

**SYNTHESIS REPORT  
FOR PUBLICATION**

**CONTRACT No** BRE2-CT92-0343  
**PROJECT No** BE 6031

**TITLE** AN INTEGRATED MONITORING AND DISPATCH SYSTEM FOR MINING INDUSTRY AND CONSTRUCTION WORK SITES

**PROJECT COORDINATOR** BAUXITE PARNAFFE MINING Co. (BAUXIPAR)

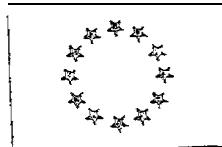
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**Subcontractor** DYNASOFT S.A.

**REFERENCE PERIOD FROM ( 01.1.92 ) to ( 31.10.95 )**

**STARTING DATE** : 01 November 1992      **DURATION :** 36 MONTHS



PROJECT FUNDED BY THE EUROPEAN  
COMMUNITY UNDER THE BRITE/EURAM PROGRAMME

DATE : 8/2/96

# **AN INTEGRATED MONITORING AND DISPATCH SYSTEM FOR THE MINING INDUSTRY AND CONSTRUCTION WORK SITES**

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## **ABSTRACT**

This paper describes an integrated monitoring and dispatch system which has been developed to meet the requirements of small-to-medium size open pit mining operations and construction work sites, that deploy mobile earthmoving equipment, such as trucks, loaders and shovels. The system incorporates state-of-the-art technology, and has a modular architecture that permits its potential user to install only those modules that fit to his own job or site specific characteristics. The whole system, as developed, consists of hardware and software modules (sensors, mobile control units, GPS-based equipment positioning system, data radio communication, real-time production monitoring, production management and information, dispatching, simulation and animation, equipment health monitoring and predictive maintenance), which were integrated and tested in an open pit bauxite mine operated by Bauxite Mining Co. in Greece.

## **INTRODUCTION**

Shovel-truck or wheel loader-truck systems are of paramount importance in modern open pit mining, quarry and construction project's earthmoving operations. The system is characterised as the most flexible system for excavating-loading and transporting soft-to-medium hard formations, and, in combination with a drilling and blasting operation, for loading and transporting hard rocks.

The goal for all these load-haul operations is to select, match and operate the equipment at minimum cost, while meeting the production objectives over time. This is a rather complex mission which involves many disciplines, but considering that truck haulage represents 50% or more of operating costs in most surface mines (Kennedy, 1990), there is a need for efforts to reduce shovel-truck system's operating cost.

For a given fleet of trucks and loading units, one approach towards reducing operating cost is to increase the fleet's availability by increasing the reliability and maintainability of the individual equipment and of the whole load-had system. Another approach is to apply procedures that would improve the utilisation of the available truck units, in order, with existing truck and shovel resources, to increase production or to meet desired production targets, which may depend upon job-specific requirements, such as variations in the waste/ore handling rate, ore blending to cover market's demand and quality constrains. In addition mine management needs to have accurate and timely information on a variety of operational parameters, and it should be able to monitor the operation using the minimum necessary number of supervisory personnel.

An Integrated Monitoring and Dispatching System, to be market under the name MODIS,(which stands for MOnitoring & Dispatching Information System) for this kind of operations has been developed under a European Union Brite-EuRam project (BE-603 1). The main objective of the project was to provide on-line information about the operation of shovel-truck systems, in order to improve the system's productivity through better operation and maintenance planning and management, while meeting the requirements of the European mining and construction industry, which is characterised by medium-to-small size operations with limited number of trucks and loading units.

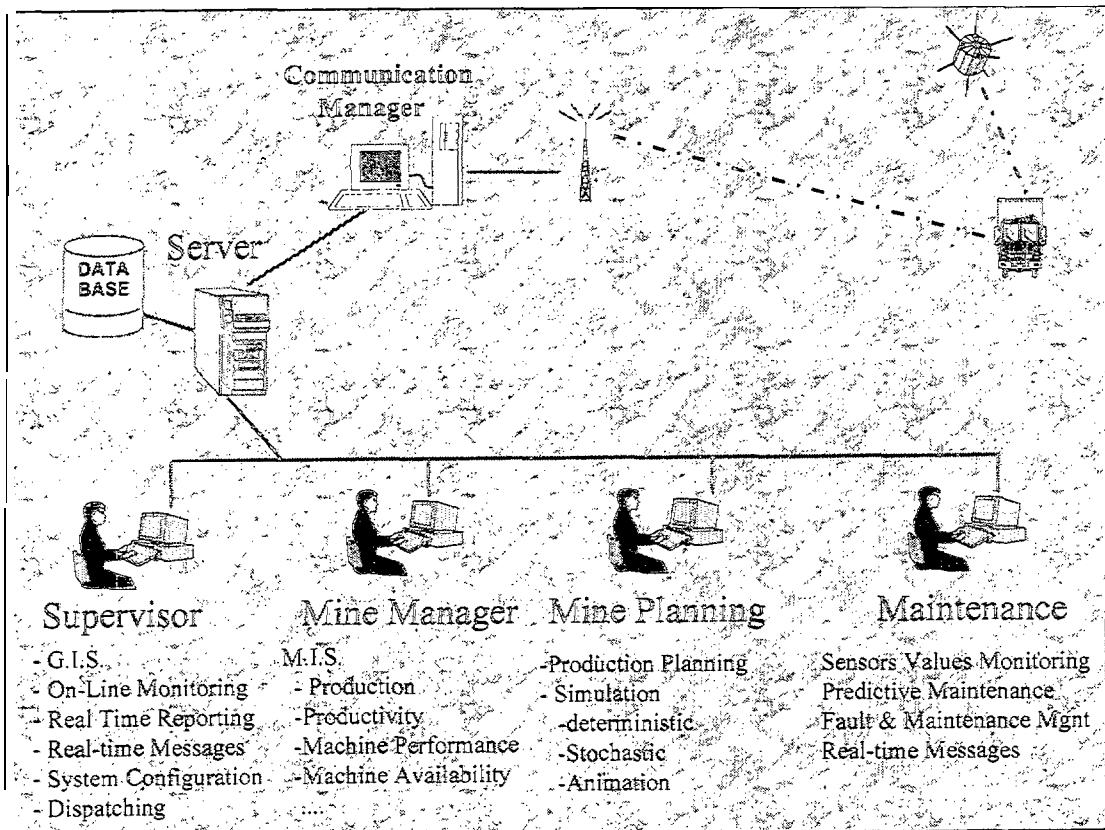
The system consists of hardware and software modules, developed by project partners, which were integrated and tested in an open pit bauxite mine operated by Bauxite Parnasse Mining Co. in Greece.

## MODIS - AN OVERVIEW'

A Mobile Control Unit (MCU) has been installed on each load and haul equipment operating at the test mine site, in order to collect data provided by various sensors installed on certain components of the equipment (engine, transmission, hydraulics, weight etc. sensors), operation cycle times, and production figures. The same unit is also used to display messages to shovel operators and truck drivers. A Global Positioning System (GPS) Unit has been installed onboard the mobile units in order to locate the position of the equipment on computerised mine maps using an appropriate software interface. All data gathered by the MCU are transmitted via a dedicated radio link to a computer located in the operation's control room, where they are manipulated by a Production Management and Information System (PMIS), and finally they are stored in a database.

In addition, the user of the MODIS is provided with the following software tools which share information with the PMIS:

- A Production Planning Module which includes simulators and animators
- A Predictive Maintenance Module, and
- A Real-time Dispatching Module (BEDisp).



## MODIS - TECHNICAL DESCRIPTION OF BASIC MODULES

### On-board Sensors

A number of equipment parameters were selected to be remotely monitored and the appropriate sensors were installed on-board the mobile equipment. The monitored parameters are divided into two groups:

a) *Operational parameters*. These parameters are required to identify the events marking the different phases of equipment's operational cycle, as well as to acquire data regarding machine performance, and include basically the following ones: payload, engine running (on/ofY), body box down (on/off), park brake switch (on/off), gear selection.

b) *Machine health parameters*. These parameters are required to monitor equipment's condition, in particular the engine and transmission components, and are used for real time machine health monitoring and for predictive maintenance purposes. These parameters are: engine oil pressure, turbo pressure, transmission oil pressure, torque converter pressure, engine oil temperature, engine coolant temperature, transmission oil temperature, torque converter temperature, engine speed (rpm), wheel speed (rpm).

Most of the sensors were acquired from the market, selecting always rugged and tough units capable to withstand the harsh temperature, dust and vibration environment of a mining operation. However problems were faced in the performance of some sensors, mainly due to machine vibrations, that were solved by changing the types and models of the sensors initially selected. Some other sensors were developed specifically to meet the requirements of this project, such as a "repeater box" to monitor and decode the gear selection from the supervision of control lines status in the electro-hydraulic transmission system, or a number of signal interface units (mainly pulse counters and dividers). The development of the latter sensors was carried out by AITEMIN, who also constructed the necessary junction boxes and designed, in collaboration with Bauxite Parnasse, the cabling layout on board the equipment.

### Equipment localisation system

In the initial design of the project it was provided that radio beacons would be used to localise mobile equipment, but soon after the start of the project the use of GPS receivers to localise equipment was considered as an interesting alternative, since they could provide coverage of the total area where the mining activity is taking place, and they do not require the installation of ground-based localisation equipment within the mine site. The broader availability of OEM GPS receivers at a reasonable price, and the completion of NAVSTAR satellite constellation, were also important reasons backing this option.

Some preliminary tests and studies, carried out with conventional stationary GPS units, indicated that a position accuracy of  $\pm 100$  m could be obtained, however this accuracy would not be enough for an open pit mine operation or a construction project site. Therefore, a Differential GPS mode was applied, what is based on the use of a reference GPS unit installed in a fixed known position (base station), and the appropriate software that calculates the relative errors and provides the correct readings regarding the position of the GPS units on the mobile equipment.

The localisation system finally developed is based on low-cost OEM components from Motorola and provides a checked accuracy of  $\pm 10$  m, which is considered to be adequate for this type of applications. The use of OEM components made it possible to integrate the GPS localisation system in the Radio Communication Controller developed by AITEMIN.

The performance of the localisation system has been very positive, even under the difficult conditions of a mountainous region like the one at Bauxites Parnasse mining area.

### Radio communication system

Data transmission is performed via a dedicated radio frequency using a Master/Slave architecture, being the base station computer the master and the Mobile Control Units (MCUs) the slaves, AITEMIN developed a Radio Communication Controller (RCC) which supports a data communication protocol specially developed for this project. The protocol includes all types of messages to and from the mobile units, including not only continuous data transfer (real-time monitoring) but also special messaging facilities. The protocol provides also the exchange of configuration data, so that the

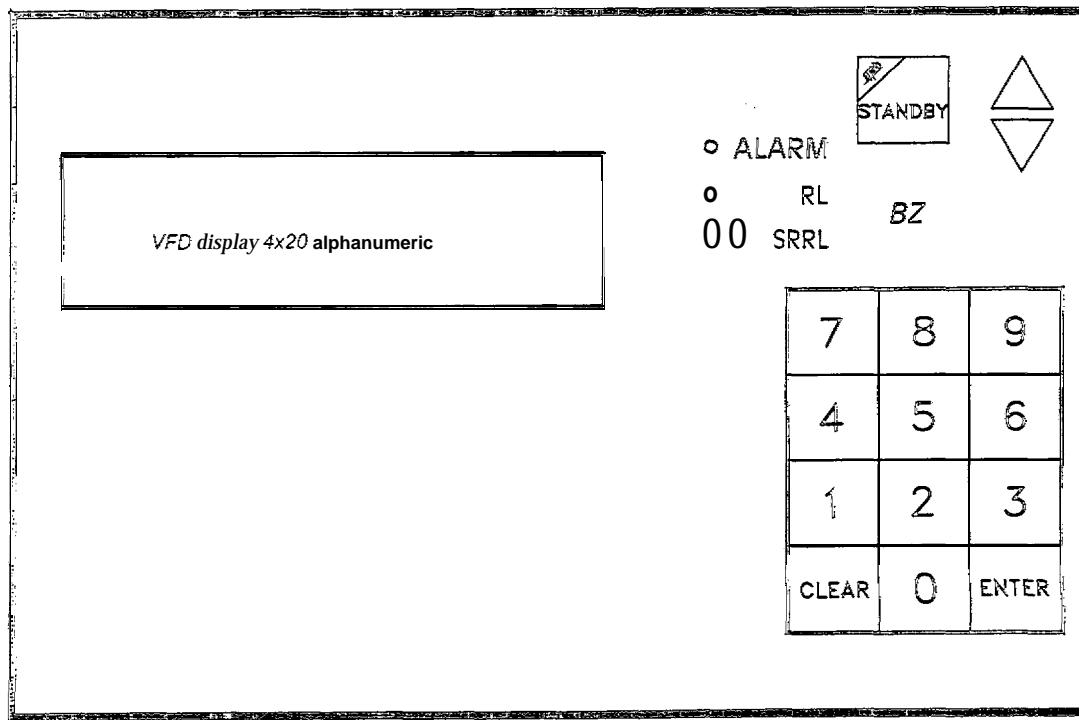
As mentioned above, the data communication system also supports the transfer of differential correction data required by the GPS units, in a mode that is transparent for the data terminal equipment (base station computer and Mobile Control Units).

Each RCC consists of a microcomputer (which runs the communications firmware), a GPS receiver, a Radio Modem and a power supply capable of delivering 6 A at 12 V. The RCC can be powered at any DC voltage between 12 and 60 V, and can in turn supply power to any standard radio transceiver. All components are placed into a sturdy steel box. RCCs are fully software configurable as master or slave in the radio network, and all operational parameters, especially timing, are also software configurable.

Commercial radio frequency transmitters were used for the radio link, one of the frequencies used at the mine site for voice communication being dedicated to data transfer, which work at 1200 BPS. Although the use of a single frequency for data transmission obviously introduces a significant bottleneck in terms of the achievable data throughput, the results obtained during the operation of the test system (3 trucks and 1 shovel) were very positive. An increase in the number of units (more than 10 units) would require a different arrangement in the radio link.

#### Mobile Control Unit (MCU)

The Mobile Control Unit (MCU) which is installed on each mobile equipment (Figure 1) can be used as a *Stand-Alone* or *Network device*. It will operate on a multi-tasking basis, with separate batch processes being used for such things as monitoring the RL, the SRRL, the sensors, and *Standby mode*, and for bringing to the MCU operator's attention any display messages transmitted from headquarters.



*Fig. 1 - MCU Front-panel /BZ : Buzzer, AL: Alarm LED (red), RL : RL-Active LED (yellow), SRRL : Reception LED (yellow) on left, Busy LED (green) on right].*

All sensor data is checked for coherency, so as to eliminate any distortions caused by spikes, etc. For reliability reasons, it is recommended that all sensors used should be well known proprietary brands. The standard 12-bit resolution is used for A/D conversion. Sensors are assumed to have an accuracy of no greater than 1 %, and all

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analogue input channels are read once per second (1 Hz). As far as possible, each installed sensor will operate at a standard 12V DC power supply, this standard power supply being installed close but external to the MCU. Any non-standard power supplies required will also be installed externally from the MCU. All required power supplies have a 0V common earth, and are regarded as being logically part of the sensors themselves. As such, the required power supplies is included within the MCU hardware, but rather is obtained along with the required sensors during another phase of the project.

As already stated, all digital sensors are opto-isolated when connected to the MCU. Furthermore, for each digital sensor configured as a pulse counter, the opto-isolator will also include filtering and shape-reconfiguring functions, as such signals are prone to surges and noise.

The *Master* is able to detect automatically certain status conditions of a vehicle, by means of a combination of sensor readings and GPS. In principal, the sensors to be installed in a vehicle are customer-dependent. However, for the vehicle status conditions to be detected, and for complete trip data to be maintained, a standard base-set of sensors must always be installed in a truck. This standard base-set will consist of the following sensors: *Body-Box Up* (True/False), *Vehicle speed*, *Gear Position* (which may be implemented using several sensors), *Mileage*, *Tonnage*.

Note that a loader need not have a standard base-set of sensors installed, its sensors are completely customer-dependent.

Each installed sensor is classified in the configuration data as either an *operation* or a *maintenance* sensor. These two groupings will allow separate access to operation and maintenance sensor data at the MCU.

*Standby mode* functions may be accessed only by the MCU operator after he has clocked-on with his driver-id. or with the supervisor-id. The supervisor is able to access stop-time statistics, and, when in *Stand-Alone mode*, to request a local data configuration or a *Stand-Alone* initialisation.

Each stop-code is classified in the configuration data as either a *normal* or a *queuing* stop-code. A *normal* stop will end when the vehicle resumes motion, and a *queuing* stop is deemed to have ended after 15 seconds of continuous vehicle motion in *forward gear*. This will allow the vehicle to move short distances as it advances in the queue, without terminating a *queuing* stop-code. A vehicle can have the stop-code *LOADER* included in its configured list of stop-codes. When such a stop-code is entered for a vehicle, the vehicle is deemed to be a loader. When the *LOADER* stop-code is active at a vehicle, the stop will end only when another stop-code is explicitly chosen. For the duration that the *LOADER* stop-code is active, loader functionality is available at the MCU.

The SRRL is intended for use by the site loadmaster, who will normally be the loader driver. The SRRL electronics (transmitter and receiver), while logically being a separate device, is physically installed inside the MCU housing. By means of a software switch, the MCU installed inside the loader is identified as such. The loader driver will identify the mineral quality at his MCU, and as long as this quality remains the same, he need not enter the quality again. The SRRL has an operating range of 25m. The purpose of the SRRL is to indicate to the MCU installed in a truck the quality-id. of the truck's load; a quality-id. will indicate both the ore/waste and its

grade/type. The loader driver will identify the truck by entering at his MCU the id-no. corresponding to the id-no. painted on the truck, and will thereafter initiate an SRRL transmission of the already-identified quality to the truck. Upon receipt of an SRRL transmission, the truck will transmit an *ACK* message to the loader, in order to confirm that the desired truck has been successfully communicated with. The loader MCU will automatically attempt a transmission up to 3 times until an *ACK* message is received.

A truck's destination should be communicated by the *Master* to the driver, after he has clocked-on. The destination could be a loading point, an unloading point, a parking point, a maintenance point, etc., but should always contain enough precision for the driver to know where he should go (e.g. mine/shovel, mine/loader, mine/dump). If a destination is manually selected during an RL failure, the *Master* should check the selected destination upon the RL becoming active again. If necessary, the *Master* can change the destination and alert the driver to this fact.

A data configuration command from the *Master* or the supervisor is able to provide various configuration data in the MCU database:

- For each sensor: name, operation/maintenance flag, unit, range, and lower & upper limits where applicable.
- Date & time.
- Vehicle-id.list (relevant only to a loader).
- Operator-id. list for vehicle.
- Departure-point.
- Station-list for vehicle (list of destinations and departure-points).
- Quality-list for vehicle (list of quality-ids. and associated descriptions).
- Stop-code list for vehicle (for each stop-code: no., associated description, and normal/queuing flag).
- RL time-out interval in seconds.
- Threshold stop-time in minutes (each stop-time > threshold is separately logged).
- Zero-weight threshold (any *weight* reading <= the *zero-weight* threshold is regarded as indicating that there is currently no load in the vehicle's body-box). The *zero-weight* threshold is in the same unit as is configured for the weight sensor.

A *Master* data configuration command will also be able to request an initialisation of the MCU database.

The *zero-weight* threshold is relevant in determining trip status. Its purpose is to permit the detection of an empty body-box on a vehicle, whilst allowing for the possibility of certain remnants of a previous load still being in contact with the box, and thereby resulting in a positive *weight* reading. As a configuration parameter, the value of the *zero-weight* threshold is of course be customer-dependent.

The *Master* or the supervisor may configure a *Slave* MCU at any time. However all configuration parameters is stored on battery-supported SRAM at the MCU. Therefore, on subsequent data configuration commands after the first, only those parameters whose value has changed need be specified; any parameter which is

omitted from the data configuration command will retain its current value at the MCU. In *Stand-Alone* mode, the supervisor can request that configuration parameters be loaded into the MCU from RAM-card. In order to prevent the inadvertent loss of configuration parameters, the concept of ultra-protected memory has been adopted. Ultra-protected memory will only be initialised during a *virgin* initialisation.

For ease of maintenance support, all texts must be regarded as being country-dependent. Therefore, a text-chip is prepared for each country in which the MCU is to be marketed, although of course a particular text-chip may be suitable for more than one country which have a common language (e.g. Germany and Austria).

In the MCU database each record on the operator-id. list will contain two supplementary fields. These fields will record the time of the last clock-on and the time of the last clock-off for each operator on the operator-id. list. On each occasion that an operator clocks-on, the time of his last clock-off is set to a null value. Note that these two supplementary fields are not part of the configuration data, they are added locally at the MCU after the operator-id. list has been configured. The *Master* will, however, be able to request from the MCU the last clock-on/off times of any operator-id. stored on the operator-id. list.

Threshold stop-time will by default be 3 minutes, and is updatable only by the *Master* or by the supervisor. It will also be privacy-protected so that its value can never be known to an operator of the MCU; the supervisor can only select a new value, he cannot ascertain what the current value is. This will prevent a driver or any other unauthorised user who finds out what the supervisor id-no. is, from using the MCU to discover what the threshold stop-time is. Furthermore, threshold stop-time statistics is accessible at the MCU display only by the supervisor. Threshold stop-time statistics will at all times be available to the *Master* on request.

The MCU has been designed with its own *Stand-Alone* functionality, allowing full access at the MCU to all sensor readings taken. Whilst the RL is active the MCU can act as a *Slave* to the *Master* RL. Although the actual *Master* is the central computer at headquarters, as far as the MCU is concerned the *Master* is the RL itself. A *Slave* MCU will never initiate an RL transmission of its own accord, it will only respond to a specific request made on a *Master* poll. Every 30 seconds the MCU will update a *journal* file with a snapshot of sensor readings. A snapshot is stored in the next free buffer, or in the occupied buffer with the oldest data. The *journal* file will consist of 10 buffers, meaning that it will represent a record of the readings taken during the preceding 5 minutes. After an RL failure it is up to the *Master* to request *journal* data. Fixed and cumulative data is stored per *trip*, with the System being able to store data for up to 60 trips, in a file with an organisation of the type indexed-sequential with complementary records. The main data for a trip is stored in the first free indexed record, or in the occupied indexed record with the oldest data. It is up to the *Master* to request trip data before it has to be overwritten in the *trip* file. Each trip indexed record has a complementary record written for each unauthorised stop made during the trip. There is no specific limit on the number of complementary records which can be written for a trip indexed record, but there is a global limit of 500 complementary records for the entire *trip* file. This is able to cope with an average of over 8 unauthorised stops per trip.

The MCU will automatically prompt the driver for the entry of a stop-code, when the vehicle has been stopped for 3 minutes or more without a stop-code having been identified for the stop. The driver is alerted to the need for the entry of a stop-code by a display message and a continuous buzzer tone.

Consistent with the MCU's ability to function when the RL or SRRL are down, trip data such as destination, quality, departure-point, and date & time may be entered if necessary at the MCU keypad.

### **Real-time production Monitoring System**

The real-time production monitoring system is developed by OMASS.A. It is a mining productivity tool, which provides on-line information to the supervisor for the efficient operation of the loader/truck system.

The system processing can be divided into two major categories :

- Background Processing : it is performed automatically by the system according to the incoming information from the vehicles ( sensors values, GPS values, commands). It is completely transparent to **the end user**.
- Foreground Processing : it is performed according to user actions and requests.

#### **Background Processing.**

The background processing is performed by two different systems :

- The Raw Data Processor, which is a specifically designed program written in C++ and is installed in a dedicated Client computer. Its main task is to read continuously **the** incoming information from the Communication system ,validate it, transform it, translate it according to the communication protocol and storing it into the central database system which operates on the Server.
- The central database and automatic processing system, which resides on the Server. The system includes a powerful suite of programs (database triggers, deamons etc.) that recognizes all the incoming information and automatically performs the following tasks:

#### ***Pattern Recognition.***

The system automatically recognize the operational working status of each vehicle using Pattern recognition techniques that is based on a specific set of operational sensors ( Payload , Body Up/Down, Gear Box Position, Speedometer ) and the GPS location values. It enables the system to automatically recognize the operational working status of each vehicle and store this information in log files together with time stamps ( loading times, traveling times, delay and standby times, break down times etc.).

#### ***Work Parameter generation.***

The production in Mines is described by the working cycles of the trucks (loading - traveling - waiting for dumping - dumping -traveling empty - waiting for loading). The working cycles are characterized by certain parameters that the

system automatically generates according to sensor values, GPS values and certain drivers commands and links them together. Such parameters are: Truck id, Truck driver id, Loader id, Loader driver id, Deposit-Bench-Face, Dumping place, product id and the Weight.

#### *Work Calculation.*

This module is activated automatically when a truck is coming to the status that declares the end of the working cycle( e.g. status = dumping). The purpose of this module is to collect all the truck working parameters that have been linked together during the last working cycle(driver id, deposit, product, weight, etc.) and store them in the work done file.

#### *Message generation.*

The system generates messages according to abnormal sensors values and certain drivers actions. These messages are constructed with appropriate text and other information and stored in the database.

#### *Command handling.*

The system receives from machines a set of commands that has been defined in the Communication protocol and responds automatically by executing the appropriate command handlers. Such commands are: Drivers Clock on /off, Quality Definition, user defined stop codes ( Fault StarL'End, Maintenance start/end), etc.

#### *Automatic System initiation.*

The system every morning, before the work start, performs the appropriate tasks so the system gets ready for the new working day.

It performs certain tasks for closing the previous working day [updating the log file with the operation working cycles and work done of each machine, the total working hours of each machine in maintenance files, populating historical files with consolidated information etc. ] and also tasks for initiating the new working day (initiating vehicle status, the working shifts per deposit, the general wages per product, the ASCII communication files, deletes temporary data base files, etc. ).

### *Foreground Processing*

The foreground processing provides the supervisor and other users with an integrated suite of facilities of the loader/truck system.

#### *Monitoring Facilities.*

Supervisor and maintenance department have an enhanced real-time tool for monitoring purposes. The main monitoring facilities are:

#### *Geographical Information system (GIS).*

The GIS system is positioning all vehicles on the area of a digital map using coordinates that are supplied by the localization units (GPS) and are stored in the database system. The location of the machines is mapped in real time mode showing

vehicle movements and their working status is indicated in the map by an appropriate color.

This system provides also in tabular format information about critical parameters e.g. ongoing production.

#### *Real - Time Reporting System.*

This system allows supervisor to monitor in real-time mode the operational status and the transactions that are taking place on the ongoing production of each working day. The information is provided as report or as live graphs. The main real - time reporting functions are :

- Production ( per Deposit, Bench, Face, Product).
- Productivity ( per Deposit, Product).
- Work per Machine ( per Deposit, Product, Machine Type, Machine id).
- Trucks Hauled travels ( per Deposit, Truck Type, Truck id).
- Machine Availability ( per Deposit, Machine Type, Machine id).

#### *Message Monitoring System.*

The messaging system has been developed as a separate application that can work independently and simultaneously in the same screen where other monitoring functions are taken place. It displays in real-time the messages that are generated automatically by the system in two different windows, one for alarms/warnings on sensors values and the other for the drivers messages.

#### *Sensor Values Monitoring.*

The sensors values monitoring system allows the maintenance department to monitor sensors values of each machine on the screen either as a report or as graphs with drill down facilities. On graphs, the system maps together sensors that belong to a certain group as defined by the user. Such sensors groups are engine condition group and transmission system group. The system offers the facility of a visual comparison between values representing sensors belonging to the same group.

#### Control Facilities

The main control facilities are :

#### *Configuration the MCUs parameters and communication manager settings.*

It supports an easy way for transferring vital configuration information from Central computer database files to the MCUs database. It generates appropriate format ASCII files and send it via communication manager. This information is about :

- Sensors that are installed on each machine.
- Drivers that can work on machine.
- Loading and Dumping points (station list).
- Quality list.
- Vehicle list assigned to each loader.
- Stop Codes list.

#### *Operational Control Functions.*

*Supervisor can perform the following operational control functions:*

- Add/Delete/Modify operating parameters for Deposits, Benches, Dumping places, Machines, Machines status, Drivers, Service teams, Products, Sensors, M.C. Us., G.P.Ss., Shifts, Products, Graphics groups, Reasons of Delay.
- Customization of Deposits-Shifts (shift assignment to Deposits with work hour setting and allocation of workers to each *Deposit* per actual shift).
- Modification of parameters, such as :
  - Truck, loaders and auxiliary equipment status
  - Work area of equipment.
  - Material hauled by a truck.
  - Truck assignments to loaders.
  - Shift assignments to equipment.
  - Worker allocation to equipment.
  - Definition of Priority of input (between sensors and drivers in case of sensor's fault).

### *Message Sending*

Within the system there is also support -for message sending to the vehicle drivers. User can type the messages on his screen and they automatically transferred and displayed to machines MCU and also stored in the database files.

### *Machines Faults and Maintenance control.*

The maintenance department can control the working condition of each machine and record detail information about the faults and maintenance procedures made on each machine.

### **Production Management and Information System**

The production management and information system includes comprehensive reporting features and provides detailed mine operating information and time accountability. It maintains accurate either analytical or consolidated information about the operational history of the mobile equipment and their productivity measures and delivers them quickly and visually to managerial and supervisory personnel.

The system supplies the managers an easy way to define focusing level on the available data with the appropriate tuning of operational parameters, reference dates and grouping options.

Attached is a sample list of the information facilities provided by M.I.S. accompanied by their relative parameters and grouping options.

Information Facility	Parameters (focusing level)	Grouping Options
1. Production	Deposit, Bench, Face, Product	Shift, Day, Month, Year
2. Accumulated Production	Deposit, Bench, Face, Product	Current month, Current Year
3. Productivity	Deposit, Product	Day, Month, Year
4. Loader Performance	Deposit, Loader Type, Loader id	Shift, Day, Month, Year
5. Accumulated Loader Performance	Deposit, Loader Type, Loader id	Shift, Day, Month, Year
6. Truck Performance	Deposit, Truck Type, Truck id	Shift, Day, Month, <b>Y e a r</b>
7. Accumulated Truck Performance	Deposit, Truck Type, Truck id	Shift, Day, Month, Year
8. Loader Availability	Deposit, Loader Type, Loader id	Shift, Day, Month, Year
9. Accumulated Loader Availability	Deposit, Loader Type, Loader id	Day, Month, Year
10.Truck Availability	Deposit, Truck Type, Truck id	Shift, Day, Month, Year
11.Accumulated Truck Availability	Deposit, Truck Type, Truck id	Day, Month, <b>Year</b>
12.Machines Conditions	Machine Type, Machine id	
13.Incom@g messages	-	-
14.Outgoing Messages.		

### Dispatch Decision Making Module

NTUA developed a real-time truck dispatching computer programme which meets the requirements of the European mining and construction industry, were operations are of small-to-medium scale, with limited number of trucks and loading units. The programme is code-named: BEdisp.

BEdisp is a low-cost PC-based MS-Windows™ application written in the MS-Visual C++ programming language using object-oriented programming methodology, and under MS-Windows 3.1 or higher as a 16bit application, while a 32 bit version is also available for Windows 95 or Windows NT.

BEdisp is capable to manage fleets which consist of up to 22 trucks, 3 loading units and 4 dumping sites (waste dumps or ore silos). The user-interface provides continuous visual information on the position and status of each truck and loading unit, and statistics concerning the operation of the shovel-truck system. The dispatcher may either select one of the following dispatching rules to be applied automatically to the system: Maximise Truck Utilisation, Maximise Shovel Utilisation, Optimise Match Factor, Fixed Truck Assignment, or he can override them and carry on with a manual assignment procedure.

BEdisp is a multi-windows application, and in addition to the Main Dispatching Window eight more windows are available to the user/ dispatcher: Truck Info, Loader/Shovel Info, Dump Info, Route Settings, Set Ties, Set Dispatching Priorities, Set Objectives, System Settings.

These windows are used either to monitor a specific system unit (truck, loader or dump site) or to set the state of various units and of the system itself.

Dispatching is based on equipment cycle times and state, production objectives and shift time schedule using heuristic rules. Data collected and managed by the Real-Time Production Monitoring System are used, while the dispatch decision is based on the historical cycle times of the system's equipment (weighted statistical mean values) recorded by the monitoring system. This approach aims to provide BEdisp with mean equipment cycle times that are likely to be observed in the real system due to weather and road conditions, as well as due to equipment and operator's performance.

The functions that provide communication between BEdisp and monitoring system are grouped in a data input/output unit which, using SQL procedures, queries the system's data managed by the monitoring system. This communication approach, using the ODBC standard, provides BEdisp with flexibility to communicate with monitoring systems developed under any RDBMS (the Real-Time Production Monitoring System of this project being developed in ORACLE) without changes to the BEdisp's source code. The latter gives to BEdisp real modular characteristics.

## Production Planning and Simulation Module

The Production Planning and Simulation Module (PPSM) consists of a family of simulation programs, which simulate shovel/loader and truck operations in open pits, and provide the user with production and cost estimates, utilisation, availability and breakdowns of equipment, and queuing situations at loading, dumping and repair-shop areas.

NTUA developed a group of programmed, under the code-name STRAPAC [Shovel TRuck Analysis PACkage], which consists of three basic modules:

1. A deterministic simulator (DETSIM) which simulates the performance of a given type of truck along a specified haul route. The main purpose of DETSIM is to provide truck travel times when time-study data of the shovel-truck system under analysis are not available.
2. A series of stochastic simulators (ASTOSIMx, STOSIMx, x=1,2,...,6, and BAUXSIM1, BAUXSIM2) each of which simulates the operation of a shovel-truck system with different equipment combination and layout configuration. Dispatching rules and delays due to equipment breakdowns have been incorporated within the stochastic simulators.
3. Animation programmed (ANBAUX 1, ANBAUX2) which animate the operation of the shovel-truck systems operating in the project's test mine site, that previously have been simulated by the BAUXSIM 1 and BAUXSIM2 simulators.

This modular approach gives to the user two benefits: first, to purchase only the modules that fit to the mine situation he is going to work with, minimising in this way the cost, and second, to use each time the modules that meet his requirements, minimizing in this way the time spent for data input and the runtime for the analysis of different shovel-truck operation scenarios.

#### *DETeministic SIMulator (DETSIM)*

The Deterministic Simulator DETSIM simulates the performance of off-highway trucks when they travel along a specified path (e.g. between loading and dumping stations), as a function of the characteristics of the road and of the truck itself.

The performance of a truck is simulated by moving it along the haul-return path, which is divided into sections according to the characteristics of the road (grade, rolling resistance, traction, speed limits, etc.) and the specifications of the truck type. For the latter, DETSIM either uses data from its own database, with truck types available in the market, including the truck types operating at the Bauxite of Parnasse mines, or the user may provide himself the required input data if a truck type is not included in the data base. Apart of its main scope to provide truck travel times, DETSIM provides additional useful information on the performance of a truck along a specified route. Therefore, it can support decisions concerning shovel-truck systems, especially the selection of the appropriate truck type and route layout, at a time when the shovel-truck system is in the design stage.

#### *Stochastic Simulators (STOSIM)*

The Shovel-Truck Operations SIMulators (STOSIM) is a group of discrete-event stochastic simulators that have been developed in order to study the performance of shovel-truck systems of various complexity, and to provide mine management with production planning tools, using real mine life time-study data for the truck-cycle events, machinery breakdowns and repair times, cost figures, and dispatching rules.

Each simulator has a modular design consisting of a data input pre-processor, the simulation engine-model and a simulation report post-processor.

NTUA developed in total fourteen (14) different and job-specific simulators. Table 1 presents the basic characteristics of each simulator and can serve as a chart for selecting the appropriate one of each situation.

*TABLE 1. STRAPAC: Shovel-truck system simulators applicability chart.*

SIMULATOR	SHOVELS	TRUCK TYPES	DISPATCHING	BREAKDOWNS REPAIRS	PARAMETRIC ANALYSIS
BAUXSIM1	1	1			✓
BAUXSIM2	1	2			✓
ASTOSIM1	1	1			✓
ASTOSIM2	1	1		✓	✓
ASTOSIM3	2	1	✓		✓
ASTOSIM4	2	1	✓	✓	
ASTOSIM5	3	1	✓		✓
ASTOSIM6	3	1		✓	✓
BSTOSIM1	1	max. 3			
BSTOSIM2	1	max. 3		✓	
BSTOSIM3	2	max. 3	✓		
BSTOSIM4	2	max. 3	✓	✓	
BSTOSIM5	3	max. 3	✓		
BSTOSIM6	3	max. 3	✓	✓	

ASTOSIMx ( $x=1, \dots, 6$ ) simulators are dedicated to shovel-truck operations with a single truck type.

BSTOSIMx ( $x=1, \dots, 6$ ) simulators are dedicated to shovel-truck operations with up to three different truck types.

BAUXSIMx ( $x=1,2$ ) simulators are dedicated to the shovel-truck operations of Bauxite of Parnasse, and have their user interface [input - output] in Greek.

The simulators are capable to simulate a variety of shovel-truck systems with one, two or three shovels, any number of trucks (up to three different types), two different materials {m-e-waste}, any number of dump bays or ore silos, while equipment breakdown and repair times for both shovel and trucks are taken into account in the system's analysis. When a system with more than one shovels is analysed, then truck assignment to shovels is done by either the "maximizing truck use" or the "maximizing shovel use" dispatching procedures, that may also include priority status for the shovels. After a run the simulator provides the user with a customised detailed simulation report which include production and cost estimates, utilisation, availability and breakdowns of equipment, queuing statistics at loading, dumping, dispatching and repair-shop areas, and a parametric analysis of critical parameters for different number of trucks in the system.

It should be noted that simulation models are not universally valid but are designed for specific purposes. However, the STOSIM simulators have the flexibility to simulate the majority of shovel-truck operations and, in addition, thanks to their modular design, can be easily modified to meet specific customer requirements.

#### *Animation Programmes*

The purpose of the animation programmes is to provide better means for understanding the operation of the shovel-truck system being simulated, as well as to serve as a tool for system verification and validation.

Since animators are based on the site specific characteristics of an operation, two animation programmed were developed, that animate the shovel-truck systems operating at the Bauxite of Parnasse test mine site. The animation programmed ANBAUX1 and ANBAUX2 are file-driven programmed that use files created in pm-pose by the BAUXSIM 1 and BAUXSIM2 simulators respectively, and they have been developed using the Proof Animation Software.

It should be noted that simulators ASTOSIMx and BSTOSIMx have been developed in such a way that, should this is required by a user, they can be modified to produce an animation of the shovel-truck system they simulate.

All the stochastic simulators and the animators run as full MS-Windows applications (both 16bit and 32 bit versions are available) while the GPSS/H run time module is required to run the large three-shovel simulators. The Proof animation environment is required to run the animation programmed.

#### **Predictive Maintenance Module**

The main objective of this module is to predict the failure of a piece of equipment in advance so that maintenance actions can be planned at a convenient time. The module is based on condition monitoring of critical parameters and the reliability analysis of the failure time data collected by the monitoring system. The module has been developed for both real time and non-real time applications. The former is designed to generate alarms whenever a monitored parameter exceeds its limit value, in real time. The latter is designed for fault diagnosis and maintenance planning using trend, correlation and reliability analyses. Maintenance management reports concerning the utilisation, availability, reliability and maintainability of each piece of equipment can be generated periodically or on demand.

#### **Conclusions**

Partial integration tests of the various system's modules were carried out at different levels during the course of the project. These tests indicated the need for introducing changes in the system, mainly on issues such as the type of the sensors installed on the mobile equipment, the communication protocol and the definition of the interfaces between high level application software modules.

After finishing the sensor and equipment installation on board the mining machinery at the test mine site (by middle 1995), all project's effort was focused on firmware and software debugging, as well as on system integration, tuning and commissioning. The validation period for the system, as provided in the original project's work-programme "is considered to be short for the size and complexity of this project, and will be extended after the contract termination date till the end of 1996. The initial results obtained till the time of writing this report are positive and shows that the project's objectives have been met. However, the partners of this project feel that it is necessary to continue and complete the validation procedures for the final assessment of the system in terms of performance and reliability.

### Acknowledgements

The authors would like to thank the Commission of the European Union for the financial support of this research project through the MUTE-H-RAM Programme (project No BE-6(I31, contract No BRE2-CT92-0343), and the personnel of their respective companies/organisations for their efforts to carry out the tasks required for the completion of the project.

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