

DEVELOPMENT AND IMPLANTATION OF SIMULATION MODELLING IN ROAD CONSTRUCTION PLANNING: THE CASE OF ROADSIM

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Road construction is very expensive, unpredictable and highly influenced by uncountable factors, like weather, type of soil, environmental issues, etc. This has led to difficulties in developing accurate construction plans and modelling construction operation using traditional simulation system. In this context, the paper introduces a road construction-oriented simulation system which was designed and developed to automate road construction planning process.

The system is a decision support tool, conceived to provide results referring to the productivity of the resources involved in a road construction operation.

The system has specific-domain characteristics and was developed using a knowledge-based methodology to allow the incorporation of road construction rules.

The system is designated RoadSim and was designed to model the road construction operations that usually are included in road construction projects and, therefore, automate the respective planning process.

The construction operations have been identified through a comprehensive analysis of a large number of road projects. For every road construction operation a template model was defined with the consideration of the factors influencing the productivity of the resources involved in this type of construction. Using the productivity results obtained by the system, RoadSim automates also the scheduling of the works and provides elements to study the resource allocation.

This paper refers the principles followed for the development of RoadSim and explains its main features through the use of the system in real-world road construction projects. The results obtained using RoadSim are compared with the elements collected in a control process, demonstrating the accuracy and usefulness of the system.

Keyword: Road Construction, Simulation, Knowledge base, Planning

INTRODUCTION

For some researchers the terms leadership and management are associated and are used interchangeably especially when leadership is considered under the decision-oriented point of view. In fact management and leadership can be coincident in what refers to the achievement of organisational goals, which in construction means the technical competence in meeting time and cost goals. However, leadership goes beyond the day-to-day operations and thinks strategically about the future, creating a vision of the future where new products, new construction methods and new construction planning processes are developed aimed at the reduction of construction cost and construction time.

Therefore, while management administers, leadership innovates.

In fact, innovation has been highlighted as being one of the ways to obtaining the technical competence necessary to a correct determination of goals to be achieved (planning) and for the verification of how the objectives are being achieved (control). That type of competence is required to respond to the growing competitiveness associated to the globalisation and to the fact that projects have become larger and more complex, hence to respond to the increased risk faced by the construction companies (Tah and Carr, 2001).

As part of the efforts aimed at the development of systems oriented to improve construction planning and therefore the decision-making process, this paper discusses the methodology used for the development of a system destined to automating road construction planning. The system is a road construction-oriented simulation modelling developed using a knowledge-based methodology that allowed the definition of atomic models referring to the action of the resources used in road construction. The atomic models defined through a knowledge acquisition process have been used as modules for the modelling of road construction activities, therefore allowing the simulation of road construction operations. The simulation system was designated RoadSim.

SIMULATION IN CONSTRUCTION

Since Halpin developed CYCLONE (Halpin, 1977), a purely network based system to simulate construction operations, a meaningful number of systems have been created for construction purposes. CYCLONE does not have the capacity to recognise the state of the a construction system at a certain point and it is unable to differentiate the situation of similar resources working in the same construction operations. The system was found useful for modelling of repetitive activities, such as concrete mixer plants (Woods and Harris, 1980, Lluch and Halpin, 1982) and tunnelling operations (Touran and Asai, 1987). Many of the systems developed after CYCLONE are implementations that have tried to overcome some shortcomings of the initial system. RESQUE (Chang, 1987) is an implementation using a process description language that allows the identification of the situation of similar resources working in the operations. COOPS (Liu and Ioannou, 1992) is a resource-oriented process in which a construction operation is considered an integration of the various resources used in its carrying out process. CIPROS (Odeh et al. 1992) is a knowledge-based library containing construction methods and construction resources that are selected for the modelling process. LBS (Oloufa and Ikeda, 2000) uses also a library for the selection of the resources for modelling activities. RISim (Chua and Li, 2001) takes construction resources as objects, considers the respective interactions and establishes the operation logic to model a construction operation. KMOS (Kim and Gibson, 2002) assembles basic states that resources can assume to model construction activities.

Other simulation systems include visualisation of the construction process, i.e. provide visual understanding of the construction process, either in terms of physical aspect or in terms of sequence of execution (Op Bosch, 1994). In these types of systems can be included a methodology proposed by McKinney and Fischer (1998) for the generation, evaluation and visualisation of construction schedules using a 4D CAD. Maruyama et al. (2000) built a computational environment to develop a virtual construction simulation planning dubbed VR-Coms. VIRCON is another 4D modelling system allowing the elaboration of the tradeoffs between the sequencing of the works and respective spatial distribution (Kelsey et al. 2001; Winch, 2002; North and Winch, 2002; Dawood et al. 2004).

However, and despite the number of systems developed by the research community, the reality is that simulation is still used in limited way by industry in construction planning

(Kamat and Martinez, 2001; Oloufa and Ikeda, 2000; Gue and Fayek, 2001; Kim and Gibson, 2002). The chief argument to explain the reluctance in using simulation modelling in construction planning is the fact that the developed systems have not been tailored to fit specific requirements of construction managers.

The conclusion was that systems conceived, designed and implemented for a specific construction domain could provide a better response to specific needs of construction managers dealing with problems related with that domain. The limitation of the scope of a simulation system to a confined construction domain can also allow a detailed analysis of the operations included in that domain and the definition of the rules governing the actions and interactions pertaining to the referred to construction domain. The rules can be established by identifying and collecting data and information regarding to the selected construction domain, i.e. using a knowledge acquisition process.

KNOWLEDGE ACQUISITION

Aimed at the definition of the elements required for the development of a simulation modelling system to be used in road construction planning, a research was undertaken using a knowledge-based methodology.

The following steps composed the knowledge acquisition process:

- Analysis of road construction operations;
- Analysis of road construction process for the identification of activities, resources, execution methods, working conditions and interactions;
- Modelling of activities.

Analysis of Road Construction Operations

Analysing road construction operations it was verified that breaking down the initial system into sub-systems of lesser complexity could reduce the complexity of any activity. At the final stage of the breaking process, an indivisible element is found that could be considered as an atomic model (fig.1). This division process has been proposed by Ziegler (1987), by Luna (1992) and by Odeh (1992) and its main purpose is the reduction of complexity.

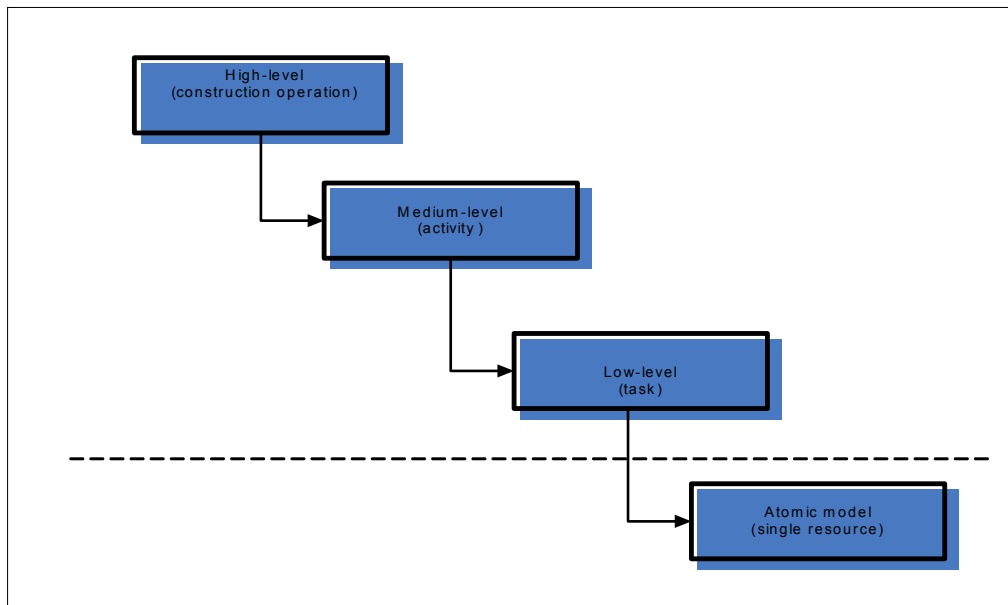


Fig. 1 – Atomic model concept

Therefore, a construction activity can be seen as the result of coupling of atomic models.

Figure 2 highlights the fact that an activity can be associated to a molecule composed by several atoms (atomic models). Observing one of the atoms, it can be seen that the same is composed by different parts, being the principal a sort of nucleus and the rest a sort of electrons. Each part of the atom represents a single point in the action of a resource, in the case the “loading” electron, the “dumping” electron and the “travelling” nucleus. Each part of the action receives influences that affect the respective performance, such as “hauling distance”, “type of accesses”, “site organisation”, “availability of space”, etc. Therefore, the analysis of each part of the atom (representing the action of a construction resource) can be done by tracking the events and time elapsed during successive events.

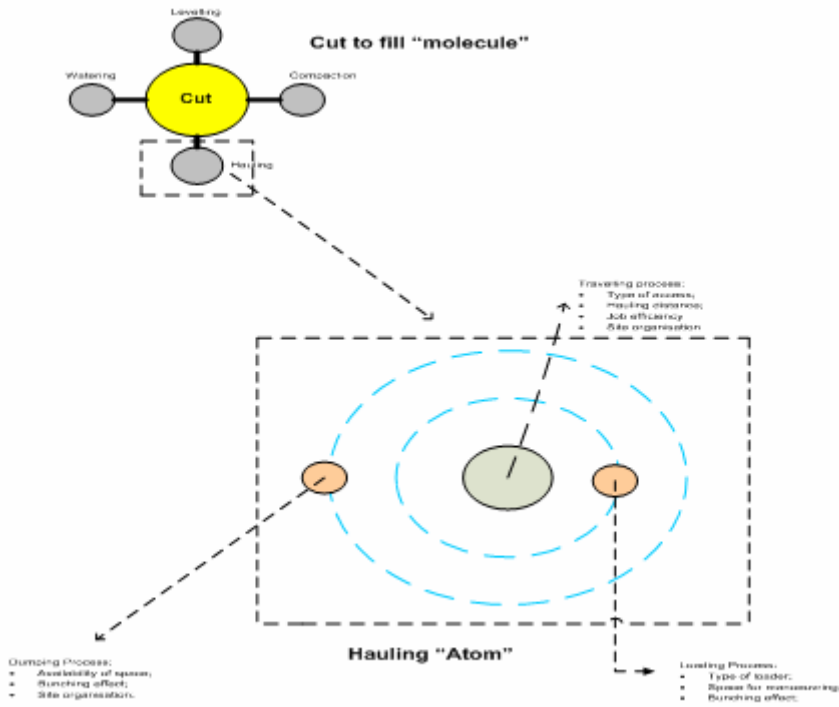


Fig. 2 – Activity and atomic models

That assertion is illustrated by the activity of the tipper truck depicted in fig.3, in which it can be seen how the cycle time can be obtained by tracking events and times.

Time	T1	T2	T3	T4	T5	T6	T7
Event	Arrival	Loading	Travel loaded	Manoeuvre	Dumping	Travel empty	Queuing

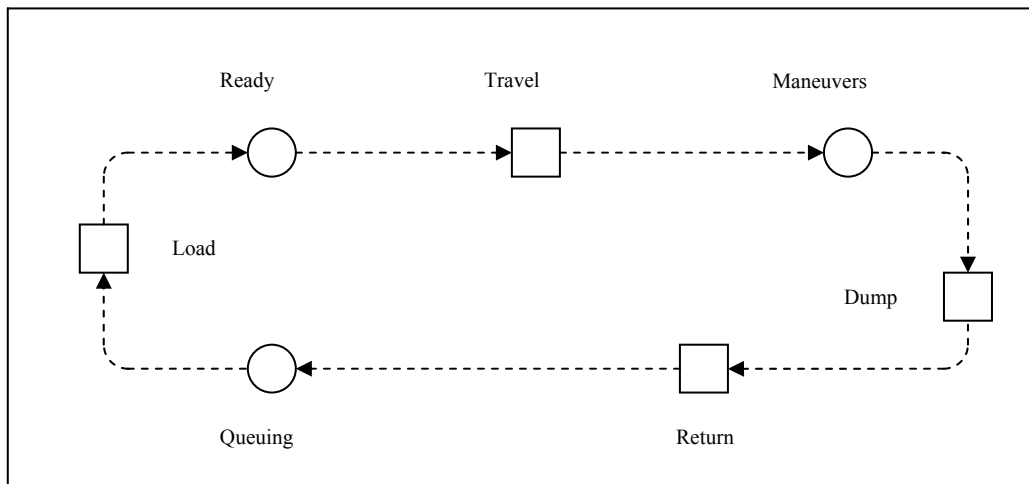


Fig. 3 – Identifying changes in the state of a construction resource

The total cycle time of the action (T_c) is the sum of the partial times (T_i) spent in each point by the resource and represented by:

$$T_c = \sum T_i$$

This can therefore be used to determine the basic productivity (P_b) of the resource as follows:

$$P_b = (H * C_b) / T_c$$

In which C_b represents the capacity of the resource and H the unit of time (usually "hour").

As indicated in fig.2, this basic productivity only becomes real after the consideration of the factors influencing the action of the resource.

The definition of the atomic models has another particularity, since it was observed that a given resource could be used in the carrying out of different construction activities. For example, the tipper truck of the fig. 4 can be used in different activities such as "asphalting", "concrete transportation", "cut to fill", "fill from borrow", etc. The action of the truck is always the same: what changes is the working conditions. This creates a sort of modularity enabling the use of the atomic model of the truck in the modelling process of different activities.

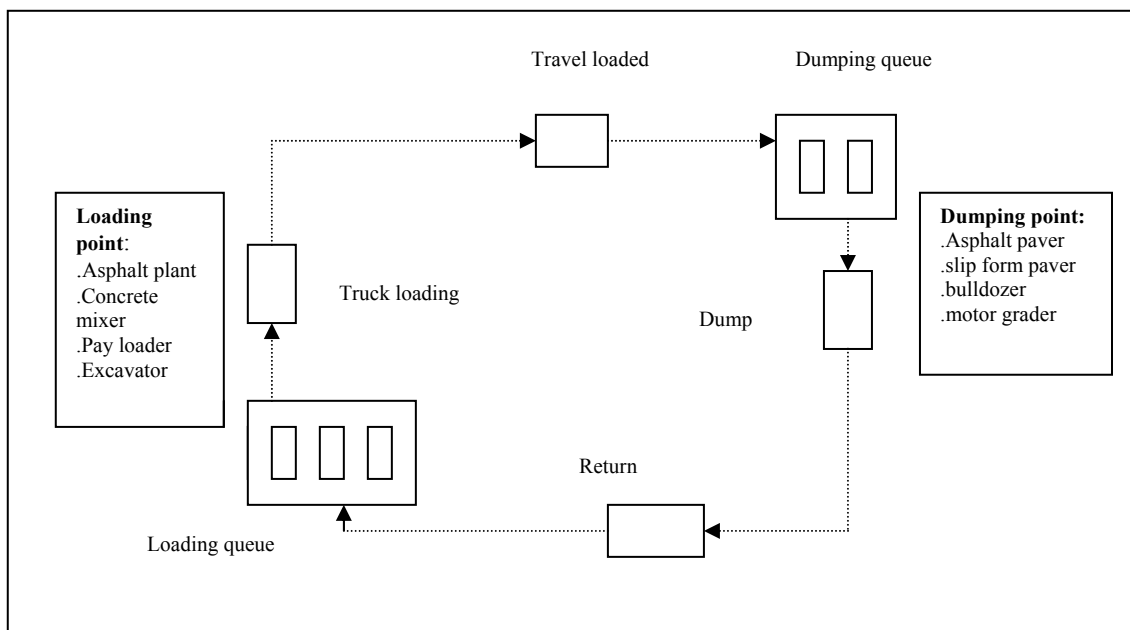


Fig. 4 – Concept of modularity

Passing to a higher level and dealing with the totality of the actions of the resources included in the construction activity, it was observed that between atoms there are other factors influencing the coupling of the respective atoms.

These factors are divided into interactions and working conditions (fig. 5) and deal with the real conditions in which the resources are working, such as technical specifications applying to the project, the site organisation quality (accesses, job efficiency, impact of breakdowns, quality of site management, quality of site work force, type of materials being processed, etc.) and capacity of the resources, number of resources working in the operation, compatibility of resources, etc.

The identification and modelling of all those factors have been done through the analysis of the road construction process.

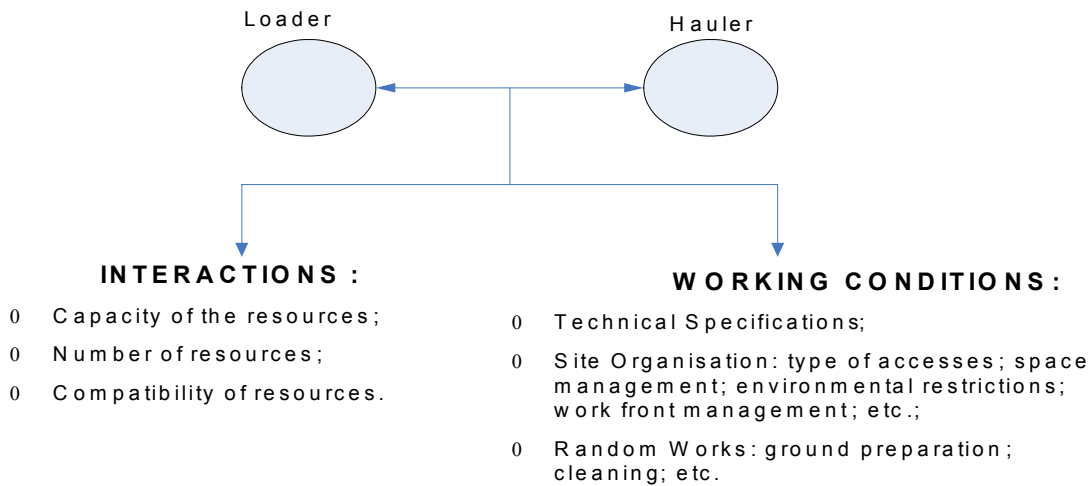


Fig. 5 – Coupling of atomic models

Analysis of Road Construction Process

This analysis aimed at the identification and definition of the activities pertaining to road construction projects, resources used to performing the activities, alternative construction methods and the influencing working conditions and interactions.

For the identification of the activities that make up road projects, 145 road contracts have been analysed. The activities identified have been grouped into three sub-domains: “earthworks”, “drainage” and “pavement”. As an example, table 1 shows that earthworks are always part of a set constituted by the following tasks: *cut + hauling + dumping + levelling + watering + compaction*. Table 1 also shows the different construction methods that have been identified by the research to carry out earthworks activities.

Table 1 – Earthworks activities and corresponding tasks

Activity	Execution Method	Tasks (by resources)
Cut	Method 1	Dozing + pay loader
	Method 2	Excavator
	Method 3	Pusher + motor scraper
Haul / dump	Method 1	Tipper truck
	Method 2	Dumper
	Method 3	Motor scraper
Levelling	Method 1	Motor grader
	Method 2	Bulldozer (mass earthworks)
Watering		Water tanker
Compaction	Method 1	Vibrating roller
	Method 2	Sheep foot roller
	Method 3	Pneumatic roller

The same exercise has been done for works included in the subgroups “drainage” and “pavement”.

In what resources is concerned, the main attention was directed to equipment since road construction is considered an equipment-intensive process.

By capturing professional knowledge, historical records and manufacturers information, a basic package of equipment used in road construction was defined, taking advantage of the fact that manufacturers trend to produce similar types (capacity and functioning) of equipment units. For the identified units it was observed that some associations of equipment could be defined, meaning that some types are “forced” to work in a sort of partnership with others. For example, a motor scraper never interacts with a tipper truck, since the scraper has been designed to work and interact with a bulldozer (pusher) at the loading point and with a bulldozer or motor grader at the dumping point. The possible associations are shown in table 2.

Table 2 – Association of equipment resources in road construction

RESOURCE	EQUIPMENT PARTNER
Bulldozer	<ul style="list-style-type: none"> ✓ Pay loader ✓ Motor grader ✓ Roller
Motor scraper	<ul style="list-style-type: none"> ✓ Bulldozer ✓ Motor grader
Pay Loader	<ul style="list-style-type: none"> ✓ Bulldozer ✓ Tipper truck ✓ Dumper
Excavator	<ul style="list-style-type: none"> ✓ Truck ✓ Dumper
Motor Grader	<ul style="list-style-type: none"> ✓ Tipper truck ✓ Dumper ✓ Motor scraper ✓ Roller ✓ Water tanker
Tipper truck	<ul style="list-style-type: none"> ✓ Excavator ✓ Pay loader ✓ Asphalt plant ✓ Concrete plant ✓ Crane ✓ Motor grader ✓ Asphalt paver ✓ Slip form paver
Dumper	<ul style="list-style-type: none"> ✓ Motor grader ✓ Excavator ✓ Pay loader

The identification of these associations is useful since it allows the study of the possible interactions between equipment partners, in what refers to compatibility related with their capacities.

In what refers to the working conditions and interactions, the same reasoning and procedure was adopted (professional knowledge, historical records and equipment manufactures information) to obtain the identification and definition of the influence of the respective factors. Numerical coefficients have been attributed to each factor,

therefore allowing the determination of the real productivity of the resources performing an activity in the following way:

$$P = P_b * w_1 * w_2 * w_3$$

With the characters having the following meaning:

P = real productivity of the considered resource;

P_b = productivity of the atomic model;

W₁ = factor referring to the working conditions;

W₂ = parameter referring to the interactions with the “partner” resource;

W₃ = parameter related with the random works of possible execution during the construction process.

With all these information, mathematical equations have been defined for the determination of the productivities of every resource in a given activity. Eventually, all process was summarised graphically as shown in fig. 6, which represents the actions and interactions of a motor scraper and bulldozer in push and load task.

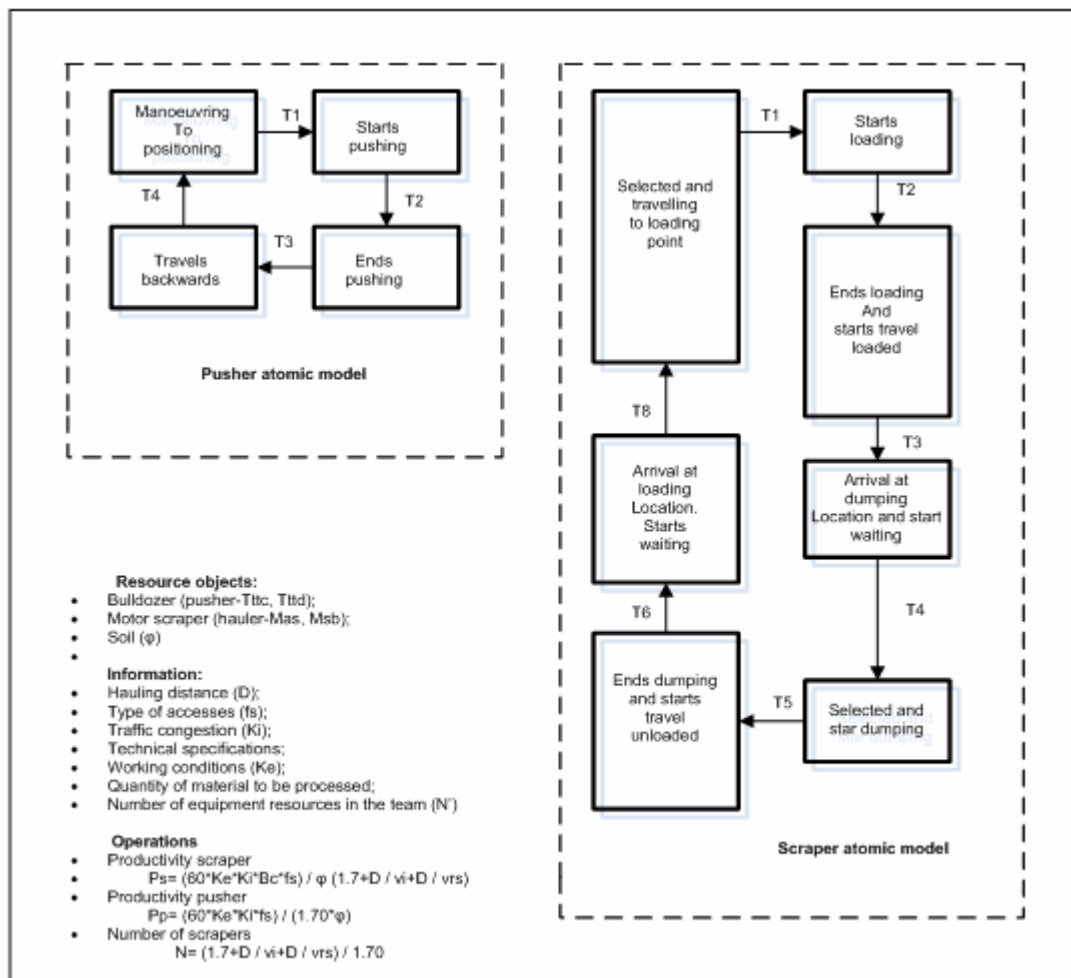


Fig. 6 – Graphical representation of the atomic models

DEVELOPMENT AND TEST OF THE SYSTEM

The elements obtained in the knowledge acquisition process were used to develop a simulation system, which has a database as the core infrastructure. The database was populated with the activities composing road construction projects, resources used and respective characteristics, coefficients referring working conditions and interactions between resources and the productivity of the atomic models defined for every resource. The functional model of the system is depicted in fig. 7.

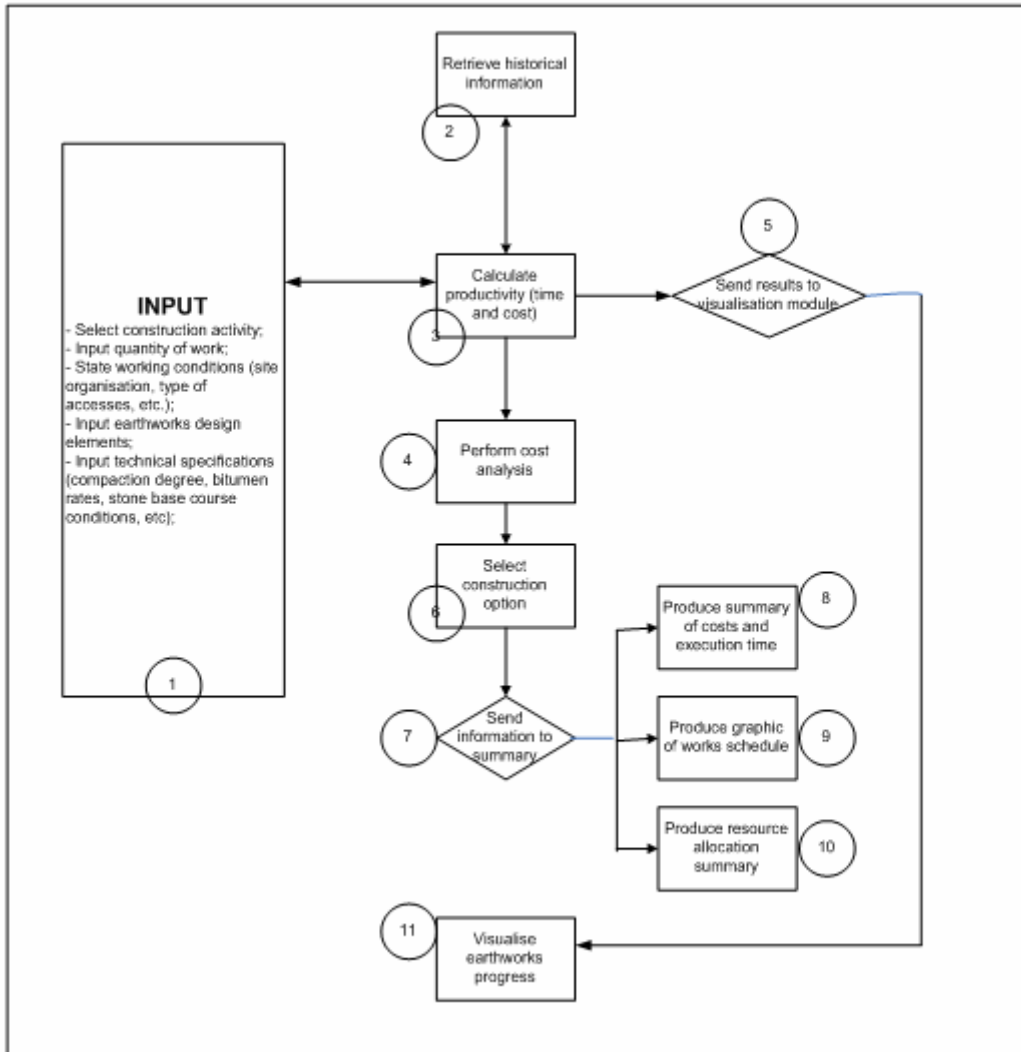


Fig. 7 – Functional model of the system

The system was tested using three real case studies, constituted by 3 sections of a major highway under construction. Comparing its outputs with the values obtained from the site control process did the evaluation of the accuracy of the simulation modelling system (table 3), showing that the results of the system closely resemble the elements of the control process. The system was also found faster than traditional construction planning methods (CPM/PERT and time-chainage methods). Therefore, the system can improve the quality of the site planning.

Table 3 – Comparison of outputs of the system with elements from control process.

Lot	Value of the contract	Number of activities simulated	Cost of works simulated (€) (a)	Cost same works in control process (€) (b)	Difference (€)	% a/b
Lot 2	39 425 587	30	12 576 804	12 576 015	- 1211	- 0.0096
Lot 3	34 919 000	43	20 648 983	20 601 074	+ 44 909	+ 0.22
Lot 8	51 018 250	42	29 965 874	29 276 272	+689 602	+ 2.35

FURTHER RESEARCH

The methodology used in this research for the modelling of road construction activities can also be used in other construction sectors, especially in those with linear characteristics such as water distribution networks, sewerage systems, railways construction and similar.

One of the further developments envisaged by this research is the incorporation of visualisation of road construction activities, either in 3D or 4D.

CONCLUSION

This paper presented the basic steps followed to obtaining the elements necessary to develop a simulation modelling system destined to automate road construction planning and evidenced that the use of knowledge-based methodology can allow an accurate modelling of complex construction operations as those included in road projects.

Using knowledge-based methods to identify and define activities, resources types and characteristics, interactions and working conditions factors, enables the incorporation of construction expert rules as patterns and provides a good method to predict the behaviour of construction systems in different scenarios.

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