SIMULATING THE IMPACT OF SUPPLY CHAIN MANAGEMENT PRACTICE ON CONSTRUCTION PROJECT PERFORMANCE

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Supply chains have been identified by researchers as one of the main problems in the construction industry which lead to poor performance. On construction sites, supply chains encompass the flows of materials, labour, equipment, plant and information which originate from the different parties, viz., main contractor, suppliers, subcontractors and client/architect. Any problems with these flows will eventually disrupt the project performance. This paper describes the building of a simulation model to predict how supply chain management (SCM) practice may impact on construction project performance. A CPM network of a typical school building has been used to develop the model to which the problems of supply chain flows have been applied. The extent of the problems regarding supply chain flows were identified using questionnaires sent to UK contractors and these results will be used to develop the model using Pertmaster Risk Expert™. At the time of writing, no results are available, but the paper will describe the nature of the tests to be conducted using the simulation model.

Keywords: CPM network, project performance, supply chain management practice.

INTRODUCTION

While the construction industry is one of the oldest industries in the world, few would consider it to be an advanced, well-managed and sophisticated industry. Recent research has reported that the construction industry is known for its poor performance and low profit margins (Agapiou *et al*., 1998; Yeo and Ning, 2002; Cox and Ireland, 2002) and many construction processes are said to be affected by delays, budget overruns, quality issues, poor controllability and waste (Saad, 1996; Kornelius and Wamelink, 1998; Vrijhoef and Koskela, 2000). Analysis of these problems suggests that a major part of them are associated with supply chains (Vrijhoef *et al*., 1999).

The concern with supply chains in the construction industry it is still a relatively recent phenomenon (Arbulu and Ballard, 2004). Although some efforts have been made to widen the understanding of construction supply chains, as Arbulu and Ballard (2004) state, people in construction, i.e. clients, contractors, suppliers and subcontractors, are still exploring what supply chain management is, how it works to increase competitive advantage and what are its dynamics. There are also different

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views among researchers regarding the scope of supply chain management in the industry as reflected in the way they define it. For this research, the definition proposed by O'Brien and Fischer (1993) is adopted with some refinement, as follows; *"supply chain management is the management of suppliers, subcontractors, related parties and all the processes from delivering information to planning, ordering, producing, delivering, and installing materials and services for a construction project through a network of organizations"*.

Supply chains in the construction industry can be very complex, with hundreds of subcontractors and suppliers involved, especially in a large scale project (Briscoe *et al*., 2001). A typical construction supply chain involves the flow of information (e.g. orders, schedules, forecasts, etc) as well as the flow of materials (e.g. supplies, production, deliveries, etc) (Vrijhoef and Koskela, 2000). Cox and Ireland (2002) argue that construction supply chains consist of material supply chains, labour supply chains and equipment supply chains. In addition, a reliable flow of work is also seen as critical in construction (Howell, 1999). Any problems with these flows will eventually disrupt the project performance. For example, on a construction project, any delay in material delivery may have a knock-on effect on delaying the works, and if the works that require the materials are critical, the project will likely be delayed as a consequence. The same may also happen for late completion of the subcontractor's works. To gain an understanding of how different supply chain practices can affect project performance, this research describes the building of a simulation model that embodies delays resulting from problems in the supply chain.

METHODOLOGY

The steps taken in this research were: literature review, regular visits to construction projects, questionnaire survey, and simulation. The literature review helps to understand construction supply chains thoroughly and integrate and summarize what is known in the research area. To reinforce this understanding gained from the literature, regular visits to construction projects were made to learn how supply chain management was practised on site in a real life situation. Based on the literature review and the site visits, a questionnaire survey was then undertaken to obtain the data needed for the simulation. A simulation model was then developed.

Literature review

The literature review was carried out to provide a sound understanding of supply chain management in construction. As the research developed, the literature was also used to identify details of delays associated with the supply chain (SC delays) with the eventual aim of using these to build the simulation model. All the various delays identified in the literature were listed and then evaluated based on their relevance to supply chains in construction. Only those delays that could be said to be associated with the supply chain were earmarked for use in the model.

Regular visits to construction projects

In order to gain a thorough understanding of supply chain management practice on construction sites, regular visits were made to two construction projects over a period of 6 months. Both projects were school building projects located in Tyne and Wear, UK and were carried out by different main contractors. School projects were chosen, since this type of project is normally medium-sized and not too complicated, allowing supply chain management practice and its major impact on the projects to be identified and more easily understood.

Through the regular visits, the learning process was achieved by immersion in the projects. Useful lessons were obtained during the visits through direct observations, interviews, examination of project documents, attending project meetings, etc. From the visits, particular types of problems and delays on site related to supply chain management practice were identified. For example, a window glass was damaged on arrival on site due to careless handling by a worker and it took several days to get a replacement. In another example, the installation of windows and doors was delayed because they were delivered later than the scheduled date. These were useful examples from the real life situation on site, and reinforced the understanding of how problems with the supply chain can impact on project performance. A specific CPM network from one of the projects visited was obtained and this became the basis of a generic CPM network for a school to be used in the simulation model.

The questionnaire survey

A questionnaire was developed using the inputs obtained from the literature review as well as from the regular visits to the two school projects. Its aim was to gather data to be incorporated into the simulation model. To give the respondents a context to help them respond, it was stated that the questionnaire referred to a typical school or similar project in the UK and a picture of a typical school was included. In general, the questionnaire asked the respondents to identify specific examples of delays in the construction supply chain that were likely to occur on such a site, e.g. which materials would typically be delivered late, which subcontracted works would typically start late, etc. They were then asked to indicate, in percentage terms, how often these delays would occur, to represent the probability of occurrence, and to indicate the extent of the impact if they did occur. The extent of the impact was represented by 3 values, i.e. minimum, most likely and maximum, to define a distribution that could be used in the simulation. The following is a typical example of the questions in the questionnaire, “Which materials would typically be delivered later than the scheduled date?”, “How often would this occur?”, “When these delays did occur, please estimate their duration (minimum, most likely and maximum).”

The process of developing the questionnaire, involved a number of steps. The first step was to list as many types of delays on construction projects as could be found from the literature. Examples of delays learned from the site visits were also added to the list. In order to make the list clearer and avoid confusion, it was necessary to remove some delays which overlapped and others that were duplicated. Not all the delays in this list were relevant to supply chain issues, and hence to simplify, the next step was to select only delays which were related to supply chain issues and remove those which were not.

The remaining delays could be seen from the perspective of time of occurrence, as they may occur either before the project starts or during the construction period. However, the simulation model only deals with delays that occur during the construction period. For delays that do occur during the construction period, they may happen before a particular activity starts, which eventually may prevent it from starting on time, or during the project activity, which may extend the activity duration. To narrow down the focus, the next step was to identify which delays may impact on the start date of activities and which ones may impact on activity duration.

As has been mentioned previously, the questionnaire was intended to gather data for simulation, hence, the probability of an event occurring and its extent if it does occur were required. With regard to this requirement, the delays must be able to be

operationalised, meaning that it must be possible to know the probability of an event occurring and also its extent if it does occur. However, not all the delays identified as related to supply chain issues on construction sites could be operationalised. For example, poor material planning is one of the causes of delays related to supply chain issues on a construction site, but it is difficult to operationalise, because it is very difficult to know the probability that poor material planning will occur or to know its impact when it does occur. Hence, this delay and the other delays which could not be operationalised were removed from the list.

The delays which could be operationalised were then classified based on the flows identified in the construction supply chains, i.e. workflow (subcontracted work), material flow, equipment/plant/temporary work flow, labour flow, and information flow (see table 1 column 1). Questions were then developed for each flow category (see table 1 column 2).

To test whether questions in the questionnaire were clear and could be answered by respondents, the questionnaire was tested on 2 site managers from different companies. They had been in the construction industry for 15 and 38 years respectively and both had experience in building school projects, thus, they were considered eminently eligible to test the pilot questionnaire. In general, they commented that the questions were reasonably clear and could be answered, although (as expected) not very easily. Some very minor changes in terms of wordings were proposed. All in all, the questionnaire was considered workable

The questionnaire was then distributed by mail to a selection of 105 UK construction companies who were found to be involved in building projects and a response rate of 22% was obtained. The respondents were site managers (12), project managers (7), quantity surveyors (3) and building managers (1).

Table 1 column 3 below shows the examples of SC delays for each category obtained from the questionnaire survey, e.g. *mechanical and electrical work*, *steelwork, brickwork, roofwork and groundwork* were examples of the typical works that would be subcontracted, while *bricks*, *windows and doors*, *steel frames* and *roofing materials* were among the typical materials that would be delivered late. Each came with a probability of occurrence indicated in percentage terms and the extent of delay when it does occur indicated by 3 values, minimum, most likely and maximum.

To deal with various feedback from the respondents regarding materials, activities, subcontracted works, etc, it was necessary to group those which were close or similar. For example, respondents wrote down the following terms, “steel frame”, “steel work”, “structural steelwork”, “steel erection”, which actually refer to the same work. In another case, a respondent wrote down “groundwork and substructure”, another respondent wrote down “substructure and drainage”, others simply wrote “groundwork”, “drainage” or “foundation”. To simplify and make this data workable, the terms which actually refer to the same or similar activity were then grouped into one variable and given an appropriate label. In the first example mentioned above, a label of “structural steelwork” was used. The terms which overlap, as shown in the second example, were broken down and placed into the correct variables. In this case, three variables of “groundwork”, “drainage” and “foundation” were used. This means that “groundwork and substructure” can be broken down into “groundwork” and “foundation”, while “substructure and drainage” can be broken down into “foundation” and “drainage”. The mean of the frequencies and the extent of delays (min, most likely and max) of each variable was then used for the simulation.

Table 1: Data obtained from the questionnaire survey

Construction supply chain flows	**Detail Questions**	**Examples of responses**	**Impact on the activity if delays occur**	
			Start date	**Duration**
(1)	**(2)**	**(3)**	**(4)**	**(5)**
Workflow (subcontracted works)	Typical works to be subcontracted	Mechanical electrical, steelwork, brickwork, roofwork, groundwork	Y	-
Material flow	Typical material to be delivered late + time buffer	Bricks, windows & doors, steel frames, roofing materials	Y	-
	Typical material delivered with the wrong specifications	Bricks, windows & doors	Y	-
	Typical material delivered with insufficient quantity	Bricks, concrete, timber	-	Y
	Typical material delivered damage on arrival	Windows, doors, shower cubicles, ceiling	Y	-
	Typical material difficult to obtain in the market	Special bricks, fixtures & fittings	Y	-
Equipment/ plant/ temporary work flow	Typical Equipment/plant /temporary work in shortage	Scaffoldings, cranes	-	Y
Labour flow	Typical skills in shortage during construction period	Bricklayers, joiners, plasterer, plumbers, steel work erectors, concrete gang	-	Y
Information flow	Activity affected by delays of information flows.	Foundations, finishes & decoration, steelwork, groundwork	Y	-

Simulation

As mentioned earlier, the research was intended to predict how supply chain management practice may impact on construction project performance. This can be achieved by developing a simulation model that incorporates SC delays and running the model with different scenarios. Pertmaster Risks Expert 7.81 was used to produce the simulation model and the CPM network used was obtained from one of the school projects visited. Originally the project plan was in the form of a bar chart without links connecting the activities in the project, so to be able to examine the logic of the activities in the project, links were added. Some modifications were then made to make the CPM more general and less complicated. The next section discusses the development of the simulation model in more detail.

DEVELOPMENT OF THE SIMULATION MODEL

To build the simulation model, the data obtained from the questionnaire survey was synchronised with activities in the CPM network. In other words, the activities in the CPM network were identified as being linked with possible SC delays. For example, in table 1 column 3, *bricks* were identified as typical materials which would be delivered late, delivered with insufficient quantity, delivered with wrong specifications or difficult to obtain in the market. In addition, *bricklayers* were identified as typical skills that would be in shortage during the construction period. The activity *brickwork,* one of the activities in the CPM network using these materials and skills, could clearly be affected as a consequence and so these delays were linked with this activity. All of the identified delays were linked to relevant activities in the

same way. The following section explains the assumptions used in the simulation model.

Assumptions in the model

To reduce the complexity of the simulation model, the following assumptions were made:

1. The duration of activities in the CPM is deterministic, meaning that each activity has only a single duration. The implication of this deterministic duration is that for each activity, it is assumed that a late start will cause a late finish. It is, of course, recognised that the durations of activities are subject to variation, but this assumption is very important as it allows the model to show the impact of SC delays on the project performance which otherwise cannot clearly be identified.
2. The frequency of occurrence of the delays is as defined by the respondents and the extent of the delays follows a distribution defined by the three values of minimum, most likely and maximum, also as reported in the questionnaire results.

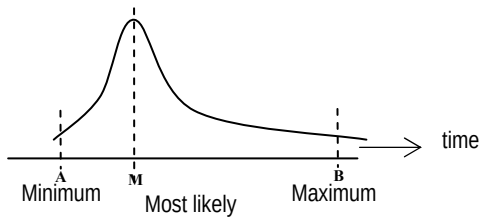

Figure 1: A distribution with minimum, most likely and maximum values for the extent of delays

3. Resequencing of activities is not allowed. In practice, when delays occur causing an activity to be unable to start on time or to stop for a period, the site manager might decide to start other activities instead. To be able to clearly show the impact of SC delays on the project performance, the current version of the model has no opportunity for such rescheduling.
4. For all subcontracted work, it is assumed that there is only one delay, called the subcontractor delay. This delay, assumed to be the responsibility of the subcontractor, basically encompasses other delays, i.e. delays related to material flows and equipment/plant/temporary work and labour flows.
5. The materials for an activity are needed on the first day the work commences. For example, it is assumed that the bricks are needed from the very first day of the brickwork activity. Hence, any delay with the bricks' delivery obviously will delay the start date of the brickwork.

Introducing SC delays to activities in the model

In general, delays can occur prior to the start of an activity or during the activity. When the delays occur prior to the start of an activity, the start date of this activity may be delayed as a consequence. Similarly, when the delays occur during the activity, the duration may be extended so that the finish date may also be delayed. Figure 2 below shows how both types of delays can be modelled.

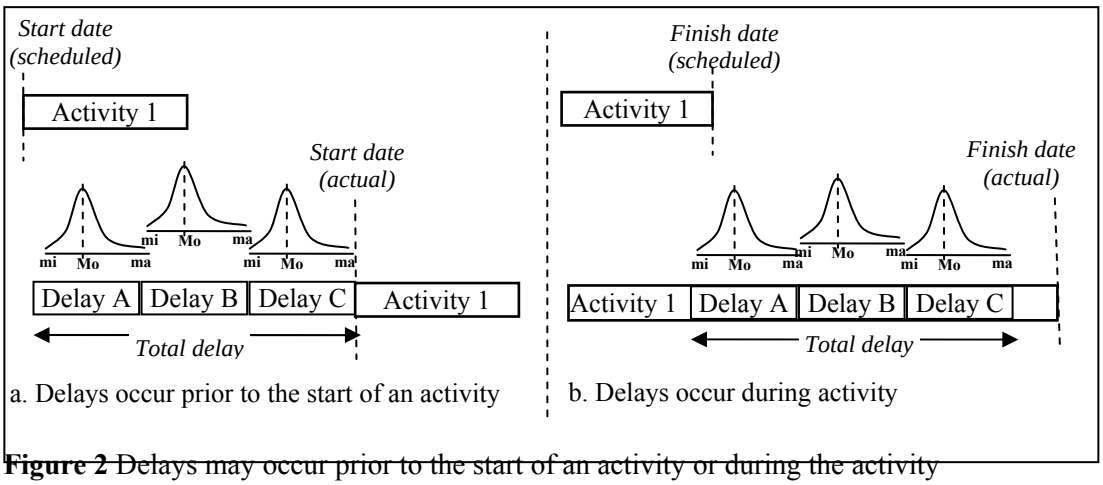

Figure 2 Delays may occur prior to the start of an activity or during the activity

The software used in the simulation allows the delays to be placed prior to the start date of an activity, as shown in figure 2a, but it does not allow the delays to be inserted into the duration of an activity, to represent the delays occurring during the activity, as shown in figure 2b. To cope with this problem in the model such delays were positioned following the scheduled finish date of the affected activity.

In practice, it is possible that a delay may occur prior to the start of an activity and then occur again during the activity. For example, deliveries of materials can be one-off deliveries prior to the start of an activity or multiple deliveries prior to and during an activity, depending on the type of materials or agreement with the suppliers. Similarly, skills shortages can also occur prior to or during an activity, etc. For the simulation, it is necessary to simplify by making assumptions of how the delays may impact on the activities, i.e. delay the activities' start date or extend the activities' duration. These assumptions for each SC delay are shown in table 1 columns 4 and 5.

From this table, it can be seen that SC delays which were assumed to impact on the start date of activities include: subcontracted works, delivery of materials later than scheduled delivery date, material delivered with the wrong specifications, material delivered damaged on arrival, material difficult to obtain in the market, and delays of information flows from client/architect. These delays were then positioned immediately before the related activities. The other SC delays: material delivered with insufficient quantity, equipment/ plant /temporary work in shortage, and skills in shortage during construction period, were assumed to impact on the activities' duration, hence, they were positioned immediately following the activities' scheduled finish dates.

Combining Delays

On a construction project, several delays can occur and impact on an activity consecutively or simultaneously as the following examples illustrate. A package of material was delivered later than the scheduled date (delay A). When it arrived, it was damaged due to careless handling on site (delay B). Since it took several days to get the replacement material, the work using the material could not start on time. Another example to illustrate delays occurring simultaneously is as follows: The bricks were expected to be delivered on site at a particular time, which did not happen (delay A), while at the same time the bricklayers were not available on site to do the work (delay B). The brickwork could not start on time as a consequence.

To illustrate these two examples in the model, the delays can be positioned either in series for delays occurring consecutively, or in parallel to represent delays occurring simultaneously, as illustrated in figures 3a and 3b. The implication is that for the delays positioned in series, the total delay is simply the sum of each delay, while for the delays positioned in parallel, the total delay is the longest of each separate delay. If the delays are positioned both in series and parallel (figure 3c), the longest delay between them will determine the total delay.

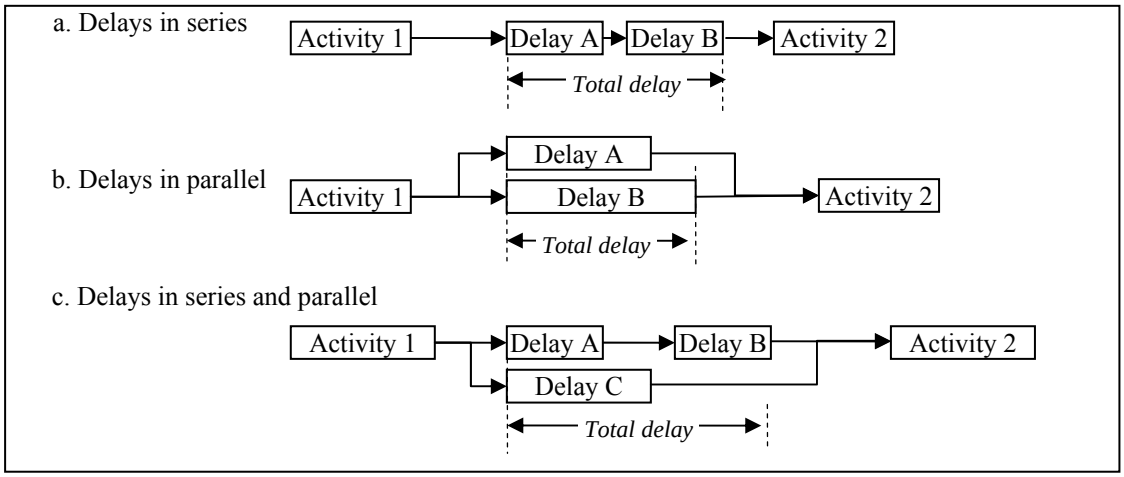

Figure 3: Possible positions of delays in the model

Time buffer

In practice, to reduce the risk of having work start late due to late delivery of materials or for other reasons, suppliers are sometimes asked to deliver the materials several days in advance of the start date of the activity which needs the materials. In other words, a time buffer is provided to absorb the risk. If this delay (late delivery of materials) does actually occur and its extent is less than or the same as the provided time buffer, the work that needs the materials can still start on time. However, if the extent of the delay is more than the provided time buffer, the time buffer cannot absorb it all, and hence the work will start late. Figure 4 shows how this is modelled in the simulation.

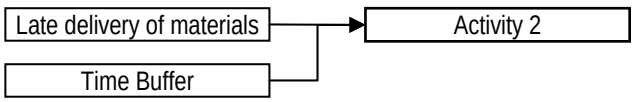

Figure 4: Modelling time buffer position toward material delivery

Scenarios that can be tested

There are various scenarios than can be tested using the model as shown in table 2 below. Basically, these scenarios are simulated by inserting the relevant SC delays into the model to understand their impact on the project performance.

Once the results of the simulations from the various scenarios have been obtained, they can be considered either individually or compared one result with another to appreciate the variability of project performance due to various SC delays. The simulation results should also allow an understanding of which of the SC delays have the greatest impact on the project performance.

Table 2: Various scenarios to be tested

	Scenarios	SC delays to be simulated on the CPM network	What can be learnt
1	All the works are carried out by the main contractor	Since there is no subcontracted work at all, all the SC delays, except *the subcontractor delays,* are inserted into the simulation model for all activities.	The impact of SC delays on the project, if all the works are carried out by the main contractor.
2	The works are carried out by the main contractor and the subcontractors	All the SC delays including subcontractor delays are inserted into the simulation model	The impact of SC delays, if the works are carried out by the main contractor and some are subcontracted.
3	Delays related to Material flow	Only delays related to *material flow* are inserted into the simulation model.	The impact of SC delays related to material flows on the project performance
4	Delays related to Plant / equipment / temporary works flow	Only delays related *to plant / equipment / temporary works flow* are inserted into the simulation model	The impact of SC delays related to plants / equipment / temporary works flows on the project performance
5	Delays related to labour flow	Only delays related to *labour flow* are inserted into the simulation model.	The impact of SC delays related to labour flow on the project performance
6	Delays related to information flow	Only delays related to *information flow* are inserted into the simulation model.	The impact of delays related to information flow on the project performance
7	Time Buffer	Varying time buffers for *material delivery* are inserted into the simulation model.	The impact of providing different time buffers on material delivery on the project performance

Example of the simulation model

The following are two snapshots of the simulation model showing a few of the activities in the model (not a complete view). The first snapshot (figure 5) shows the model when scenario number 1 is applied. The simulation model following scenario number 2 is shown in figure 6. For the purpose of visual clarity, these two snapshots were produced using MS Project™ software.

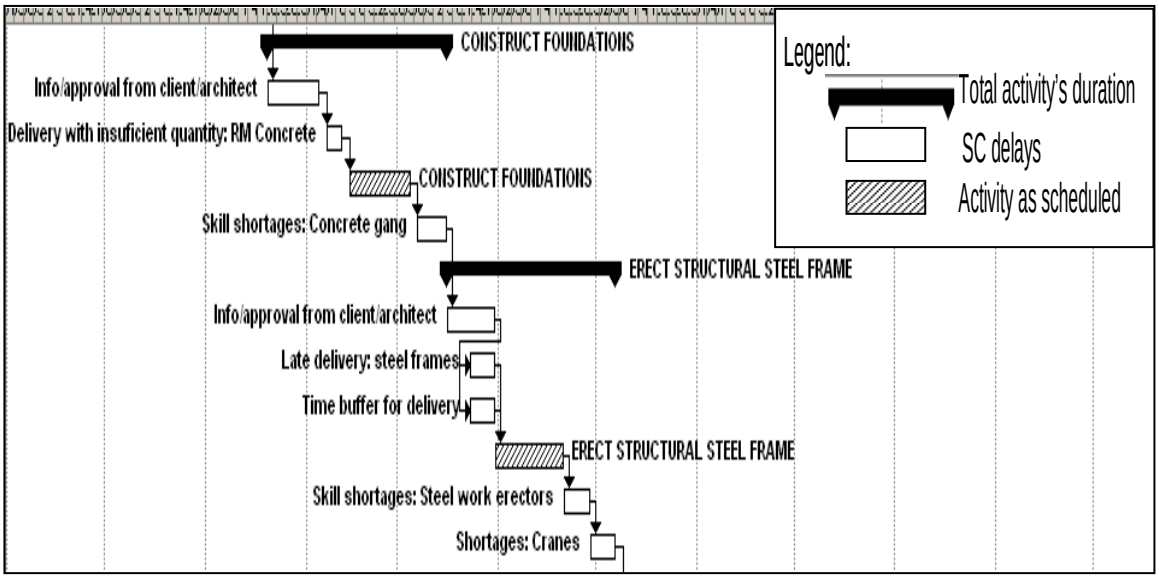

Figure 5: Scenario 1, all the works are carried out by the main contractor

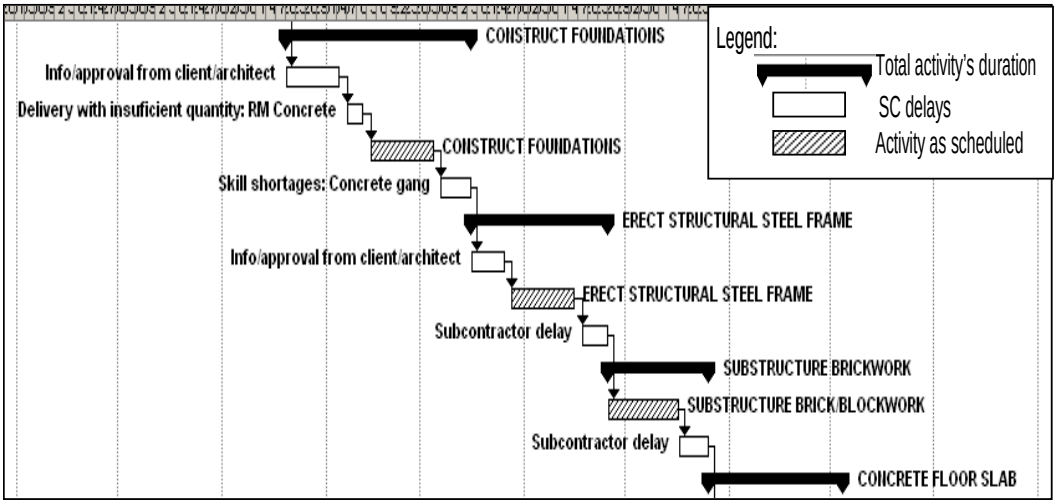

Figure 6: Scenario 2, the works are carried out by the main contractor and some are subcontracted to subcontractors

CONCLUSIONS

This research is arguably the first attempt to simulate the impact of supply chain management practice on construction sites on project performance. The process of developing the simulation model has been explained including various possible scenarios. Through these scenarios, some alternative SCM practices can be simulated and their impacts understood. The future work following completion of the models' development will be to find out how these various scenarios may impact on project performance. For example, by running different versions of the model (e.g. with/without subcontractors, or with different time buffers for delivery of materials) it will be possible to gain an understanding of the impact of these management actions on project completion time.

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