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Design, Simulation and Development of Software Modules for the Control of Concrete Elements Production Plant

Georgia Garani and George K. Adam
Technological Educational Institute of Larissa
Dept. of Informatics and Telecommunications
41110 Larissa
Greece

1. Introduction

Manufacturing and control procedures for automation require many different technologies. The last decade has seen computer technology applied widely in industrial production, particularly in manufacturing processes not generally associated with high technology. The technology used in the automated production of moulded concrete elements for the architectural and building industry has changed dramatically in recent years. The introduction of Computer Integrated Manufacturing (CIM) between 1960 and 1980 (Trybula & Goodman, 1989), e.g., numerically controlled machines, followed in the 1980 to 1990 developments in robotics, e.g., advanced robotics (Shell & Hall, 2000) had a significant impact on automating the production of moulded concrete elements.
The types of system that produce concrete elements are mainly machines using hydraulic compression and extraction. This is the most common method used to form the complex product shapes required by the architectural and building industry. These machines can be either stationary, or they can be mobile, with automated mobile machines being the machine of preference these days. Other relevant ancillary equipment used in the automated production of concrete elements are aggregate mixers, material storage silos and conveyors.
The concrete elements required by architects and builders often include complex geometric shapes; it is for this reason that the central process in their production is the hydraulic press. Complex geometric shapes in concrete and their quality control can only produced using automated compression machinery (Isayev, 1987; Reinhart, 1987). The various phases of this process are (1) material mixture; aggregates of variable form tightly compressed into a mould and (2) compression to form and extract the desired product.
The application of computer aided systems to hydraulic press machines has increased the range and variety of concrete elements that these machines can produce for the architectural and building industry (e.g., ZENITH, KNAUER, BESSER, etc.). The consistency and quality control of landscape and architectural products, such as concrete blocks, curb stones, palisades, paving stones, etc., has improved through introducing computer aided systems. Computer-control systems, teleoperation and automation technology, modelling and simulation tools are some of the technologies and techniques used to acquire the desired

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functionality in operation control and quality in production (Chryssolouris, 1992; Gutta & Sinha, 1996; Marvel & Bloemer, 2000).
However, quite often various problems arise during the attempt of systems modelling and control, in most cases due to insufficient structuring of the system in the real world. In these cases, usually artificial intelligence techniques are being applied (Fishwick & Luker, 1991; Hwang et. al., 1995). For this reason, the design and control of automated production system requires an effective development system that enables the design specifications to be implemented and tested prior to the actual implementation and control of the production system. The generation and implementation of such systems has become essential to the development of automated production systems (Rao et al., 1993; Nise, 1995; Shetty & Kolk, 1997; Srovnal & Pavliska, 2002).
Qualitative modelling approaches have been applied for a long period of time with quite successful results in most of the cases (Forbus, 1984; Groumpos & Krauth, 1997; de Kleer & Brown, 1984; Trave-Massuyes, 1992; Garani & Adam, 2007). One of the aims of this research was to accomplish an adequate control structure for a synchronised co-operation of the plant machines. Previous work on applications of qualitative modelling techniques (Adiga & Gadre, 1990; Lamperti & Zanella, 2003; Mak et. al., 1999; Zhang et. al., 1990) shows that there is still further need of work to be carried out for the development of highly intelligent qualitative modelling approaches.
This chapter presents the application of design, simulation and software development techniques for the operation and control of a concrete elements production plant and particularly, an automated mobile press machine (RoboPress). Teleoperation is required in operating the mobile press machine for performing the actual production procedures. The plant is consisted of various machines such as a press machine for concrete elements production, a mixing machine for aggregates mixing, aggregates storage silos, transport buckets and conveyors, etc. The design, operation and control of a concrete mixer machine and an autonomous mobile hydraulic press machine are discussed in detail. The whole system automates the production of moulded concrete elements for architectural and building projects. The research work demonstrates how the design of a state-of-the-art industrial plant can be optimised by using qualitative modelling and simulation from artificial intelligence and other engineering software tools. Further on, it shows how an efficient control algorithm for operating the group of machines can be derived from a qualitative modelling approach.
The rest of this chapter is structured as follows: the following section describes the application environment of this research; in section 3 a detailed description of the overall plant control system is provided; section 4 provides details of the modelling and simulation techniques used for the development and verification of the overall system's operation and control algorithm prior to its implementation; in section 5 details are given for the system performance evaluation and implementation procedures of the software control modules and algorithms. The chapter is concluded in section 6, which presents the outcomes and future research work.

2. Application environment

The concrete plant under investigation and control is consisted of a group of machines including a mobile press machine for the concrete elements production, an aggregates' mixing machine, aggregates' storage silos, a forklift loader, feeding conveyors, etc. Other

basic machine components include the electronic control board based on a Hitachi EC series programmable logic controller of type EC-60HRP. That unit offers up to 60 I/O points, direct PC connection (RS232) and monitoring. A number of solid state inductive proximity sensors of Telemecanique type XS7C40NC440 for industrial applications and PLC compatible are employed, in perfect compatibility with the electronic automated system for presence detection. The overall control is based on a closed-loop control system, with the PLC unit to control real-time processes, under the operator's control. The driving force behind the above control system is the control software, the creation of which is based on the construction and execution of descriptive qualitative models.
The concrete elements production of the plant varies from 6000 blocks per day (8hours) up to 14000. Two of the main machines of interest, press and mixer machine, are shown in Fig. 1 while an overall configuration of the concrete plant is shown schematically in Fig. 2.

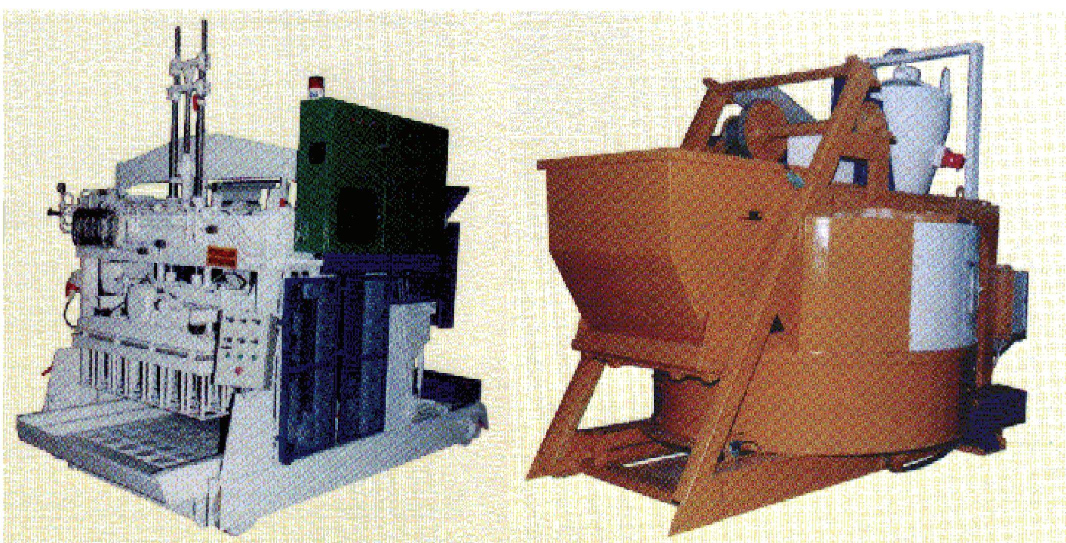

Fig. 1. Press and mixer machines

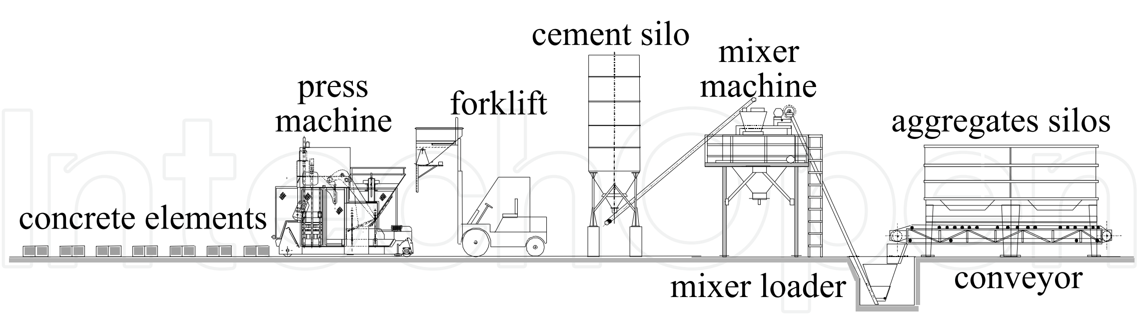

Fig. 2. Concrete plant configuration

The press and mixer machines are constructed mainly of mechanical and electrical parts and devices, incorporating electrical boards, PLC units and other electronic equipment. Basically, the plant operates as follows: aggregates from the storage silos are being supplied through a feeding conveyor into the mixer machine and the wet concrete produced is transported by a forklift loader into the press machine for the actual production of the concrete elements. A simplified functional diagram of plant's overall operation cycle is shown in Fig. 3.

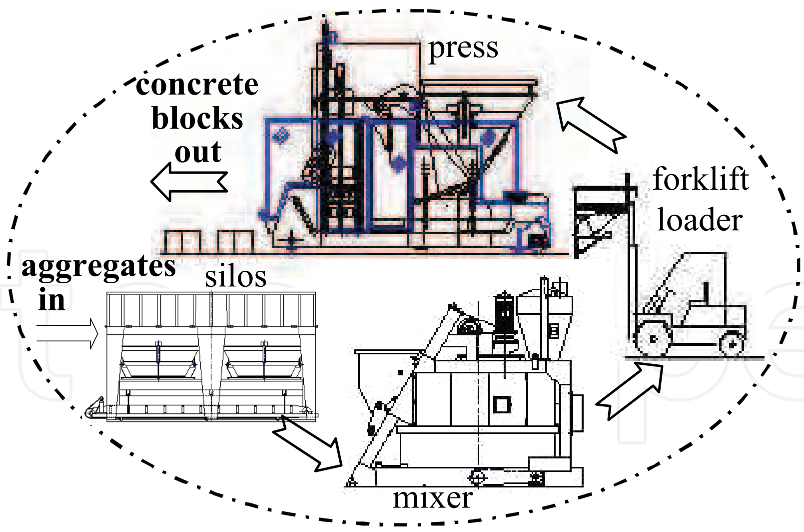

Fig. 3. Plant's operation cycle

2.1 The mobile press machine

The press machine is one of the most important production units of the concrete plant (Fig. 4). The machine produces a variety of concrete products such as blocks, curbs, paving stones, etc. It is consisted mainly of mechanical and electrical parts and devices, the electrical board and the electronic control system based on a PLC unit (Hitachi EC series) and other electronic equipment. The machine is mobile, based on a four wheels metallic base. Other basic machine components include a mould table and a tamper head fitted with a pair of vibrators each, the aggregates' hopper, the oil pump system, the electro-valves and the hydraulic pump system. The mould and tamper units lie on an anti-vibrating mounting system to reduce the wear of moulds.

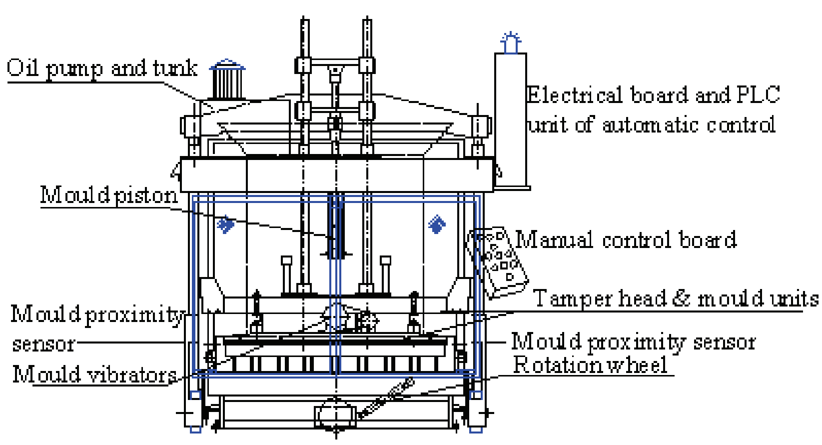

Fig. 4. Schematic representation of the autonomous mobile press machine (RoboPress)

The machine is electrically operated of hydraulic functioning, with automatic control based on the PLC unit. The machine operates on a concrete floor slab, inside or outside a building. Concrete elements are demoulded directly onto the concrete floor slab during a vibrating (starting and main vibration) and compressing cycle. The machine is equipped with a bilateral track corrector, with automatic track collision detection and avoidance, automatic concrete feeding control and automatic shutdown in interfering with safety grates. The machine's motion is enabled by an electro-motor device in conjunction with a mechanism of cogs at the back of the machine. The machine can move in a bidirectional route (forward-backward) in two gear speeds, or turn (left/right) using a fifth wheel. The speed that develops is within the range of 10km/h (first gear speed) to 20km/h (second). The electro-motor (reductor) is of 2kw power. The operation of the machine is performed in automatic (or semi-automatic) mode, driven by an electro-hydraulic control system based on electro-valves and the PLC control unit.

2.2 The mixer machine

The mixer is planetary of roughly mixing vertical high resistant steel shaft fitted with mixing blades of strong-wearing cast-iron. The machine is equipped with a turnover feeding bucket, an electronic cement weighing mechanism, an electro-reductor for bucket's elevation with brakes and two spiral drums for wire rope wrapping. The machine performs the mixing of the mineral aggregates with water and produces the wet concrete that is fed (through a forklift loader) to the mould of the press machine, where is vibrated and compacted. A portion of the plant with the mixer platform and materials storage and feeding system is shown in Fig. 5.

Fig. 5. The materials feeding and mixing platform

2.3 Press and mixer machine operation

In order to describe the dynamic configuration of the machines' processes, prior to the actual specification of the control structures, basic details on machines' requirements and activities have to be defined. In consequence, using that information a system's control model is constructed and executed. The resulted performance of the model is analysed and accordingly in cases that is necessary, its design structure is modified. Finally, the appropriate structure of the control algorithm is implemented.

There are various machine processes and activities under control (Fig. 6), such as the aggregates mixing process, mixer feeding process, concrete transfer process and concrete elements production process, and activities such as aggregates bucket fill operation, aggregates drawer transfer motion (backwards/forwards), tamper head and mold table motion (up/down), the hydraulic arms actuators motion, vibrators operation, etc.

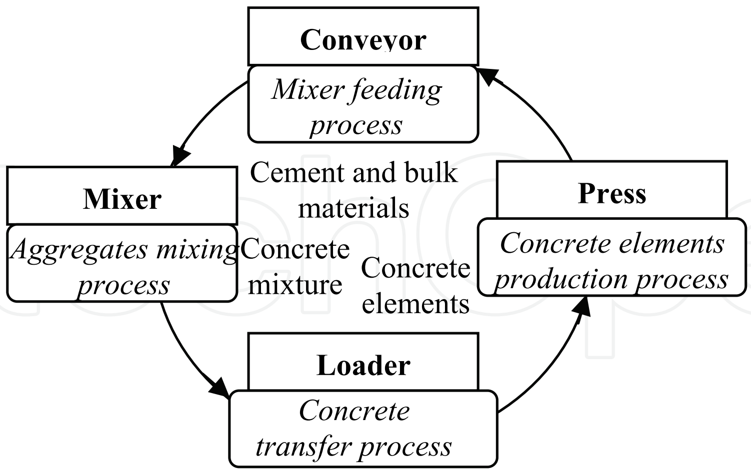

Fig. 6. Plant's operation cycle

Beyond the above machine processes, an important machine function under strict control is press movement along a trajectory path (forward/backward route and left/right turns) and its correcting maneuvers according to sensors input, in order to avoid collision with any obstacles. A generalised view of the control algorithms of those structural processes is presented in Fig. 7. In particular, the left part of the figure is a diagrammatic form of the

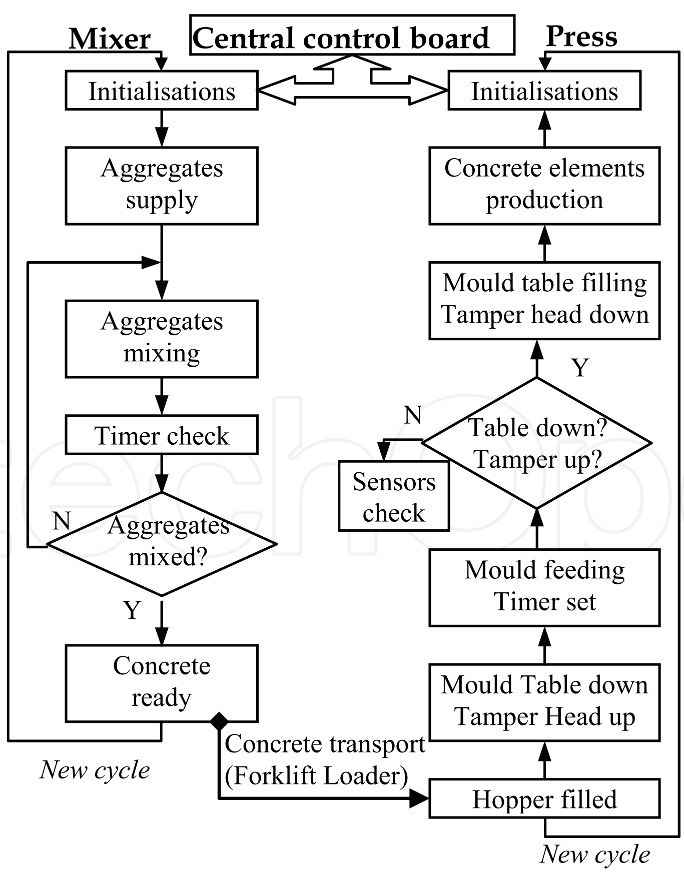

Fig. 7 Generalisations of press and mixer machine operation algorithms

basic processes running in the mixer machine, while the right part of the processes running in the press machine. The communication link between the processes is established through a transport loader. In both diagrams, the processes are running on cycles. On each machine operation cycle, certain initialisations (or re-calibrations) are carried out, materials and parts positions are checked (e.g. aggregates mixture state, mold table and tamper head position), until the final output is produced (e.g. concrete extraction and concrete block elements, respectively).

3. Control system

This section provides details of the control structures and algorithms developed and used for data acquisition and process monitoring for the overall plant control and operation. Particular details are provided for the automatic control of the mobile press machine that performs (in cooperation with the mixer machine) the production of moulded concrete elements for architectural and building projects.
The overall monitoring and control is based on a closed-loop control system with the human in the control loop, for establishing the most optimum control operation. The central control board (based on a PLC unit – Hitachi EM-II series) monitors the machines' operations which provide feedback in the form of analog input signals through the electrical data transmission lines, installed for this purpose. The PLC is programmed to process the data signals acquired. All the electronics for the control of the mixer and aggregates feeding systems are incorporated into a control console which is pushbutton operated. The mobile press machine has its own separate electric control board, with the PLC unit incorporated into the main panel and a receiver (antenna) for remote operation (start, stop and turn manoeuvres).

3.1 Data acquisition and control

The data acquisition and control system is consisted of sensor devices for detecting and transmitting in real-time signals about the processes status, such as aggregates' level and status, as analog/digital signals into the programmable control unit for processing. Solid state proximity sensors (of inductive type and PLC compatible) are employed for presence detection. The central control board (based on the PLC unit) processes the inputs and controls the equipment by producing analog control signals in outputs. The end-receiver of those control signals are the electrical valves actuators, which control (open/close) the fluid rate of hydraulic valves that activate the silos openings, the mixer machine rotation and other processes. The driving force behind the above data acquisition and control system is the control software programmes, installed using a combination of programming packages.

3.2 Press machine remote control and operation

The control system is based on a Hitachi EC series programmable logic controller of type EC-60HRP that offers up to 60I/O points and direct PC connection (RS232) and monitoring. The actual programming of the machine control unit is carried out using the Hitachi PLC programming software (ActGraph, Actron A.B. Co.) for EC PLC series. The program stored is processed in a cycle with an execution speed of 1.5μs per basic instruction. All the logic program functions of the overall machine control are controlled by that PLC unit.
A number of solid state inductive proximity sensors of type Telemecanique XS7C40NC440 for industrial applications and PLC compatible are employed, in perfect compatibility with

the electronic automated system, for presence detection. The usable sensing range and response time is 0-15mm (.47"), appropriate for metallic targets passing the sensors at durations that are not critical. The use of sensors is essential for the accurate control of the various machine operations and processes. The PLC reads the status of the inputs, solves the logic programmed and updates the outputs.

The overall machine remote control and operation could be summarised in four stages: cart and mould filling operations, compression molding (pressurisation) and mould extraction operation. Compression molding basically involves the pressing of wet concrete mixture (aggregates) between two halves of a mould (tamper and table) to fill the material in the mould form. Compression pressure varies from 150 bar to 200 bar. That functionality of the sensory system is shown in Fig. 8.

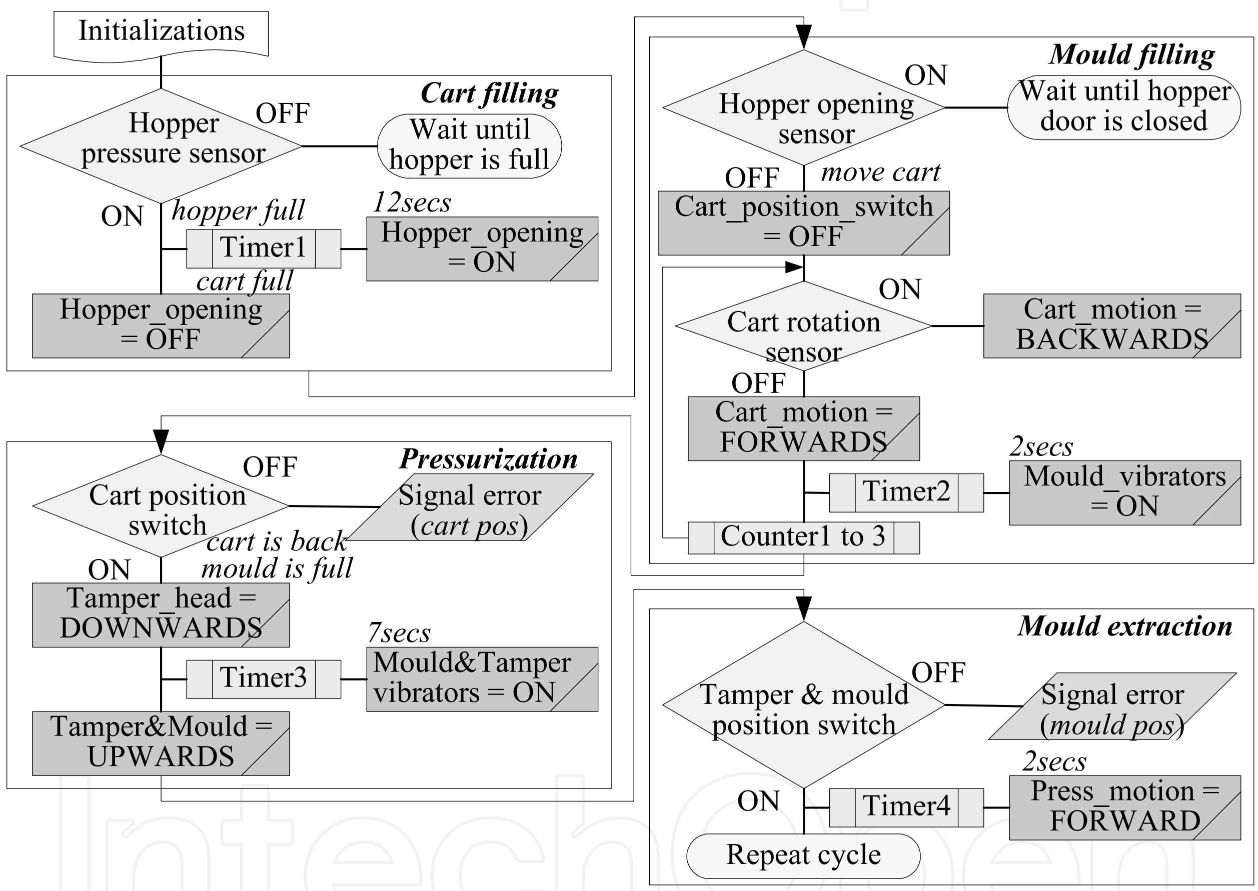

Fig. 8. Simplified sensory system operation flowchart

The study of the machine's overall operation has enabled the specification of the sensory information required. A schematic view of the sensory system developed is shown in Fig. 9. The machine's hopper is periodically supplied with aggregates (wet concrete mixture), the level of which is sensed with a pressure sensor. Once the hopper is filled with aggregates, the door opens (hopper opening sensor turns ON) for certain time interval (materials flow timer T1: 12secs), so that the aggregates transfer-cart to the mould gets filled. Then, the door closes (hopper opening sensor turns OFF) and the transfer-cart moves forward (in a reciprocal way) in order to fill the mould. Each time the transfer-cart moves forward, a sensor is activated and the cart starts to move backwards. This is repeated three times (cart pass counter C1: 3). However, after the second pass, a vibrator on the mould is activated (timer T2: 2secs) for the mixture to be distributed equally in the mould. Then, a third pass of the cart follows and the mould is filled. Once the cart is back (cart position switch is ON) and the mould is filled with wet aggregates, the tamper-head begins to move downwards squeezing the mixture in the mould. At the same time, two sets of pairs of vibrators (one pair in the tamper and the other in the mould table) are activated (until the tamper goes up, about 7secs) in order for the concrete product to become denser. The overall pressurising procedure lasts about 10secs. After that, the tamper-head and the mould-table move up and the machine moves forward (~1m) to the next production point.

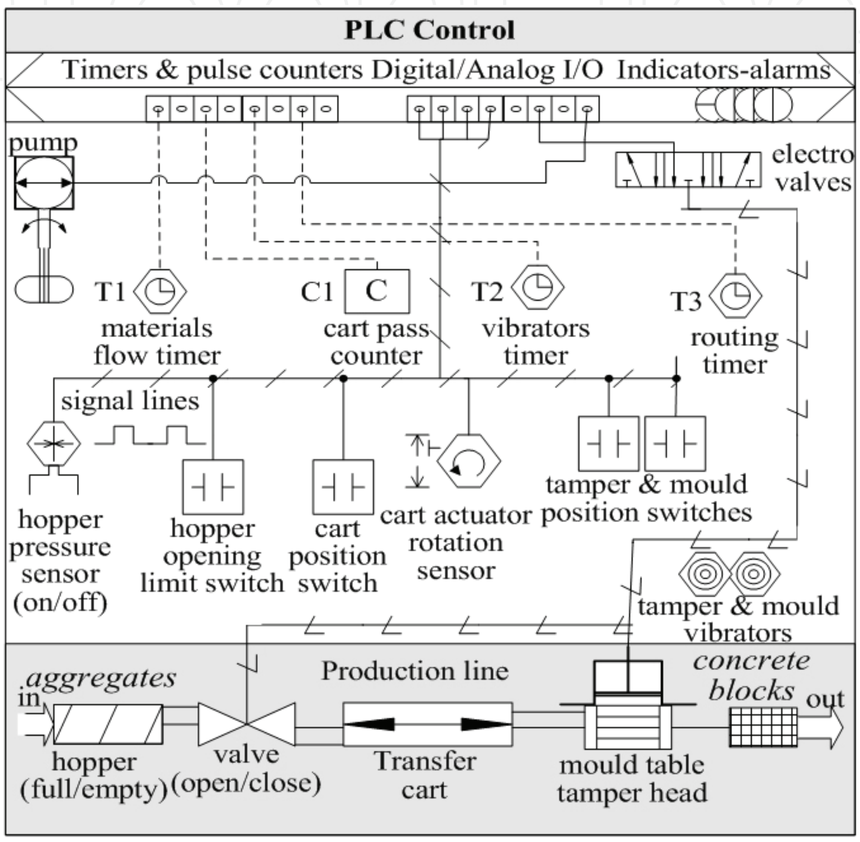

Fig. 9. Sensory system

It is evident that the sensory system plays an important role in the overall operation of the compression press machine. The normal operation of the machine is based on correct sensory information. In case an error is detected (sensor signal error), the machines fall into a faulty state. A schematic description of the machine states taking in consideration the functionality of the sensory system, is given in Fig. 10. Based on that functionality the control software is created and downloaded to the PLC unit.

The mobile press machine is also equipped with a receiver (antenna) for remote control of its operation. Beyond the start and stop operations, teleoperation of the machine is required in performing the manoeuvres necessary to proceed with the next production line. During the navigation along a production line, the machine follows the route automatically based on the mounted sensors. If necessary (in case of the machine falling out of the specified linear trajectory), automatic route correction is carried out based on the lateral sensors signals the machine is equipped with and using the fifth wheel for performing the actual correction manoeuvres. A schematic diagram of the mobile press navigation terrain is shown in Fig. 11.

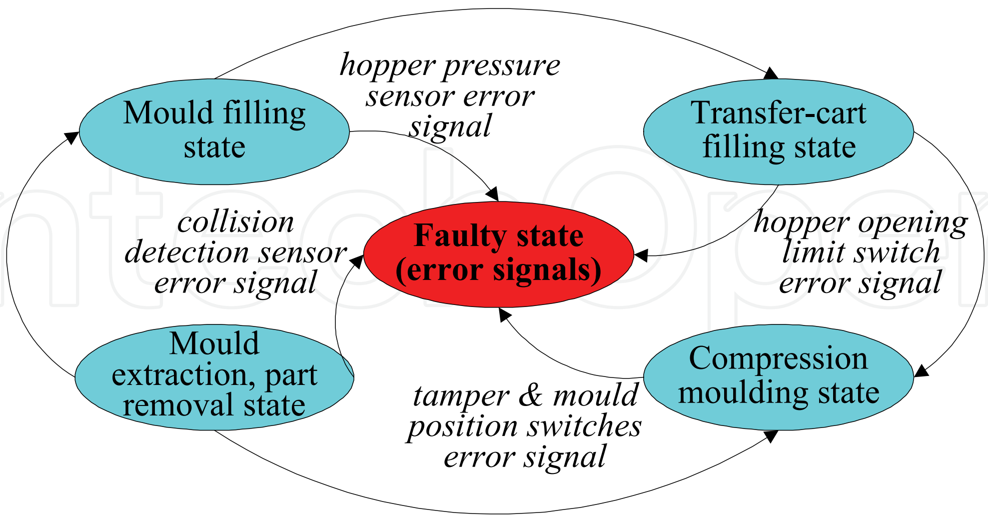

Fig. 10. Normal operation and faulty states diagram

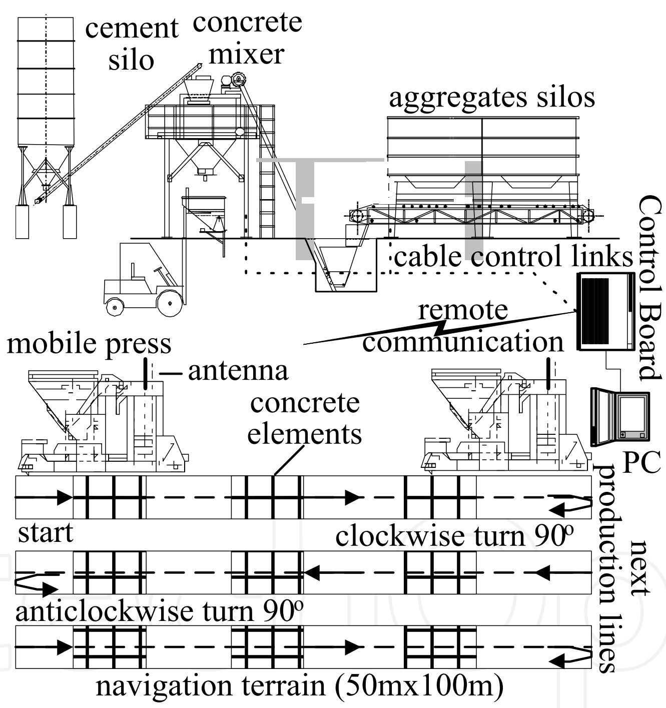

Fig. 11. Press machine navigation and remote control

3.3 Mixer remote control and operation

The mixer is loaded periodically with a specific volume of aggregates and cement which are mixed with water for a certain period of time (~15min). The aggregates silos and the feeding conveyor (of the bucket that loads the mixer with aggregates) are controlled manually from the central control console. However, the cement and water volumes fed into the mixer are controlled automatically, once a certain load is achieved. At this stage, mixing operation starts automatically. In case of insufficient material volume or weight, the mixing operation does not start and the corresponding indicators are illuminated at the control console.

3.4 Overall plant remote control and diagnosis

The overall plant monitoring and control is carried out through the central board of control (Fig. 12). The board of plant control presents an operating and monitoring system. This is consisted of a panel of push buttons, key switches and lamp indicators for immediate visualisation of the processing signals. The operation of the plant from the central board is based on indicating and alarm elements. In order to make the operation simple, a graphic plan (mimic diagram) of the plant under control is integrated within the control board, which shows at each time point the visualisation of operations flow.

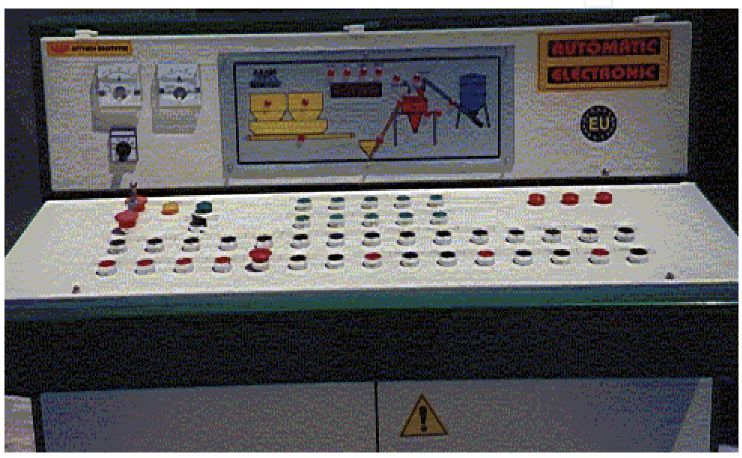

Fig. 12. The central board of plant control and monitoring

In addition, an external PC is connected directly (through RS232C) to the central control board in order to perform regular maintenance tasks (e.g., programming the internal PLC unit) and collect statistical results about the values of specific parameters (e.g., aggregates' flow) for further analysis and diagnosis of the plants' operation.

4. Modelling and simulation

This section describes the modelling and simulation techniques used for the development and verification of the overall plant's operation and control prior to its implementation. Considering the complexity of the concrete plant machines' operations, MATLAB Simulink simulation tools were considered to describe and analyse its performance. However, although quantitative modelling techniques provide much of the required information to describe a manufacturing system (e.g., using MATLAB SimMechanics), they are often too complex for real-time dynamic systems. For this reason, in addition to the above, QMTOOL, a qualitative modelling and simulation tool already applied successfully in robotics research (Adam & Grant, 1994), was used to overcome the shortcomings, due to systems complexity and extensive numerical computations. Using that tool, we have dealt successfully with some of the uncertainties in the positioning of the various machine parts and the control of press machine processes. Prior to the actual implementation of the control structure and machine operation, qualitative models are generated describing the functionality of the processes involved and tested for their effectiveness. The qualitative models are introduced at a high-level abstraction form, using relatively small amount of information, similar to human reasoning on studying complex system's behaviour.

4.1 MATLAB Simulink model

The design and control of such an automated plant requires an efficient development system that would enable the design specifications to be implemented and tested prior to the actual development. In order to describe the machines' operation with MATLAB Simulink models, several factors have to be considered. This is because there are various machine processes and activities under control, such as the aggregates input/output operation, the linear movement of aggregates' transfer drawer, the concurrent movements of tamper head and mold table during moulding, vibrators operation, etc.
Provided that the press machine's overall operation could be described in operational states, as shown in a diagrammatic form in Fig. 13, a working model was created. The equations that describe the machines' states are given by the following relationships:

$$\begin{aligned} ST\_A &= (ST\_A + ST\_C \cdot Mv_{off}) \cdot ST\_A \cdot Mf_{off} \\ ST\_B &= (ST\_B + ST\_A \cdot Mf_{off}) \cdot ST\_B \cdot Mp_{off} \\ ST\_C &= (ST\_C + ST\_B \cdot Mp_{off}) \cdot ST\_C \cdot Mv_{off} \end{aligned} \tag{1}$$

where:
ST_0: Initial conditions machine state
ST_A: State of aggregates filling
ST_B: State of machine press up/down
ST_C: State of machine route
ST_E: State of machine fault operation
Mf: Variable of ST_A (on-off)
Mp: Variable of ST_B (on-off)
Mv: Variable of ST_C (on-off)
Merror: Machine error
Mferror: Mould filling fault
Mperror: Aggregates pressing fault
Mverror: Machine route fault

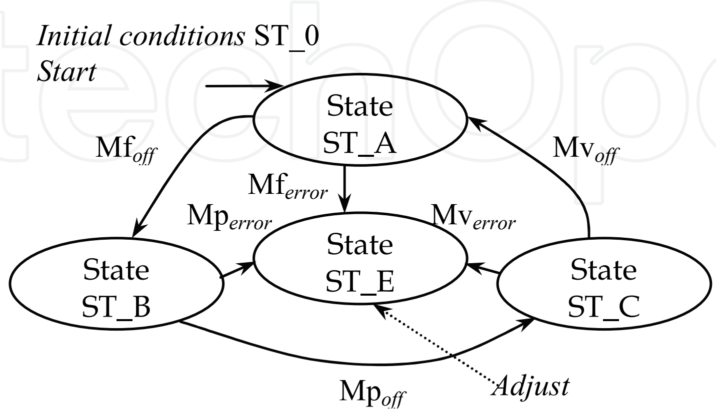

Fig. 13. States diagram of the press machine control and operation algorithm

A partial view of the overall press machine operation structure, using Matlab-Simulink, is given in Fig. 14.

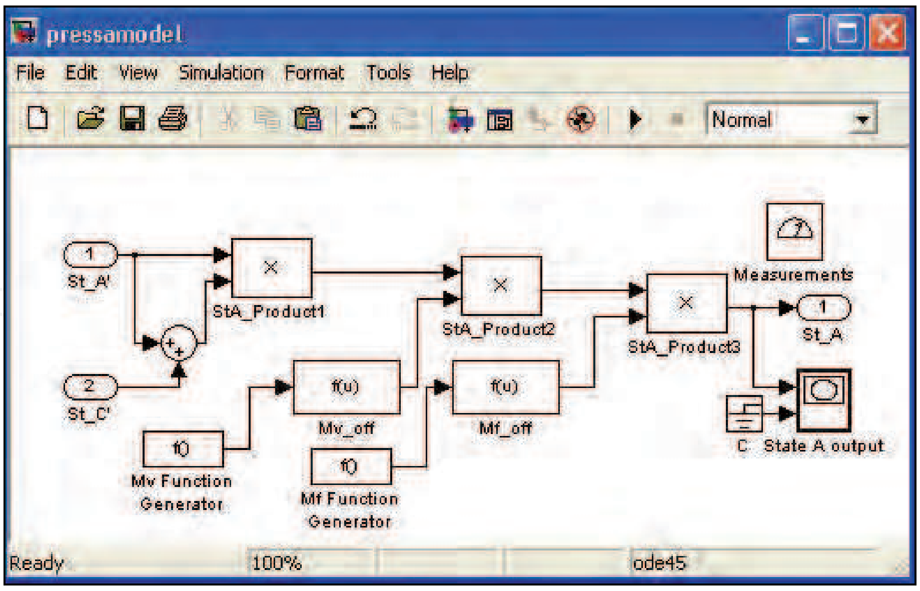

Fig. 14. Partial view of Simulink-based control system model of press machine

Particularly, for the description of the compression molding operation and the creation of models for simulation analysis, the hydraulic driving units had to be studied. The use of hydraulic actuators is of main importance in the overall machine operation, particularly for compression molding. So, one of the main goals in compression molding modelling is to verify the design and operation of the pressurisation system. For this purpose, a motion controller was developed to regulate the pressure (up/down) in the actuators valves of the mould units for simulating the action of compression molding. The final position of the hydraulic piston is monitored. A ramp reference input was used to evaluate the tracking ability of the subsystems in the model. The actual pressurisation subsystem (see Fig. 15) enables to control and monitor the operation pressure which is supplied to the molding system (tamper head and mould table) actuators. The control pressure generated is proportional to the area and the mass of the hydraulic cylinder piston under control.

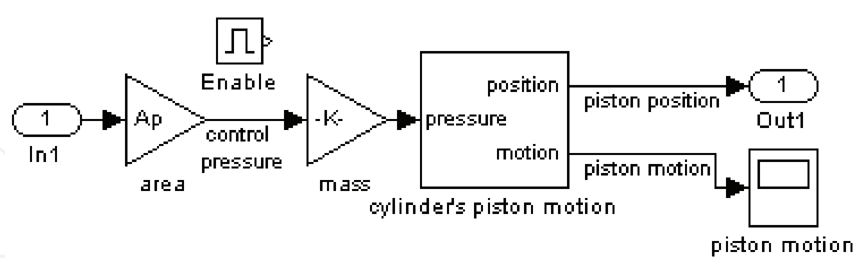

Fig. 15. Pressurisation subsystem

Another goal is to verify the design and operation of the sensory system. For this purpose, a sensor cell subsystem was developed that emulates the behaviour of a proximity sensor. In particular, an inductive proximity sensor senses the proximity of a metal object using an oscillator principle. It is essentially comprised of an oscillator whose windings constitute the fencing face and where an electromagnetic field is generated. When a metal object is positioned within this field, the resulting currents induced into the target form an additional load and the oscillations cease. This causes the output driver to operate, producing an ON or OFF output signal. Based on this principle of operation, a basic sensor cell subsystem was created (Fig. 16), upon which the overall sensory system model was build. A simple function called *turn_sensor(mode)*, where mode is {ON, OFF}, is created to simulate the sensor state status.

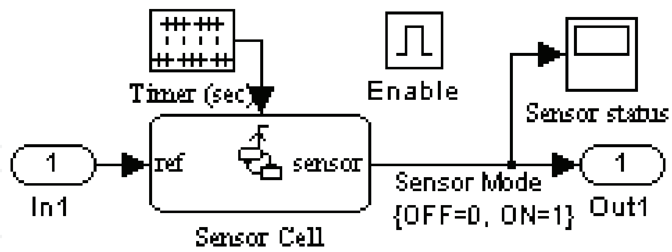

Fig. 16. Sensor cell subsystem

4.2 QMTOOL model

One of the key advantages of qualitative reasoning in general, is that it can work with partial knowledge and information, thus overcoming some of the difficulties of quantitative modelling. Although in most of the manufacturing cases predominate the dynamic continuous systems, however most of them could be described in a discrete-event manner. This is because, in most of the cases, their status changes instantaneously at specific time points or time intervals at which events take place, triggered by some actions or activities. For example, the operation of the industrial compression molding press machine, although it is continuous in time, its individual compression actions (e.g., mould actuators pressure up and down) could be described as being executed at specific or separate time points. In other words, a discrete-event simulation model could be build and executed, although it is also known, that a discrete model is not always used to describe a discrete system and vice versa. In addition, their operation usually involves an unknown number of input parameters that change in a random way, which is difficult to describe analytically.
In order to test and validate the operation and control of the press and mixer machines, prior to their actual operation control implementation, simulation models were build, based on given set of parameters and associated relationships.

4.2.1 QMTOOL model construction

It is important to determine the appropriate control and operation algorithm of the machines (in synchronisation) prior to their installation in plant and cooperation with the rest of the machines' group. It is also necessary to find the tools to test and modify such a control structure, even at the design specification level, without an in-depth requirement for programming skills.
QMTOOL is used to produce working models of the machines under control and test them in order to acquire the desired functionality. The main focus is in the processes running in press and mixer machine. This modelling tool, based on object-oriented techniques methods and objects, provides an interactive environment that eases the modelling process. During the modelling phase, system models are created by simply connecting *input*, *state* and *output* variables (represented as objects) and assigning to them and their connections qualitative values of their magnitudes and relationships. Providing that a physical system is given, the user selects from a type menu the types of variables needed to define the model and to describe sufficiently the structure of the model. The individual attributes for each variable,

such as name, initial value, operating range limits (min, max), etc., are assigned from a data menu.
During the execution phase, the system converts qualitative attributes into numerical data in order for the appropriate simulations’ calculations to take place. This conversion is based on qualitative to numerical values conversion tables, describing basic numerical factors such as the operating range of the main variables (machine parameters) in a machine process, etc. An example of such a qualitative to numerical values conversion table is shown below in Table 1.

Max Min Sign	+++	+-+
Range	Max - Min	Max
Step	(Range/5)*Sign	(Range/5)*Sign
Nvalue'	QVal * Step	QVal * Step
Upper Lim	Min + Nvalue'	Nvalue'
Lower Lim	Upper - Step	Upper - Step
NValue	(Upper+Lower)/2	(Upper+Lower)/2

Table 1. Qualitative to numerical values conversion table of variables relationships

The operating range of a variable (Range) is determined and divided (qualitative partitioning) by the amount of qualitative values this variable can obtain (e.g., in our case: xl, l, m, s, xs). Then, after is taken in consideration the actual sign of the qualitative value the variable is assigned to, the numerical value (Nvalue') is determined by multiplying that value with a numerical factor that corresponds to this qualitative value (QVal). This numerical factor ranges from 1 to 5, respectively for xs (extra small), xl (extra large) and 0 (zero). However, in practice it was determined, that the final numerical value (Nvalue) should actually be between its respective step-range determined by the Upper and Lower limit values.
In order to clarify the above and understand the role of the qualitative to numerical values conversion table, lets examine the following single-variable case example. Suppose that a variable is assigned a large qualitative value (numerical factor 4), with a positive sign (+) and an operation range defined between 0 (Min) and 100 (Max). Then, according to the conversion table, it’s numerical value (Nvalue') would be determined by the following set of equations:

$$\begin{aligned} &\text{Range} = \text{Max} - \text{Min} &&\Rightarrow \text{Range} = 100 \\ &\text{Step} = (\text{Range}/5) * \text{Sign} &&\Rightarrow \text{Step} = 20 \\ &\text{Nvalue'} = \text{QVal} * \text{Step} &&\Rightarrow \text{Nvalue'} = 80 \end{aligned} \tag{2}$$

However, as it was mentioned above, this value should be between its respective step-range (determined by the Upper and Lower limit values), namely equal to 1/2 of that range. As a result in this example, the actual numerical value will be determined by the following equations:

$$\begin{aligned} &\text{Upper} = \text{Min} + \text{Nvalue'} &&\Rightarrow \text{Upper} = 80 \\ &\text{Lower} = \text{Upper} - \text{Step} &&\Rightarrow \text{Lower} = 60 \\ &\text{NValue} = (\text{Upper}+\text{Lower})/2 &&\Rightarrow \text{NValue} = 70 \end{aligned} \tag{3}$$

The above conversion process is being carried out similarly for all the qualitative values described in each system's model until they have been converted to quantitative values.

4.2.2 QMTOOL model simulation

A QMTOOL system model is defined as a structure of interconnected components (machine's activities and processes) presented as input, state and output objects and their relationships presented as connection objects.
The system model of the press machine is based on the given set of parameters and associated relationships, examined by the control algorithm. It is build using the types of variables that correspond to the following machine parameters:

- Input variables: initial values of parts' positions, sensors, etc.
- State variables: machines bucket feed rate, tamper head and mold table states, etc.
- Output variables: machine move, concrete elements production rate, etc.

Similarly, the system model of the mixer machine is based on the given set of parameters and associated relationships examined by the control algorithm and build using the types of variables that correspond to the following machine parameters:

- Input variables: initial values of aggregates conditions, etc.
- State variables: machines bucket elevation rate, mixture state, bucket door state, etc.
- Output variables: concrete production rate, etc.

Qualitative values are assigned to the components (parameters) and their relationships, in order to describe how these variables are linked together, interactively. The system objects have already embedded behavioural rules and functionality as (prolog) predicates, which however could be easily modified (menu-driven properties) according to the specific model construction requirements. Using relatively a small amount of qualitative information to define the structure and behaviour of the machines being modeled (symbolic computation), prototype models were created and executed (Fig. 17), in order to produce the dynamic machine behaviour that reflects the functional requirements for the system. This simulation model is a decision-support tool. It presents the dynamic behaviour of the machines and reflects the functional requirements for the concrete plant system. It enabled to test and redefine the machines operation control models prior to their application, in order to verify and finally achieve the desired overall control system cooperative functionality.

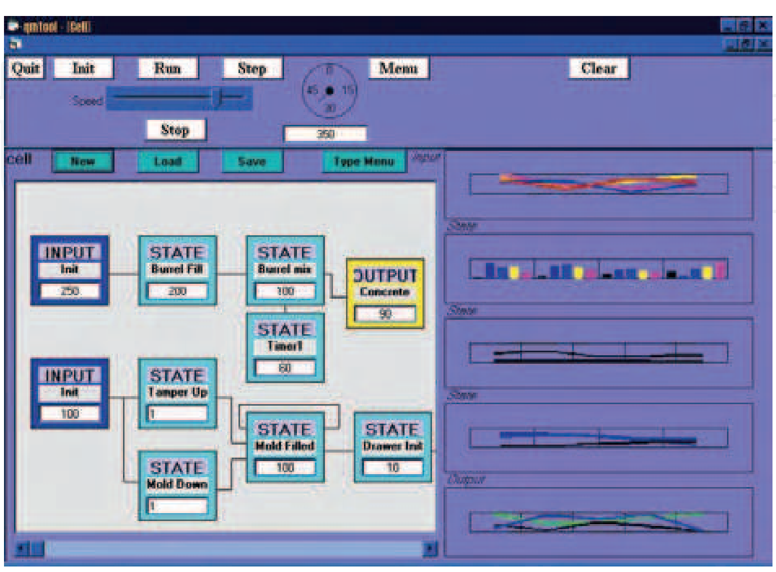

Fig. 17. Partial view of QMTOOL-based control system models of press and mixer machines

In order to show how the actual relations between the input, state and output variables are represented qualitatively, the following notation is used:

$$M+(Stvar,Invar),\ M-(Stvar,Stvar),\ f(Outvar,Stvar) \qquad (4)$$

where M+, M- and f simply indicate that there is a relationship (influence), positive or negative (qualitative terms representing the magnitude of the functional relationship) between these variables.
The actual value calculation of the State variable is based on its current value (State(t)) plus a sum of values (Influences) of the preceding variables (predecessors), namely:

$$State(t)=State(t+1)+Influences(i) \qquad (5)$$

A single influence is calculated taking in consideration the value of the predecessor PredVal and the magnitude ConMag of this connection, expressed in qualitative terms (i.e. 0 (zero), s (small), m (medium), etc.), namely:

$$Influence=f(Predval,ConMag) \qquad (6)$$

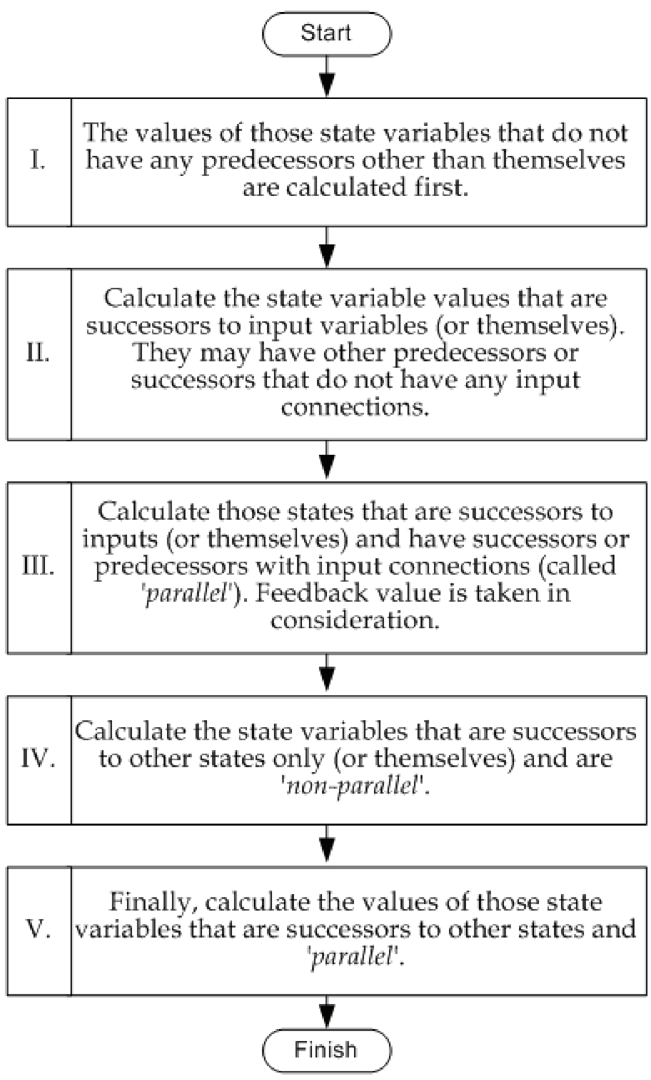

Fig. 18. State variables calculation order algorithm

In order for state variables' values to be calculated appropriately at the correct time interval, the system arranges them in a specific order according to their interconnections within the structure of the model. To achieve this, a set of rules is defined that determines the order in which the state variables should be calculated. The order of calculations is defined by the algorithm given in Fig. 18.

The mapping of mathematical equations (relationships) into qualitative descriptions is carried out using functional M+, M-, arithmetic add, minus, etc. and derivative incr, steady, decr, etc. constraints. For instance, the press machine's movement (Mv) is in functional relationship with the mold table and tamper head states positions (TTp) and the sensors input (Ps), expressed in the following way:

PressMachineMovement: M+{Ps},M+{TTp}
MoldTable FeedRate: M+{Ds} (7)

Internally, qualitative modelling involves the interpretation and execution of such equations, based on qualitative methods for modelling physical systems (Pearce et. al., 1989; Kuipers, 1986). A graphical representation of these constraints, indicating the functional relationships between the parameters of interest, is shown in Fig. 19.

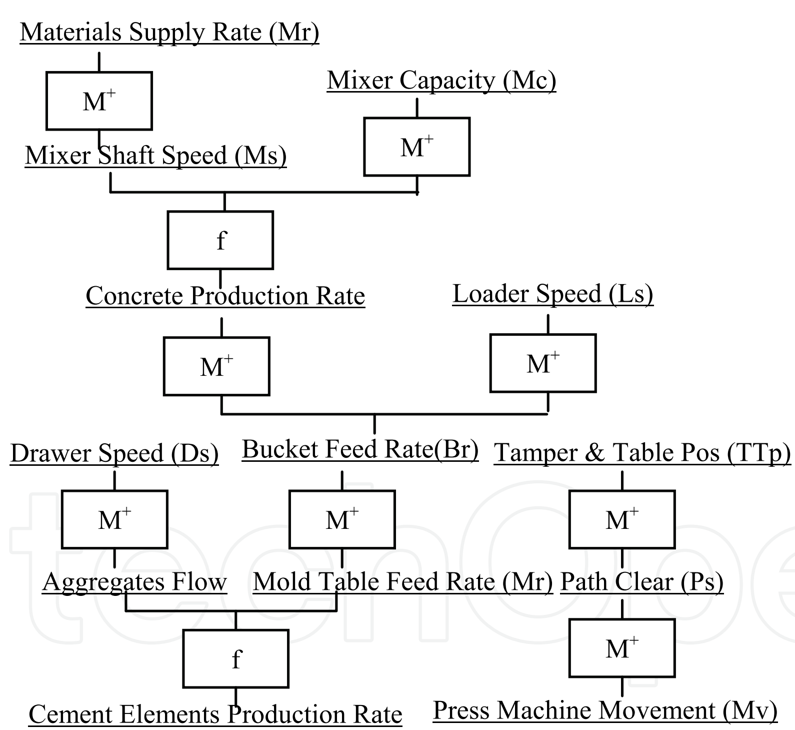

Fig. 19. Partial constraints of the machines system models

The overall behaviour produced from models simulation, is derived from the behaviour of individual components of the system throughout the models structure. This behaviour is presented graphically as Cartesian plots of sequences of time-varying qualitative states. The interactions occurring in the system during the simulation process can be easily analysed and visualised (see Fig. 20).

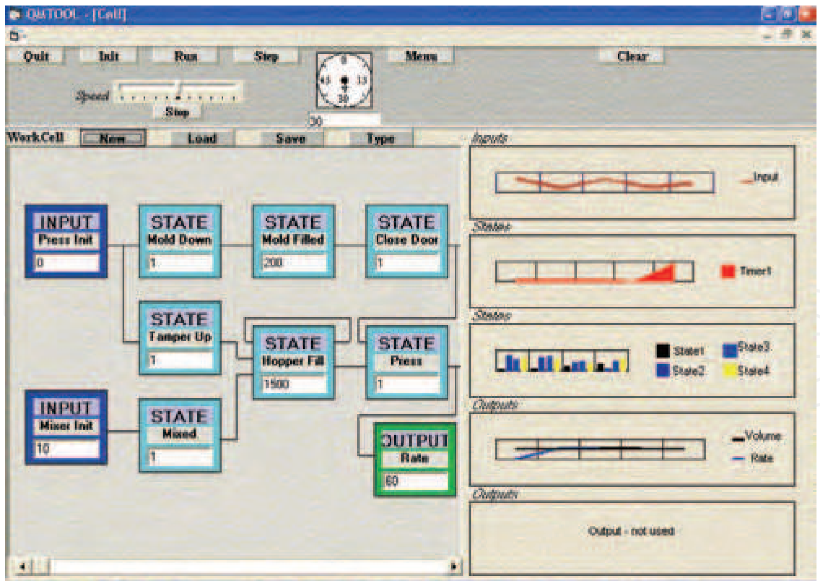

Fig. 20. Partial view of graphical simulation results

The importance of using a model for testing real time control operation algorithms, priori off-line and evaluate it's performance applying alternative solutions back at the design stage, is obvious of the following:

- Describe and analyse the static and dynamic behaviour of machines processes.
- Test and verify the machines overall cooperative functionality.
- Verify the control of each individual machine component.
- Adjust or redefine the design of the overall plant control system early at the specification stage.

Furthermore, using a qualitative approach, the actual productivity abilities of the machines could be estimated on a qualitative basis, closer to human understanding.

5. Implementation

This section describes the generation and application of the control software modules derived from the simulation models.

5.1 Control software implementation

Qualitative machine models were created off-line in order to ensure in safety that machines control and operation within the plant could be established in cooperation quite efficiently. Once the corresponding machine models have been created and tested extensively for their efficient and cooperative control, the overall machines group control system had to be implemented.

A major component of the overall plant operation system is the control software. The control software modules were derived from the creation and implementation of system models. The overall control and actual programming of the machines group is carried out using QMTOOL in conjunction with appropriate Hitachi PLC programming software for EC PLC series, for the implementation of the instructions and PLC download.

The implementation of the control software and the final programming of the central plant control board, as well as the individual PLC unit of the press machine, were realised using

ActGraph software (Actron A.B. Co.). ActGraph allowed the PC to interface with the Hitachi PLC EC series. ActGraph code, in form of a ladder diagram, allows for a final check and then, produces a list of instructions. These PLC instructions are then downloaded for execution in the PLC. A sample of the PLC code and ladder diagram is given in Fig. 21.

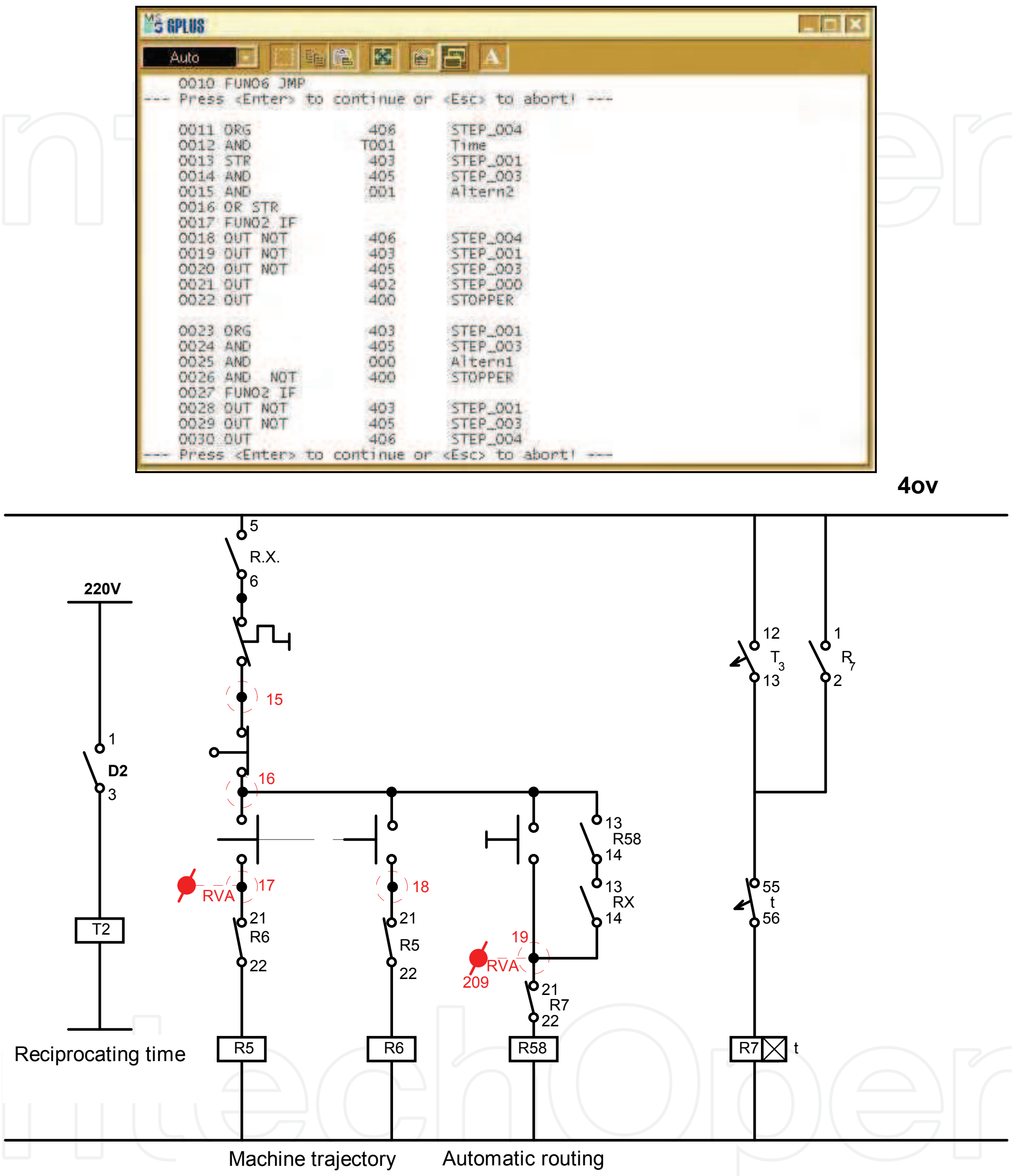

Fig. 21. Sample of PLC code and partial view of control diagram

The ladder diagram in Fig. 21, as well as the PLC code listing, are just a sample of the overall control system of the plant machines. In particular, the above are part of the mixer machine control system. Each rung of logic in the diagram (e.g. digital or analog inputs/outputs, contacts, switches, output coils, relays, etc.) corresponds to certain PLC instructions or subroutines, as in the above code listing. In practice, in most of the cases prior to the actual implementation of the operation control modules and creation of the instructions listing, the ladder diagram is being created first. Based on such simple schematic descriptions, the actual code listings are then created and downloaded into the programmable control unit.

6. Conclusion

Since most of the modern concrete elements production plants today are often faced with increasing market demands for further automation, as well as the growing international competition, computer-control systems, teleoperation and automation technology, modelling and simulation tools are some of the technologies and techniques used to acquire the desired functionality in operation control and quality in production. The last decade has seen computer technology applied more widely in industrial production, particularly in manufacturing processes not generally associated with high-technology. Often, such technology was not considered because it was difficult to model manufacturing processes using conventional mathematical modelling tools.

Here, the operation and control of a concrete elements production plant was presented. A qualitative modelling approach has been shown to improve production procedures and manufactured product quality. The creditability of the overall control system was validated using a simulation tool that utilises both conventional numerical methods and more advanced qualitative techniques, in order to deal efficiently with the dynamic processes present in the concrete plant. Qualitative modelling tools and commercially available software were used as tools to aid in the operation and control of concrete elements production machines. Once an optimised control model was obtained, via simulation with QMTOOL, etc., tests were carried out with machines manufacturing concrete elements. The effectiveness of the overall plant control using this approach is defined by the following attributes:

- The ability to describe and analyse the static and dynamic behaviours of machine processes.
- The ability to evaluate the operation of important sub-systems within the machines.
- The ability to easily redefine the design specifications to optimise the machines control.
- The ability to produce a realistic and reliable description of the cooperative plant machines based on qualitative models.
- The ability to plan and test path planning scenarios (e.g. route planning) in safety.
- The ability to reduce the cost of the machines manufacturing and minimise the risk of machines malfunctioning.

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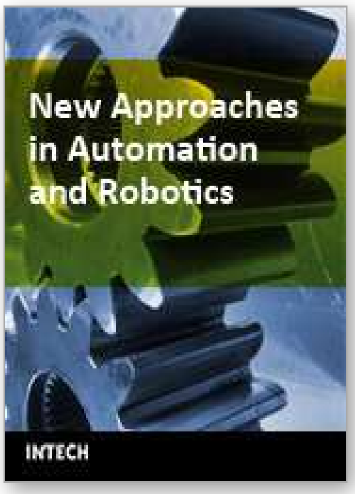

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The book New Approaches in Automation and Robotics offers in 22 chapters a collection of recent developments in automation, robotics as well as control theory. It is dedicated to researchers in science and industry, students, and practicing engineers, who wish to update and enhance their knowledge on modern methods and innovative applications. The authors and editor of this book wish to motivate people, especially under-graduate students, to get involved with the interesting field of robotics and mechatronics. We hope that the ideas and concepts presented in this book are useful for your own work and could contribute to problem solving in similar applications as well. It is clear, however, that the wide area of automation and robotics can only be highlighted at several spots but not completely covered by a single book.