THE ROAD MODEL - ROADROBOT'S EXPERIENCE IN APPLYING STANDARDS TO ROAD CONSTRUCTION PROCESS' MODELS

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ABSTRACT: This paper starts by presenting, in short, the architecture developed within European Project ESPRIT III 6660 RoadRobot (Operator Assisted Mobile Road Robot For Heavy Duty Civil Engineering Applications), that aimed towards the full automation of road construction sites. The purpose of the architecture was to lay the basis for the development of a system capable of integrating a set of applications in a common architecture based on the use of a standard (ISO 10303-STEP).

The presented architecture has demonstrated the full integration of information and control, starting by loading the information from the selected CAE system (InRoads from Intergraph), down, through the intermediate steps, to the automatic control of a Road Paver from German manufacturer VÖGELE.

The main focus of the paper is on the standard-based information models that have been developed to represent project information throughout the road construction cycle.

The initial Road Model Kernel created by TNO has been extended to support road specifications that include an update on the specification of asphalt layers for road paving, but also the addition of geological information for the specification of excavation activities.

A set of models has been developed for the maintenance of information regarding planning and scheduling of activities, which takes into account the project information.

A model for resources is used form maintaining resource information for allocation during planning and scheduling.

Finally a control model has been developed for control of execution of activities.

The RoadRobot has demonstrated the use of this architecture, and its underlying information models on a demonstration where information downloaded from the CAE system has made its way to a road paver who paved a road segment without on-site human intervention.

KEYWORDS: Modelling, STEP, Road model, Architecture, Standards

1. THE ROADROBOT'S ARCHITECTURE

The purpose of this section is to present the RoadRobot's architecture, in order to give the user a better understanding on the levels that were considered under the modelling task of the RoadRobot project.

Further detail on the RoadRobot's architecture can be found in Pimentão, J., et al. (1996).

First the purposes and concepts used in the system are presented, followed by a presentation of the implemented architecture.

1.1 The overview of the system

An overview of the system, which was implemented, can be found in Figure 1.

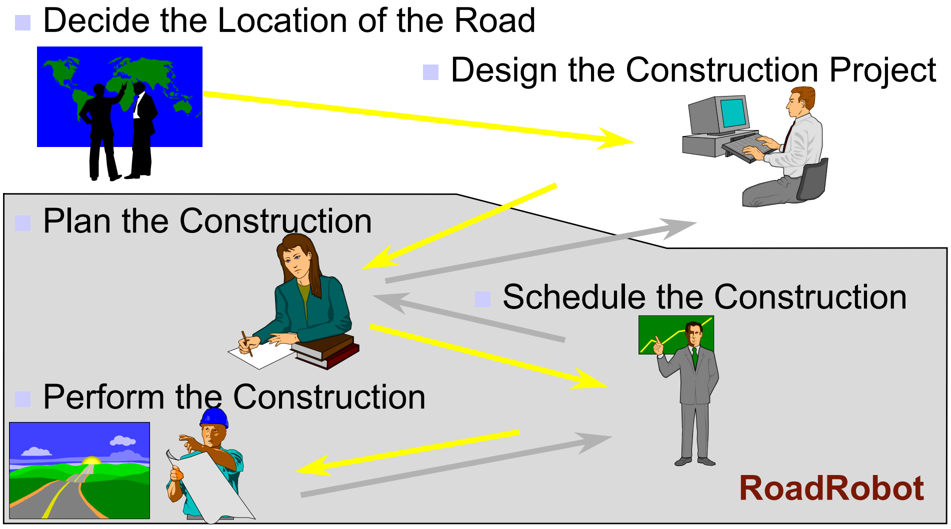


Figure 1. The RoadRobot project overview.

The primary purpose of the RoadRobot project was to demonstrate that a flexible architecture could be devised for road construction, allowing the control of road construction activities, from the design of the road, down to the control, of the machines and humans, performing the construction.

To this end, the RoadRobot System starts its operation by the reception of the road's design information, from a CAE system (in this case InRoads from Intergraph was the selected tool). The road's design information is then processed in order to create a graph of activities that have to be performed in order to achieve the ultimate goal of the road construction. These activities are generated, based on the information of the tasks to be performed and on a concept of cell (composition of machines and human resources, devoted and with skills to perform a given set of activities – e.g. Pave, Excavate, Vertical Signalling, and Horizontal Signalling).

Afterwards, the planning of the construction is performed. A set of cell types is defined in order to be allocated to the graph of tasks to be performed. Based on the set of real cells available at the construction site and on the time constraints, the construction is scheduled where individual tasks are assigned to specific cells to be performed.

On the cell level, the tasks are then decomposed in terms of sub-tasks that will go through planning and scheduling phases according to the resources available.

Each resource will then, in due time, receive the scheduled information, and proceeds to further decompose plan and schedule the activity for each of its tools.

The feedback communication between the various levels of the architecture was only devised in terms of task control. It was understood, but not implemented, that a lack of resources to perform a given task at a cell level, would imply the need of replanning that given task, or even be the originator for changes to be performed at an higher level (even going all the way to the design phase).

1.2 The architecture

In order to accomplish the objectives presented, an architecture was formulated that encompasses the concepts of:

- A **Site** (as in construction site) that manages and supervises the work of a set of construction cells;
- A **cell,** composed by a set of resources, humans and machines performing their scheduled work;
- The **machines** receive their activities and schedule the work of the individual tools;
- The **tools** perform their machine allocated activities.

A computer controls each level of the architecture, and is named "controller" of the given level.

An overall scenario of the architecture is presented in Figure 2.

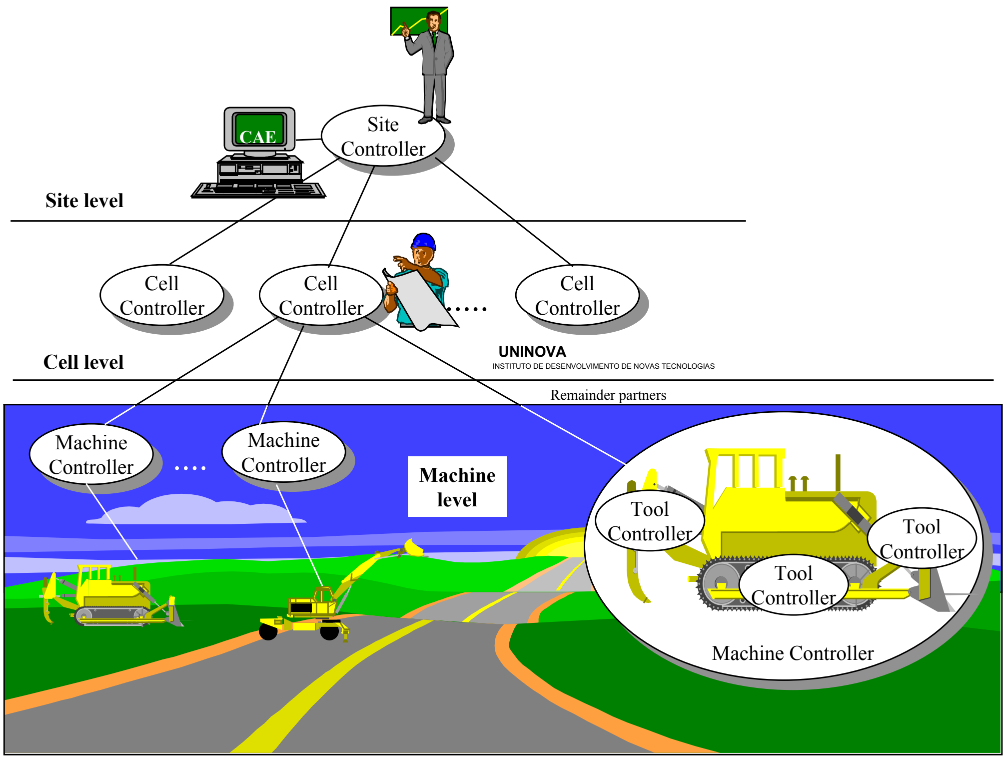
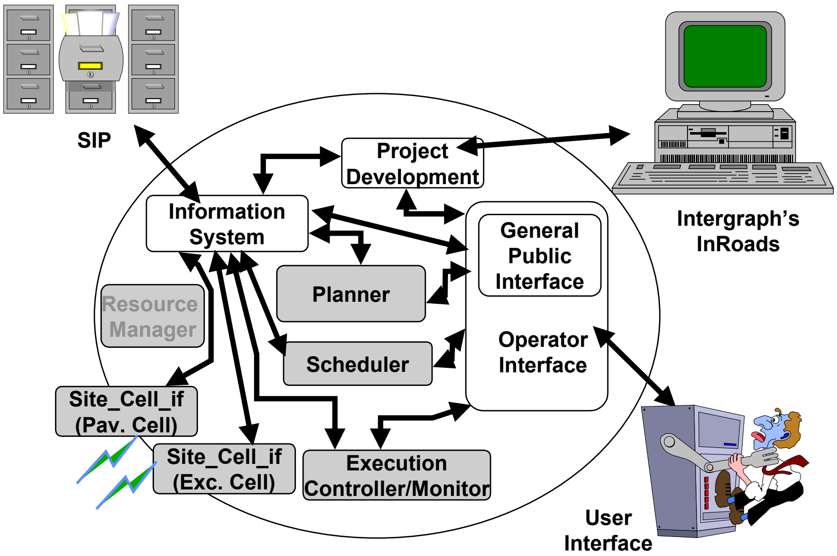


Figure 2. The RoadRobot architecture

Further details on communication within the machine controller (machine to tool) can be found on Sousa, P. et al (1999).

In general, each of the controllers is composed by a set of applications that communicate with each other through a centralised information system located at each level. Figure 3 depicts, as an example, the set of applications present at the site level.



Fig*ure 3. The applications/modules that are present at the site level.*

Once presented with the problem of having all these applications communicate with each other and being able to share data and pass control among them, the consortium decided to use UNINOVA's experience on the emerging standard ISO 10303 – STEP. Therefore, excluding the tool level, (since here a fieldbus was to be used in order to have speedy and strong control), all communication between levels were to be done using the STEP standard.

2. FROM THE ROAD MODEL KERNEL TO THE ROAD MODEL

The first step in the whole process is to incorporate the information from the CAE system. In the early stages of the process, since no Application Protocol was available for this specific area of business, we tried to find any available previous work on this area. The search led us to the work produced by TNO Business and Construction Research Willems, P. (1990), the Road Model Kernel (RMK).

After a thorough analysis of the RMK, discussions with a wide range of entities involved in the road construction process and a deep analysis of the available information concerning the outputs of the InRoads tool, the conclusion was the need to expand the Road Model Kernel. This was done in order to be able to represent all the information produced by InRoads that was relevant to the identified processes.

In general, the two major problems identified were:

- the lack of functionality to represent the particular type of road curve, clothoid, that is widely used in road construction, and

- the fact that the RMK had been developed with the purpose of representing the finished road thus lacking the ability to represent information that would lead to activities other than paving activities. Even in the case of paving, the model did not cope with the need to represent information pertaining to the paving process, such as paving parameters – e.g. compaction of the asphalt.

The RMK was therefore extended to support the needs of the RoadRobot project, that included, besides the representation of clothoids, the adequate level of process specification for paving activities and the information on geological layers that would be the basis for the definition of the other activity considered under the scope of this project: excavating. The result (the Road Model) although more complete than the RMK is not, by any way, the definite model for representing the whole construction process.

2.1 The Road Model Kernel

For the Road Model Kernel, a road is a list of road sections, where a road section is composed by a list of road axis.

A road axis denotes a portion of the rode, comprised between two road nodes (relevant pints, such as road crossings, bridges, etc.) whose road profile is maintained throughout the whole axis.

A road profile is divided into the profiles of the two carriage ways (this does not limit the number of lanes. In the most general sense the profile of the inbound carriageway may differ from the profile of the outbound one.

A carriageway is represented by a carriageway section, which is a list of carriageway axis.

A profile and a starting and ending carriageway nodes define a carriageway axis.

The RMK also supports the representation of the road's vertical alignment in a similar way to the one presented for the horizontal alignment.

The horizontal alignments reflect if the road goes to the right or to the left, where vertical alignments reflect the fact that the road goes up or down.

2.2 The Road Model

Due to the needs presented by the project and after a set of interviews with people involved in the road construction process, from the road owner to the contracted companies, significant changes were made at all levels, in order to cope with the needs presented.

A road, in the Road Model is still a list of Road Sections.

A road section still points to a list of road axis, who have now a deeper meaning in terms of road geometry, which now incorporates clearly information both on the profile – given by the cross section entity – and on the alignment that represents information both on the horizontal and vertical aspects of the road alignment.

The cross section represents the full information pertaining to the activities to be accomplished in order to create the "bed" of the road, and on the activities to be performed to asphalt the road. To this end, the components of the cross section are the set of sections that compose represent the profiles along the given axis.

The sections represent not only the final profile of the road, but also the original profile of the terrain, whose decomposition into additional layers allows the representation of the geological characteristics of the terrain, by association a material representation to each of the layers. Another component of the section is the list of asphalt layers that represents the layers, and the respective materials that will have to be used for each of the paving layers of the road.

Another significant change had to do with the road alignments, that represent both the vertical and horizontal alignment of the road axis. Although most of the road design can be done with straight lines and curves, in the horizontal alignment, we had to include the concept of clothoid (a curve with variant radius that is used in the connection between straight lines and curves). To our knowledge, clothoids are scarcely used in the United States of America but frequently used in Europe.

Additional information that is part of the road construction project and is not supplied by the CAE tool is the information on the composition of the paving layers (e.g. degree of compaction to be attained). Therefore the model was changed in order to support the incorporation of these parameters, which were imported through a text file with relations to the STEP axis and sections of the road as represented in the road model.
Further details on the Road Model can be found in Azinhal, R. (1994). The full road model is available at our site, with the URL http://www.uninova.pt/~rdrobot/all/rm.htm.

3. PLANNING THE ROAD CONSTRUCTION

On the early phase of the process, the Site Controller receives the project information from the CAE tool, represented using the Road Model. A set of activities to be performed is then defined based on the set of cell types available and a sequence of activities is created which is represented by a graph of activities.

3.1 From the project to the activities

The question was then, how to define the activities to be performed. The project designer associated with the road owner produces a set of road axis that are partitions of the road project. However, these partitions do not necessarily reflect the activities to be performed by the contracted construction company, whose restrictions may depend on other factors and constraints. Among these factors is the set of resources available at a given time, and the need, for instance, to balance earth movements, that if unbalanced would mean that the constructor would have either to acquire earth, or to have a place for temporary storage.

The definition of a software tool able to cope with these types of restrictions was not possible under the scope of this project. Therefore, given the project objectives, the consortium decided on the development of a limited version of the software tool. This tool, receives the road description, using the road model, and provides a set of activities for the construction cell types at hand (paving cell and excavating cell), based on the similarity of the sequence of actions to be performed. Regarding excavation, the activities were identified by dividing the activities into excavate and fill, meaning that a change of the type of activity would lead to the start of a new activity.

Regarding paving activities, the division is made in terms of the similarity between the values for the parameters to be used. For instance, a clear point for separating activities, is that a different asphalt layer corresponds to a different activity and, when the horizontal alignment changes, the parameters of the road paver will have to change, and this will give rise to a new activity. The result from these restrictions is a large set of activities with small granularity. This tool will have to be updated with more information in order to produce an adequate set of activities based on the knowledge from “the people in the fields”.

3.2 The planning of the activities

Once a road construction project is imported from the CAE tool, a set of activities will be made available for planning. A project-planning tool was developed to allow the user to associate a given activity to a given cell-type and to organise the activities in a graph that allows the definition of precedence relationships between the activities. The graph assumes the possibility of performing activities in parallel and the existence of an infinite number of cells to perform the activities.

The result is a graph of planned activities that will, on a scheduling phase, be assigned to a set of construction cells.

At the site level, the planned activities link together a planned cell (responsible for defining the type of cell that will be required), the geometry information for the activity and the required activity parameters.

The full schemata for the site plan model can be found at the RoadRobot's site with the URL http://www.uninova.pt/~rdrobot/all/spm.htm.

3.3 The planned cells

In order to devise a way of organising the activities in terms of construction cells, it was decided to have the functionality of one resource define the functionality of the cell (e.g. a cell with at least one road paver is a paving cell).

A planned cell is, therefore, a cell whose functionality is represented by a set of resource constraints, which represent the minimal number of resources of each resource type that must be present in any given cell of that type.

4. SCHEDULING THE ROAD CONSTRUCTION

The next step in the process is to schedule the execution of the activities. Beforehand, with the set of resources available at the construction site, and with the plan, the site manager will have to organise the resources available, abiding to the constraints placed by the defined planned cells, thus creating the cells, which will be used to perform the work.

Scheduling is then performed by rebuilding the graph of planned activities, connecting them with actual cells, adding time constraints and making sure that, whenever parallel activities are involved, no one cell will be used in more then one activity at the same time.

This is, of course, a naive form of looking at the process of scheduling activities. Nevertheless it depicts both the process that was implemented with the development of a software tool, and the change that occurs from planned activities to activities to be executed. The resulting activities are represented in a graph that is a shuffle from the graph of planned activities and has time constraints added to the activities.

The scheduled activities, besides the information that allows them to define the sequence of activities, are described by group of three time constraints that specify, respectively, the "start no early then", the "finish no later then" and the "bootstrap" restriction.

The bootstrap instant is defined as the instant to start the preparation of the cell components and was defined because, in the case of road construction, some heavy-duty equipment may have to be moved between locations in the construction site, prior to the execution of the assigned task.

The set of all models that are used at the site level can be found at the URL http://www.uninova.pt/~rdrobot/site.htm.

5. FROM CELL ASSIGNED ACTIVITIES TO RESOURCE ASSIGNED ACTIVITIES

The process of turning cell assigned activities into resource assigned activities has not been implemented. It was clear that, for instance, once a cell is assigned a paving task, some other subsidiary activities will have to be assigned to the other resources (e.g. human) working in the cell that will involve preparing the machine and accompanying the machine in its operation. However given the purpose of the project it was not possible to develop the planning and scheduling tools in all the needed detail.

Therefore, the translation from the cell activities to the machine activities is a direct copy.

The processes are a repeat of the processes that were implemented at the site level; i.e. from each activity coming from the site to the cell, a machine planned activity is created and the process of planning and scheduling is quite similar to the ones performed at the site level.

The counterpart for the cell is now a given resource, and the counterpart for the set of resources is now the set of tools that will have to equip the resources.

6. CONTROLLING THE ROAD CONSTRUCTION

All communication and control among applications within the controllers is performed by exchanging messages in STEP format. To this end an effort was put on the definition of the interfaces among applications and of the data and control streams that flow through these interfaces.

The full detail of the interfaces and data streams can be found in RoadRobot (1993).

At each level special attention was paid to the interfaces with the higher and lower levels of the architecture.

Messages going downwards, from generic levels to specific levels are divided into commands and tasks.

Messages going upwards are called responses. Every response relates, by ID, to the message that originates it. To this purpose, an unsent message (communication link active) was created, in order to keep the system orthogonal, by allowing unsolicited responses to be sent to the upper level controller. An example of an unsolicited message is “request manual control”, which is sent to the site controller when the cell operator requests it at the cell controller.

Communication that relates the site controller with the cell controller was divided into cell independent messages and cell dependent messages. The formers include commands to control the execution, such as starting, pausing, resuming and stopping assigned tasks. The later represent the tasks that may be requested to a given cell and represent the information pertaining to the task to be executed.

At each controller a user interface was designed to allow communication of the humans with the controller. At the site level, communication is achieved through the "Operator to Site Interface" that, besides the usual commands to control the execution of tasks has specific tasks to be executed at site level, that include "design road", "plan road construction", "estimate budget", etc.. The first two tasks have been implemented and their functionality was already described. Budget estimation and calculation of real costs was one of the tools identified as very relevant by several contractors, however it fell out of the scope of the RoadRobot project.

At the other levels of the controllers a similar interface was made available for the respective operators.

7. CONCLUSIONS AND FUTURE WORK

The purpose of the RoadRobot project has been achieved in demonstrating that it is possible to have a wider use of information technology in the field of road construction.
The work performed also allowed us to realise that there are a huge number of areas that might benefit from the introduction of some of the concepts that we have demonstrated, and of others that we have identified. There is room both for research and for the actual production of commercial software solutions.

Nevertheless, some a priori effort must be put on the development of the information models to support the information exchange at the various levels.

We believe that the first point, which should concern the community, is the creation of an Application Protocol for Road Construction, to which we believe we have given a valuable contribution. Our effort will be concentrated in trying to gather the synergies necessary to evolve in this direction.

8. ACKNOWLEDGEMENTS

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