Dynamic Actor Network Steering And Control

Managing Actor Networks In The Construction Process

J. Burger, R.P. de Graaf, and G.J. Helmerhorst
Delft University of Technology
Berlageweg 1
2628 CR Delft
The Netherlands
jeroen.burger@tudelft.nl

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Abstract: In response to the changing nature of the construction industry, increasingly multi-actor and pluricentric, this paper presents a management system for multi-actor decision-making based on the soft-systems approach. Two key system concepts are the dynamic solution space and the equal collaboration structure based on mutual interdependence. In order to implement these ideas, commonly-used critical path algorithms are not sufficient, a Linear Programming model is used instead. An experimental tool, currently in early development, is described.

1. INTRODUCTION

In the construction process nowadays, the decision-making takes place in pluricentric decision-making arenas (concerning the design, the costs, the construction itself, and so forth) using multi-actor interaction. Due to mutual interdependency between the actors involved and ever-changing partnerships, managing this process is a complex task. Hence, trying to steer and control this process by means of traditional project-based hierarchical planning is nearly impossible.

To aid this process the Open Design Research Group has developed a special management system for multi-actor decision making, using the soft systems approach. The system models the multi-actor process as a multi-level network, which consists of actors and the decision-making relations between them. As a result it provides each actor with the possibility to manage and enhance both his formal organisational and his personal networks. Two key system concepts are the dynamic solution space and the equal collaboration structure based on mutual interdependence.

In order to implement these ideas, commonly-used critical path algorithms are insufficient, and a Linear Programming model is used instead. An experimental tool, currently in development, is described. Furthermore a conducted test is explained where four professionals were asked to take place in a simulated environment. The simulated environment consisted of the experimental tool and the role descriptions. The participants were assigned to stakeholders (actors) that represented the following organizations: actor 1, the Province of South Holland; actor 2, the United Villages; actor 3, the Port of Rotterdam; and actor 4, the City of Rotterdam. (Van den Doel, 1993; Van Loon, 1998.)

2. THE SYSTEMS CONCEPT

We will first describe two main system concepts of this management system: 1) the optimisation of the decision making process within a common dynamic solution space, and 2) the equal collaboration structure based on mutual interdependence. We will then cover, on an abstract level, the mathematical tools employed to model this system. We will finish with a brief description of our current, early experimental implementation.

We deliberately choose to base both concepts on the soft systems approach.6 This approach was an answer to the drawbacks of the hard system approach in which well structured problems and clearly defined objects form the basic premises. As described by Checkland (1976, in Jackson, 2003, p182-183), managerial problems are vague and unstructured and need a more ‘soft’ approach. While the models produced by the ‘hard’ approaches are meant to be models of the real world, the ‘soft’ models of human activities concerning management situations are or should be contributions to a debate about change. This approach therefore incorporates the possibilities to cooperate while there are different views and perspectives at hand.

2.1 System concept 1: Optimisation of the decision making process within a common dynamic solution space

To prevent actors working only on their own individual decision making process, and the subsequent bottleneck that arises when their processes are combined (the so-called combinatory explosion), the actor network system includes the possibility of first defining and modelling a common solution space for all the individual sub-processes together. A search can then be made for combinations of sub-processes.

Arriving at this common solution space is a question of cooperative work – establishing the external constraints and the conditions which the actors themselves have set for the possible alternative group processes.

The modelling of the common solution space is intended to give the actors insight into the feasibility of their own decision making process, given the boundaries of this space. These processes should in any case fall within these boundaries. The actors can then, as part of the negotiating process, look for the most optimal combinations of all their sub-processes. This takes place in successive rounds of making proposals (interactive computer input) and 'calculating' (computer output) the most optimal combination from each round. This enables the actors to arrive jointly at a feasible group optimum that is acceptable to all the participating actors.

In this process of holding rounds, the actors have the opportunity to propose both sub-processes and changes to the original constraints of the common solution space, and to put forward new constraints and have them included in the (modified) common solution space. This final aspect merits attention because it creates a degree of flexibility in the negotiating positions. The group optimisation process then takes place in a common dynamic solution space. After all, it is well known that actors assess the sub-processes of others in terms of commonality with their own, and on compliance with the constraints that they have set for the total set of the sub-processes.

2.1.1 The concept of the dynamic solution space

The solution space in a multi-actor process is in fact fluid, being as it is negotiable, up for discussion, and can also be changed while in use. At the start of the process the solution space, as a collection of possibilities, will be very unstructured – for example, various configurations for the division of functions over rooms, a loose collection of buildings to be erected, an urban area with potential for many different functions, or an investment budget, and matters such as the conditions that apply to the environment, the configuration of an area, the composition of the new amenities and the surface area available for building.

The planning goals are also rather vague at the beginning: a nice building, sufficient space, energy-efficient, a sound residential environment, etc. The further the process has progressed, the more structure there will be in the solution space. Initially, sub-solutions (sub-structuring of certain resources) are generated, alternative proposals examined and evaluations carried out. Sub-solutions are then combined into larger entities, agreement is reached about the deployment of the resources, alternative solutions found, as is the end solution. During this process, the initial options, conditions and goals, all of which are still vague, will be developed further, so that it becomes clear what the explicit requirements and explicit limitations to the available resources will be. As the process progresses, the 'space' within which the end solution can be found will gradually take shape.

This means the construction of the common solution space and the way it is handled are interwoven. In multi-actor situations this produces many benefits. For example, the actors can see from the sub-solutions whether the associated preconditions of the common solution space are acceptable. Opinions about the solution space will often differ. Every actor judges matters from the perspective of his own interests, and will want to influence the nature of the solution space to the advantage of those interests. The construction of the solution space has therefore become a multi-actor process.

This taking-shape-aspect of the common solution space has a special significance in group optimisation processes. To make the problem of choice – what is the best combination of all the sub-solutions? – easier in terms of making a decision, and therefore to formally find a solution, preferential values will have to be awarded to the features of the alternative combinations. However, the number of alternatives and the number of components may be so large in practice that the problem of choice becomes too complicated and too extensive. A limit can in that case be imposed, based on Simon's satisficing principle (Simon, 1969). This principle states that a decision-maker may be satisfied by examining just a limited number of alternatives – that is, the alternatives with which he will be satisfied. From this limited number, the best option will be selected. This satisfaction can be expressed in terms of whether the preconditions are fulfilled or not, so that the scope for decision-making is divided into a 'permitted' (or attainable) area and a 'forbidden' area, because all the combinations that meet the conditions are acceptable, while those that do not will be rejected.

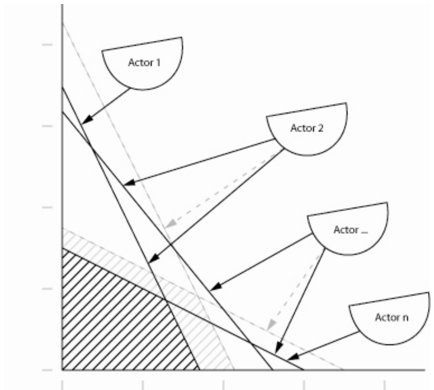


Figure 1. The dynamic solution space

2.2 System concept 2. Equal collaboration structure based on mutual interdependence

The system concept 1 assumes that actors, or groups of actors, work together as equal partners in decision making teams. Teams of this nature almost always comprise a range of disciplines in the construction practice, because different types of expertise are required. Whereas it was previously the norm for there to be a central leadership body (with a hierarchy and a top-down structure) that assumed final responsibility for the process, nowadays it is almost impossible to find any trace of a central and hierarchical power-based relationship between the collaborating actors, especially in the case of complex construction projects. This is because parties work increasingly closely together and have become mutually interdependent.

This change in practice has been technically translated in the actor network system in the form of a matrix-type network of positions and relationships between the actors. In a network of this kind, each actor (commissioning party, specialist designer, skilled specialist, adviser, user, etc.) can make his own contribution to the process – in their own time, from their own perspective, and through their own sub-network of relationships.

2.2.1 The equal collaboration structure

In a network-type collaboration structure with equal partners it is impossible to show in advance from what positions and via which contacts a process will take its course. The individual decision makers (Decision makers, Dn) can of course operate within the process in sub-groups: a users' pressure group, a team of experts from a particular department, a consortium of investors, etc. This only means that a number of decision makers have combined their contributions into one set, and that they will attempt to have this set put into practice via the decision maker network as a sub-group. In terms of positions and contacts, the network-type decentralised collaboration structure has the following features:

1. The decision makers are in parallel positions of power in relation to each other. The decision makers (experts and non-experts alike) are equal partners. Each has their own goals and their own resources. This contrasts to the centralised, hierarchical collaboration structure characterised by superior and subordinate positions.

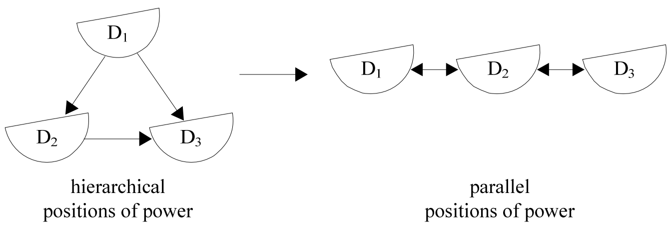


Figure 2. Positions of power

2. The decision makers each have their own Decision Area, DA. The decision makers in each area take their decisions on an autonomous basis, in contrast to the centralised structure where every decision area forms part of a higher-ranking decision area.

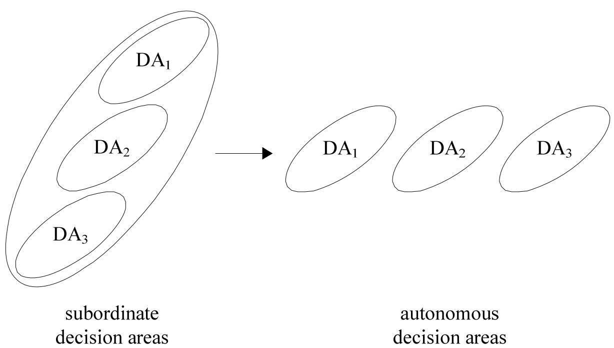


Figure 3. Positioning of decision areas

3. The decision makers have primarily negotiating relationships. The decision makers negotiate about the deployment of their own resources

and those of others, in contrast to the centralised structure which is characterised by resources being allocated.

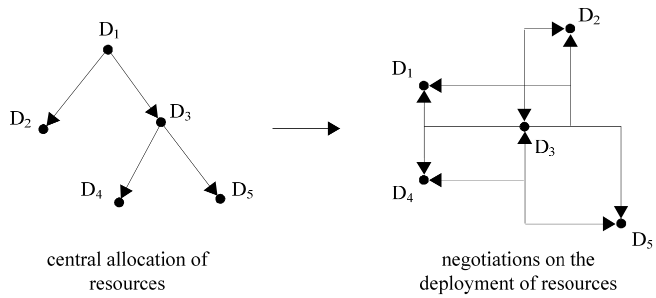


Figure 4. Decision-making relationships

4. The decision makers also have participatory relationships. They each have their own relationship with the decision environment and therefore their own image (own conception) of the decision-making task and the decision outcome. This contrasts with the centralised structure in which environment and assignment are structured in advance, usually on the basis of professional opinions and insights of the situation.

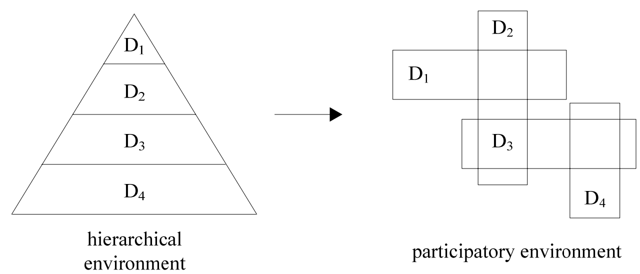


Figure 5. Decision-making environments

3. OPTIMISATION OF ACTIVITY NETWORKS WITH LINEAR PROGRAMMING

In order to implement the system concepts described above for actor network planning of construction projects, it is necessary to be able to determine optimal activity durations and total project duration given an activity network, and the actors' constraints on activity durations (optimistic/pessimistic duration estimates). The network defines the structure of the dynamic solution space, the flexible constraints define the positions of its boundaries.

Commonly used (backwards-counting) algorithms for finding critical paths in activity networks, and hence total project duration, require a network with fixed activity durations to calculate on. Therefore, they cannot determine optimal activity durations, and cannot be used to implement the system concepts. The Operations Research technique of Linear Programming inherently supports the concept of a dynamic solution space. The activity durations can each be given upper and lower bounding constraints, rather than a fixed value. The connections between activities are directly modelled as constraints on the possible values of pairs of activity durations (the model does not need to determine the actual network paths). When modelled in this way, a linear optimisation algorithm can be used to find optimal values for the activity durations in the network, while minimising overall project duration. (Radford and Gero, 1988; Render, Stair, Hanna, 2003.)

Figure 6 shows a trivial network planning as an example. There is a Start and a Finish node, between which there are five activities in the form of nodes A to E. The network has two alternative paths, via C or via D. Figure 7 is an abstracted representation of the example network modelled in a Linear Programming matrix form. Broadly, the columns represent the nodes and the rows represent the connections between them. Each connection is constrained by the minimum activity duration of the 'from' node, given on the right. The blank cells are filled in by the optimisation routine: The column of blue cells contains the optimal activity durations. The row of white cells contains the activity start times. The final red cell contains the minimal overall project duration. The final column of white blank cells contains the dual values, which will be considered next.

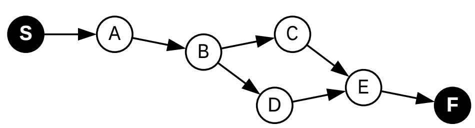


Figure 6. Example network

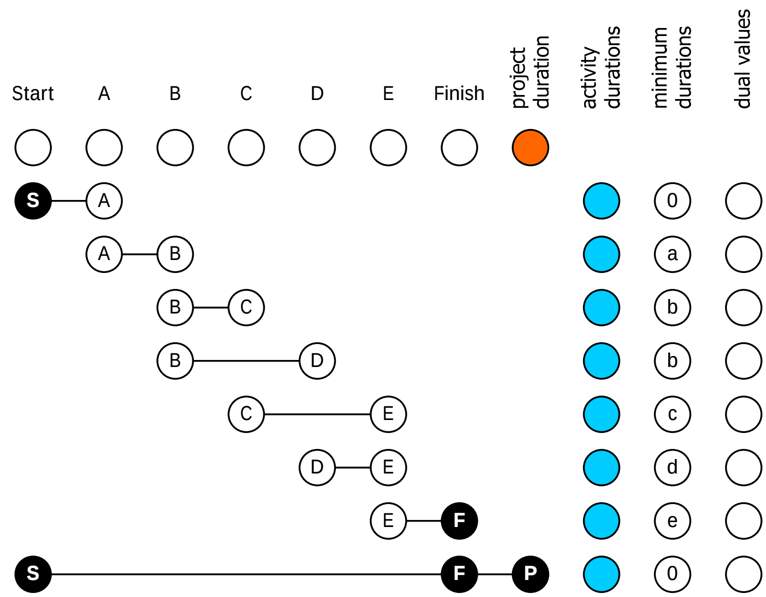


Figure 7. Representation of example network in Linear Programming matrix form

3.1 Dual values: finding risks and opportunities in the network

The coefficients of the objective function are called relative cost factors or dual values. These dual values indicate by how much the optimisation value – in this case the overall project duration – will change if the associated variable is changed by one unit. Dual values are valid within a certain range. Outside this range the basic feasible solution will either change or become infeasible. Within our model only the dual values of the constraints – here the connections – are important.

Even more so than the slack values, dual values and their ranges can alert actors to constraints that have a high risk of becoming critical. Additionally, from the dual values actors can discern the activities which would be most promising to shorten.

3.2 Supporting multi-actor networks

The structure of the basic model described above allows each constraint to be allocated to an individual actor. In this way they can take decisions in their own decision areas autonomously, yet as part of the whole network. Actors can readily and with clarity negotiate on these constraints. The simulation of alternative network paths is easily accomplished by changing input variables.

4. DEVELOPING TOOL

A prototype tool to experiment with this management system is currently under development. It uses the drawing application within Microsoft Excel as main interface to draw the actor networks (Fig. 8). Custom node designs can easily be made for individual decision arenas. When a network has been entered, its structure is read and the linear programming model is generated in Microsoft Excel. Using the solver package What's Best! from Lindo Systems, an add-on for Excel, the optimum durations are found (Fig. 9). The results are then sent back to Visio and displayed: the duration and start time are displayed per node, and the critical path is coloured.

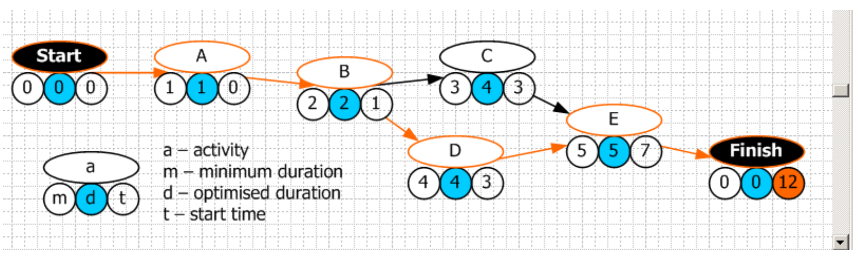
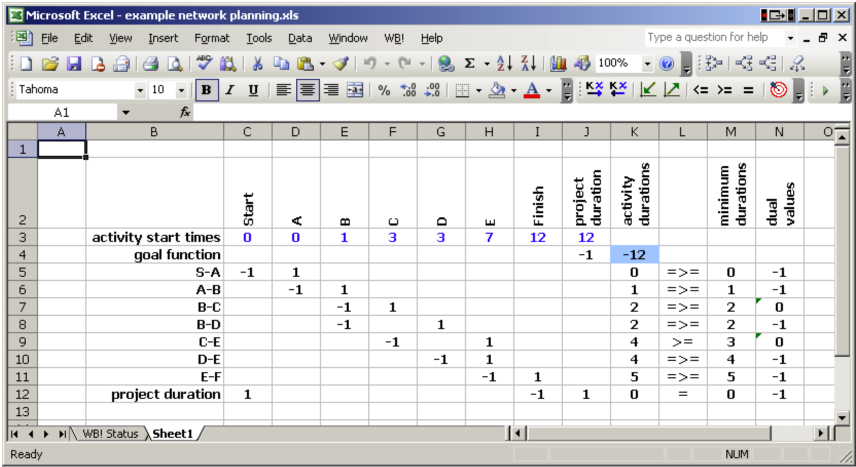


Figure 8. Example network drawn in Excel, with duration, start time, and critical path output



	Start	A	B	C	D	E	Finish	project duration	activity durations		minimum durations	dual values
activity start times	0	0	1	3	3	7	12	12				
goal function								-1	-12			
S-A	-1	1							0	=>=	0	-1
A-B		-1	1						1	=>=	1	-1
B-C			-1	1					2	=>=	2	0
B-D			-1		1				2	=>=	2	-1
C-E				-1		1			4	>=	3	0
D-E					-1	1			4	=>=	4	-1
E-F						-1	1		5	=>=	5	-1
project duration	1						-1	1	0	=	0	-1

Figure 9. Example network modelled in Excel with What's Best! add-on

5. PRACTICE

We conducted a test where four professionals were asked to take place in a simulated environment. The participants were assigned to stakeholders (actors) that represented the following organizations: actor 1, the Province of South Holland; actor 2, the United Villages; actor 3, the Port of Rotterdam; and actor 4, the City of Rotterdam. A short introduction was given to define the context of the test environment: a meeting about an industrial area redevelopment case. The participants where given different role descriptions, which gave information about the background of the stakeholders and their role in the meeting. (Fig. 10.)

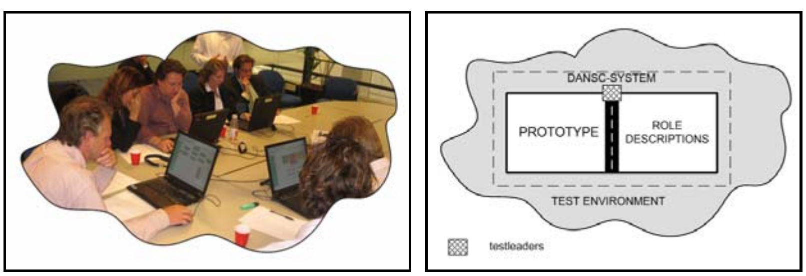


Figure 10. (a): Participants in the simulated environment;
(b): Abstract representation of the simulator

5.1 The first round

The goal of the first round was to test the ability of the stakeholders to draw their own networks in the prototype based on their to-do list. The participants were asked to think of the activities they had to conduct after the meeting in order to complete their to-do list. The actors had to plan their own tasks and activities, and the tasks and activities of those whose input was also needed to complete the to-do list. In the prototype the actors were able to visualize these steps in a network diagram (Fig. 11). This network was created by placing the activities from the to-do list in their order of completion. Each actor has his or her own order based on personal preferences, experience, and the structure of the organisation the actor represents. For each activity (node) the participants were asked to give an estimated duration of that particular activity. At the end of round one the critical paths of the different networks were calculated. The calculation showed that the actor that represented the Province of South Holland needed more time than the other participants to complete the to-do list network.

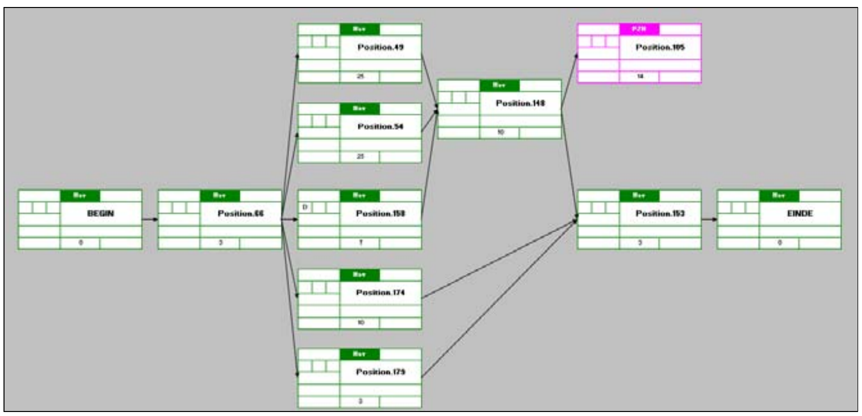


Figure 11. Network drawn in DANSC

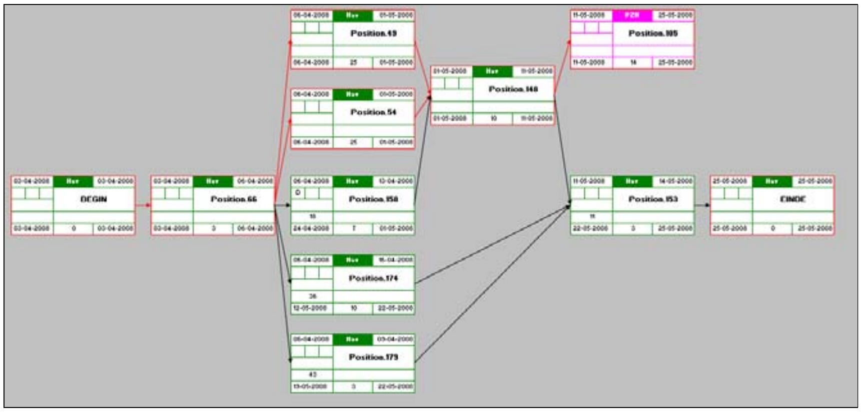


Figure 12. Critical path after calculation

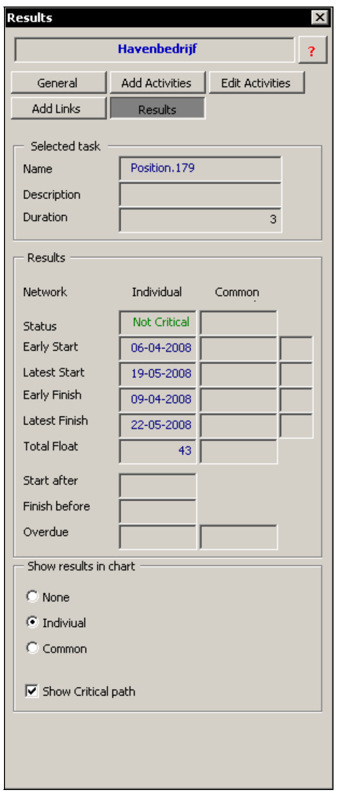


Figure 13. Results after calculation

5.2 The second round

In attempt to minimize the longest critical path in order to plan a date for the next meeting, the goal of the second round was to test the possibilities of shortening the time found to be needed by the actor who represented the Province of South Holland, in conjunction with the planning of the other stakeholders. The mutual interdependence of the different actors, of different levels and of different subjects, is visible in each stand alone network. Combined they define the dynamic solution space and represent the entire the network representing the total set of activities of all actors. The actors entered these mutual interdependencies into the model as dependencies between nodes in their individual networks. Therefore we were able to focus on the coordination of these activities in order to shorten the critical network duration. For example, a particular research activity took a certain department of the Province twenty-eight days to complete, but by cooperating with the Port of Rotterdam, the actor Province of South Holland was convinced that his department could complete the activity in fourteen days instead of twenty-eight.

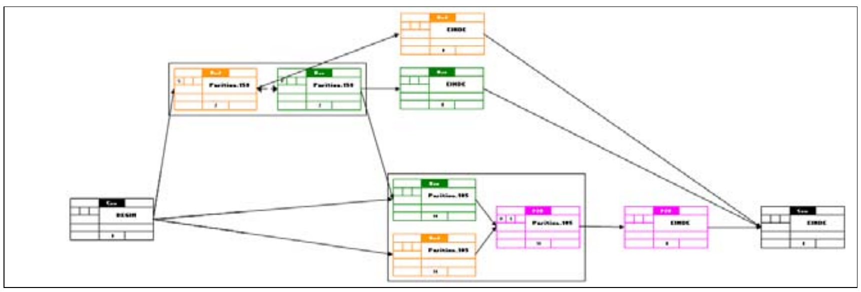


Figure 14. Group network connected, common activities are shown in relation to each other

6. CONCLUSION

In response to the changing nature of the construction industry, increasingly multi-actor and pluricentric, a management system for multi-actor decision-making is being developed. Two key system concepts are the dynamic solution space and the equal collaboration structure based on mutual interdependence. In order to implement these ideas, commonly-used critical path algorithms are insufficient, and a Linear Programming model is used instead. An experimental tool is currently in development.

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