COORDINATION AND VISUALIZATION OF DISTRIBUTED SCHEDULES IN THE CONSTRUCTION SUPPLY CHAIN: A POTENTIAL SOLUTION

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ABSTRACT: *The current construction supply chain is characterized by multiple subcontractors that perform most work on a construction project, provide their own resources, and coordinate between themselves under the general guidance of a main contractor. In such an environment, schedules are distributed and heterogeneous and as a result their coordination is a challenging task. Although schedules coordination is a crucial aspect, it has not attracted much attention from researchers and commercial software providers. This paper outlines the planned development of a tool for the coordination of schedules in the construction supply chain. While enabling coordination, the tool aims to put minimum constraints on planners, to accommodate planning information coming from different commercial planning tools, and to provide decision making capabilities. In addition, the tool is envisaged to be integrated within a 5D planning environment where schedules can be visualized and rehearsed.*

KEYWORDS: *Supply chain management, Construction supply chain, Supply system, Schedules coordination, 4D/5D planning.*

1. INTRODUCTION

Supply chain management is a relatively new concept within the construction industry. This concept imported from the manufacturing sector has been indicated as one of the ten key best practices that should deliver real added value to the construction industry and shape its direction in the near future (SECBE, 2006). A construction supply chain should be well thought-out networks of interrelated processes to satisfy end customer needs (Tommelein et al., 2003). Unlike the manufacturing sector, where high levels of integration are achievable, the construction industry is highly fragmented and characterized by poor communication, win-lose relationships and lack of commitment between trading partners and therefore, integration is far more challenging than in the manufacturing sector. In addition, due to the vast range of products and services involved within the construction industry, it would be impossible for any organization to manage all of its suppliers. For these reasons, leading organizations are currently organizing elements of the supply chain which are the most critical to their operation. One of these is the coordination and synchronization of multiple sub contractors and installers on site and the integration of key component suppliers. Existing research and available commercial tools either did not pay much attention to this aspect or tackled it within significant limitations and assumptions. Along with the problem of the coordination of multiple subcontractors on site, the construction supply chain requires an effective management of supply systems in order to achieve on-time completion of projects' milestones. Supply system management consists in the definition, design and implementation of temporary production systems that incorporate temporary flow of physical resources (e.g. labor, material, equipment) and information (Arbulu et al., 2003). The construction supply chain usually contains more than one supply system.

This research is concerned with both aspects: the synchronization of multiple subcontractors at the construction site and the management of the supply systems. This paper addresses the first aspect and outlines the current development of a module that allows the synchronization and coordination of the schedules of multiple subcontractors and the main contractor on the construction site. A further module, which aims at organizing the supply systems of the construction supply chain, will be developed and integrated with the current module. This research is currently being undertaken in collaboration between the Centre of Construction Innovation and Research (CCIR) and Deepdale Solutions Ltd in accordance with the research roadmap presented at CONVR 2008 (Table 1).

Table 1: Medium term multidimensional research roadmap at CCIR (Benghi and Dawood, 2008)

Stage	Function of current tools	Active research topics	Further development
Design			- Semi automated cost and plan generation
Planning	- Schedule rehearsal	- Cost Integration - Scenario evaluation - Integrated plan development	
Construction	- Schedule communication	- Programme control and adjustment	- Sub-contractors schedule synchronization
Operations			- H&S control and training

2. UNDERSTANDING THE CONSTRUCTION SUPPLY CHAIN COMPLEXITY

The construction supply chain is currently characterized by a high degree of fragmentation and specialization, which shape both the work on the construction site and the upstream supply systems of each participant on site. To exacerbate this situation, the attitude and mindsets of participants make it difficult to build a win-win situation and to accept new tools and processes. Table 2 presents a number of factors influencing each of the three problems in the construction supply chain (i.e. coordination of multiple participants, management of supply systems, attitude and mindsets) and the research areas tackling each problem.

Table 2: Factors affecting the construction supply chain

	Factors	Research areas/Initiatives
Coordination of multiple participants	- Fragmentation and specialization - High number of participants - Lack of formal processes for coordination - Lack of IT tools and integration solution (interoperability difficulties) - Change factors (schedule and scope changes, weather, party wall, etc.) - Dependent on multiple supply systems - Communication	- 4D and 5D planning and visualization tools - Web based tools (e.g. constraint checking, information sharing) - Schedule mappings - Negotiation-based planning and control systems - Database synchronization technology
Management of supply systems	- Low reliability of suppliers (poor OTIF performance) - Demand variability, non-matching demand-supply - Lead times of engineered to order products and design changes - Communication	- Web-based tool (e.g. based on last planners for information sharing) - Service-oriented approach - Construction project extranets (CPE) - ERPs
Attitude and mindsets	- Win-lose relationships - Resistance to change in adopting new tools and processes - Temporary nature of construction	- Partnering initiatives - Early involvement - Management of change

2.1 An example

Nowadays, major construction contractors have become aware of the cost savings and benefits that can result from better supply chain practices. One of the policies they are implementing is to reduce the number of companies in their supply chain and only use those capable of integrating with their scheduling systems and managing the lower

part of the supply chains efficiently. This is along with other requirements that sub-contractors should adopt such as the capability of increasing their off-site production.

Deepdale Solutions Ltd (DSL), a sub-contractor involved in the building envelope industry as a designer, manufacturer and installer, is taking part to and funding this research. It aims to take advantage of these developments by enhancing its coordination and supply chain management activities. The delivery and fitting of DSL's products are on the critical path for weather-proofing of buildings. Therefore, the need to develop better site coordination and supply chain management capabilities is crucial for companies involved in the façade industry like DSL. A typical arrangement of the construction supply chain is shown in figure 1, which shows the dependency between multiple participants working on site and their distributed schedules. It also clarifies how the supply chain can be formed by a number of supply systems (three supply systems are shown in figure 1). The following tiers can be identified:

- Tier 1: Composed of subcontractors that are directly appointed by the general contractor to deliver works on site;
- Tier 2: Formed of manufacturers/suppliers that supply the main elements making up a building (e.g. building envelope elements, precast concrete elements);
- Tier 3: Formed of manufacturers/suppliers of components and materials (e.g. aluminium profiles, cement) used in the manufacturing of the main element. Third-tier occupiers can, in turn, have their own suppliers (tier 4: e.g. metal forming companies that carry out operations such as aluminium casting and extrusion for third-tier aluminium profile suppliers).

In most cases, in accordance with the supply chain trends mentioned above, a single company/trade occupies the first and second tier simultaneously (e.g. DSL as a manufacturer - second tier and as an installer - first tier).
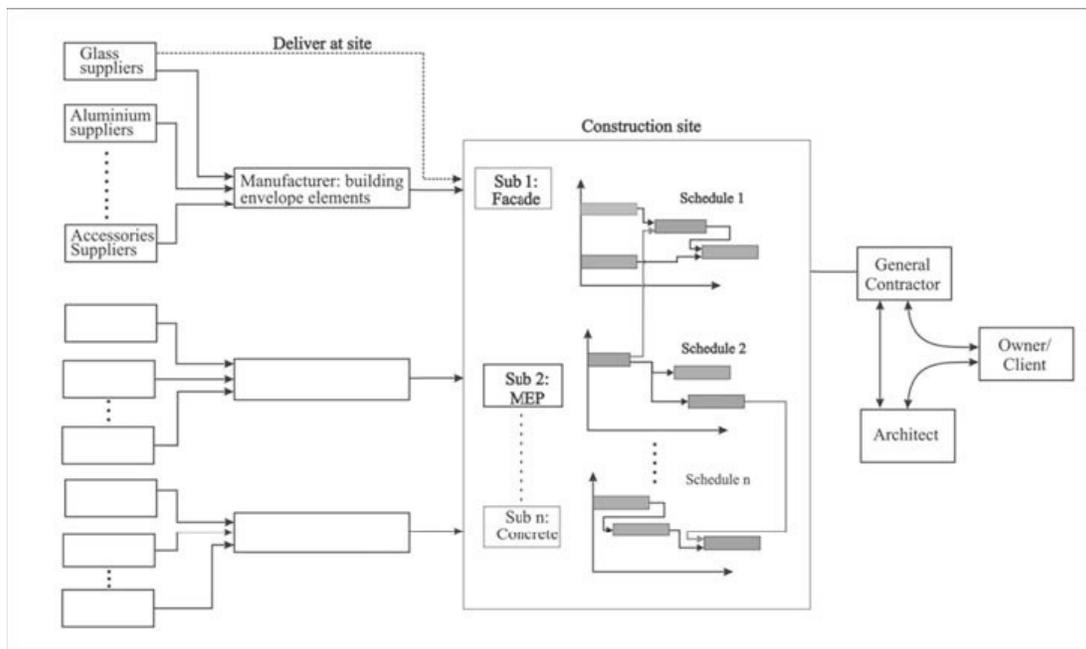

Fig. 1: Typical arrangement of a construction supply chain

To explain the difficulties of the construction industry in meeting site target dates, the following two facts are highlighted:

- In a typical project, the third-tier suppliers can be numerous. On one project, DSL has more than 20 suppliers, who can deliver either to the manufacturer premises (tier 2) or directly to the site (tier 1) (figure 1). DSL's processes on site cannot start until all materials from suppliers are available. If there are 15 suppliers with a probability of 90% of on-time delivery (high performance), then DSL's probability of meeting the site target date is: $0.90^{15} = 20\%$. Therefore, even with a reliable supply system, DSL only has a 20% chance of meeting its target date. A fishbone diagram of the main causes that can make DSL miss its site target dates is illustrated in figure 2.

- Likewise DSL, all other subcontractors have their own supply systems and similar causes of delays as the ones depicted in figure 2. As there is a dependency and interaction between first tier (figure 1) occupants, the supply system of each participant disturbs the supply system of other participant. This results in a combination of causes of delay that decrease substantially the chance of on-time delivery of a construction project.

If what have been said so far is true, readers may wonder how many construction projects are being delivered on time. This is obviously solved by building up a large buffer of finished products along the supply systems and on site. The consequences for actors like DSL are poor cash flow (they are paid for what has been successfully installed), higher storage costs, reduced quality and safety due to damage of stored materials, and stored material being at risk of design revisions and programme changes.

The above example gave a clear explanation as to why this project is tackling both the coordination of multiple participants on site and the management of the supply system. Both areas can be seen in figure 3. This paper is concerned only with coordination of multiple participants and a review of previous relevant work is presented in the next section.
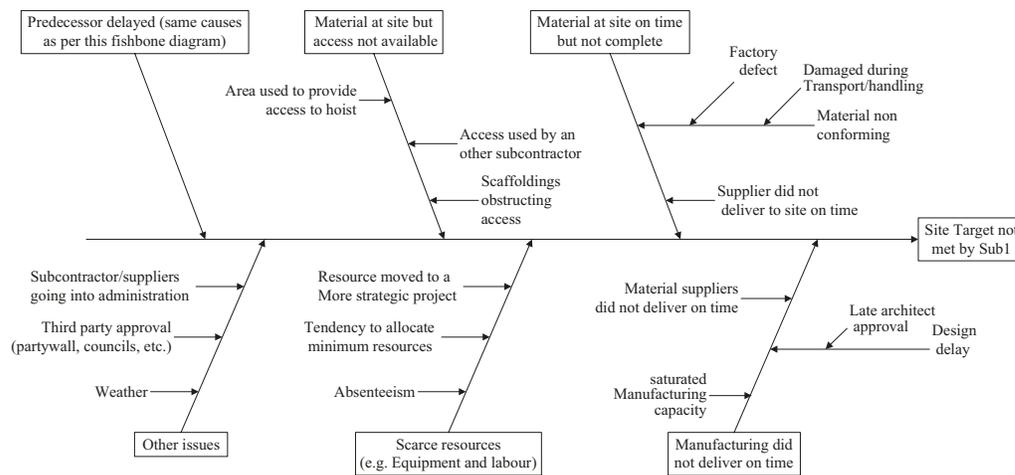

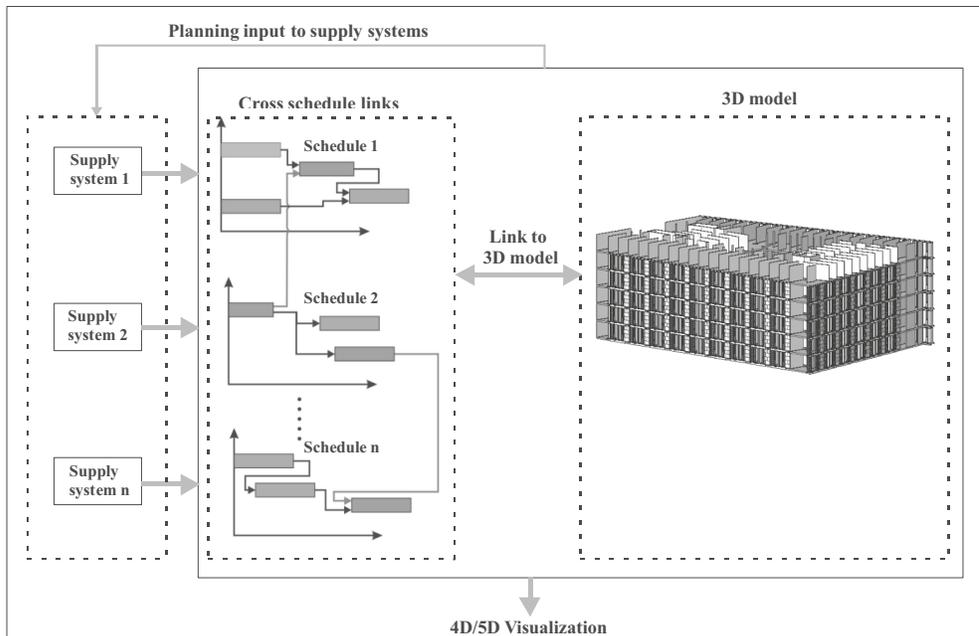Fig. 2: Typical arrangement of a construction supply chain

Fig. 3: Visual tool for the construction supply chain management

2.2   Related literature

The current construction industry entails more than ever quick, large, complex and uncertain projects with a high degree of specialization. As a result, subcontracting has become a way of life today. Subcontractors perform most of the work on a project and provide their own resources and often, subcontractors working on the same project have different project management objectives with different Work Breakdown Structures (WBS) and level of details. Scheduling capabilities vary among subcontractors as well as the planning applications used.

Two leading UK main contractors interviewed by the authors stated that they currently give sub-contractors site target dates or interface schedules (spreadsheets) and overview the process through weekly progress meetings on site. These site target dates are derived from three month look-ahead schedules that contain the main elements of subcontractors' WBSs. Subcontractors with formal scheduling capabilities have detailed schedules for these elements of the WBSs, and they may use spreadsheets or any of the commercial planning applications (e.g. Primavera, MS Project, Asta Powerproject) to produce such plans. Some subcontractors load the resources within their schedules, while others manage the resource separately (e.g. using spreadsheets with the number of operatives required daily) and they use the schedules just to express the logical sequence and the start and finish dates of tasks. Within such an environment, schedules are distributed and heterogeneous and their coordination is an extremely challenging task. Consequently, conflicts are very difficult to detect and resolve. They could be the result of either temporal conflicts or overallocated shared resources such as labor, equipments and working space with limited access capability.

Although the coordination of distributed schedules in the construction supply chain is a crucial aspect, it has not attracted much attention from researchers and commercial tools providers:

Kim et al. (2001) presented an Agent-Based Compensatory Negotiation (ABCN) methodology and developed a Distributed Subcontractor Agent System (DSAS), where agents (subcontractors) negotiate among themselves to reach a workable solution. The main objective of the negotiation is to minimize a utility function, which is the sum of subcontractors' costs associated with their resource constraints when a change occurs. However, this method has important limitations, as resources are not the only constraints in a project and it requires a high level of sophistication on the part of the participants involved, where computer programs (agents) represent the interests of each subcontractor. In addition, as subcontractors are reluctant to show information about their resources costs even in 'live negotiation', they are unlikely to do so with the DSAS.

Choo (2003) developed a synchronized database for multi-project schedule coordination. The rationale behind the method is to combine information about participants in one place on the WEB (data repository and sharing) where a checklist of constraints (contract, drawings, labor, equipment and pre-requisite site conditions) is entered by different participants on the project. Using this information, the project coordinator can release a work package only if all constraints are satisfied. However, this system has no link with the master schedule or the schedules of multiple participants and it is developed without any regard for scheduling software tools.

Siddiqui (2008) presented a method for the coordination of distributed schedules. This method aims to identify temporal conflicts using schedules mapping, where a group of tasks from one schedule can be linked to a group of tasks from another schedule. Although this method recognizes the 'distributed' nature of schedules, it only detects the temporal conflicts and requires a complex analysis of the schedules to obtain the mapping. The current incarnation of the tools to support this methodology deal with MS project schedules only; and more importantly, the schedule mapping approach introduces new constructs and terminology which are not familiar to planners and project managers.

Sriprasert and Dawood (2003) developed a system for multi-constraint information management and visualization, which is used in collaborative planning and control in construction. Information such as drawings, specifications, method statements, resources information are integrated into a central database named as Lean Enterprise Web-based Information System (LEWIS). The system also generates 4D constraints-based models by linking CAD objects (PBS) with schedules (WBS) using Uniclass standards and by associating other types of constraints within the LEWIS. Although this solution filled many existing gaps and represented an advancement of existing solutions, it requires that all subcontractor schedules exist at a predetermined level of detail and are closely tied to the general contractor schedule. So, it considers one schedule only rather than a number of distributed schedules. Finally, it constrains planners and designers to use Uniclass standard codes which are not of easy interpretation.

From this review, it can be concluded that existing methods have addressed the problem of the coordination of distributed schedules within the following significant limitations:

- Based on assumptions (e.g. willingness to cooperate between participants, availability of detailed information) that are unlikely to be satisfied in the construction environment;

- Developed for one specific software tool (e.g. MS project), while in the construction industry, numerous planning applications are used;

- Constrain planners of different participants to use some standard codes (e.g. Uniclass) for their tasks or to use new constructs and terminology which are not familiar with.

This paper presents the outlined developments of a potential solution for the coordination of multiple schedules in the construction supply chain. The authors believe that any solution must be able to integrate data from different planning applications and should place few if any constraints on planners or the project coordinator. In addition, potential solutions should have the capability to provide 4D/5D visualization of the construction process and generate useful inputs for the management of the supply systems making part of the supply chain.

3. MULTIPLE SCHEDULES COORDINATION: OUTLINE OF THE DEVELOPMENTS

The tool under development aims at helping multiple participants to plan and coordinate their supply chain activities. As stated earlier, this involves schedules coordination, site visualization and the management of the supply chain (supply systems). The outlined developments in this paper are mainly concerned with schedules coordination with some insights into the site visualization. After analyzing the existing research and reviewing real world practices, the authors suggest that in order to achieve these objectives, the tool should:

- Have the ability to accommodate the schedules of multiple subcontractors, which are created with different scheduling software tools (e.g. MS project, Primavera, Asta Power Project) and the schedules of the entire supply chain of a single company;

- Link or create cross-schedule relationships;

- Provide either the ability to create tasks or edit task attributes (SD, FD, relationships) within its environment (i.e. used as standalone software) or be synchronised on input and export with the most common scheduling software tools;

- Analyse the effects of delays of one schedule on other schedules and provide some decision making capabilities;

- Be capable of linking schedules' tasks to 3D models and provide 4D/5D visualisation.

The two leading commercial applications (i.e. Navisworks and Synchro) and the ndCCIR, which is a 5D planning application developed by the Centre for Construction and Innovation Research (CCIR), were reviewed as to these requirements. Such a review is summarised in Table 2.

It is important to highlight that this comparison did not consider the server-based version of these commercial tools, which allow all parties to share data within a central integrated database. This is because these applications are still limited to a very small number of major projects and are still unable to reconcile and contain the multiple views and needs of all participants (Amor and Farag, 2001; Turk, 2001; Zamanian et al, 1999). O'Brien et al. (2008) have further argued that whatever the advances of industry standards, semantic heterogeneity is likely to remain a significant barrier to integration (O'Brien et al., 2008). From the comparison in Table 2, it can be concluded that the ndCCIR, with the outlined developments (boxes shaded with grey), would represent a solution for the supply chain schedules coordination and visualization. These developments are being written in C# taking advantage of a Rapid Application Development (RAD) such as Microsoft Visual Studio 2008.

Table 2: Review of software tools with regards to the requirements of supply chain management

	Navisworks Manage (2010)	Synchro professional (2010)	ndCCIR
MS project	Import and export in XML	Import and export in XML	Import and export in XML
Primavera	Import with synchronisation, export	Import with synchronisation, export with synchronisation	Import with synchronisation, export
Asta Powerproject	Import with synchronisation, export	Import with synchronisation, export with synchronisation	-

Change task attributes (SD, FD and relationships)	Not required as schedule are synchronised with their native software	Not required as schedules are synchronised with their native software	Yes
Import multiple separate schedules	Yes	-	Yes
Create Cross schedule links	No – (can be linked without real dependencies, used just for the sequence of visualisation)	No	Yes
Conflict management of cross linked schedules	Only visual	Only visual	Initial detection of conflicts (temporal conflicts) based on a logic and then visually
Schedule crashing	No	No	Yes
Cost visualisation	No	No	Yes

3.1   Cross-schedule links

The ndCCIR tool currently can import the multiple schedules of different participants. However, it does not provide a way of creating cross-schedule links. With the outlined development of a module called 'ndCCIRLink', the software would become capable of creating these cross-schedule links. This will be enabled in two ways:

3.1.1   Graphically

The tool allows the linking of one or more tasks from one schedule to one or more tasks from another schedule. To graphically link one task from one schedule to one task (one to one) or more tasks (one to many) from another schedule , it is necessary to select a task bar in the first schedule and then, while keeping the shift button pressed, select one or more task bars from the other schedule. When the shift button is released, a window will pop up with the name of the tasks selected from both schedules (figure 4). Figure 5 shows the windows for the many to one relationship. Cross schedule links can be created for two schedules at a time. Using the windows in figure 4 and 5, it is possible to edit the selected tasks, if there were some mistakes in the graphical selection and to define other attributes such as the precedence relationship and lag time. Temporal conflicts among schedules are detected and checked at this stage, based on the real work logic (logical relationship) dictated by the planner. For example, if, based on the logical dependency (e.g. 'install window and doors' is a predecessor to 'plaster'), the planner is linking task 1 (i.e. install window and doors) to task 2 (i.e. plaster) in a 'finish to start relationship' and the start date of task 2 (plaster) is before the finish date of task 1 (install doors and windows), a pop up window will warn the planner about this conflict. Then, the planner can undertake the corresponding actions (e.g. delay the start date of task 2) and resolve eventual other conflicts arising within the schedule affected by the change.
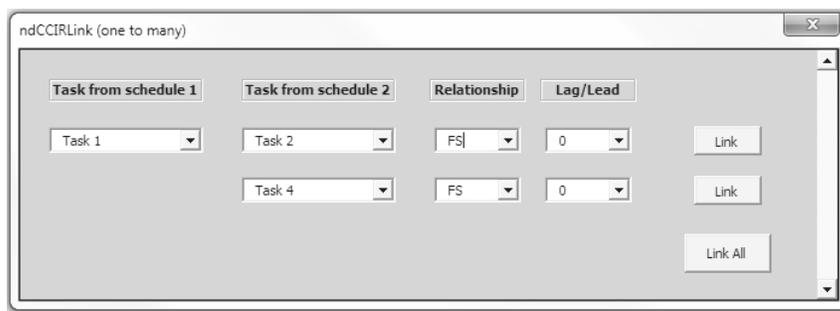

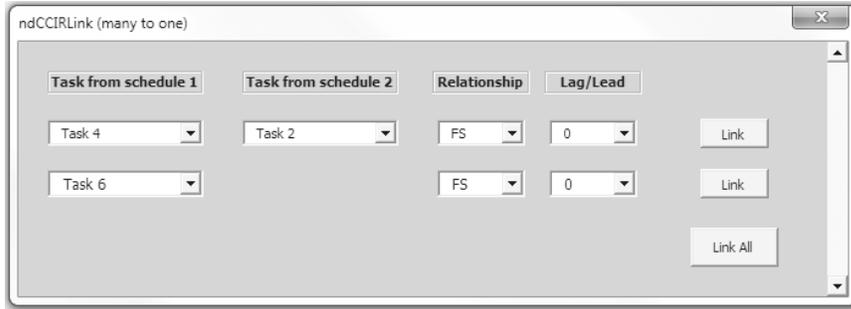Fig. 4: One to one and one to many cross schedule linking window

Fig. 5: Many to one cross-schedule linking window

Once the tasks are selected and the relationships are defined, by clicking "link", the schedules are updated by taking into account these new relationships. This can be done either every time a cross-schedule link is established (clicking "link" line by line) or after all cross-schedule links are established (clicking "link all"). It is recommended to carry out the cross-linking line by line, as it is easier to sort out eventual schedule conflicts once at a time.

3.1.2   Through a user interface

The graphical way of linking may become cumbersome and time-consuming if schedules have a large number of tasks. For this reason, a user-friendly interface can be used to create cross schedule links (figure 6). By using this user interface, tasks can be linked from two schedules at a time. Firstly, the two schedules have to be selected. Once the type of link is selected (e.g. one to many), the user interface displays a suitable number of lines for such a relationship. To speed up the selection of tasks, the field "task tag" should be selected first: this allows the displaying of only the relevant tasks under task field name. The list of attributes for the field 'task tag' is reported in table 3. These tags will not only speed up the process of linking but will also help identifying the tasks that conflict with others on shared key resources. The linking can be made line by line at a time or for all lines together by clicking 'link all'. Temporal conflicts are also detected at this stage as explained earlier.
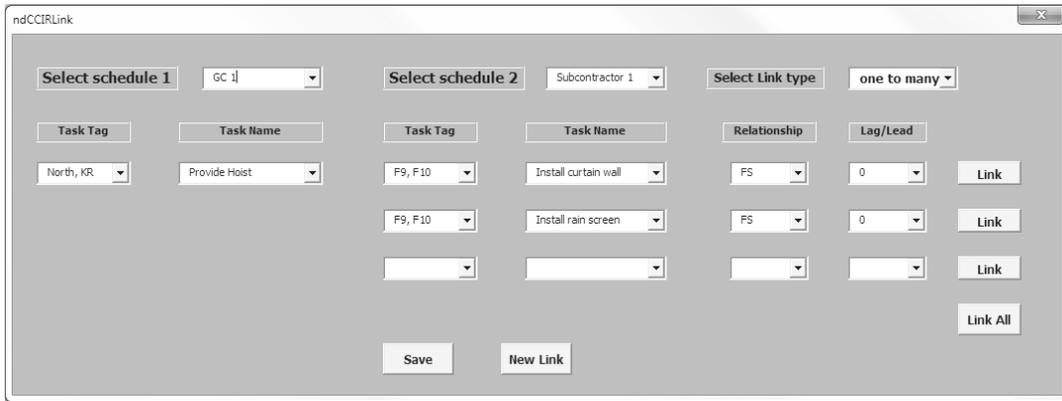

Fig. 6:   One to many cross schedule linking window

Table 3:   Attributes of tasks' tags

Field	Attribute	Explanation	Attribute	Explanation
Task	KR	Key resources	D	Design
Tag	F	Foundation	P	Procure
	GF	Ground floor	M	Manufacture
	F1, F2, .., Fn	Floor 1, Floor 2, .., Floor n	I	Install
	Pe	Penthouse	North, East, South, West	Reference to the elevation or scope of work

3.1.3 Analysis

An analysis interface (figure 7) allows a range of analysis that includes the following:

- *Data summary:* gives a summary of all cross-linked activities, the name of the schedules they belong to and the type of precedence relationships they are involved in;

- *Dates after linking*: once the cross-schedule linking has been established, the ndCCIRlink allows the comparison of start and finish dates for each subcontractor schedule before and after the linking (figure 8). By clicking on 'show details', the activities that have had some changes after the linking are listed for each sub-contractor and activities attributes (SD, FD and duration) are compared before and after the linking. The important tasks (e.g. tasks with deadlines) that are delayed after their key dates are also highlighted and reported separately in the report generated;

- *Updates*: once the cross-schedule linking has been established, new changes to task attributes (e.g. start date delayed) automatically affect other schedules' tasks. The cells of the tasks that are impacted by these updates get highlighted in light green. A summary of the impacts of the updates on different subcontractors is useful to generate as they might be used for the negotiation between subcontractors and the general contractor. This summary report can be obtained by clicking on 'update' (figure 7). Important tasks (i.e. task with deadlines, must finish on, milestones) are also highlighted as explained earlier;

- *Schedules crashing:* the tool displays all critical activities in a table where the planner can enter the allowable crash days for each activity. Then, the tool automatically calculates the crash cost for each activity and the new project duration resulting after the crashing of each activity on the critical path. The crashing process enabled is limited to the original critical path. Therefore, the tool has the ability to check if the number of crash days entered causes another path to become critical and warns the planner whenever this occurs. Once allowable crash days are entered and crash ratio (cost/day) is calculated for each activity on the critical path; based on the amount of time to recover (i.e. delay, reduction in project duration), the tool automatically selects the list of critical path activities that produce this reduction in project duration for the lowest cost;

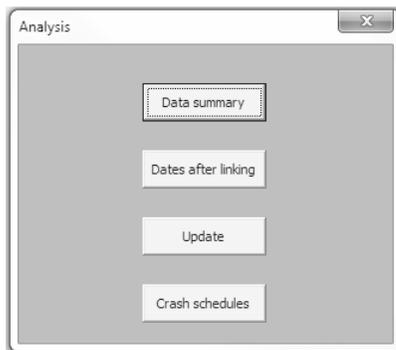- *Reports:* each of the results explained at the previous points can be saved as a report with a suitable name.

Fig. 7: Summary of the analysis

Fig. 8: Summary of the supply chain's programmes after linking

4. CONCLUSIONS

Supply chain management is a relatively new and still somewhat an uninvestigated concept within the construction industry and a clear roadmap for conducting the research within this area is still missing. Firstly, this paper aimed at explaining the different facets of the problem using a real example. This has led to the conclusion that the research in the construction supply chain management should be focused on two main areas: the coordination of the multiple participants on site and the management of the upstream supply systems forming the supply chain. Secondly, this paper presented a requirements specification for the coordination of multiple participants. These specifications are under development and would allow the coordination of multiple schedules. Unlike existing research, the proposed solution does not introduce new constructs and terminology and does not place any constraints on planners. Schedules involved can also be linked to a 3D model where 4D and 5D visualization is enabled. This visualization represents a second stage of the coordination process which can validate the initial coordination of the schedules and offer new capabilities (e.g. 4D/5D visualization, H&S issues, etc.). Future work will aim to develop a coordination module for one supply system (i.e. façade industry) in order to generate useful planning inputs for the supply system in terms of material delivery to the site.

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