD-ADCS integration requires the utilization of the entire WLAN provided at the mine site. Also, a permanent and centralized server, hosting DBMS (e.g., MS SQL Management Studio), is used for the database administration of both information systems (IS).

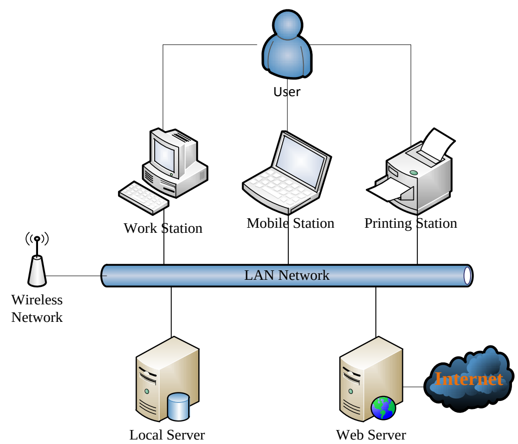


Figure 2.3 Office environment hardware requirements

Equipment Hardware refers to the combination of passive and active computer components added to the mining equipment (e.g., trucks and loaders). This cluster of components is similar to that of an office environment (e.g., computers, modems, and receivers). The design and development phases (Phase I and Phase II) of this research project require the installation of hardware for wireless communication, GPS signal reading, data storage, and ultimate user interaction (Figure 2.4). As a result, the hardware additions for field equipment are:

- a portable touch-screen computer (also as remote server),
- a GPS receiver,
- a radio transmitter antenna,
- WLAN PC modem, and

- miscellaneous passive computer components.

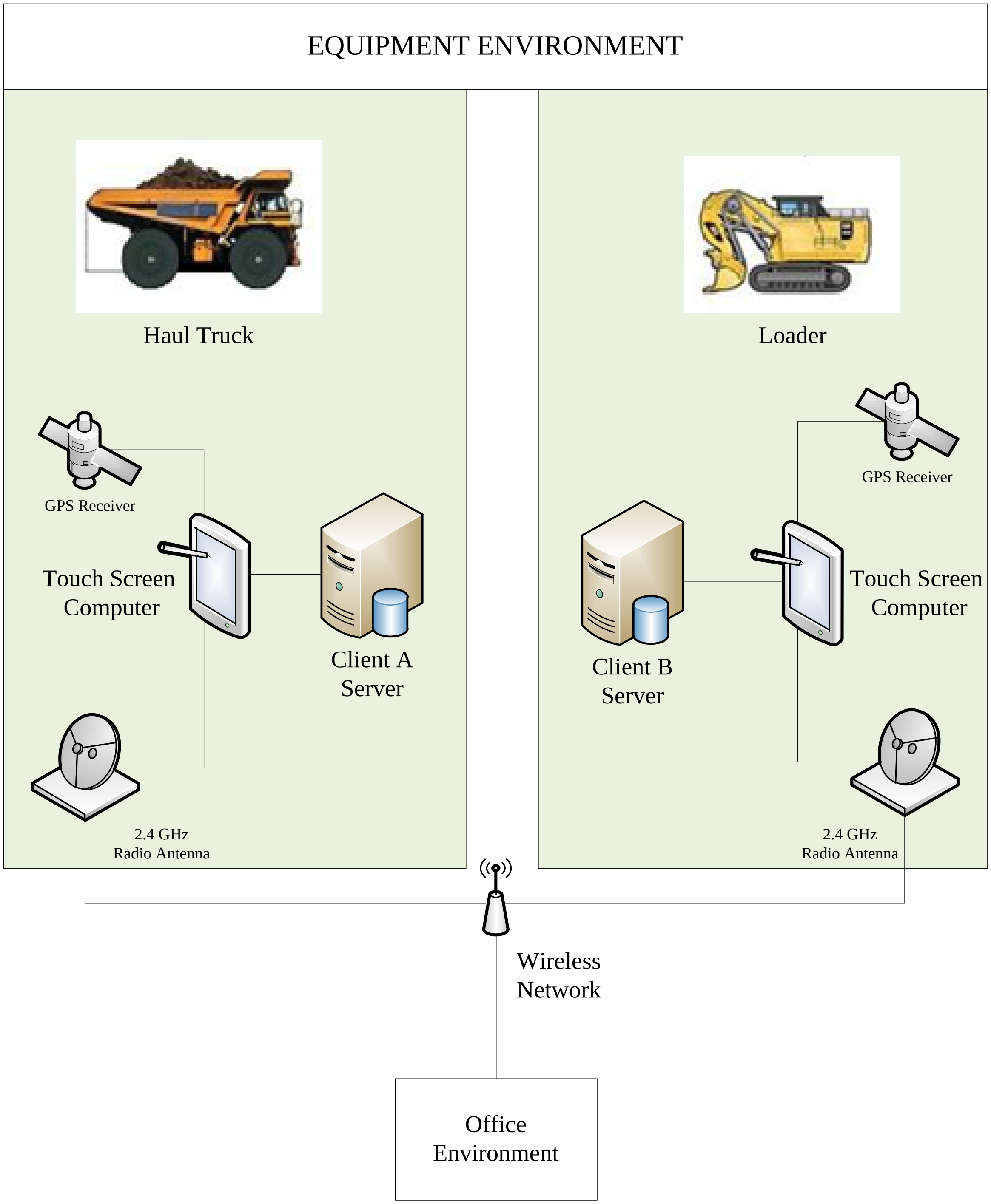


Figure 2.4 Equipment environment hardware requirements

2.4.1 Portable Computer – Touch-screen display

For the development of the TCD-ADCS, equipment on-board computers must:

- have a touch-screen display,
- use MS Windows as the operating system (OS),
- include PC wireless modem and radio antenna compatibility, and
- be vibration resistant.

The Panasonic Company offers a Fully-Rugged version within its product line of personal Toughbooks (Figure 2.5). This portable computer features a 10.4-inch touch-screen and high durability ideal for the constant interaction between the user and the TCD-ADCS (Panasonic, 2011). One advantage of this particular PC is the high resistance to rough mine environment conditions.

Figure 2.5 Panasonic Toughbook 19

2.4.2 High Sensitivity GPS Receiver

For this research project, position accuracy is not a major concern. Using a low-precision and high-sensitivity GPS receiver is not only more practical but also lower in cost than using a high-precision device. The TCD-ADCS requires a receiver proficient in reading multiple GPS sentence formats. As it interprets the information from incoming sentences, the information system (IS) is able to acquire values such as longitude, latitude, elevation, and ground speed. The Garmin GPS 18 USB receiver (Figure 2.6) includes a magnetic base structure that is ideal for attachment to the mobile equipment.

Figure 2.6 Garmin GPS 18 USB receiver

Portable computers do not feature RS-232 serial ports; therefore, the TCD-ADCS requires a GPS receiver with a USB connection. The Garmin 18 USB receiver has a USB connector compatible with standard USB 2.0 ports. The technology used throughout this project requires a Communication Port (COM port) to access external hardware (e.g., GPS receiver). Garmin Ltd. provides software systems used to address hardware incompatibility issues. The GpsGate Client software is capable of creating a “Virtual COM Port” which enables interaction between the GPS receiver and the TCD-ADCS (Garmin, 2011).

2.4.3 PC Modem Card and 2.4 GHz Radio Antenna

The TCD-ADCS requires reliable and continuous communication between the mining equipment and the office environment. Since surface mines cover vast areas, the industry can apply an open wireless networks (i.e., wireless ad-hoc networks). For instance, a Mesh Wide Area Network (MWAN) enables 2.4 GHz Mesh Solo users to launch communication wirelessly to a broadband network. Motorola Solutions Inc. offers a wide selection of hardware for implementing MWAN (i.e., Motorola Mesh 6300 Wireless Modem Cards) (Motorola, 2011). Also, PCTEL Inc. offers 2.4 GHz Low Profile Whipless Antennas that provide superior coverage for mobile and fixed applications (PCTEL, 2011). This company offers "a design with leading performance and high reliability, with minimum losses and no tuning required" (PCTEL, 2011). The Wireless Modem Card and a 2.4 GHz radio antenna (Figure 2.7) can be installed directly on portable computers. Additionally, it eliminates the need for external modem installation and electric wiring.

Figure 2.7 PCTEL 2.4 GHz radio antenna and Motorola Mesh 6300 PC card

2.4.4 Miscellaneous Hardware

The installation of equipment hardware also requires miscellaneous passive computer components. These components are:

- *PC power supply* – The permanent wiring and installation of a DC power supply and AC adapter is required to power the on-board portable computer.
- *USB Extension Cord* - Garmin provides three-feet of wire for most their GPS receivers. An extension cord is required to proceed with external installation of the Garmin 18 USB GPS receiver.
- *Antenna Mount Brackets* – PCTEL radio antennas are compatible with 1-1/18" -18 thread steel mounts.

- *Coaxial Cable* – Cable is needed to establish communication between the 2.4GHz radio antenna and WMC6300 Motorola Wireless Modem Card.

2.5 Software Requirements

During Phases I through IV (design, development, testing, and integration), multiple computer programs and applications were used (Figure 2.8). The development of the TCD-ADCS requires a comprehensive database server and information platform (e.g., MS SQL Server), DBMS (e.g., MS SQL Server Management Studio), and an integrated development environment (IED) for MS Windows applications (e.g., MS Visual Studio) (Halvorson, 2008). Also, the Franson GPSGate Client software was used for interaction between the automated information system (AIS) and Equipment hardware as previously discussed.

SOFTWARE REQUIREMENTS			
Phase I	Phase II	Phase III	Phase IV
➢ MS SQL Sever Express Edition 2005	➢ MS SQL Sever Express Edition 2005 .mdf database .sdf database ➢ MS Visual Studio 2008 VB.NET	➢ MS SQL Sever Express Edition 2005 ➢ Integrated Production Management Systems (IPMS)	➢ MS SQL Server Management Studio Express ➢ Integrated Production Management Systems (IPMS) ➢ Franson GPSGate Client 2.6

Figure 2.8 TCD-ADCS development software requirements

2.6 Phase I – Design

The design phase began with a visit to the mine and coordination with management personnel. The mine provided a written proposal as well as a verbal explanation of the project's specifications. The design phase required detailed knowledge of both the field data structure and the current data management techniques. In other words, there was a need to define "what" data to collect and "how" to collect it from the field. The information collected from the first interview consisted of a SQL Server database (.mdf file), IPMS Windows application (Figure 2.9), paper-based forms used for daily recording, and user interface schemes.

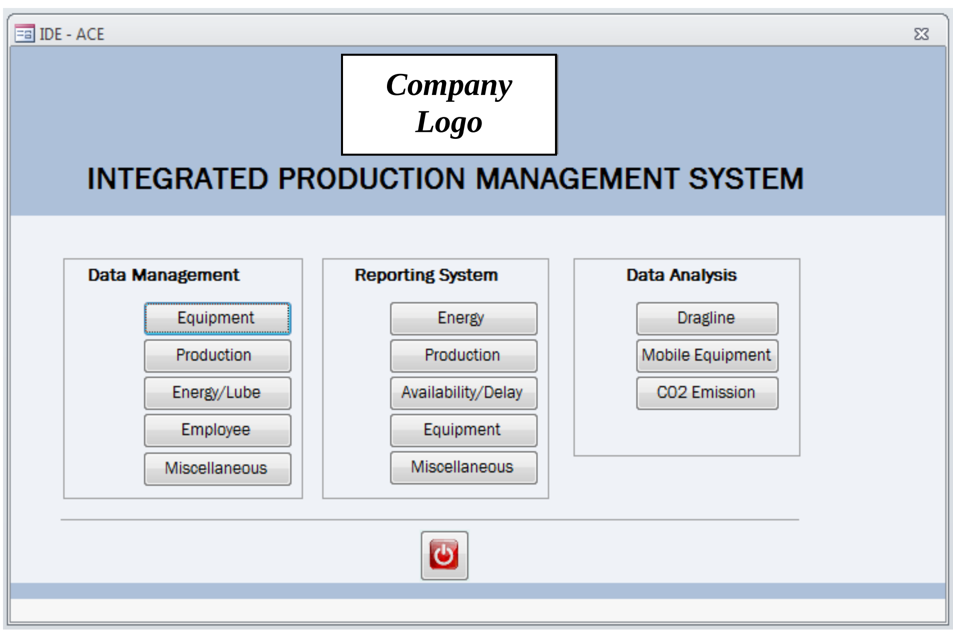


Figure 2.9 IPMS front end-user interface

The database file provided by the mine management consists of over seventy tables and corresponds to the IPMS database structure. These tables contained employee data, crew definition, scheduling, and field equipment. They were required for proper field data generation. Along with these tables, additional necessary production and delay tables were included in the design of the TCD-ADCS. The remaining sections of the IPMS, including energy consumption, cost analysis, dragline, dozer push, CO2 emission, and weather, were not in the scope of this design.

The design of an information system (IS) that is compatible with the IPMS needs to maintain an identical data structure to establish a suitable interaction between the two systems. Tables considered sharable between systems defined the communication direction between the IPMS and the TCD-ADCS. Using data modeling and a database to develop a Database System (DBS), the ADCS separates tables of interest by incoming data tables and data source tables. Data source tables are referred as "general data tables" and incoming data tables are referred to as "field data tables".

General data tables refer to those containing data previously generated in an office environment (IPMS environment), and which cannot be modified by any circumstances at the equipment environment. These data include:

- employee identification numbers,
- employees' full names,
- equipment serial numbers,
- equipment categories, equipment fleet,
- crew codes,
- crew rotation schedules,
- delay categories,
- delay descriptions,

- haul location,
- haul description,
- material dump areas,
- material description,
- shift IDs, and
- shift description.

The second category (field data tables) hosts data that can only be recorded directly in the equipment environment. Field data needs to be accurately linked to specific values found in the general data category every time a new record is reported. Combining both data table classes is the optimal solution for creating detailed truck production cycle and delay information.

Table 2.1 shows two main classes of tables for collecting incoming field data from an equipment environment. The IPMS was not initially developed with the intention of storing detailed truck cycle data; thus, the need to expand the current database structure and accommodate new tables to store field data was clear. A solution involved generating a replica of the main data structure, in addition to truck cycle tables, in a temporary database (TDB).

Table 2.1 Original table set from IPMS database

Table Classification	Table Type	Table Name	Environment Direction
Field	Truck Production	PRO TRUCK TEMP	Equipment → IPMS
	Delay	DELAY TIME TEMP	Equipment → IPMS
General	Delay	DELAY CATEGORY	IPMS → Equipment
	Delay	DELAY CODE	IPMS → Equipment
	Loader	LOADERS	IPMS → Equipment
	Load Location	HORIZON	IPMS → Equipment
	Dump Location	HAUL LOCATION	IPMS → Equipment
	Shift	SHIFT	IPMS → Equipment
	Crew	CREW ROTATION	IPMS → Equipment
	Crew	CREW CODE	IPMS → Equipment
	Equipment	EQUIPMENT	IPMS → Equipment
	Employee	EMPLOYEE PRODUCTION	IPMS → Equipment

The creation of new cycle tables formed a depository for field data, such as loading and dumping time, haulage distance and time, and GPS coordinates. Simultaneously, tables for equipment operating hours, loader application, and the GPS tracker were created and introduced to the temporary ADCS database. All developed tables were designed to collect field data from an equipment environment for transfer to the IPMS (Table 2-2).

Table 2.2 New field data tables introduced in a temporary database

Table Classification	Table	Table Name	Environment Direction
Field	Loading and Dumping Records	LOAD DUMP CYCLE	Equipment → IPMS
	Log In Records	LOGIN rec	Equipment → IPMS
	Loader Broadcast	SENT MSG LOADER	Equipment → IPMS
	GPS Tracker	GPS LOCATION RECORD	Equipment → IPMS

2.6.1 Truck Cycle Field Tables

As mentioned before, this ADCS must store data generated during truck production cycles. To achieve this goal, the TCD-ADCS is designed based on the premise that the total cycle time is the sum of all time intervals that describe cycle stages and unexpected events that take place while the equipment returns to the same starting position. Most commonly, the starting location is adjacent to the loading equipment. A single truck cycle is composed of spotting/queuing, loading, material haulage, turning or positioning, dumping, returning, and delays (Figure 2.10). However, for the design of the TCD-ADCS the truck cycle is simplified to loading, hauling, dumping, returning, and delays (Figure 2.11). This simplified version of total truck cycle time merges spotting/queuing time with delay times and turning or positioning time with hauling time. Such approach is essential because it simplifies the data collection process and eliminates potential margin of error.

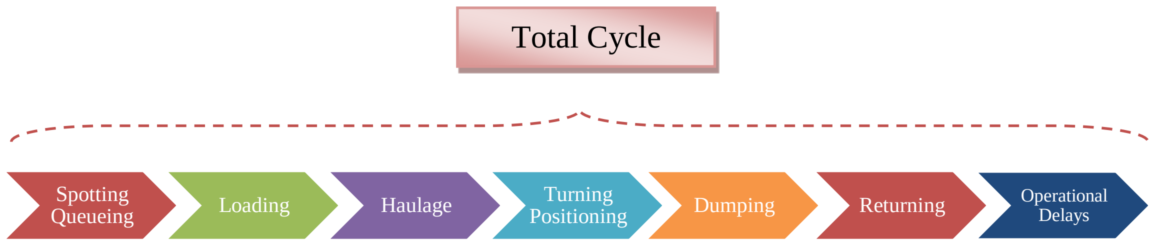


Figure 2.10 Theoretical truck cycle time

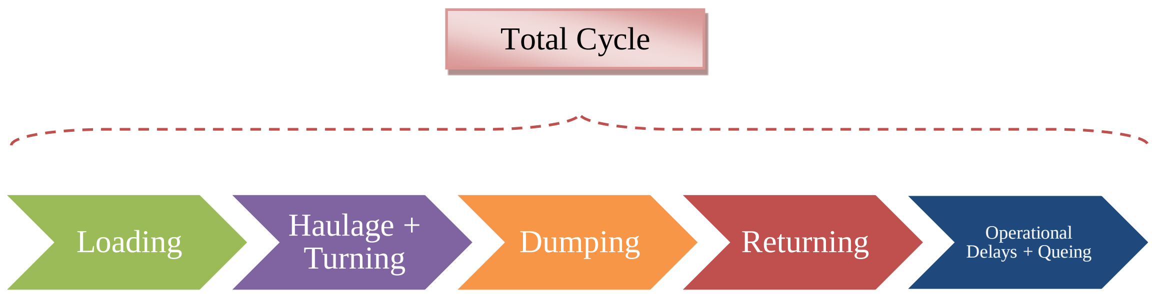


Figure 2.11 TCD-ADCS truck cycle time

<u>Loading and Dumping Table</u>

The incoming truck cycle data from the equipment environment is distributed in three relational tables. Starting with loading and dumping records, the *LOAD DUMP CYCLE* table links event duration times with data such as equipment numbers and employee numbers. Concurrently, values for northing, easting, elevation, and a time stamp are collected every time a loading or dumping record is inserted to the database. Remaining sections of a truck cycle are recorded in production, GPS tracker, and delay tables.

Equipment Time Card Table

An operating-hour record table was incorporated into the temporary database to serve as a virtual equipment time card. This table can store the date and time stamps of when the equipment starts and concludes operation. It should also carry sufficient data for the IPMS to query a distribution of operating hours by employee. A new record should be introduced at the beginning of every shift, operator rotation, end of shift, or if the equipment is shutdown.

GPS Tracker Table

Travel time and duration values measured in the hauling and returning stages of the truck cycle should be stored in a GPS tracker table. Even though new records are constantly generated throughout the cycle, they must be segregated and linked to each independent cycle run. Advanced SQL database techniques were required to optimally separate incoming records by each independent truck cycle. Every truck cycle generates a unique cycle identification number assigned in production records. This identity number should also be linked to every single record introduced in the GPS tracker table. Such value is maintained as a constant until the beginning of the subsequent cycle. Along with the production cycle ID number, this table should include fields for time and date, northing, easting, elevation, distance from previous point, and equipment and employee numbers.

Like many other GPS manufacturers, Garmin's GPS receivers are based on the National Marine Electronics Association's NMEA 0183 ASCII interface specification. This particular model (Garmin GPS 18 USB) is not capable of transmitting NMEA 0183 sentences; instead it uses its USB serial interface to receive NMEA 0183-compliant

Garmin property sentences (Garmin, 2011). These are GPS sentences that begin with the characters “PGRM”. However, in the software requirement section of this thesis, it was specified that the ADCS will use a Virtual COM port using Franson GpsGate software. This software application also functions as a Spanner or “an application that can provide NMEA output via a Virtual Port” (Garmin, 2011). This feature enables selection of specific GPS sentences that fit the design phase of this research. Using multiple NMEA 0183 sentences is not a major concern since the receiver can acquire new readings at least once per second.

The TCD-ADCS focuses on collecting four values incoming to the GPS receiver: northing, easting, elevation, and ground speed. These four critical values can be found within multiple NMAE 0183 and Garmin property sentences. Some GPS sentences provide more information than others. Since there is no right or wrong in properly selecting GPS sentences for this application, the selection was arbitrary. During the development phase of the TCD-ADCS, a combination between “GPGGA” and “GPRMC” sentences were selected for coordinates and ground speed reading, respectively. Garmin (2011) provides a reading structure for both GPS sentences selected during the development of the information system (IS) (Table 2.3 and Table 2.4).

Table 2.3 GPGGA sentence structure (Garmin, 2011)

$GPGGA, <1>,<2>,<3>,<4>,<5>,<6>,<7>,<8>,<9>,M,<10>,M,<11>,<12>*hh<CR><LF>	
<1>	UTC time of position fix, hhmmss format for GPS 18x PC or LVC
<2>	Latitude, ddmm.mmmm format for GPS 18x PC/LVC (leading zeros will be transmitted)
<3>	Latitude hemisphere, N or S
<4>	Longitude, ddmm.mmmm format for GPS 18x PC/LVC (leading zeros will be transmitted)
<5>	Longitude hemisphere, E or W
<6>	GPS quality indicator, 0 = fix not available, 1 = Non-differential GPS fix available, 2 = Differential GPS (WASS) fix available, 6= Estimated
<7>	Number of satellites in use, 00 to 12 (leading zeros will be transmited)
<8>	Horizontal dilution of precision, 0.5 to 99.9
<9>	Antenna height above/below mean sea level, -9999.9 to 9999.9 meters
<10>	Geoidal height, -9999.9 to 9999.9 meters
<11>	Null (Differential GPS)
<12>	Null (Differential Reference Station ID)

Table 2.4 GPRMC sentence structure (Garmin, 2011)

$GPRMC, <1>,<2>,<3>,<4>,<5>,<6>,<7>,<8>,<9>,<10>,<11>,<12>*hh<CR><LF>	
<1>	UTC time of position fix, hhmmss format for GPS 18x PC or LVC
<2>	Status, A = Valis position, V = NAV receiver warning
<3>	Latitude, ddmm.mmmm format for GPS 18x PC/LVC (leading zeros must be transmitted)
<4>	Latitude hemisphere, N or S
<5>	Longitude, ddmm.mmmm format for GPS 18x PC/LVC (leading zeros must be transmitted)
<6>	Longitude hemisphere, E or W
<7>	Speed over ground, GPS 18x PC and LVC: 000.0 to 999.9 (leading zeros will be transmitted)
<9>	UTC date of position fix, ddmmyy format
<10>	Magnetic variation, 000.0 to 180.0 degrees (leading zeros will be transmitted)
<11>	Magnetic variation direction, E or W (westerly variation adds to true course)
<12>	Mode indicator (only output if NMEA 0183 version 2.30 active), A = Autonomous, D = Differential, E = Estimated, N = Data not valid

The transformation of Longitude (LON) and Latitude (LAT) from the polar coordinate system to the English unit system can be very complex. However, an alternative solution in the TCD-ADCS has been applied for coordinate transformation. The alternative solution assumes the shape of the earth as a perfect sphere. This may not be the most precise assumption, but for the purpose of this research, it is an accurate enough solution. The values read by the GPS receiver are used to calculate point-to-point distance in one single equation (Equation 2.1). $\text{Distance}_{[A\text{-}B]}$ is the radius of the earth times the difference in longitude and latitude from point A to point B.

$$\boldsymbol{Distance}_{[\boldsymbol{A-B}]} = 6{,}376.5 * 3{,}280.84 \, * \left(Acos\big(Cos(LON_A - LON_B) * Cos(LAT_A) * Cos(LAT_B) + \, Sin(LAT_A) * Sin(LAT_B)\big)\right) \quad (2.1)$$

where: $\text{Distance}_{[A\text{-}B]}$ is in feet, LAT is in degrees, and LON is in degrees.

Production Cycle Table

At the end of every shift, production supervisors were required to access the IPMS and introduce production cycle data presented in paper cards by equipment operators. Production cards included the operator's name, equipment number, and total number of cycles (Figure 2.12). The supervisor's task was to manually introduce cycle records by selecting shift description, crew code, loader number, loader operator, material description, haul location, truck number, truck operator's name, and a total number of loads accomplished by every operator.

	EQUIPMENT NUMBER	

LOADER	PREBENCH		INTERBURDENS		CONSTRUCTION	
	LOADS	TONS	LOADS	TONS	LOADS	TONS

LOADER	FROM PIT TO HOPPER			FROM PIT TO STOCKPILE			STOCKPILE RECLAIM		
	SEAM	LOADS	TONS	SEAM	LOADS	TONS	STK	LOADS	TONS

Figure 2.12 Paper-based production card

Production insertions were conducted through a Production Manager tool in the IPMS (Figure 2.13). Once data is verified, it is automatically uploaded to a main database where it can be queried at any time for analysis and report generation. Usually, the completion of this chore required approximately thirty minutes of the supervisor’s time at the end of every shift. The Production Manager tool stores truck production data in the *PRODUCTION TRUCK* table found in the main IPMS database. For the design phase, the ADCS database replicates the *PRODUCTION TRUCK* table’s structure by introducing a new temporary truck production table (*PRO TRUCK TEMP TABLE*). Identical in structure, the temporary table includes fields for production record ID, time and date stamps, shift and crew IDs, equipment and employee numbers, material description, material dump location, average payload, loader equipment number, and loader employee number. The ADCS was designed with the capability to generate field records directly into the IPMS environment through data synchronization. As a result, the supervisor’s obligation is reduced to data validation only.

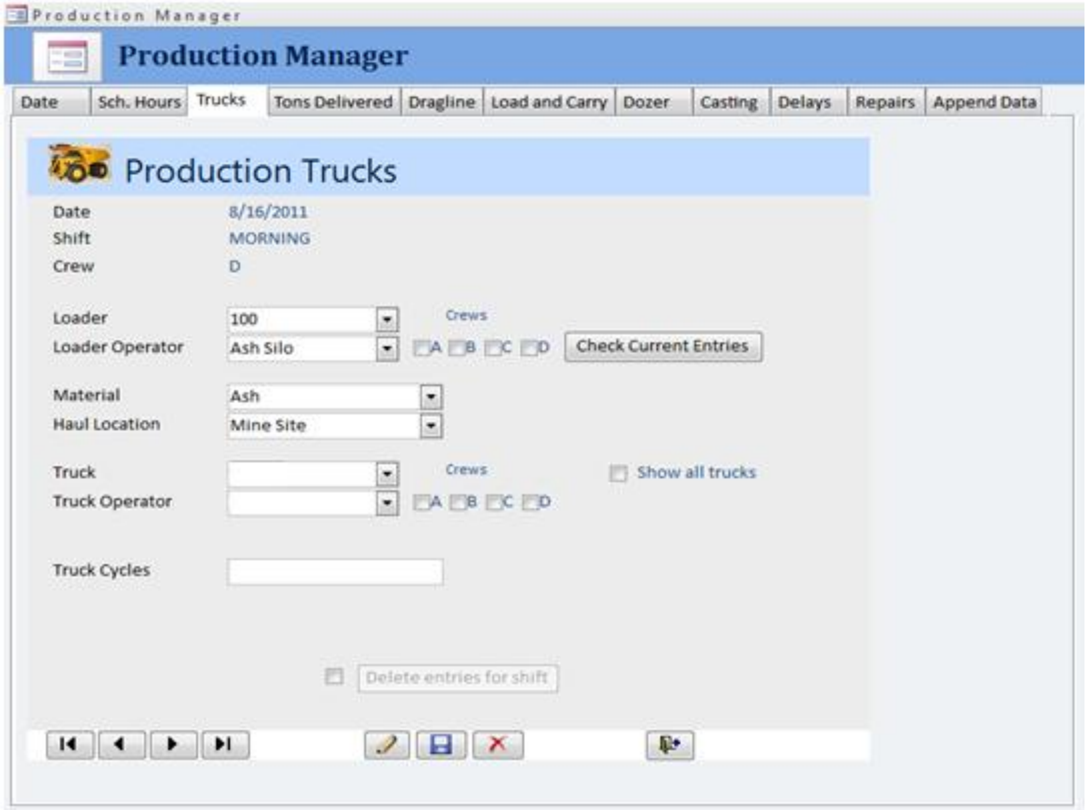


Figure 2.13 Production Manager (IPMS interface)

2.6.2 Truck Delay Field Table

The two main types of operational delays are fixed and variable. Fixed delays are all events that can be predicted, including the time of occurrence and duration. These delays are not included in the total cycle time. For instance, pre-shift inspections fall under the fixed delay category. On the other hand, variable delays are all events that occur unexpectedly and whose duration cannot be predicted. Waiting or delay time in truck cycle can usually be explained by over-trucking, bunching, mismatching, weather, or operator performance (Kennedy, 1990). These unpredicted events are considered waiting which result in the elongation of operational cycles, with the exception of mechanical delays. A mechanical delay is the only variable delay that can recess a truck cycle at any time without extending the total cycle time.

Delay records used to be hand written by equipment's operator in delay cards, which were later introduced into the IPMS database by supervisors. Delay cards allowed the operator to record delay start and end time along with a code number, which described a delay cause (Figure 2.14). Just like the Truck Production feature in the Production Manager Tool, the IPMS is capable of accepting manually-introduced delay records (Figure 2.15). New delay records are inserted into the main database under a *DELAY TIME* table. The ADCS also imitates the structure of the *DELAY TIME* table and introduces a temporary *DELAY TIME TEMP* table. The temporary table is designed to store delay ID and code numbers, delay category, time and date stamp, shift and crew IDs, equipment and employee numbers, start time, end time, and duration. Again, the ADCS alleviates the supervisor's responsibility by introducing an automated equipment delay recording system.


EQUIPMENT NUMBER

EQUIPMENT DELAY CARD | START OF SHIFT ____________ AM PM | END OF SHIFT ____________ AM PM

EMPLOYEE NUMBER		EMPLOYEE SIGNATURE	
SUPERVISOR INITIALS		DATE	

DELAY CODE	DESCRIPTION OF DELAY	DELAY START TIME	DELAY STOP TIME	DELAY HOURS

DELAYS: (1) Weather Delay (2) Safety Shutdown (10) Pre-shift Inspection (16) Training/Meetings (18) Wait on Loaders (20) Machine Stuck (23) Fueling/Lubing (30) Other (60) Maintenance (99) De-scheduled

Central • 072104

Figure 3.14 Paper-based delay card

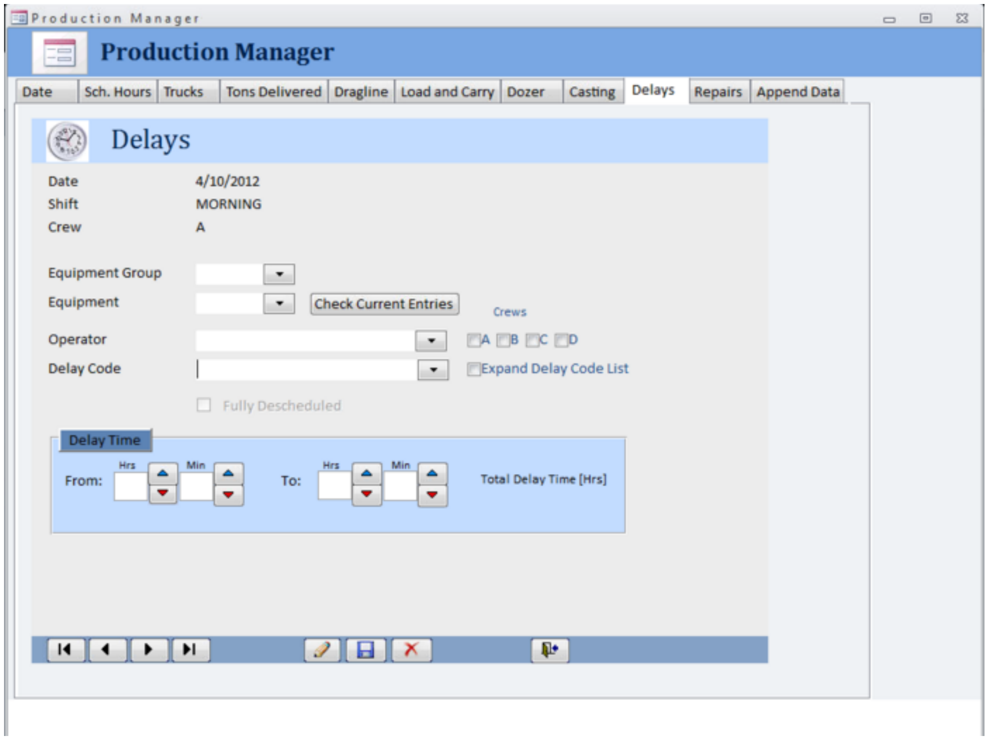


Figure 2.15 Delay Screen within the Production Manager tool in the IPMS

2.6.3 Loader Communication Table

The TCD-ADCS database structure also requires a table to emulate communication techniques between loading equipment and haul trucks. This technique consists of using the available wireless ad-hoc network and data synchronization methods instead of implementing hardware expansion for peer-to-peer communication. For the TCD-ADCS, loaders play an important role as primary equipment for the generation of production cycle records. The loading equipment operator is in charge of pre-selecting and defining specific material description and dumping locations values during truck cycle runs.

Dump location and material description data can be transferred in the form of a message broadcast, which is the synchronization of data created by the loader and retrieved by trucks from a centralized server. Loaders use a data broadcast table (*SENT MSG LOADER*) which includes fields for loader employee ID number, equipment number, horizon ID, haul location ID, northing, easting, and elevation. The broadcasting table reports data to a centralized server, where trucks can later collect values for accurate production cycle recording. This feature reduces the interaction between truck drivers and the ADCS by automatically introducing pre-selected data into field records.

2.6.4 Temporary TCD-ADCS Database Structure

A database structure was created using programming skills in MS SQL server and SQL language (Dobson, 2005). It includes a combination of both general data and field data tables. Table 2.5 illustrates the database structure designed for the TCD-ADCS including table names, categories, structures, data types, and relations to any associate tables. This MS SQL server database is known as the Temporary Database (TDB).

Table 2.5 TCD-ADCS - TDB database structure

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Employee	ATRZD EMP	EMPid CREW LastName FirstName PrimaryEQP PrimaryCrew	Integer nvarchar (255) nvarchar (255) nvarchar (255) nvarchar (50) nvarchar (10)	Primary Key	ATRZD EMP
Equipment	ATRZD EQP	EQPnumber EQPserial EQPyear EQPmanufacturer EQPmodel EQPtype EQPfleet PRPid EQPpayload	nvarchar (255) nvarchar (255) Integer nvarchar (50) nvarchar (50) nvarchar (50) char (50) Integer Real	Primary Key	ATRZD EQP
Crew	CREW CODE	CRCid CRCname	Float nvarchar(5)	Primary Key	CREW CODE
Crew	CREW ROTATION	CRRid CRRdate SFTid CRCid	Float datetime Float Float	Primary Key	CREW ROTATION

Table 2.5 TCD-ADCS - TDB database structure – Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Delay	DELAY CATEGORY	DLCid	Integer	Primary Key	DELAY CATEGORY
		DLCname	char (20)		
		DLCdescription	nvarchar(255)		
Delay	DELAY CODE	DLCODEid	Integer	Primary Key	DELAY CODE
		DLCODEdescription	nvarchar (255)		
		DLCODEtype	nvarchar (255)		
		DLCODEcategory	nvarchar (50)		
		DLCODEtypedetail	nvarchar (30)		
Delay	DELAY TIME TEMP	DLTid	Integer	Primary Key	DELAY TIME TEMP
		EQPnumber	nvarchar (255)	Foreign Key	ATRZD EQP
		DLTdate	datetime		
		SFTid	Integer	Foreign Key	SHIFT
		DLCODEid	nvarchar (255)		
		DLCODEcategory	decimal(18,3)	Foreign Key	DELAY CODE
		DLThours	datetime		
		DLTstart	datetime		
		DLTend	Integer		
		EMPid	Integer	Foreign Key	ATRZD EMP
		DLTMtccode	datetime		
		DLTMtcDlyHrs	Float		
		DLTMtcDuration	Float		

Table 2.5 TCD-ADCS - TDB database structure - Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Delay	DELAY TIME TEMP FIELD	DLTid	Integer	Primary Key	DELAY TIME TEMP
		EQPnumber	nvarchar (255)	Foreign Key	ATRZD EQP
		DLTdate	datetime		
		SFTid	Integer	Foreign Key	SHIFT
		DLCODEid	nvarchar (255)		
		DLCODEcategory	decimal(18,3)	Foreign Key	DELAY CODE
		DLThours	datetime		
		DLTstart	datetime		
		DLTend	Integer		
		EMPid	Integer	Foreign Key	ATRZD EMP
		DLTMtccode	datetime		
		DLTMtcDlyHrs	Float		
		DLTMtcDuration	Float		
GPS Record	GPS LOCATION RECORD	DT	datetime	Primary Key	PRO TRUCK TEMP
		PROTid	nvarchar (255)		
		PPDistance	Float		
		Northing	Float		
		Easting	Float		
		Elevation	Float		
		PRODL	Integer	Primary Key	GPS LOCATION RECORD
		EQPnumber	nvarchar (255)		
ump Location	HAUL LOCATION	HAULid	Integer	Primary Key	HAUL LOCATION
		HAULlocation	nvarchar (50)		
		HAULdescription	nvarchar (50)		

Table 2.5 TCD-ADCS - TDB database structure - Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Load Location	HORIZON	HRZid	Integer	Primary Key	HORIZON
		HRZname	nvarchar (50)		
		HRZmaterial	nvarchar (50)		
		WCDid	Integer		
Loading and Dumping Records	LOAD DUMP CYCLE	LoadDumpID	nvarchar (100)	Primary Key	LOAD DUMP CYCLE
		EQPnumber	nvarchar (255)	Foreign Key	ATRZD EQP
		EMPid	Integer	Foreign Key	ATRZD EMP
		LoadDumpCode	Integer		
		Cycletime	Float		
		LoadDumpDate	datetime		
		SFTid	Integer	Foreign Key	SHIFT
		Northing	Float		
		Easting	Float		
		Elevation	Float		
Loading and Dumping Records	LOAD DUMP CYCLE NEW	LoadDumpID	nvarchar (100)	Primary Key	LOAD DUMP CYCLE
		EQPnumber	nvarchar (255)	Foreign Key	ATRZD EQP
		EMPid	Integer	Foreign Key	ATRZD EMP
		LoadDumpCode	Integer		
		Cycletime	Float		
		LoadDumpDate	datetime		
		SFTid	Integer	Foreign Key	SHIFT
		Northing	Float		
		Easting	Float		
		Elevation	Float		

Table 2.5 TCD-ADCS - TDB database structure - Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Loaders	LOADERS	LOADERid EQPnumber EQPserial	nvarchar(50) nvarchar(50) char(10)	Primary Key Foreign Key	LOADERS ATRZD EQP
Log In Records	LOGINrec	LOGID EMPid EQPnumber TimeNow InOut Shutdown	nvarchar(100) Integer nvarchar(255) datetime Integer Integer	Primary Key Foreign Key Foreign Key	LOGINrec ATRZD EMP ATRZD EQP
Log In Records	LOGINrecNEW	LOGID EMPid EQPnumber TimeNow InOut Shutdown	nvarchar(100) Integer nvarchar(255) datetime Integer Integer	Primary Key Foreign Key Foreign Key	LOGINrec ATRZD EMP ATRZD EQP

Table 2.5 TCD-ADCS - TDB database structure - Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Truck Production	PRO TRUCK TEMP	PROTid	nvarchar(100)	Primary Key	PRO TRUCK TEMP
		PROTDate	datetime		
		SFTid	Integer	Foreign Key	SHIFT
		CRCid	Float	Foreign Key	CREW CODE
		EQPnumber	nvarchar(255)	Foreign Key	ATRZD EQP
		EMPid	Integer	Foreign Key	ATRZD EMP
		LOADERid	nvarchar(50)	Foreign Key	LOADERS
		EMPLOADERid	Integer	Foreign Key	LOADERS
		HRZid	Integer	Foreign Key	HORIZON
		HAULid	Integer	Foreign Key	HAUL LOCATION
		PROTload	Float		
		PROTtons	Float		
		PROTmaterial	nvarchar(255)		
		PROThaullocation	Integer		
		PROTseam	nvarchar(255)		

Table 2.5 TCD-ADCS - TDB database structure - Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Truck Production	PRO TRUCK TEMP FIELD	PROTid	nvarchar(100)	Primary Key	PRO TRUCK TEMP
		PROTDate	datetime		
		SFTid	Integer	Foreign Key	SHIFT
		CRCid	Float	Foreign Key	CREW CODE
		EQPnumber	nvarchar(255)	Foreign Key	ATRZD EQP
		EMPid	Integer	Foreign Key	ATRZD EMP
		LOADERid	nvarchar(50)	Foreign Key	LOADERS
		EMPLOADERid	Integer	Foreign Key	LOADERS
		HRZid	Integer	Foreign Key	HORIZON
		HAULid	Integer	Foreign Key	HAUL LOCATION
		PROTload	Float		
		PROTtons	Float		
		PROTmaterial	nvarchar(255)		
		PROThaullocation	Integer		
		PROTseam	nvarchar(255)		

Table 2.5 TCD-ADCS - TDB database structure - Continued

Table Category	Table Name	Table Structure	Data Type	Identity	Associate Tables
Loader Broadcast	SENT MSG LOADER	ID EMPid EQPnumber HRZid HAULid Payload Northing Easting Elevation TimeNow SentTO	nvarchar(100) Integer nvarchar(255) Integer Integer Float Float Float Float datetime nvarchar(255)	Primary Key Foreign Key Foreign Key Foreign Key Foreign Key	SENT MSG LOADER ATRZD EMP ATRZD EQP HORIZON HAUL LOCATION
Shift	SHIFT	SFTid SFTdescription	Integer nchar(10)	Foreign Key	SHIFT

2.6.5 Database Synchronization

The design phase describes a detailed structure for a TDB and its similarities to the main IPMS database. The next step is to define the purpose and application of such a temporary database. A physical copy of the TDB must be placed parallel to the IPMS main database within a centralized server located in an office environment. Also, production equipment requires a physical location to store field data individually. Therefore, the ADCS must provide a remote copy of the TDB to each piece of equipment (trucks and loaders) and is referred to as Equipment Database (EDB). The TDB should always be larger in memory storage than any EDB since it gathers data from multiple clients carrying EDBs.

Ideally, all collected data from the field equipment should not be inserted into the TDB directly. Instead, it should be inserted into the EDBs independently. Using this approach, this ADCS is equipped with a back-up unit in case network connectivity is lost. These techniques show significant documented improvements in TCD-ADCS.

Data transfer can be achieved by using multiple synchronization techniques, depending on the purpose of the system application. The synchronization direction can be:

- Snapshot,
- Download Only,
- Upload Only, or
- Bidirectional.

Snapshot synchronization consists of refreshing table structure and data during each synchronization process. This approach overwrites any modification or insertion of data done by the client and prioritizes modification made by the server. The Download Only direction is similar to Snapshot. It transfers data from the server to the client; however, it minimizes data transfer by synchronizing new insertions and updates only. This synchronization direction reduces the amount of data transferred after the initial synchronization, making the synchronization process more efficient. Opposite to the prior two synchronization directions, Upload Only can be used by clients to make updates in the server database. The client has the opportunity to insert and update records in a database without being overwritten by the server. Finally, Bidirectional synchronization allows the client to upload new data into the server and then download changes already made. This final synchronization direction results in identical data sets created at the client side as well as the server side.

Applying Bidirectional synchronization direction for data transfer in the development of the TCD-ADCS appears to be a promising solution. However, it can also result in "identity" conflicts when more than one client synchronizes field data to the TDB. Identity issues occur when data records have repeated values on the primary key (PK) columns. Bogunovic (2008) refers to the primary key (PK) as a field to ensure the referential integrity of the database structure. For instance, a PK number could represent meaningful information (e.g. an employee identification number), or it could be automatically generated by the Database Management System (DBMS).

When network connectivity is lost, the equipment has no way to know the latest subsequent record updated into the TDB. This can result in multiple pieces of equipment generating records with an equal primary key (PK) number. Identity conflicts result in data corruption. Furthermore, data can be potentially lost or overwritten in the synchronization process. In order to resolve this potential issue, the TCD-ADCS uses different identity solution approaches, along with a careful selection of data synchronization directions.

2.6.6 Identity Solution Approach

The two most common identity conflicts are: chronological sequence discontinuation and lack of unique primary key (PK). Using multiple synchronization techniques does not resolve identity conflicts when having multiple clients in the field environment. Therefore, this ADCS presents three alternative solutions to create unique PK for each individual field data record:

- Unique ID,
- Intermediate table, and
- Unique ID and Intermediate table combined.

<u>Unique ID Approach</u>

The Unique ID approach consists of generating unique identifiers for every production cycle and delay record. Such a value is generated with a chronological sequence at each

EDB independently. In order to avoid coincidental repetition by clients, the PK number must carry constant unique characters that differentiate clients from each other. Primary key (PK) numbers for production cycle and delay records are comprised of six initial digits that correspond to the equipment's identification number (e.g., 111001, 111002), followed by a seven digit number which increases chronologically as new records are generated (e.g., 0000001, 0000002). Once both numbers are joined together, a unique PK value is created and should not show signs of identity conflicts during the synchronization process (e.g., 1110010000001 and 1110010000002, or 1110020000001 and 1110020000002).

Intermediate Table Approach

Intermediate tables can be included into the TDB scheme (database structure) for synchronization purposes only. The primary goal of an intermediate table is to eliminate primary key (PK) numbers after new records reach the temporary server. Originally, production cycle and delay tables (*PRO TRUCK TEMP* and *DELAY TIME TEMP*) in the IPMS main database use an incremental sequence for generating primary keys (PK) while records are being added. When the TDB is merged with the main IPMS database (Integration Phase), newer field records are not accepted since they may not follow the already exiting sequence (Table 2.6). The PK sequence discontinuation can result in data being lost instead of being stored.

Table 2.6 Sample table for incremental sequence discontinuity on primary keys

Sequence Logic	Primary Key Sample	Phase	Problem
Incremental	1561	Pre-ADCS	
	1562	Pre-ADCS	
	1563	Pre-ADCS	
	1	Post-ADCS	Incremental sequence discontinued
	2	Post-ADCS	
	3	Post-ADCS	

The Intermediate Table Approach consists of replicating the structure of field data tables. The objective of this approach is to have the EDB synchronize data into intermediate tables instead of field tables.

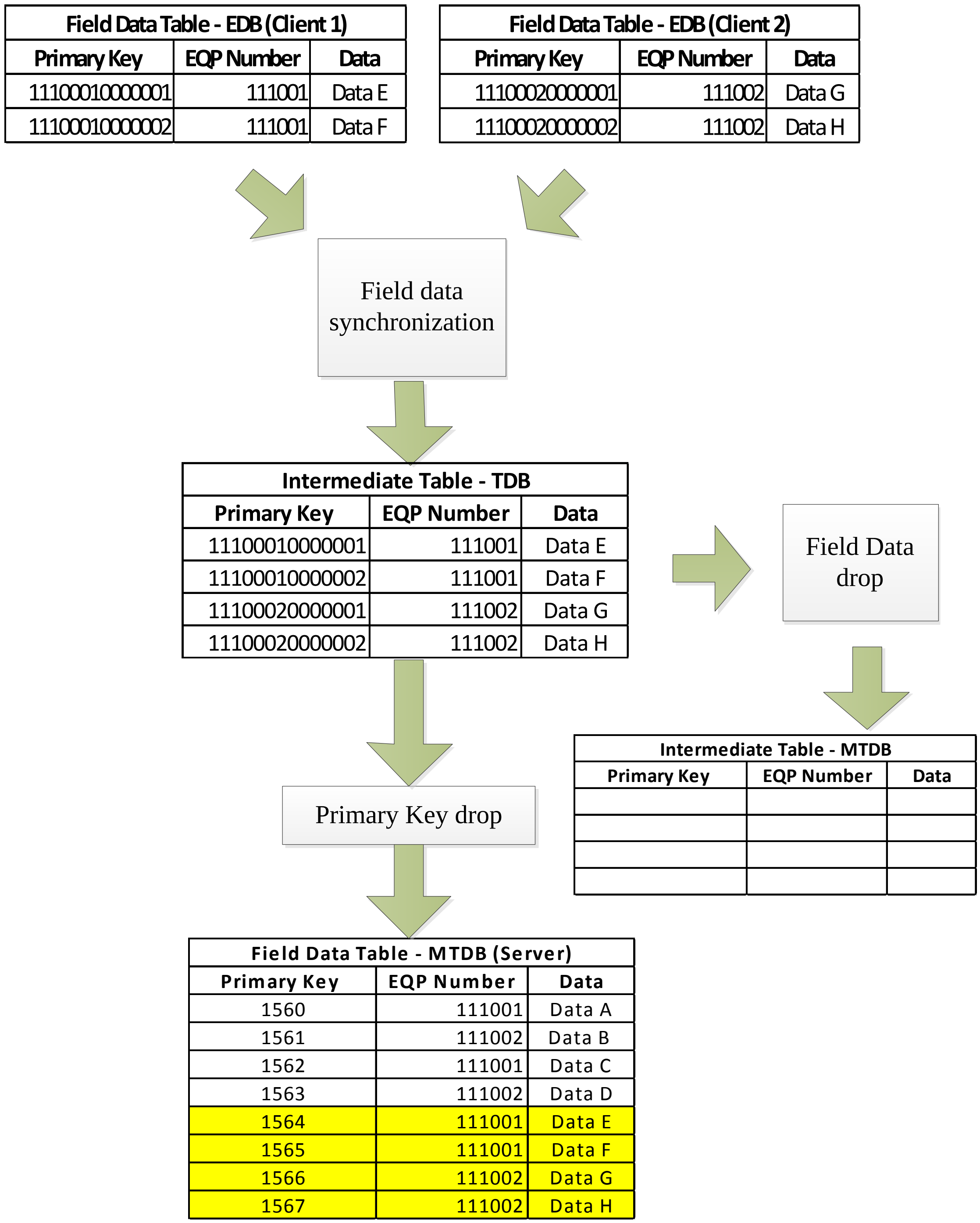
When new records are synchronized and inserted into intermediate tables, a SQL Data Replication Trigger (DRT) is responsible for copying data, dropping the primary key, inserting the copied data into field tables, and dropping each record individually from intermediate tables (Dobson, 2005). Intermediate tables may appear to be empty at all times. It might seem like a long process, but these actions are almost instantaneous. To solve identity issues, field tables are capable of generating new identity values as primary keys (PK) for every new record and still maintain the existing incremental sequence.

Unique ID and Intermediate Table Combined

Both previous approaches, Unique ID and Intermediate Table, help the TCD-ADCS solving identity duplication and identity discontinuation sequence issues, respectively. A combination of both techniques is applied during the design to overcome potential synchronization errors. Through this transformation the final primary key (PK) must always

- uniquely identify each record in the table,
- contain unique values,
- not be null,
- not be a multiplied field,
- contain a minimum number of fields necessary to define uniqueness,
- not be optional in whole or in part, and
- directly identify the value of each field in the table (Bogunovic, 2008).

Figure 2.16 shows how primary keys (PK) can be transferred from multiple EDBs to the TDB using combined identity approaches. Initially, PKs are generated using the Unique ID approach while on the EDB. Field data is later synchronized using the Upload Only direction for the population of intermediate tables. A DRT is in charge of dropping the PK, generated at the equipment environment, and inserting data records into field tables, where a new PK is generated by the DBMS.



Field Data Table - EDB (Client 1)		
Primary Key	EQP Number	Data
11100010000001	111001	Data E
11100010000002	111001	Data F

Field Data Table - EDB (Client 2)		
Primary Key	EQP Number	Data
11100020000001	111002	Data G
11100020000002	111002	Data H

Intermediate Table - TDB		
Primary Key	EQP Number	Data
11100010000001	111001	Data E
11100010000002	111001	Data F
11100020000001	111002	Data G
11100020000002	111002	Data H

Intermediate Table - MTDB		
Primary Key	EQP Number	Data

Field Data Table - MTDB (Server)		
Primary Key	EQP Number	Data
1560	111001	Data A
1561	111002	Data B
1562	111001	Data C
1563	111002	Data D
1564	111001	Data E
1565	111001	Data F
1566	111002	Data G
1567	111002	Data H

Figure 2.16 Unique ID and Intermediate table approach

Bogunovic (2008) indicates that a successful database development includes the following stages: “(1) Analysis of existing database; (2) Creation of data structures; (3) Determination and establishing table relationships; (4) Determination and definition of business rules; and (5) Review of data integrity”. Following all development stages, the TCD-ADCS was presented with an adequate database infrastructure.

2.6.7 System Application Structural Design

After defining the database scheme and selecting adequate synchronization techniques, the Design Phase also provides a basic structure for both truck and loader system applications. Both system applications were designed to have direct interaction with equipment operators and to perform during regular operating hours by following a logical shift structure from beginning to end. All possible operational events were included in the design of the software applications of the TCD-ADCS.

2.6.7.1 Loader System Application Structure

During the design of the TCD-ADCS, the loading equipment was assigned with the responsibility of reporting the following information: loader employee ID number, equipment number, material description (Horizon), dump location, and GPS coordinates. Data generated by the loader/shovel operator is transmitted to dump trucks, using the centralized server as a communication bridge. The process of information dissemination is referred to as “message broadcasting”. The loader system application provides an end-user interface for the pre-selection of material description and dump location prior to the generation of truck cycle field data. A software application presented through a Graphic User Interface (GUI) facilitates the generation of message broadcasts. The construction of loader messages consists of selecting existing data from general tables (*HORIZON AND DUMP LOCATION*) and introducing equipment and employee identification numbers into the *SENT MSG LOADER* within the EDB. This process must be repeated while excavation advances and concluded when there is a change in operator or at the end of the shift (Figure 2.17).

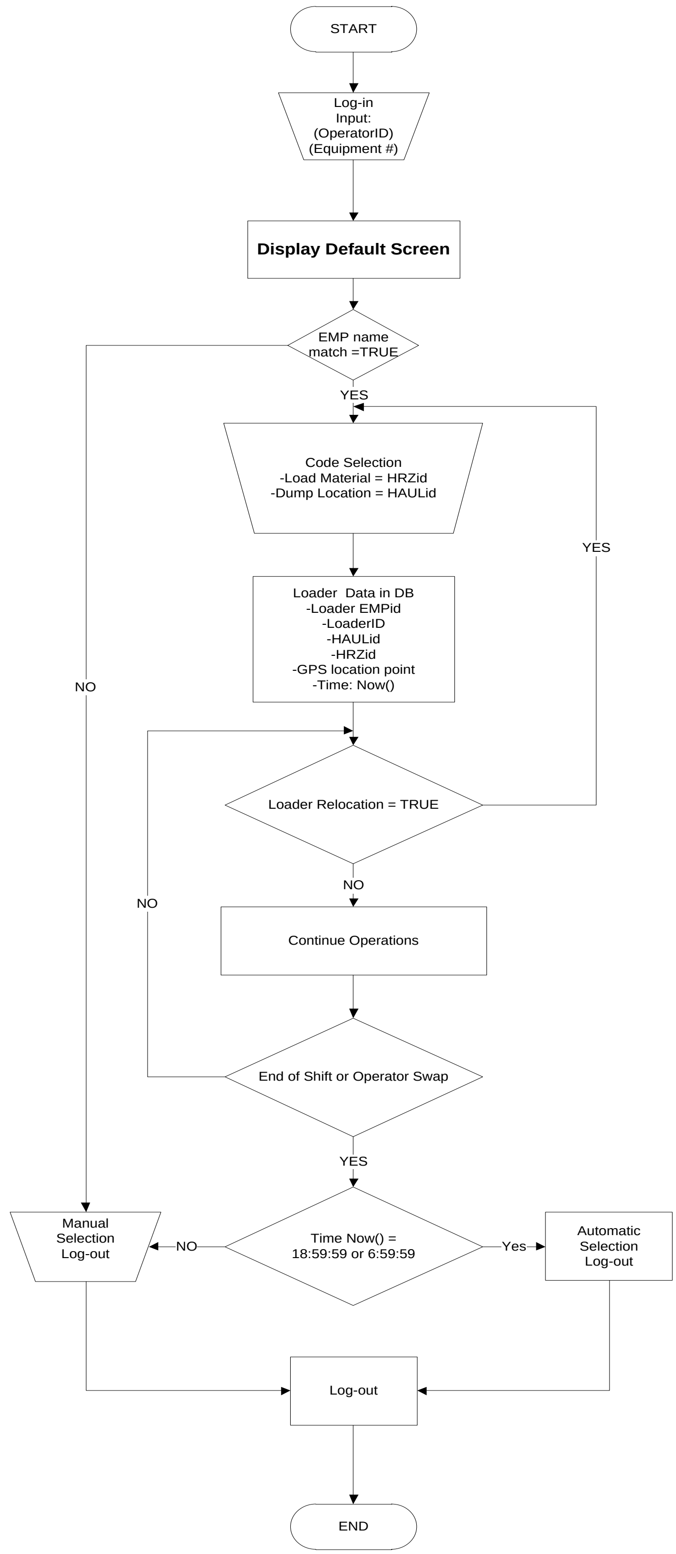


Figure 2.17 Loader application flow diagram

2.6.7.2 Haul Truck System Application Structure

The design of a truck system application includes adequate features capable of collecting various data types throughout truck cycle runs. Initially, all potential field data must be stored in field data tables within the EDB. Also, the classification of data by employee and equipment allows the TCD-ADCS to report raw data for operator and equipment performance studies.

The design of the truck system application includes the Log-In, Default, and Delay modes, where production cycle and delay data is generated. The Log-In mode provides an environment in which the equipment operator must introduce unique employee identification and equipment numbers. This information is attached to all data recorded by the ADCS.

One special feature included in the Default mode is the space for interaction between loaders and trucks. Loader messages can be interpreted by the Default mode prior to field data collection. Also, the design of the Default mode includes physical space for displaying general production information, such as shift statistics and average payload. While in this mode, a tracking system that measures haulage distance and time was included. Also known as GPS data, the truck system application inserts field recordings into the *GPS LOCATION RECORD* table, along with a production cycle ID number.

GPS technology provides ground speed measurements that are used for the prediction of potential variable delays. Non-movement conditions were included in this design to determine when the application should change from Default to Delay mode. Using the same principle with reverse logic, the end of operational delay can also be predicted. The purpose of the Delay mode is to present physical space for the manual selection of delay codes that accurately represent the stopping cause (e.g., weather, fueling/lubing, safety shutdown, and maintenance). With the exception of maintenance delays, all variable delays can extend the total truck cycle time. If equipment maintenance breakdown occurs, the production cycle can be interrupted by disabling ground speed measurement. This exception allows the equipment to travel from its current location to maintenance facilities without terminating the Delay mode.

Most of the time, loading and dumping events also meet minimum speed (stopping) conditions that force the system application change to a Delay mode. Such events are not considered variable delay since they form part of the truck cycle structure. To address this issue, the Delay mode was designed to capture loading and dumping events separately from variable delays by providing additional features within the Delay mode. The equipment operator must manually indicate if the stopping reason is in fact due loading or dumping. This acknowledgment indicates to the system application that the total duration time of such event should be treated separately in the *LOAD DUMP CYCLE* table instead of in the *DELAY TIME TEMP* field table. The flow diagram for trucks is shown in Figure 2.18. At the same time, this diagram shows the integration between loader and the truck system applications.

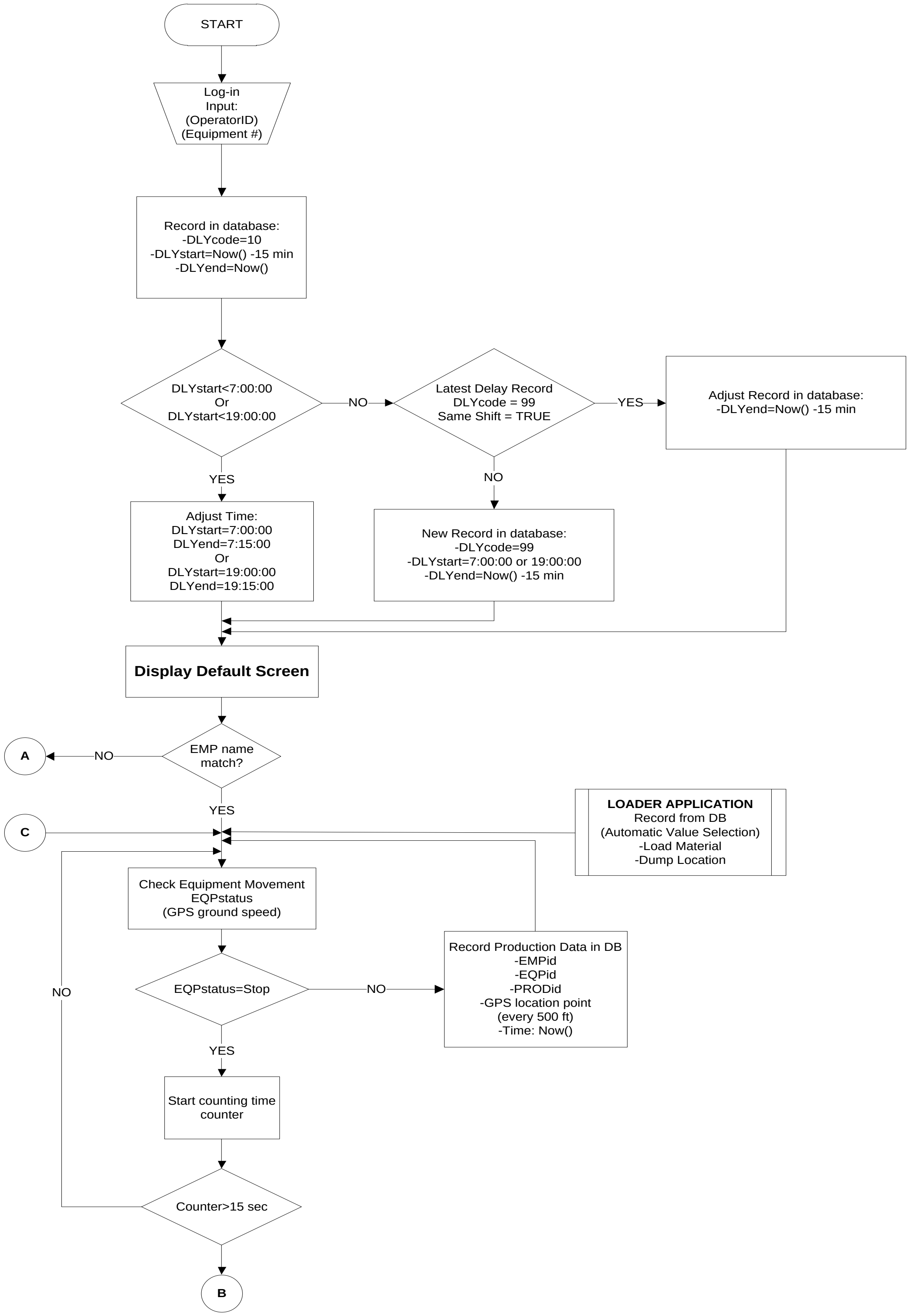


Figure 2.18 Truck application flow diagram

Figure 2.18 Truck application flow diagram - Continued

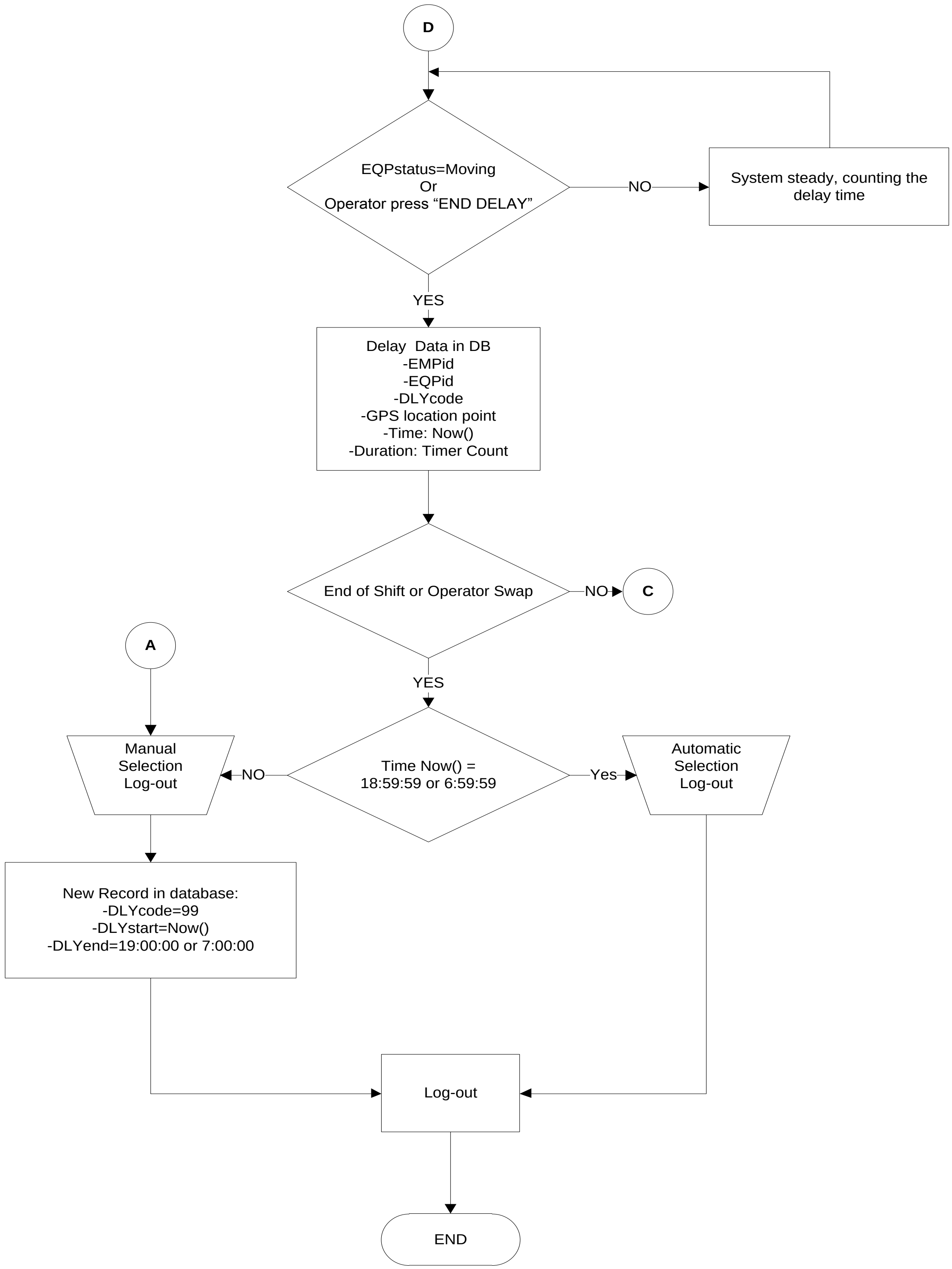


Figure 2.18 Truck application flow diagram - Continued

2.7 Phase II – Development

This phase includes the physical development of the following components in the TCD-ADCS: Loader Environment System Application (LSA), Truck Environment System Application (TSA), and Synchronization Agents. The combination of all these three components led to the development of a Production Equipment Environment (PEE) information system (IS) remotely integrated to an Office Environment (Figure 2.19).

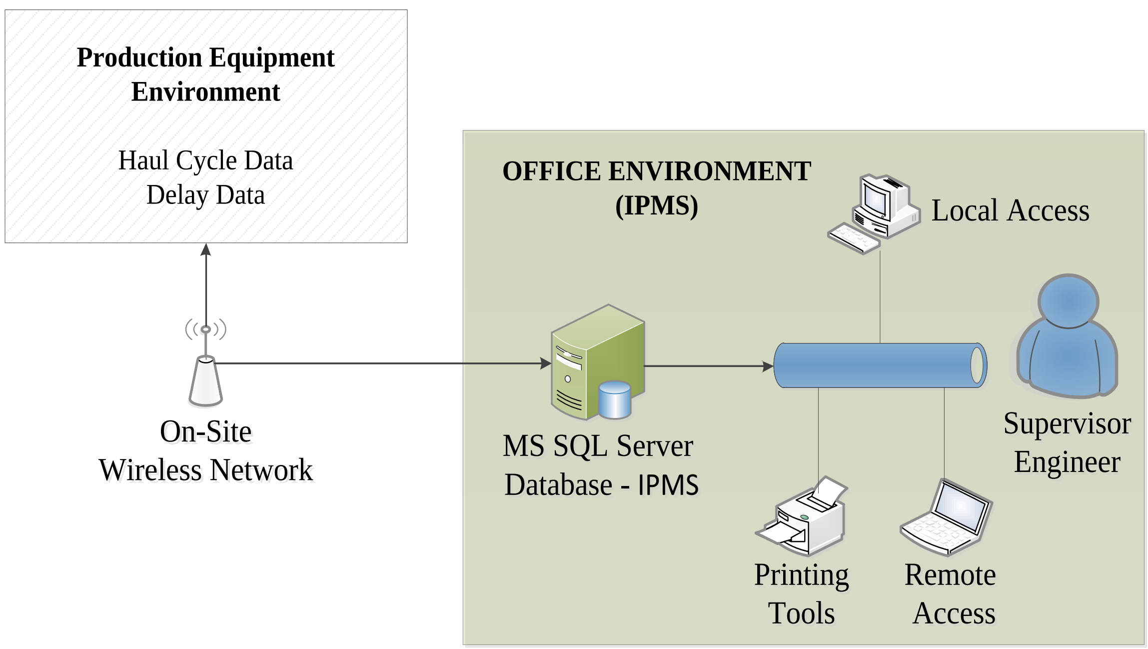


Figure 2.19 Production equipment environment integration with IPMS

2.7.1 Loader Environment and System Application – LSA

A loading equipment environment is a collection of hardware, software, and a unique SQL Server environment (Figure 2.20). This equipment environment is capable of transmitting a loader message to the truck fleet through a wireless network. Following the structure diagram in the Design Phase, the physical development of a Loader System Application (LSA) was accomplished by using MS Visual Studio as a programming infrastructure. The structure of a loading equipment environment includes:

- an end-user interface developed for MS Windows applications,
- a database engine for equipment application (EDB),
- data synchronization features, and
- hardware implementations.

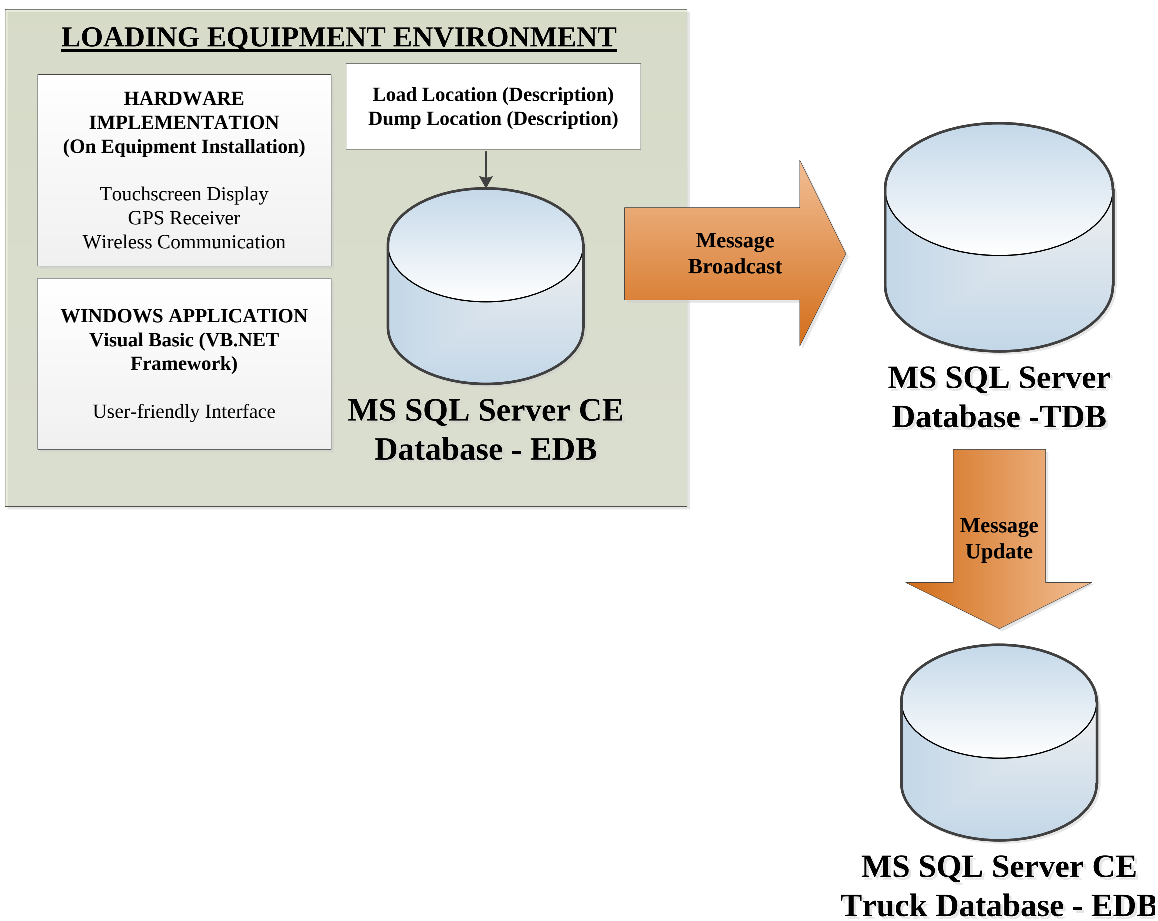


Figure 2.20 Loading equipment environment

The structure design of the LSA does not include features for the generation of loader cycles, fixed delay, or variable delay data. The functionality of this system application is reduced only to the pre-selection of a Horizon and Dump location for truck production cycle data generation. In addition, the LSA is used as an alternative medium for peer-to-peer communication (loader-to-truck). The *SENT MSG LOADER* table found in loading equipment, haul trucks, and the TDB is used to replace the physical implementation of additional technology for the field equipment communication. The LSA includes a physical copy of the EDB which mirrors a compact duplicate of the TDB structure. The utilization of a MS SQL Server CE database (.sdf) is adequate enough for the purpose of this application.

Along with hardware and physical database implementations, the LSA is presented through a Graphical User Interface (GUI). The GUI, in direct interaction with the loader operator, is limited to a few available options (menus and buttons) in order to decrease complexity and potential sources of distraction. The goal of the loader's GUI is to allow a brief user-friendly interaction between the hardware (PC) and the operator while accomplishing the LSA objective. Starting with the Log-In screen, the GUI allows the equipment operator to manually introduce employee identification and equipment numbers by interacting with the touch screen PC. Horizon and Dump location values are selected through a combination of textboxes and dropdown lists displayed on a Default screen along with a single message broadcasting key. After the validation of a new message, the LSA can make a synchronization call, which updates of the *SENT MSG LOADER* table at the TDB.

2.7.2 Truck Environment and System Application – TSA

The development of a dump truck environment was introduced as the major data collection feature in the TCD-ADCS. The truck environment includes computer hardware, truck system application (TSA), and a physical local database engine. The physical development of EDB and TSA was accomplished using similar techniques to those of the development of the loading equipment environment. Integrating a MS SQL server CE (.sdf) database as the EDB enabled the real-time data synchronization to the remotely located TDB (Figure 2.21).

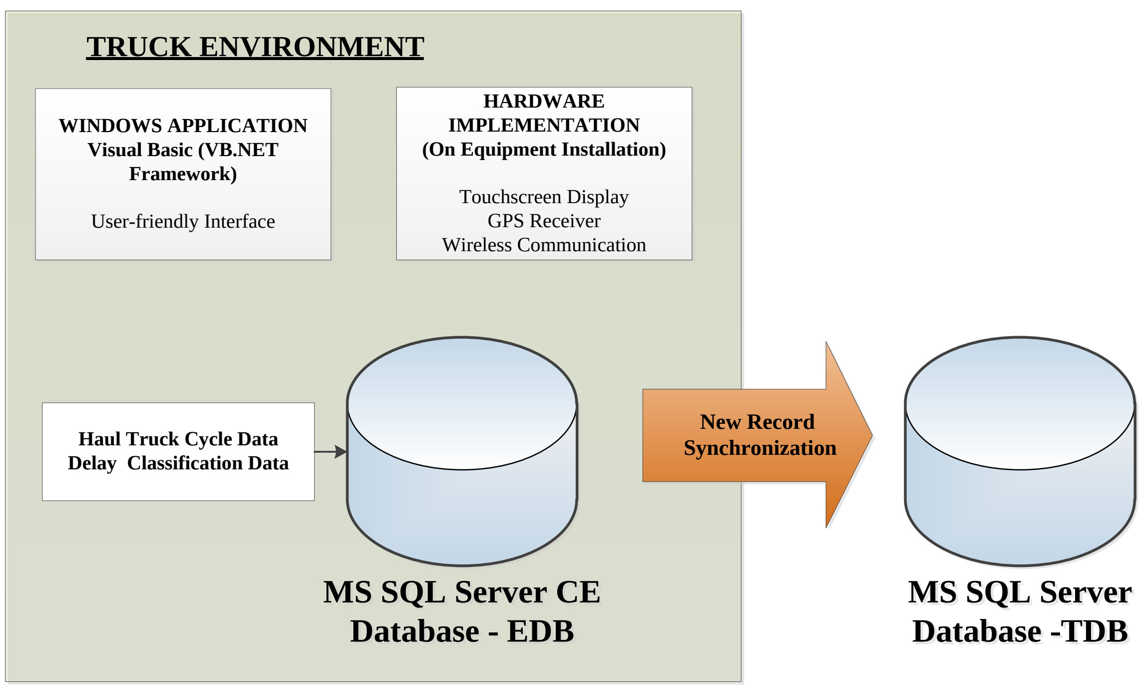


Figure 2.21 Truck environment

In contrast to the loading equipment's role in the TCD-ADCS, haul trucks employ a system application designed to generate production cycle and delay data in real-time directly from the mine site. The truck environment's responsibility is to store and report loading, dumping, hauling, returning, and delay times, along with GPS data. Also, the structure design (Design Phase) includes features that log operating hours and GPS tracking.

The objective of the TSA is to introduce an end-user interface while minimizing the interaction between the system application and the truck driver. Enabling the system application to insert most of the field data into the EDB reduces potential of human error. For example, to avoid creating false field data, the TSA's GUI does not include a feature to manually submit completed truck cycle runs into the EDB. Instead, the system application follows a logical sequence of cycle stages before inserting new records into corresponding field tables. This way the integrity of every truck cycle includes loading, haulage, dumping, return, and variable delays. The TSA uses *LOAD DUMP CYCLE*, *GPS LOCATION RECORD*, *PRO TRUCK TEMP*, and *DELAY TIME TEMP* field tables to store loading/dumping, GPS tracking, production, and delay data, respectively.

Prior to the development of the TSA, most of the data generation techniques led to the oversimplification of potential field data recovery. Originally, operators were responsible for collecting a total count of cycles accomplished in a single shift. Additionally, delays exceeding a quarter of an hour were considered and logged. The GUI for the TSA provides interaction through menus, buttons, dropdown lists, and textboxes in order to facilitate accurate data gathering. Furthermore, it provides automatic tracking of the total number of loads by Horizon.

2.7.3 Synchronization Wizard

For the benefit of the TCD-ADCS development, MS Visual Studio allows independent selection of synchronization directions for each general or field table. Data tables can be assigned with optimal Sync directions, thereby making data synchronization more efficient. General data tables should relate to Snapshot or Download Only directions since they do not require updating by the client. Preferably, general data can be synchronized using Download Only directions in order to minimize bandwidth usage. On the other hand, all field tables can be allocated with Upload Only synchronization. However, the *SENT MSG LOADER* table requires Download Only and Upload Only synchronization directions for LSA and TSA respectively. During the completion of the development phase, all field tables were assigned with adequate data synchronization directions to complete the TCD-ADCS objectives (Table 2.7).

Table 2.7 Synchronization direction designation

Table Type	Table Name	Synchronization Direction
Loading and Dumping Records	LOAD DUMP CYCLE	Upload Only
Log In Records	LOGINrec	Upload Only
Loader Broadcast	SENT MSG LOADER	Upload/Download
GPS Tracker	GPS LOCATION RECORD	Upload Only
Truck Production	PRO TRUCK TEMP	Upload Only
Delay	DELAY TIME TEMP	Upload Only
Delay	DELAY CATEGORY	Download Only
Delay	DELAY CODE	Download Only
Loader	LOADERS	Download Only
Load Location	HORIZON	Download Only
Dump Location	HAUL LOCATION	Download Only
Shift	SHIFT	Download Only
Crew	CREW ROTATION	Download Only
Crew	CREW CODE	Download Only
Equipment	EQUIPMENT	Download Only
Employee	EMPLOYEE PRODUCTION	Download Only

To complete database synchronization between equipment and office environments, this ADCS includes synchronization wizard tools provided by the Integrated Development Environment (IED). MS Visual Studio 2008 allows the integration of a new item called Local Database Cache (LDBC) (Randolph and Gardner, 2008). This item is used during development of Windows applications for defining the synchronization techniques of data tables. Introduced during the development of the LSA and TSA, the LDBC opens communication gates between clients and the server. This communication medium is only effective if both the clients and the server belong to a common network. Integration of the LDBC requires specifying the origin of data as well as the destinations. In this case, the origin of data is the TDB located at the server, and the destinations are the EDBs located at PEE. Just by adding the LDBC tools, Visual Studio automatically generates a mirror image of the TDB and plays the role of the EDB. Now, the EDB (.sdf file) can be supported on mobile devices such as hardware implementations at the field. Also, the LDBC configuration creates a second new feature known as a Synchronization Agent, or most commonly referred to as a SyncAgent. Both, EDB and SyncAgent are included in the solution explorer during the development of the TCD-ADCS (Figure 2.22)

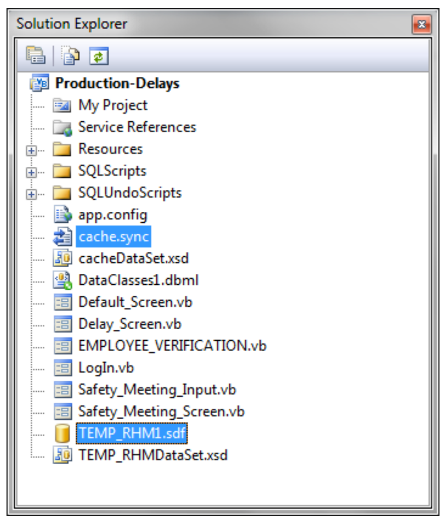


Figure 2.22 Solution Explorer with EDB and SyncAgent (MS VS 2008)

During the configuration of the SyncAgent, it is necessary to select all field tables the TCD-ADCS needs to synchronize from the server (Figure 2.23). Additionally, connection strings for the server and the client are defined to determine the physical location of TDB and the EDB. This configuration gives the system the flexibility to decide what general or field data tables from the TDB should or should not be included in the SyncAgent. The synchronization agent must include general data tables, all intermediate tables, and remaining tables that do not have an intermediate replica (e.g., *SENT MSG LOADER*). A SyncAgent is a one-direction tool, meaning that it can only perform in one synchronization direction for each table. At the same time, it modifies the original table structure at the TDB by creating two new fields in every table. These fields are: Last Date Updated and Last Date Inserted. The reason why these two new data fields or columns are incorporated in the data scheme is so the SyncAgent may recognize what data needs to be synchronized, if the synchronization direction is different from Snapshot.

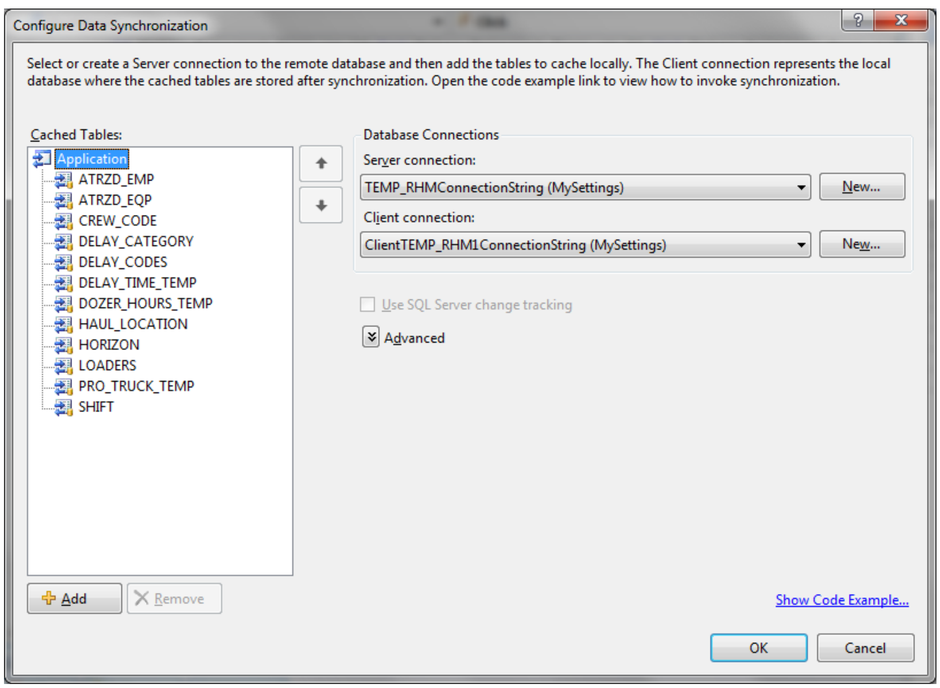


Figure 2.23 Data Synchronization wizard

Since this ADCS handles general and field data differently by using the same LDBC item, it is possible to create multiple SyncAgents. Actually, three different synchronization agents were sufficient for data transference during the development of the LSA and TSA. The following SyncAgents were included in the development of the TCD-ADCS: general data SyncAgent, field data SyncAgent, and loader broadcast SyncAgent. Each of these agents becomes active at different times during the production shift. This process is known as synchronization call.

2.7.3.1 General Data SyncAgent

All general data tables are assigned with Download Only synchronization direction. This way, only the TDB will be able to update existing data records and insert new ones into the EDBs. This synchronization call should be effective at the initiation of all windows applications (beginning of shift) to ensure the most updated general data availability before the equipment operator starts to use the TCD-ADCS. Also, both system applications LSA and TSA should make a second synchronization call when the operator abandons the equipment. This last call allows the next operator to obtain updated records from the TDB, if any were made during the prior shift. It is important to mention that general data tables are not commonly updated unless major crew rotation modifications or employee additions are made.

2.7.3.2 Field Data SyncAgent

Field data tables, opposite from general data tables, are assigned with Upload Only synchronization direction. In this manner, only the EDBs are able to update existing data records and insert ones into the TDB. Unlike the general data SyncAgent, the synchronization for field data tables is called constantly throughout the production shift. Even though it is required to report production cycle and delay data in a real-time, the synchronization calls for field data tables must be done efficiently. Therefore, a call occurs at the end of each truck cycle as well as at the conclusion of every variable delay. One final call is made automatically by logging-out from the system application or at the end of the production shift. Minimizing field data synchronization enhances the information system (IS) performance and reduces network bandwidth usage.

2.7.3.3 Loader Broadcast SyncAgent

The TCD-ADCS uses Download Only synchronization direction for the TSA and Upload Only direction for the LSA. While synchronizing with the LSA, only the EDBs will be able to update the existing loader message into the TDB. On the other hand, while synchronizing with the TSA, only the TDB will be able to update the newest message into the truck's EDB. The loader broadcast SyncAgent call for the TSA is made constantly throughout the production shift. In order to provide trucks with the most updated message available, the call should be made at the end of the truck loading process. Thus, production cycle records will not be affected if there is a LSA update while haul trucks complete current cycle runs. The newest Horizon and Dump Location data becomes available for the following cycles.

Throughout the Development Phase of this research, the following physical components were developed: truck system application (TSA), loader system application (LSA), the EDBs, the TDB, and the synchronization agents. The full development of the TCD-

ADCS was completed using an Integrated Development Environment (IDE) and information technology (IT).

2.8 Phase III - Testing

The Testing Phase began after the development of the TCD-ADCS, including GUIs for the LSA and TSA. During testing, the programming code was debugged and elements on the GUIs were rearranged. Equipment operators in the mine suggested several aesthetic modifications for the LSA and TSA. Some of these alterations involved enlarging text font and button keys for better end-user interaction. In addition, visual and hearing aids were integrated to some elements on the GUI. For example, a new beeping alarm is set off if the equipment operator forgets to select a delay code while on the delay mode of the TSA.

Initially, the testing phase took place in a closed environment where multiple mine personnel had the opportunity to interact with the TCD-ADCS. Through this process, fictional data was generated for data synchronization testing purposes. Subsequently, the testing phase continued when the TCD-ADCS was introduced to a real mine environment. Hardware was mounted and software was installed on a haul truck for the driver to use. The testing continued for multiple weeks during a summer session, with the objective of testing operator interaction with the GUI. Also, the mine wireless network communication was used for transferring real-time field data.

2.9 Phase IV – Deployment

The final phase in the process was the deployment of the Truck Cycle and Delay Automated Data Collection System (TCD-ADCS) in a surface coal mine**.** The deployment phase includes merging databases, hardware installation, and employee training.

Completion of the TCD-ADCS development required the elimination of intermediate servers between the PEE and the IPMS. Merging databases refers to the complete elimination of the TDB and readdressing all synchronization agents directly to the main IPMS database. The objective of this elimination was to reduce potential data duplication sources and to rely on a single server for the unification of the TCD-ADCS and the IPMS. New field data tables, generated during the development of this ADCS, were included in during merging databases with main IPMS database.

The hardware installation on the field equipment was accomplished with the help of the IT and maintenance departments in the mine site. Figures 2.24 through 2.27 show the on-board touch-screen computer, the 2.4 GHz radio antenna mounted to the outside railing of the truck, and the GPS receiver attached to the roof of the truck's cabin.

Figure 2.24 On-board touch-screen personal computer

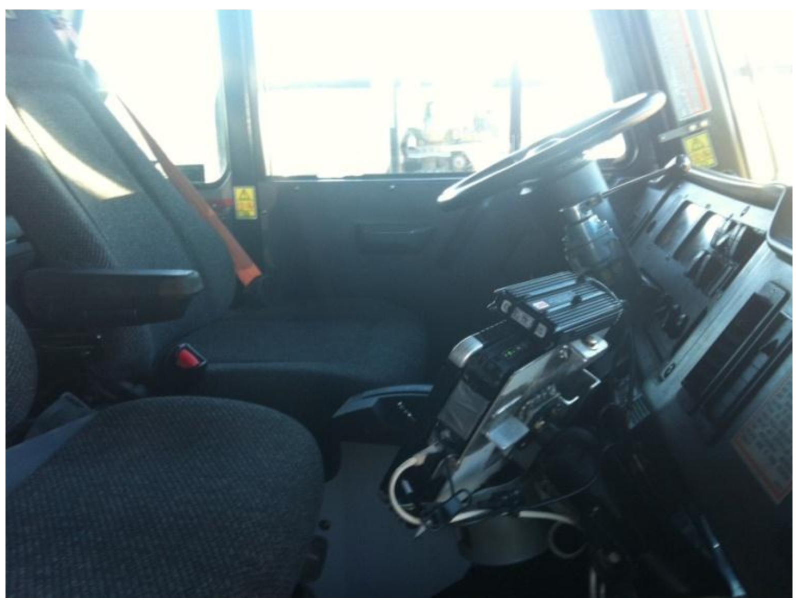


Figure 2.25 On-board computer mounted in dump truck cabin

Figure 2.26 Radio antenna mounted on hand rail of dump truck

Figure 2.27 GPS receiver mounted over operator's cabin

During the Deployment Phase, equipment operators were introduced to half-hour training sessions before using the TCD-ADCS. These training sessions answered any operational questions about the system application and provided brief verbal user guidance. The operators found the simple GUI interaction with the system application short and user-friendly. Finally, to resolve unexpected issues in real application, the Deployment Phase assigns an evaluation time period of six months before expanding the TCD-ADCS to multiple truck fleets.

Chapter 3

Results and Discussion

3.1 Introduction

The development of an AIS was the most challenging task in this research project. Data collection and synchronization are the two most beneficial outcomes of this integrated data environment. Thanks to the integration of the TCD-ADCS, mine personnel now have the necessary tools to collect truck production cycles and delays in real-time. This allows a quick response to solve issues that affect equipment and operator efficiency. Using data generated by the TCD-ADCS, the management can address independent events from the field as well as summarize and analyze information through the IPMS.

The TSA and the LSA were included in the completion of the TCD-ADCS. The simplicity of both window applications reduces the interaction time between the equipment operator and the GUIs. In addition, they reduce training time and potential sources of distraction. Another benefit of the TCD-ADCS is that it eliminates paper-based delay time cards and production logs, bringing the production monitoring one step closer to a paperless environment. Furthermore, it eliminates potential human errors during the collection of truck cycle and delay times, making the TCD-ADCS highly accurate.

This chapter provides a detailed description of the resulting system application for trucks and loading equipment included in the developed TCD-ADCS. Both system applications show front-end GUIs that help generate truck production cycle and equipment delay data. Furthermore, this chapter shows field data samples that were successfully synchronized to a centralized server containing a physical TDB. Data analysis and reporting is completed by the Integrated Production Management System (IPMS), which is located in an office environment and remotely connected to the TCD-ADCS.

3.2 Mine Description

The data and work environment for this project was provided by a surface coal mine located in the southern region of the United States. This mine is part of the largest lignite company in the nation. With coal mining operations in multiple states, this company has an estimated annual production of 33 million tons. This specific mine occupies a permitted area of 5,809 acres and has over 200 million tons of minable resources. The coal quality is as follows: 43.09% moisture, 5,120 BTU/lb, 14.40% ash, and 0.67% sulfur. Regardless of the geologic complexity and high annual precipitation (over 5 feet of rainfall per year), the mine's production crew works two twelve-hour shifts and it is able to successfully supply its client's requirement of 11,000 tons of coal per day. Using multiple surface mining methods, six out of eleven coal seams are mined (Figure 3.1). The three shallowest seams are not considered for extraction since they do not meet the quality standards. The two deepest seams are left intact due to economical and geotechnical limitations. The average thickness for the six minable seams ranges between two and six feet. The mine produces approximately 3.5 million tons of coal and 40 million cubic yards of overburden per year.

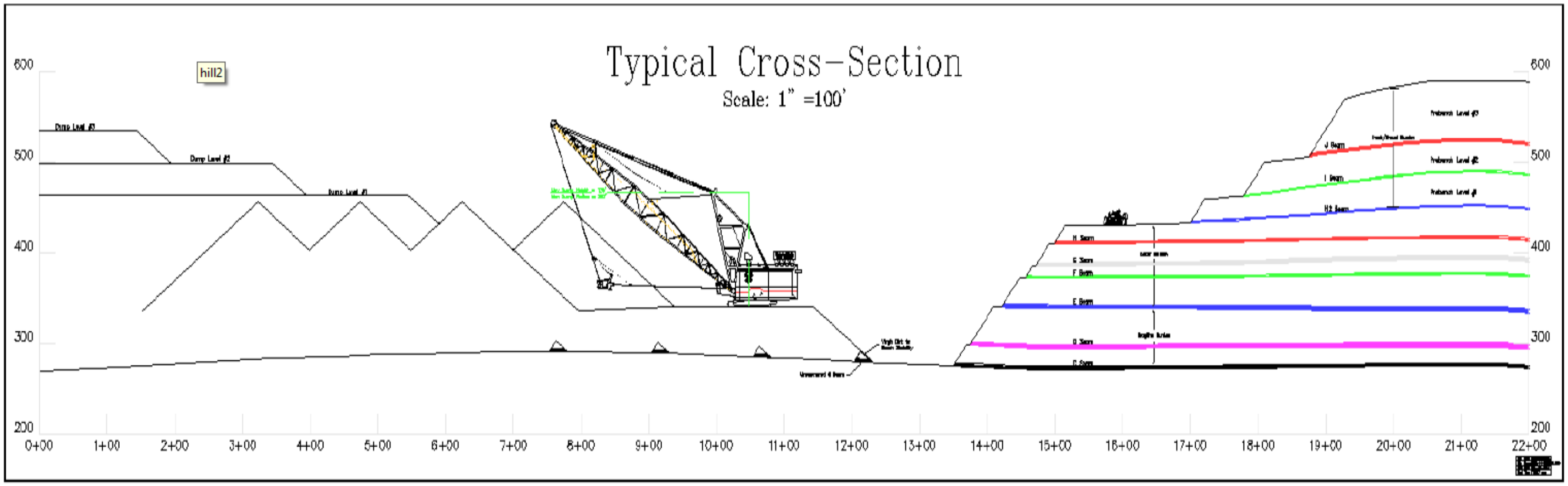


Figure 3.1 Cross-section of the mine

The surface mining process begins with typical cleaning and grubbing operations. Later, a truck and shovel fleet is responsible for topsoil stockpiling and overburden removal. Followed by a dozer-push fleet, interburden material is pushed into the excavated area. Finally, dragline operations are used for re-handling of overburden. An average pit dimension is 9,000 feet long and 170 feet wide, and mining methods are scheduled and assigned in sequence over three adjacent mine areas (Figure 3.2).

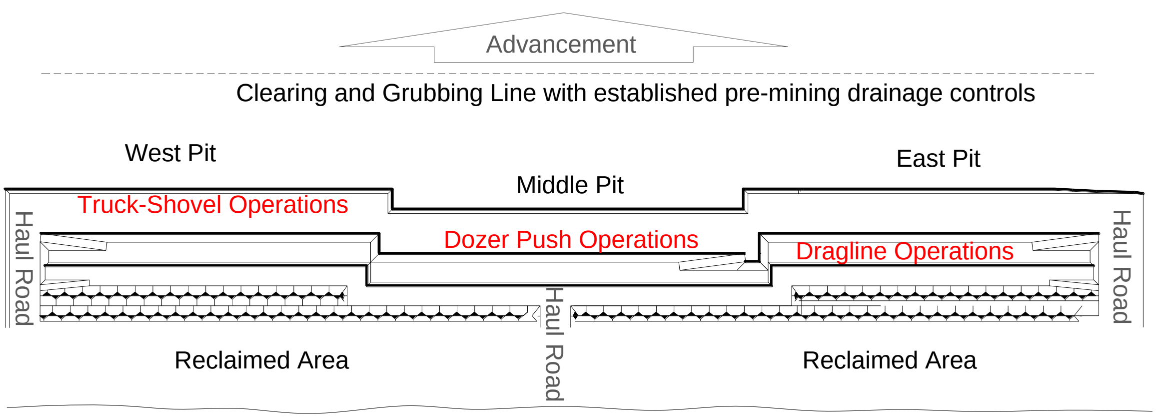


Figure 3.2 Mining sequence diagram

Usually, the clearing and grubbing operations are outsourced to private contractors. The truck and shovel fleet is composed of a P&H 2800 electric shovel with a 40 cubic yard bucket and Caterpillar 789 off-highway dump trucks. The shovel digs top material, including the first two coal seams, until the top minable coal seam is uncovered. Most of the time this phase involves removing up to 50 feet of overburden before the coal is reached. With an average of a 180-ton payload, haul trucks transport overburden to spoil dump areas. Caterpillar D10 dozers spread and bring the surface to the designed topography. Haulage distance is kept under 1.3 miles and 15 minutes for a cycle completion.

Subsequently, the second, third, and fourth lignite seams are uncovered by a fleet of four Caterpillar D11 dozers. On average, the interburden layers require about 60 feet of overburden push. The extraction of the last two feet of interburden, on top of the coal seams, is left for a rubber tire dozer or a Wirtgen 4200 Surface Miner (SM). This approach has shown highly improved results in coal recovery. Lastly, the bottom two minable coal seams are uncovered by a Marion 8200 dragline with an 82 cubic yard bucket. The dragline is in charge of moving up to 70 feet of both interburden and dozer-pushed material.

Coal seams are mined by a highly efficient SM. Lignite is loaded into Caterpillar 785 trucks with a 137 ton payload. The loading process takes approximately 4 minutes per truck. In addition to the SM, a Komatsu PC2000 excavator with a 19 cubic yard bucket is used as secondary coal loading equipment. The coal truck cycle is significantly longer than the cycle for overburden because it is hauled a longer distance to an on-site 400-ton hopper. Finally, coal is crushed and conveyed into two separate silos with a capacity of 20,000 tons each. The coal can be separated by quality and properly placed in either silo. A proper coal blend can guarantee 15.5% of ash content before reaching the customer's power plant facilities.

In addition to conventional material handling methods, the control of underground and rainfall water is required prior to mining. Underground dewatering systems, such as pumps, are installed to obtain a better ground stability control. Also, objects such as temporary sumps and collection ditches are carefully designed and constructed during pre-mining operations.

3.3 Loader System Application (LSA) - GUI

The loader system application (LSA) was not designed for equipment production or delay time data gathering. Its primary objective is to provide a GUI to select material descriptions and dump locations. The LSA uses the TDB as mediator in order to establish equipment communication. Built with two windows screens, the GUI for the LSA includes LogIn and Main modes.

3.3.1 Login Screen

Beginning with the LogIn screen, the loader system application (LSA) offers a physical platform for the registration of the loader's operator (Figure 3.3). In this manner, production records will be assigned to both truck and loader operator during IPMS reporting.

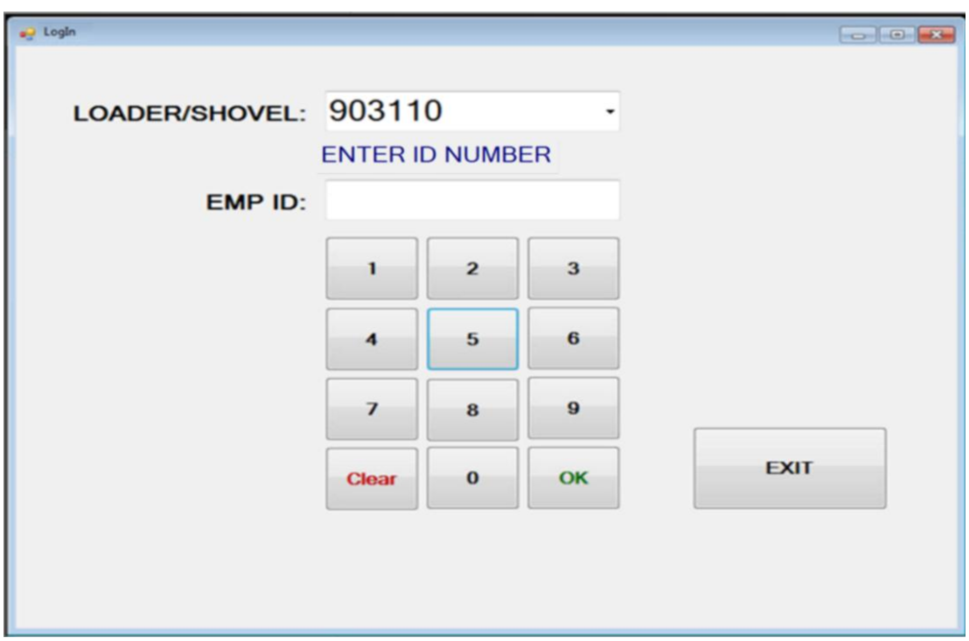


Figure 3.3 LogIn screen -LSA

The LogIn screen includes the following features:

- **Loader Selection** – The operator is required to select the loader equipment number by selecting any option displayed in this dropdown list.
- **Employee Number Display** – In this text box, the operator is able to see the employee number combination while it is being inserted.
- **Name Display** – Soon after an employee ID number is entered, the text in this field will be replaced with operator's full name. This may occur as long as EMP ID is found in the EDB. If the entry is valid, the validation key becomes available.
- **Clear Key** – This key clears the entered EMP ID at the Employee Number Display.
- **OK Key** – By clicking this key, the LSA will validate the loader and employee number, and continue to the next screen.
- **Exit Program** – Only if necessary, the operator has the option to exit the software application.

3.3.2 Main Screen

The second and most important form in this GUI is the Main screen (Figure 3.4). The Default screen has been highly simplified to produce an effective interaction with the operator. The Main screen is organized in three sections, including basic user information, Horizon and Dump Location selection, and selection history. At the top of this screen, the operator finds information introduced and selected while at the LogIn mode. This upper section also includes time and date stamps. Within the second section, the selection of Horizon and Dump location is made through combo boxes or dropdown lists. Ideally, the loader operator will manually select items that best fit the material handling. This data is reported as a message broadcast into the TDB. Later, this data is synchronized back to trucks for accurate production data generation. Finally, the last section in the Main screen is a visual reference of the latest broadcast. The operator may refer to this section for up-to-date decision making.

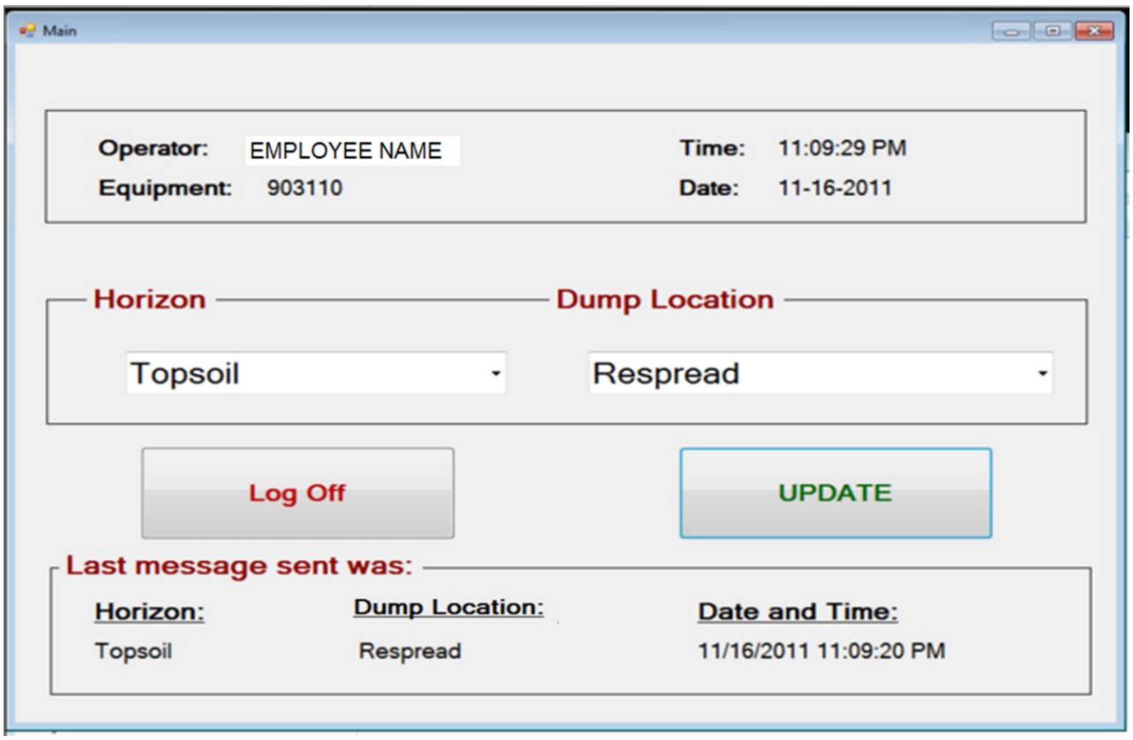


Figure 3.4 Main screen - LSA

Important elements found on the Main screen are:

- **Log Off Key –** Used to return to the LogIn screen for operator swapping.

- **Update Key –** Calls a synchronization agent where material description and dump location items are updated into the *SENT MSG LOADER* table within the TDB database.

A loader message broadcast refers to an insert or update in the *SENT MSG LOADER* table. This table is shared by the LSA and the TSA through database synchronization. Therefore, the loading equipment can easily update and consequently share the Horizon and Dump Location items with the trucks. The TSA interprets the most updated record from the loading equipment soon after the synchronization process is over. The following table shows sample data generated by the LSA in a real mine environment (Table 3.1). The indicator for the latest update is the last record reported in this data table. For instance, the newest message broadcast in this sample indicates “1” for HRZid and “22” for HUALid; which translates to “Topsoil” for horizon and “Respread” for dump location.

Table 3.1 Loader Broadcast data sample

SENT MSG LOADER Table										
ID	**EMPid**	**EQPnumber**	**HRZid**	**HAULid**	**Payload**	**Northing**	**Easting**	**Elevation**	**TimeNow**	**SenTo**
1	EMPload1	903110	3	16	Null	33.3840	89.2366	102.0000	11/17/2011 16:41	Null
2	EMPload2	903110	2	4	Null	33.3806	89.2217	121.3000	11/30/2011 13:23	Null
3	EMPload1	903110	1	22	Null	33.3840	89.2365	98.9000	11/30/2011 15:35	Null

3.4 Truck System Application (TSA) - GUI

Per safety requirements, the truck operator is responsible for completing a pre-shift equipment inspection, which usually takes fifteen minutes and should be conducted prior to boarding the truck. After this step, the personal computer installed in the equipment's cabin (Integration Phase) initializes the TSA. The GUI for trucks includes the following screens: LogIn, Default, Delay, and Setup.

3.4.1 Login Screen

Similar to the LSA, the TSA begins by showing an initial LogIn screen (Figure 3.5). The operator is required to insert and select basic personal and equipment information, respectively. Both of these entries are used throughout the field data generation process.

Figure 3.5 LogIn screen – TSA

The LogIn screen includes the following features:

- **Equipment Filtering** – By clicking on any of these three buttons (e.g., Ash Trucks, Coal Trucks, or Dirt Trucks), the LogIn screen automatically filters the truck dropdown list by categories. This makes it easier to find the equipment number when the list becomes extensive. However, the system stores the last selected equipment number in a separate text file (.txt) and uses it as a default value for next sessions. In the field environment, computer swapping is not common but it is possible. It must be taken into consideration that the TCD-ADCS was designed to be deployed in different mines. Therefore, avoiding hard coding (assigning permanent default values) in any section of the GUI was essential in its development.
- **Truck Selection** – The operator is required to select the appropriate truck number by choosing any item displayed in this dropdown list.
- **Employee Number Display** – In this textbox, the operator is able to see the number combination while it is being inserted.
- **Name Display** – Soon after an employee identification number is entered, the text in this field is replaced with operator's full name. This may occur as long as the "EMP ID" number is found within in the EDB. If the entry is valid, the validation key becomes available.
- **Clear Key** – It may be necessary for the operator to clear the entered "EMP ID" displayed on the Employee Number Display.
- **OK Key** – When the validation key is pressed, the TSA validates the truck and employee ID number before proceeding to the next screen.

- **Exit Program** – Only if necessary, the operator has the option of exiting the GUI.
- **Shutdown** – Occasionally equipment becomes unavailable and the onboard computer needs to be shutdown. This key turns off the computer automatically.

During the login process, the TSA records an employee identification number and the equipment number into the *LOGINrec* table (Table 3.2). Along with these records, the system application captures the date and time when the driver starts the shift and assigns an InOut code value of 1. The logout process is similarly recorded, and it is differentiated from the login by using a 0 code value instead.

Table 3.2 LOGINrec data sample

LOGINrec					
LOGID	**EMPid**	**EQPnumber**	**TimeNow**	**InOut**	**Shutdown**
580	EMP1	2BW1692	3/2/2012 6:59:40 AM	1	*Null*
581	EMP1	2BW1692	3/2/2012 6:42:13 PM	0	*Null*
582	EMP1	2BW1692	3/3/2012 7:00:55 AM	1	*Null*
583	EMP1	2BW1692	3/3/2012 6:43:36 PM	0	*Null*

3.4.2 Default Screen

After the login process, the operator can see the TSA's default screen (Figure 3.6). At this point, the system application is ready to start collecting field data. One of the main purposes of the GUI is to provide the driver with visual information during each cycle run. The top of the default screen displays selected items during the login process (i.e., employee name and equipment number). As mentioned in the work description section of this chapter, the mine of interest operates under two 12-hour shifts (Morning and Night).

The system application recognizes the shift description based on a login time stamp. Also, using a date stamp, the TSA assigns a Crew ID code that corresponds to the scheduled crew. This code is retrieved from the *CREW ROTATION* table in the EDB.

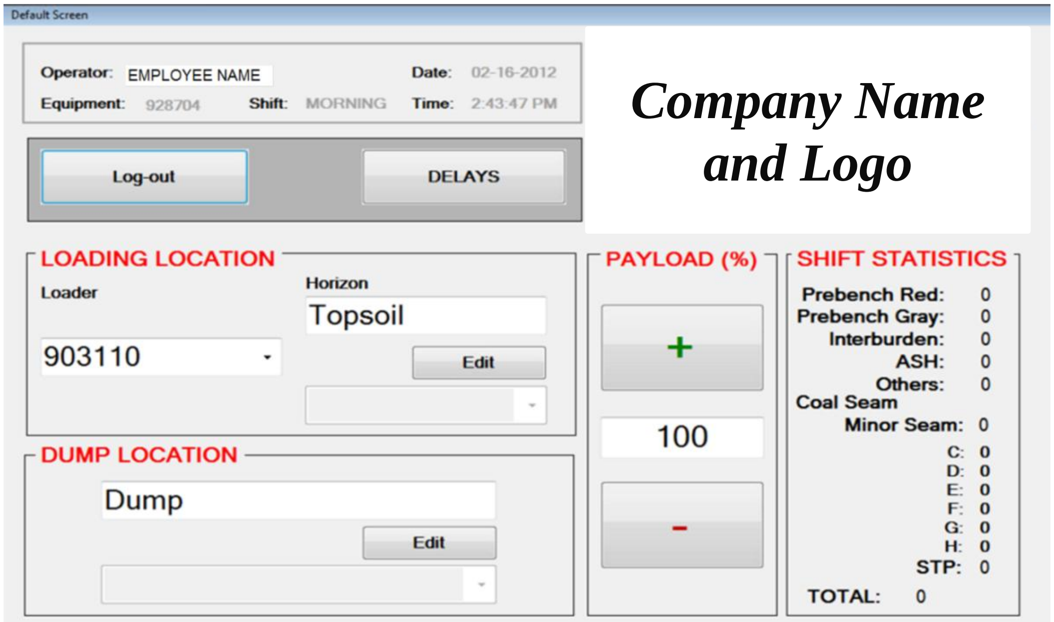


Figure 3.6 Default screen -TSA

A secondary purpose of the default mode is to collect items from the screen and use them as components of the production cycle records. For instance, the truck operator is responsible for choosing the loading equipment number with which he or she is working. Once a selection is made, the subsequent production records carry both loader and truck equipment numbers. These numbers are stored in their respective fields within the *PRO TRUCK TEMP* table. This way, the IPMS can generate production reports based on trucks or loaders separately.

At the same time when a loader number is selected, the horizon and the dump location items are automatically updated. This update procedure consists of collecting information from the *SENT MSG LOADER* table in the EDB and showing the latest record created during the LSA's message broadcast process. Therefore, the truck driver is excused from specifying the horizon and the dump location. However, the GUI provides the truck operator with features that allow a manual change of both objects. This process is done by using the Edit key. A manual object change may occur during a loss of network connectivity or if a verbal request is made by the supervisor.

Shifts statistics are also viewed at the Default screen. Prior to the implementation of the TCD-ADCS, the truck cycle number was the only data available for drivers. Now, the operator can have a visual reference of how many cycles have been completed, as well as the material cycle category. In most cases, drivers often kept a written production log with the total number of cycles. Some operators even used thumb counting-clickers to keep track of cycles. The collection of the production logs was made by supervisors at the end of every shift. This person was responsible for manually introducing the total cycle count for every truck into the IPMS. However, due to the implementation of the TSA, each production cycle is reported into the database in real-time. For instance, sample data from the *PRO TRUCK TEMP* table (Table 3.3) shows that a single truck reported a total of twelve completed cycles within a two hour period; resulting in an average time of 10.5 minutes per cycle. Along with every cycle completion, each production record includes data that describes the characteristic of the truck cycle including: date and time, shift, crew, equipment number, employee number, loader ID, loader employee number, horizon, dump location, average payload, and material description.

Table 3.3 PRO TRUCK TEMP data sample

PRO TRUCK TEMP														
PROTid	**PROTDate**	**SFTid**	**CRCid**	**EQPnumber**	**EMPid**	**LOADERid**	**EMPLOADERid**	**HRZid**	**HAULid**	**PROTload**	**PROTtons**	**PROTmaterial**	**PROThaullocation**	**PROTseam**
39565	3/3/2012 16:38	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39566	3/3/2012 16:47	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39567	3/3/2012 16:57	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39568	3/3/2012 17:09	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39569	3/3/2012 17:18	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39570	3/3/2012 17:29	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39571	3/3/2012 17:39	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39572	3/3/2012 17:49	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39573	3/3/2012 17:59	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39574	3/3/2012 18:09	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39575	3/3/2012 18:22	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil
39576	3/3/2012 18:34	1	1	2BW1692	EMP1	903110	EMPloader1	1	22	1	180	OB	Respread	Topsoil

Finally, while in the default mode, GPS sentences are constantly received by the Garmin GPS 18 USB receiver. The TSA uses GPS data efficiently, since it can be overwhelming to the EDB. A new record on the *GPS TRACKER* table is inserted after the equipment reaches a certain distance away from the most recent recording. Sample data from the *GPS TRACKER* table (Table 3.4) shows that the TSA has been calibrated to take a new positioning point (e.g., northing, easting, and elevation) at least every 500 feet. This distance value is referred to as the Point-to-Point Distance (ppDistance). Through this process, the distance travelled during haulage and return stages on each truck cycle is measured.

Table 3.4 GPS LOCATION RECORD data sample

GPS LOCATION RECORD							
DT	**PROTid**	**ppDistance**	**Nothing**	**Easting**	**Elevation**	**PRODL**	**EQPnumber**
10/13/2011 12:41	9298010000264	401.3	33.3772	89.2183	101.8000	3925	2BW1692
10/13/2011 12:41	9298010000264	516.1	33.3783	89.2193	118.1000	3926	2BW1692
10/13/2011 12:42	9298010000264	516.5	33.3794	89.2204	118.5000	3927	2BW1692
10/13/2011 12:42	9298010000264	516.3	33.3804	89.2215	115.9000	3928	2BW1692
10/13/2011 12:42	9298010000264	531.4	33.3815	89.2226	111.2000	3929	2BW1692
10/13/2011 12:42	9298010000264	520.5	33.3828	89.2233	105.0000	3930	2BW1692
10/13/2011 12:43	9298010000264	503.8	33.3839	89.2244	102.3000	3931	2BW1692

The Default screen has the following keys:

- **Log-Out Key** – This key allows the operator to return to the LogIn screen without completely exiting the system application. This may occur during operator swaps or at the end of every shift.
- **Delays Key** – This key allows access to the TSA's Delay mode.

- **Loading Location EDIT Key** – A dropdown list below is kept disabled until the edit key is pressed. This feature allows the truck driver to manually modify values in the horizon object.
- **Dump Location EDIT Key** – In this case, the EDIT key allows the manual modification of the dump location object.
- **Payload (%)** – Since the system application has no interaction with the truck's built-in scale, the production cycle records are recorded using average payload values. In rare cases, supervisors may instruct the truck operator to increase or decrease the average payload by some percentage. The default payload (%) value is presented as 100% of the average payload.

The key to reducing human error is to allow the TSA to generate new production cycle records by itself. For instance, the default screen does not offer any button or key for manual record generation. The TSA automatically records and stores field data into the EDB.

3.4.3 Delay Screen

A major feature of the TCD-ADCS is the delay recognition and delay data collection capability. The TSA's GUI includes a Delay mode which provides easy access for manual delay code selections. The Default screen includes a Delay key to active this mode. Selecting this key does not necessarily need to be done manually. The system application frequently uses the GPS integration to take measurements of the truck's ground speed. Therefore, it is possible for the system application to be aware when the equipment stops. Under the TSA's logic, a hidden timer is started when a Minimum Speed Limit (MSLa) is reached. This timer allows for a nonmoving time period known as Delay Tolerance Time (DTT) before automatically switching to the delay mode. It is not adequate to assume that all stopping events are considered delays, since some truck cycle stages require the equipment to reach stopping points. While in the Delay mode, loading and dumping events are treated differently from variable delays. At the Delay screen (Figure 3.7), the equipment operator finds a list of options containing most common variable delays. Also, loading and dumping notifications are accepted on this screen. Loading and dumping keys are explained later in this chapter.

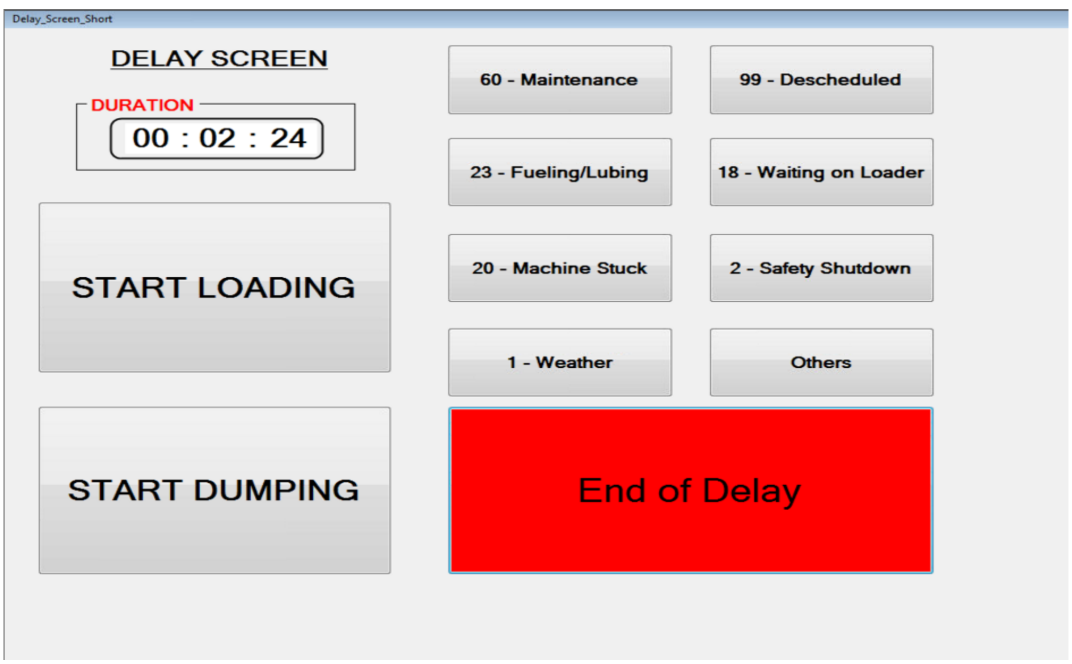


Figure 3.7 Delay screen - TSA

Experienced operators may be more familiar with delay codes instead of delay names. Therefore, the delay keys display both codes and descriptions. When a truck cycle run is interrupted by a variable delay event, it is the operator's responsibility to immediately identify the reason for stopping. This is done by clicking on one of the delay options. Once a delay code selection is made, the TSA waits for an end of delay acknowledgement. However, the system application is programmed with a default delay code in case no delay selection is made. Just like with the delay recognition logic, the GUI is able to automatically click the End of Delay key by measuring the ground speed. When the equipment gains speed after terminating a random delay, a hidden timer ensures that the truck's ground speed stays above a new Minimum Speed Limit (MSLb) for a fixed period of time, before concluding the delay recordings. This period of time is referred to as the Movement Tolerance Time (MTT). The total event Duration Time (DT) and the specific delay code are recorded at the *TEMP DELAY* table within the EDB. The End of Delay key is also assigned a data synchronization role. By ending the delay mode, the TSA calls the Field Data SyncAgent (Chapter 2). Therefore, a new delay record is transferred to the TDB soon after it ends.

Sample delay data generated in a real mine environment shows that several variable delays for a single truck can be generated throughout a full shift (Table 3.5). Delays recorded by the TSA range between a few minutes and approximately a half-hour. Each record was automatically reported to the office environment soon after they concluded. All truck delay events generated from the field are labeled with equipment number, employee number, date, shift, crew, delay code and category, duration, and start and end time.

Table 3.5 DELAY TIME TEMP Data sample

DELAY TIME TEMP										
DLTid	**EQPnumber**	**DLTdate**	**SFTid**	**DLCODEid**	**DLCODEcategory**	**DLThours**	**DLTstart**	**DLTend**	**EMPid**	**4x MTC Fields**
177269	2BW1692	3/3/2012 0:00	1	10	Operational	0.25	3/3/2012 7:00	3/3/2012 7:15	EMP1	NULL
177271	2BW1692	3/3/2012 0:00	1	23	Operational	0.155	3/3/2012 7:02	3/3/2012 7:11	EMP1	NULL
177282	2BW1692	3/3/2012 0:00	1	96	Idle	0.015	3/3/2012 8:56	3/3/2012 8:56	EMP1	NULL
177283	2BW1692	3/3/2012 0:00	1	96	Idle	0.067	3/3/2012 8:57	3/3/2012 9:01	EMP1	NULL
177286	2BW1692	3/3/2012 0:00	1	12	Operational	0.016	3/3/2012 9:37	3/3/2012 9:38	EMP1	NULL
177291	2BW1692	3/3/2012 0:00	1	18	Operational	0.088	3/3/2012 11:21	3/3/2012 11:26	EMP1	NULL
177292	2BW1692	3/3/2012 0:00	1	18	Operational	0.034	3/3/2012 11:36	3/3/2012 11:38	EMP1	NULL
177293	2BW1692	3/3/2012 0:00	1	97	Idle	0.494	3/3/2012 13:03	3/3/2012 13:32	EMP1	NULL
177324	2BW1692	3/3/2012 0:00	1	99	Idle	0.267	3/3/2012 18:43	3/3/2012 19:00	EMP1	NULL

The delay screen also includes an Others key. This key is used for the expansion of the delay code catalog. This feature allows a more accurate variable delay explanation. The Others Delay screen (Figure 3.8) offers the truck driver with additional but less common delay codes. For instance, other delays might be tours, on-shift inspections, breaks, machine cleaning, and accidents.

Figure 3.8 Other delay screen

Since the TSA has no interaction with the truck's onboard controls, the recognition of loading and dumping events can be difficult. As a solution, the system application contains a loading and a dumping key within the delay mode. While the truck is loading, the driver must indicate by clicking on the Start Loading button. Since the actual loading event starts as soon as the truck reaches the loading position and before the DTT sets the delay mode active, the total loading time (LT) is recorded as the sum of the DT and DTT minus the MTT. Moreover, by clicking the Start Loading key, the GUI immediately changes the functionality of this key to an End Loading key (Figure 3.9). And again, using the GPS ground speed measurement, the TSA automatically concludes the loading recording when truck movement is detected.

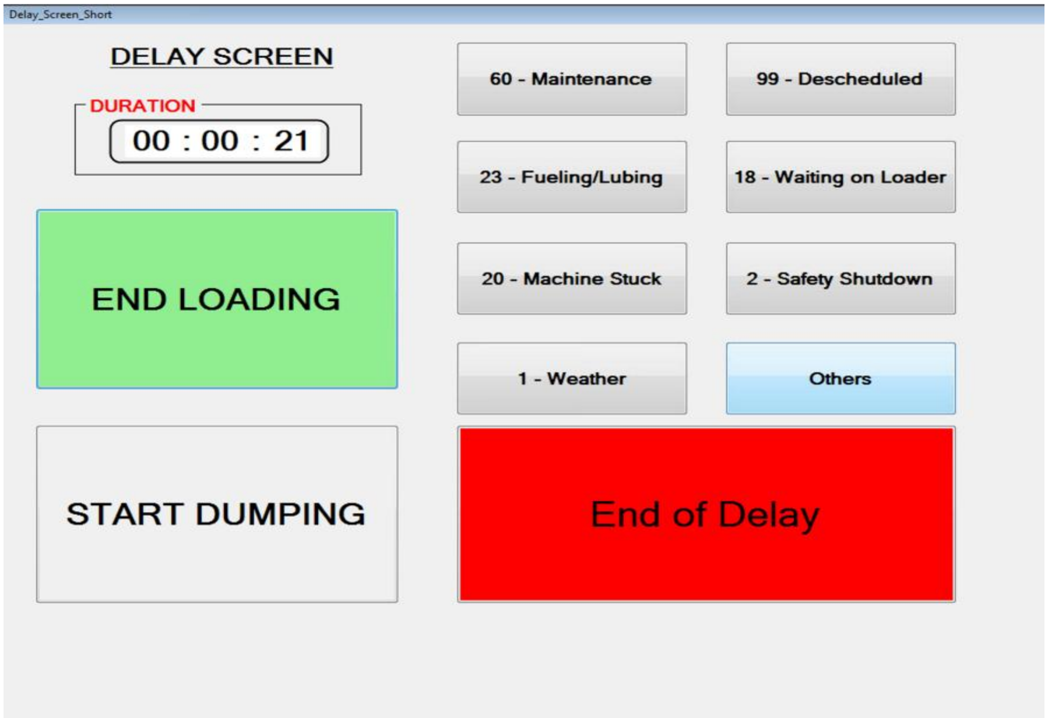


Figure 3.9 Delay screen at loading mode

Similar to the Start Loading key, the Start Dumping key follows the same procedures, except it is used for dumping events only (Figure 3.10). Additionally, this key includes a synchronization call at the end of every dumping event. This way, the TSA maintains the TDB with the most recent truck cycle data available. Since a complete truck cycle concludes at the return to the loading position, data for the return stage is not synchronized until a subsequent Field Data SyncAgent call is made. This could either be at the end of a variable delay, or at the end of the following dumping event.

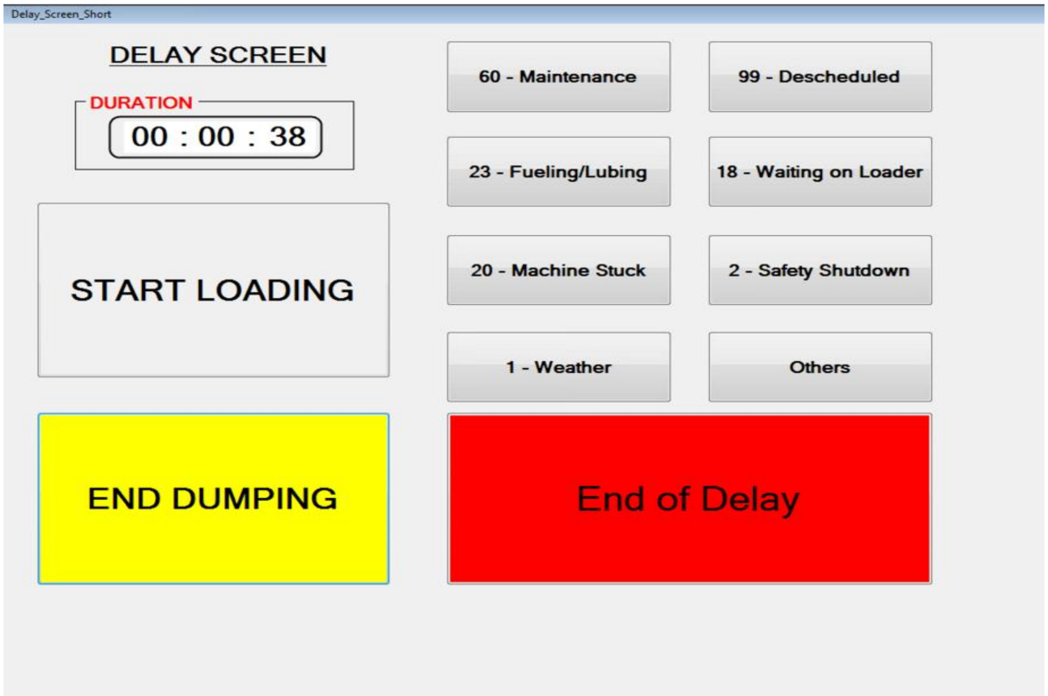


Figure 3.10 Delay screen at dumping mode

Data generated during truck loading and dumping events is stored in the *LOAD DUMP CYCLE* table. Field samples show that an average loading process (i.e., LoadDumpCode = 1) takes 81.9 seconds; while the average dumping process (i.e., LoadDumpCode = 0) is only 31.1 seconds long (Table 3.6). Along with the event duration, the TSA reports data that describes positioning measurements as well as the date and time of the occurrence.

Table 3.6 LOAD DUMP CYCLE data sample

LOAD DUMP CYCLE									
LoadDumpID	**EQPnumber**	**EMPid**	**LoadDumpCode**	**Cycletime**	**LoadDumpDate**	**SFTid**	**Northing**	**Easting**	**Elevation**
3061	2BW1692	EMP1	1	92	3/3/2012 7:20	1	33.3933	89.2545	120.7000
3062	2BW1692	EMP1	0	61	3/3/2012 7:26	1	33.3860	89.2577	136.4000
3063	2BW1692	EMP1	1	71	3/3/2012 7:31	1	33.3932	89.2546	126.5000
3064	2BW1692	EMP1	0	20	3/3/2012 7:37	1	33.3869	89.2574	136.3000
3065	2BW1692	EMP1	1	92	3/3/2012 7:41	1	33.3934	89.2541	105.1000
3066	2BW1692	EMP1	0	35	3/3/2012 7:48	1	33.3868	89.2581	151.7000
3067	2BW1692	EMP1	1	23	3/3/2012 7:54	1	33.3933	89.2544	124.5000
3068	2BW1692	EMP1	0	23	3/3/2012 7:59	1	33.3870	89.2580	134.4000
3069	2BW1692	EMP1	1	163	3/3/2012 8:03	1	33.3933	89.2545	104.4000
3070	2BW1692	EMP1	0	24	3/3/2012 8:11	1	33.3868	89.2583	130.8000
3071	2BW1692	EMP1	1	58	3/3/2012 8:16	1	33.3933	89.2544	122.2000
3072	2BW1692	EMP1	0	31	3/3/2012 8:22	1	33.3860	89.2579	125.9000
3073	2BW1692	EMP1	1	74	3/3/2012 8:27	1	33.3933	89.2546	129.7000
3074	2BW1692	EMP1	0	24	3/3/2012 8:33	1	33.3870	89.2574	133.6000

3.4.4 Setup Screen

Finally, a Setup screen is incorporated into the GUI for definition of variables. The Setup screen (Figure 3.11) can only be accessed by the supervisor or the mine engineer. At the TSA startup, and before introducing an employee ID number in the LogIn screen, the right number combination brings the Setup screen to a display. As mentioned before, no hard-coded constants are included in this system application development since it may be used in various mine locations. Each mine site may require different setups for more adequate data collection. In the Setup screen, the authorized personnel are able to change specific parameters used throughout the process of truck cycle and delay data collection.

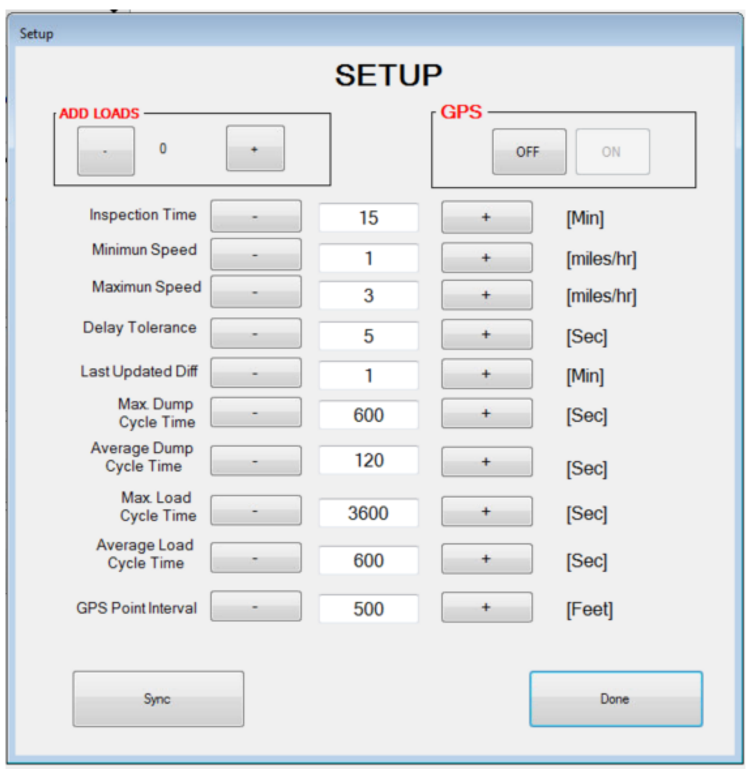


Figure 3.11 Setup screen - TSA

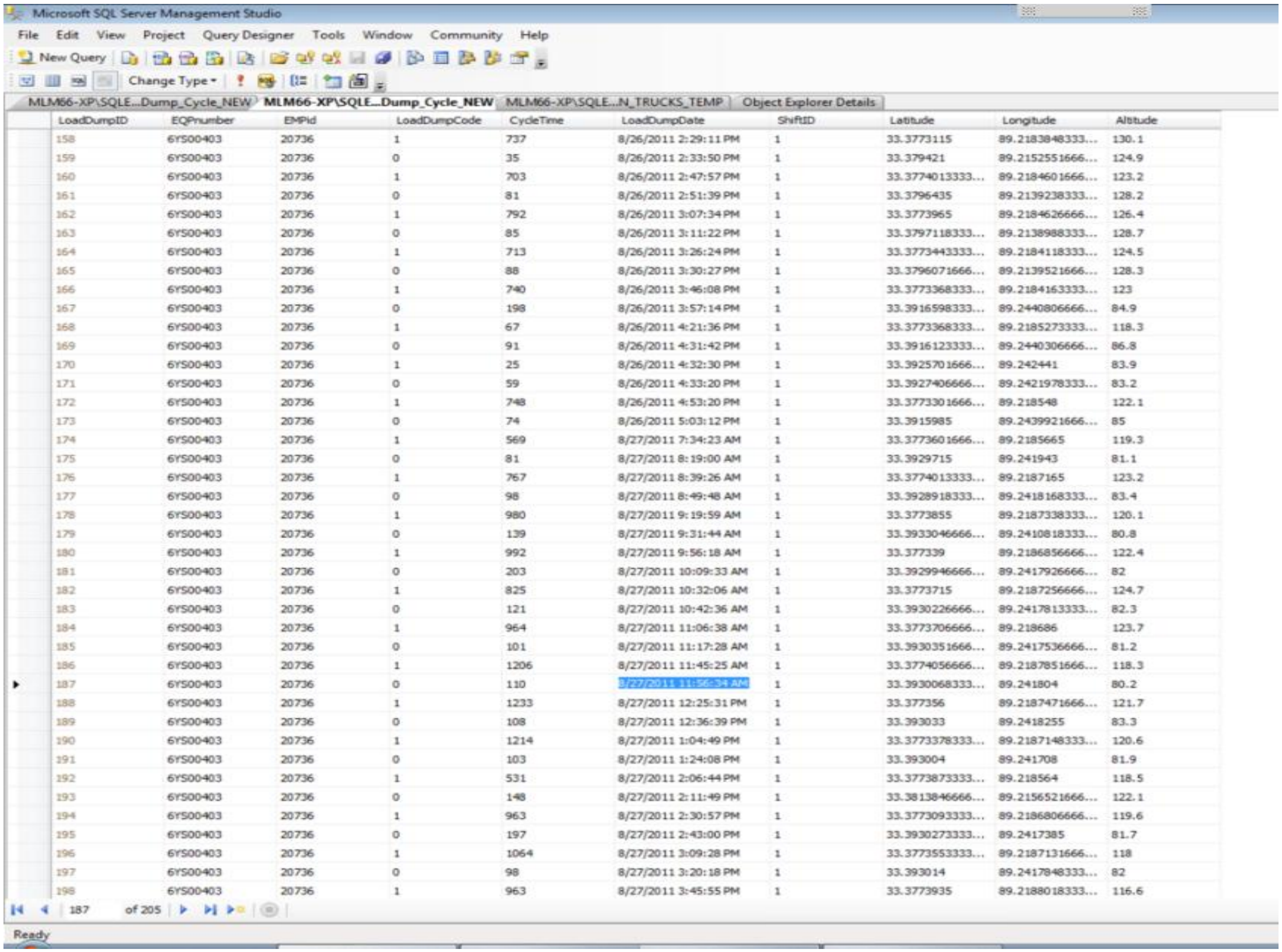
Important parameters in the Setup screen are as follows:

- **ADD Loads –** The supervisor has the authority to introduce a number of completed cycles prior to the login process and during the operators' change. This entry does not affect the total amount of truck cycles recorded into the database. It is just a visual guidance displayed in the shift statistics section of the default screen.
- **GPS –** With this option, it is possible to disable the GPS receiver. It may be required if the receiver device suffers physical damage.
- **Inspection Time - INSP [Minutes] –** This variable is used to define the time length for the initial fixed delay, referring to the pre-shift equipment inspection.
- **Minimum Speed Limit - MSLa [miles/hr] –** The MSLa defines the minimum ground speed in which the TSA triggers the DTT timer. This value cannot be assumed as zero speed since some loading processes do not require a complete stop of the trucks (e.g., loading with the SM).
- **Minimum Speed Limit - MSLb [miles/hr] –** Opposite to the MSLa, this ground speed value is used to determine the change from the Delay mode to the Default mode in the GUI. The MLSb defines when the MTT timer should be stopped.
- **Delay Tolerance Time - DTT [Seconds] –** This variable is used to determine the amount of time tolerated with a ground speed lower than the MSLa. The DTT can be set with high sensitivity. It is recommended that this value should never exceed the average dumping time (ADT). To do so would increase the chance for the TSA to miss the dumping stage of the truck cycle.

- **Last Update Difference Time LUT [Minutes] –** This variable is used to limit the TCD-ADCS to make multiple synchronization calls within a certain period of time. This feature may reduce false data generation.
- **Max Dump Cycle Time MDT [Seconds] –** The MDT is used by the TSA to set a time limit for the dumping process. If the dumping duration exceeds this value, the GUI automatically requests for a delay code selection; consequently, the dumping recognition process stops.
- **Average Dump Cycle Time ADT [Seconds] –** This value anticipates and monitors the dumping duration time. When the truck is at the dumping stage of the truck cycle, an audible warning will inform the operator if the dumping process is longer than expected.
- **Max Load Cycle Time MLT [Seconds] -** The MLT is used similarly to the MDT, but instead it is used for the loading process.
- **Average Load Cycle time ALT [Seconds] –** Opposite to the ADT, the ALT is used to estimate the average loading duration.
- **GPS Point Interval GPI [Feet] –** The GPI default value is used to determine the distance between tracking records (ppDistance). Data generation from the excessive lowering of this variable might result in the saturation of the EDB. On the other hand, if this variable is highly increased, the result can be over-simplified data generation.
- **Sync Key –** This variable is an auxiliary synchronization call. This key is a call to all SyncAgents incorporated in the TSA.

3.5 Data Transfer Results

After the integration of the TCD-ADCS, paper-based cards were eliminated and replaced with the data synchronization features included in the system application. Data transfer is automatically completed in real-time, allowing for the latest data generated in the field to appear in the TDB soon after collection. Figure 3.12 shows a screenshot of field data tables containing raw data inserted after the synchronization process. Field tables within the TDB are constantly being populated by TSAs. Therefore, paper-based cards are only used as a backup in case the TCD-ADCS is temporarily unavailable.



LoadDumpID	EQPnumber	EMPid	LoadDumpCode	CycleTime	LoadDumpDate	ShiftID	Latitude	Longitude	Altitude
158	6YS00403	20736	1	737	8/26/2011 2:29:11 PM	1	33.3773115	89.2183848333...	130.1
159	6YS00403	20736	0	35	8/26/2011 2:33:50 PM	1	33.379421	89.2152551666...	124.9
160	6YS00403	20736	1	703	8/26/2011 2:47:57 PM	1	33.3774013333...	89.2184601666...	123.2
161	6YS00403	20736	0	81	8/26/2011 2:51:39 PM	1	33.3796435	89.2139238333...	128.2
162	6YS00403	20736	1	792	8/26/2011 3:07:34 PM	1	33.3773965	89.2184626666...	126.4
163	6YS00403	20736	0	85	8/26/2011 3:11:22 PM	1	33.3797118333...	89.2138988333...	128.7
164	6YS00403	20736	1	713	8/26/2011 3:26:24 PM	1	33.3773443333...	89.2184118333...	124.5
165	6YS00403	20736	0	88	8/26/2011 3:30:27 PM	1	33.3796071666...	89.2139521666...	128.3
166	6YS00403	20736	1	740	8/26/2011 3:46:08 PM	1	33.3773368333...	89.2184163333...	123
167	6YS00403	20736	0	198	8/26/2011 3:57:14 PM	1	33.3916598333...	89.2440806666...	84.9
168	6YS00403	20736	1	67	8/26/2011 4:21:36 PM	1	33.3773368333...	89.2185273333...	118.3
169	6YS00403	20736	0	91	8/26/2011 4:31:42 PM	1	33.3916123333...	89.2440306666...	86.8
170	6YS00403	20736	1	25	8/26/2011 4:32:30 PM	1	33.3925701666...	89.242441	83.9
171	6YS00403	20736	0	59	8/26/2011 4:33:20 PM	1	33.3927406666...	89.2421978333...	83.2
172	6YS00403	20736	1	748	8/26/2011 4:53:20 PM	1	33.3773301666...	89.218548	122.1
173	6YS00403	20736	0	74	8/26/2011 5:03:12 PM	1	33.3915985	89.2439921666...	85
174	6YS00403	20736	1	569	8/27/2011 7:34:23 AM	1	33.3773601666...	89.2185665	119.3
175	6YS00403	20736	0	81	8/27/2011 8:19:00 AM	1	33.3929715	89.241943	81.1
176	6YS00403	20736	1	767	8/27/2011 8:39:26 AM	1	33.3774013333...	89.2187165	123.2
177	6YS00403	20736	0	98	8/27/2011 8:49:48 AM	1	33.3928918333...	89.2418168333...	83.4
178	6YS00403	20736	1	980	8/27/2011 9:19:59 AM	1	33.3773855	89.2187338333...	120.1
179	6YS00403	20736	0	139	8/27/2011 9:31:44 AM	1	33.3933046666...	89.2410818333...	80.8
180	6YS00403	20736	1	992	8/27/2011 9:56:18 AM	1	33.377339	89.2186856666...	122.4
181	6YS00403	20736	0	203	8/27/2011 10:09:33 AM	1	33.3929946666...	89.2417926666...	82
182	6YS00403	20736	1	825	8/27/2011 10:32:06 AM	1	33.3773715	89.2187256666...	124.7
183	6YS00403	20736	0	121	8/27/2011 10:42:36 AM	1	33.3930226666...	89.2417813333...	82.3
184	6YS00403	20736	1	964	8/27/2011 11:06:38 AM	1	33.3773706666...	89.218686	123.7
185	6YS00403	20736	0	101	8/27/2011 11:17:28 AM	1	33.3930351666...	89.2417536666...	81.2
186	6YS00403	20736	1	1206	8/27/2011 11:45:25 AM	1	33.3774056666...	89.2187851666...	118.3
187	6YS00403	20736	0	110	8/27/2011 11:56:34 AM	1	33.3930068333...	89.241804	80.2
188	6YS00403	20736	1	1233	8/27/2011 12:25:31 PM	1	33.377356	89.2187471666...	121.7
189	6YS00403	20736	0	108	8/27/2011 12:36:39 PM	1	33.393033	89.2418255	83.3
190	6YS00403	20736	1	1214	8/27/2011 1:04:49 PM	1	33.3773378333...	89.2187148333...	120.6
191	6YS00403	20736	0	103	8/27/2011 1:24:08 PM	1	33.393004	89.241708	81.9
192	6YS00403	20736	1	531	8/27/2011 2:06:44 PM	1	33.3773873333...	89.218564	118.5
193	6YS00403	20736	0	148	8/27/2011 2:11:49 PM	1	33.3813846666...	89.2156521666...	122.1
194	6YS00403	20736	1	963	8/27/2011 2:30:57 PM	1	33.3773093333...	89.2186806666...	119.6
195	6YS00403	20736	0	197	8/27/2011 2:43:00 PM	1	33.3930273333...	89.2417385	81.7
196	6YS00403	20736	1	1064	8/27/2011 3:09:28 PM	1	33.3773553333...	89.2187131666...	118
197	6YS00403	20736	0	98	8/27/2011 3:20:18 PM	1	33.393014	89.2417848333...	82
198	6YS00403	20736	1	963	8/27/2011 3:45:55 PM	1	33.3773935	89.2188018333...	116.6

Figure 3.12 Incoming raw data sample

It is important to emphasize that data analysis and reporting are not included in the scope of this research project. The TCD-ADCS is only used for the collection and synchronization of raw truck cycle and delay data in real-time. However, the data analysis and reporting are completed by the IPMS located in an office environment. Figure 3.13 and 3.14 show customized report samples for truck production and delays generated by the IPMS. These reports contain useful information about the mine production and the equipment for the management personnel to use and improve their decision making. The compatibility of the TCD-ADCS and the IPMS provides an accurate and efficient custom-made truck production monitoring system for the surface coal mine.

DAILY SHIFT REPORT

Summary of Material Moved by Loader, by Shift

Date: 7/5/2011 **Shift:** AFTERNOON **Crew:** C

MATERIAL: CO

LOADER: 905131

HORIZON	LOADS	TONS	DESTINATION
D-seam	15	1,895	Silo 1
D-seam	17	2,148	Silo 2
D-seam	32	4,043	Stockpile B
MATERIAL TOTAL =	**64**	**8,086**	

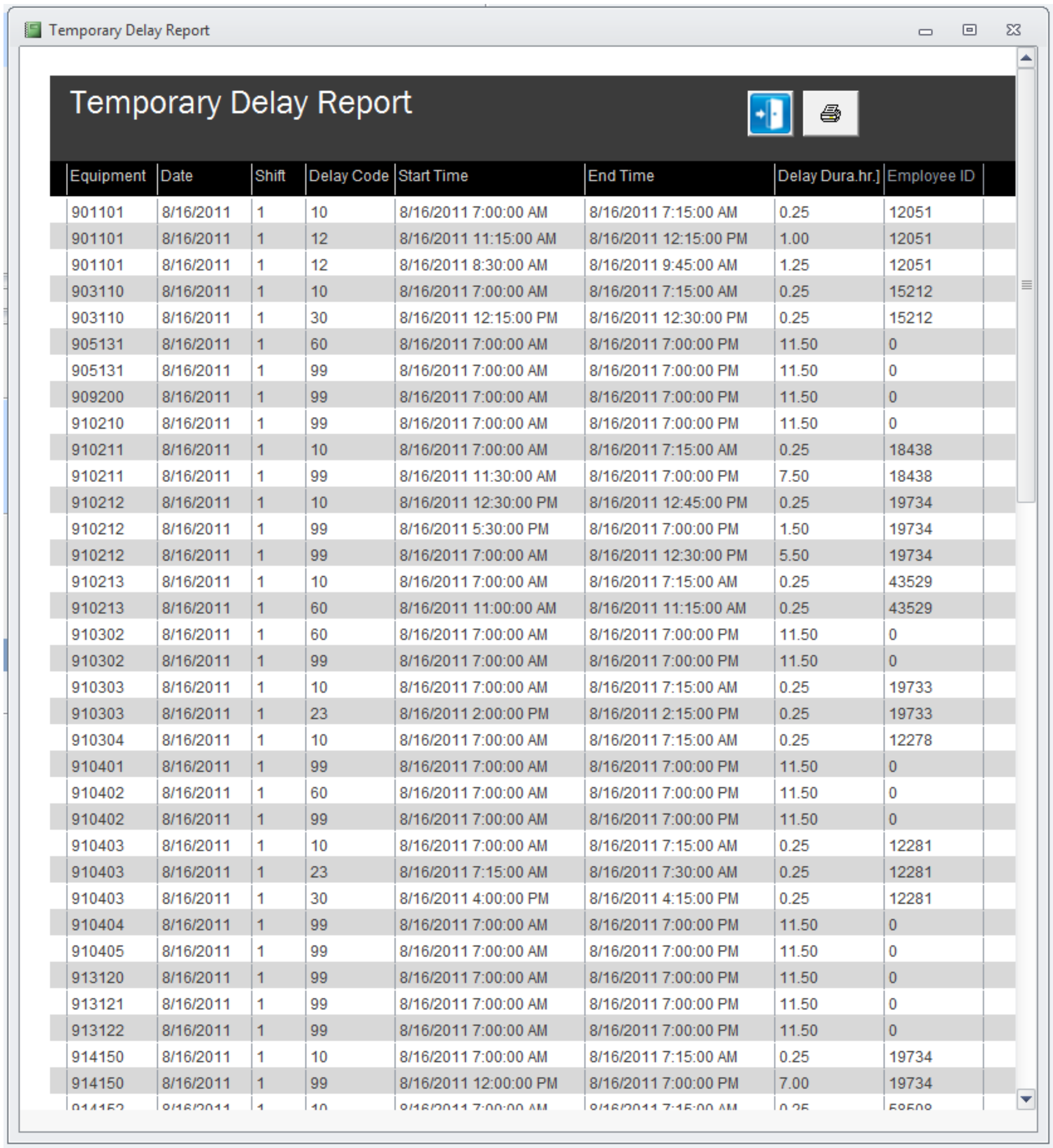
MATERIAL: OB

LOADER: 903110

HORIZON	LOADS	TONS	DESTINATION
Prebench	51	9,180	Dump
Prebench	93	16,740	Respread
MATERIAL TOTAL =	**144**	**25,920**	

SHIFT TOTAL* = **208** **34,006** **[t]**

Figure 3.13 Production report sample



Temporary Delay Report

Equipment	Date	Shift	Delay Code	Start Time	End Time	Delay Dura.hr.]	Employee ID
901101	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	12051
901101	8/16/2011	1	12	8/16/2011 11:15:00 AM	8/16/2011 12:15:00 PM	1.00	12051
901101	8/16/2011	1	12	8/16/2011 8:30:00 AM	8/16/2011 9:45:00 AM	1.25	12051
903110	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	15212
903110	8/16/2011	1	30	8/16/2011 12:15:00 PM	8/16/2011 12:30:00 PM	0.25	15212
905131	8/16/2011	1	60	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
905131	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
909200	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910210	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910211	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	18438
910211	8/16/2011	1	99	8/16/2011 11:30:00 AM	8/16/2011 7:00:00 PM	7.50	18438
910212	8/16/2011	1	10	8/16/2011 12:30:00 PM	8/16/2011 12:45:00 PM	0.25	19734
910212	8/16/2011	1	99	8/16/2011 5:30:00 PM	8/16/2011 7:00:00 PM	1.50	19734
910212	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 12:30:00 PM	5.50	19734
910213	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	43529
910213	8/16/2011	1	60	8/16/2011 11:00:00 AM	8/16/2011 11:15:00 AM	0.25	43529
910302	8/16/2011	1	60	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910302	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910303	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	19733
910303	8/16/2011	1	23	8/16/2011 2:00:00 PM	8/16/2011 2:15:00 PM	0.25	19733
910304	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	12278
910401	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910402	8/16/2011	1	60	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910402	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910403	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	12281
910403	8/16/2011	1	23	8/16/2011 7:15:00 AM	8/16/2011 7:30:00 AM	0.25	12281
910403	8/16/2011	1	30	8/16/2011 4:00:00 PM	8/16/2011 4:15:00 PM	0.25	12281
910404	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
910405	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
913120	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
913121	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
913122	8/16/2011	1	99	8/16/2011 7:00:00 AM	8/16/2011 7:00:00 PM	11.50	0
914150	8/16/2011	1	10	8/16/2011 7:00:00 AM	8/16/2011 7:15:00 AM	0.25	19734
914150	8/16/2011	1	99	8/16/2011 12:00:00 PM	8/16/2011 7:00:00 PM	7.00	19734

Figure 3.14 Temporary Delay report sample

3.6 Discussion and Observations

A few observations and recommendations were suggested by the mine personnel:

1. During the login process in the TSA and the LSA, it is important to maintain simplicity and friendly connectivity between the operator and the application.

The less interaction the operator has to deal with, the better he or she will adjust to the technology.

After introducing a correct employee ID number, the application will automatically identify the operator’s full name in order to request verification. The system could show a new pop-up form asking the operator to verify if that is the correct user name by saying Yes or No. To simplify this approach, any new pop-up should be neglected. By avoiding this step, the operator will not be frustrated by having to verify his/her name every time a log in is done.

To solve the verification issue, the GUI will have the following feature: When the operator introduces the last digit of the identification number, the system will automatically recognize the full name, and it will be displayed on the same LogIn screen. This way the operator will be able to see if the correct ID was introduced and continue without further interruption.

2. Integrating a new screen for safety meetings, safety inspection, or pre-shift inspections acknowledgement should be avoided. Initially in the interviewing process, the idea of creating an environment to define safety fix delays was considered (e.g., a form requesting the operator to introduce time values for when the safety meeting/inspection has ended. Such a form would also have the options between AM and PM to help the system determine if the operator is working on a day or night shift). However, this initial thought was discarded to necessary to avoid confusion with the operators.

One approach to simplify the GUI is to completely eliminate the safety meeting form without ignoring any fixed pre-shift delays. The application will recover the systems time and will create a hidden condition inside the login procedure. A default variable will be introduced to determine what time the safety meeting should end (INSP). If the system time passes this default value without registering any login, the application will go directly to a Delay mode. This delay will continue until someone logs in to the system application. Hiding this procedure provides one less thing for the operator to deal with on the GUI.

3. The Default screen is where all production cycle values are stored and updated to the *PRO TRUCK TEMP* table. This particular screen grants the operator the power to modify some fields in the storage procedure. These fields must be limited to Loader, Horizon, Dump Location, and payload. Other fields displayed on this screen should not be altered by the ultimate user.

4. The data structure for the *DELAY TEMP* table also includes three fields for maintenance data storage. These fields are: DLTMtccode, DLTMtcDlayHrs, and DLTMtcduration; they represent maintenance delay code, total delay duration in hours, and actual maintenance duration, respectively. All maintenance designated fields should remain unpopulated by the integration of the TCD-ADCS. Maintenance data will be fed manually through IPMS by authorized maintenance personnel.

Chapter 4

Summary, Conclusions, and Recommendations for Future Research

4.1 Summary

Chapter 1 presented a brief introduction to different information technologies (IT) and information systems (IS) used by surface mining operations. These systems aim to improve truck and shovel production monitoring. This chapter also stated the importance of integrating new technologies into the industry in order to control equipment and operator efficiency. The chapter focused on providing a problem statement for the development of a custom-made AIS for truck cycle and delay data collection, while providing a brief review of previous work in this field. Lastly, the scope of this research project was defined.

Chapter 2 proposed a technical approach to the implementation of a TCD-ADCS for the equipment data collection and data synchronization in a mine environment. A methodology related to customized software development was included, with the objective of making truck production cycle and delay reporting a paperless process. The different tasks addressed in this methodology are divided into the design, development, testing, and integration processes. Also, this chapter mentioned the implementation requirements for the development of customized information technologies (IT). These requirements included software as well as active and passive computer hardware components.

In Chapter 3, the presentation of the TCD-ADCS in application was shown. Furthermore, it introduced the resulting GUIs for the TSA and LSA. This chapter also provided the mine description, as well as the mining methods and equipment. In addition, several samples of data synchronization in real-time from the mine site were presented. This chapter concludes with a few final suggestions made by the mine management personnel.

Finally, Chapter 4 provides a brief summary of the main topics discussed throughout this dissertation. It also contains concluding analysis of the TCD-ADCS and its ability to complete the truck and shovel paperless production reporting. Furthermore, this chapter introduces recommendations for future research related to the development of customized information systems in surface mining.

4.2 Conclusions

The surface mining industry is in constant need of more effective and efficient methodologies designed to take constant and accurate field measurements. More accurate data translates in better control of equipment and employee productivity. When field data is transformed into useful information, management decision making is significantly improved.

This research was focused on the development of a truck cycle and delay automated data collection system to be used in surface mining operations. The development of this custom-made system was inspired by the previous successful incorporation of the Integrated Production Management System (IPMS). The TCD-ADCS can and will collect complete truck cycle data as well as fixed and variable delays in real-time. The data collected includes loading and dumping times, haulage and return time and distance, average payload, load and dump locations, material description, operating hours, and delay code and duration. The system also includes a GPS tracker tool for the collection of coordinate locations of operational events. Field data analysis and reporting were not included in the scope of this thesis. However, a complementary objective of this work included the creation of a system compatible with the IPMS for the analysis of data and reporting purposes.

The TCD-ADCS consists of two system applications developed for trucks and loaders. It offers user-friendly graphic interfaces for the operators. It also provides data synchronization tools for real-time data transfer from the field to an office environment. The computer hardware components used for the implantation of this automated data collection system (ADCS) include personal touch-screen computers, wireless PC modem cards, 2.4 GHz radio antennas, and high-sensitivity GPS receivers.

The results of the use of the TCD-ADCS and its outcomes can be summarized as follows:

- Successful data transfer from the field to an office environment using database synchronization.
- Constant equipment communication through wireless network connectivity.
- User-friendly GUIs for the operator interaction with the TSA and the LSA.
- Minimization of employee training.
- Successful integration with the already existing IPMS.
- Completion of paperless truck and shovel production monitoring system.

Using available technologies, it was possible to generate a field data recording system that best-fit the mine's needs. The mine management team believes that the implementation of new information systems (IS) and information technologies (IT) (i.e., the TCD-ADCS and the IPMS) has significantly changed the current production monitoring of the company. Interaction between the custom-made TCD-ADCS and the IPMS completes the data transformation cycle from raw field data to useful information, which can be used to make better management decisions.

4.3 Recommendations for Future Research

The development of custom-made information systems (IS) and information technologies (IT) for production monitoring has brought a great benefit to the surface coal mining industry. Compatible systems like the IPMS and TCD-ADCS show that the expansion of customized systems and tools for the improvement of production monitoring is possible. At the same time, the adoption of these technologies is far from over.

Further research can be focused on expanding the unification of data collection systems to a unique data environment that satisfies the company's business model. For instance, research can be directed toward the collection of production and delay data from dozers, loaders, and other mining equipment. The integration of additional loader and dozer data collection systems to the IPMS could bring production monitoring a step closer to complete data environment unification.

Additional research can also focus on the expansion of the TCD-ADCS with additional safety features. Computer hardware components used by the TCD-ADCS can fulfill secondary functions for the development of truck safety systems. The GUI provided by the TSA can be expanded to include features such as speed control and proximity warning systems. It is expected that the implementation of safety features to the TCD-ADCS could help the surface mining industry become a safer work environment.

The tools and systems developed in this project contribute to the ongoing research of this field. As the technology available progresses, we can only expect that the use of custom-made systems in the mining industry will continue to enhance the operations of mines all over the world.

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