

HEURISTIC SOLUTION FOR RESOURCE SCHEDULING FOR REPETITIVE CONSTRUCTION PROJECTS

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Abstract

Construction project planning and control are core processes for building project management. In practice project time management is achieved by computer based techniques like Precedence Diagramming Method (PDM). Many researchers and practitioners claims that Networking techniques as such do not provide a suitable model for construction process, especially in repetitive projects. Construction process modeling, for repetitive projects in particular, should incorporate for specific features of resource flows through project activities. With the aim of improving resource scheduling with PDM, a heuristic algorithm for repetitive activity scheduling process is presented (REPNET), based on a precedence network plotted on a resource-space chart. The heuristics of REPNET are used to carry out resource timing in two phases: in the first phase as soon as possible project schedule is performed; in the second phase the REPNET algorithm search for resource scheduling optimization by minimization of resource idle time in repetitive activity performance. The work continuity constraint is relaxed in order to maintain the PDM minimum project duration. Optimized project schedule of case study is compared with original schedule and discussed.

Keywords: activity network, Precedence Diagramming Method, resource scheduling, repetitive construction, location based scheduling.

INTRODUCTION

Construction project planning, scheduling and control are core processes for building project management. The plan of a construction process should be a forecast of the best way to construct the building and to control the process itself. Thus a major objective of planning should be a tool by which to control the actual process (Birrel, 1980) to give feedback information in relation to the plan for the process. This can be done in an effective way mainly developing a realistic model of the construction process.

In practice project time management is achieved by computer based techniques like Precedence Diagramming Method (PDM). PDM is a network-based planning instrument where building processes are represented topologically by means of an activity network. Activity network is a time oriented building process model where resources are simply loaded to corresponding activities as an attribute or a label.

Networking techniques represent the state of the art of construction project planning and scheduling in most real life projects, but many researchers and practitioners claims that these techniques do not provide a suitable model for construction process, especially in repetitive projects. This is mainly because activity network is discrete while construction process is basically a continuous flow of working operation performed by specialized resources. Many scheduling methods have been proposed in literature in order to improve repetitive construction project efficiency.

Literature overview

Building construction projects often include considerable amount of repetitive activities that are carried out in a cyclic manner (start-operations-close) from one space unit to another one. Such efforts are called repetitive projects. In repetitive projects like high – rise building, housing, highway projects and pipeline constructions, resources are required to perform the work on similar activities in the various locations of the project. As a matter of fact construction crews move from one space unit (i.e. storey of the building) to another one in a sequence. This is mainly because the building of a construction item performed by trade crews (i.e. floor concrete slab) can be divided into specific activities associated with particular units (i.e. floor concrete slab at each floor of a multi-storey building).

Repetitive construction projects can be classified according to the direction of sequence of work from one space unit to another one (Vanhoucke M. 2006). In horizontal repetitive projects the activities are performed horizontally e.g. highway or pipeline projects. These projects are also classified as continuous repetitive projects or linear projects due to the linear nature of the end product of the construction process. In vertical repetitive projects the repetitive activities are performed vertically e.g. multi-storey building or high – rise building. Discrete repetitive projects consists of a repetition of a unit network through the project, like floors of high – rise building, factory buildings of an industrial plant, housing projects. In continuous repetitive projects space is not discrete, like highways or pipeline networks (Yang and Ioannou 2001). Kang, Park and Lee (2001) argue that construction projects can consist of both horizontal and vertical repetitive processes among several multi-storey structures and classify this projects as multiple repetitive projects.

Basic instrument suggested by researchers and practitioners for the planning and scheduling of a repetitive projects are time / space diagrams, in which activities performed by resources are plotted as line or other geometrical shape on a time/space chart.

Researchers have proposed many scheduling methods, that can be classified as Line of Balance for Projects with discrete space units, and Linear Scheduling Method for continuous space projects. El-Rayes and Mosehli (1998) suggested that resource – driven scheduling accounts directly for crew work continuity and facilitate effective resource utilization. They suggested that resource – driven scheduling of repetitive activities requires the satisfaction of three constraint: precedence relationship, crew availability and crew work continuity. Basic concept of resource – driven scheduling of a repetitive project is to account for: a) numbers of crews to work simultaneously on different space units of repetitive activities; b) interruption of crew work continuity. Harris and Ioannou (1998) created the scheduling repetitive model that ensures continuous resource utilization with a flow view and a PDM view of the model. Arditi, Tokdemir and Suh (2001, 2002) integrated non – linear and discrete activities into LOB calculations and defined time and space interdependencies among activities as a base concept for repetitive project scheduling.

Kang (2001) observed that in a multiple repetitive construction project construction cost and duration are dependent on: number of work areas, proper crew grouping, size of work areas, frequency of repetition of each activity, and provided an heuristic approach to allow optimal

construction planning. Kenley and Seppänen (2009, 2010) observed that locations are important in construction because building can be seen as a discrete repetitive construction process, a series of physical locations in which work of variable type and quantity must be completed. They also observed that the location based methodology does not exclude Critical Path Method (CPM), in fact dependencies between activities in the various locations and between tasks that are made up of activities of the same work item are realized with CPM logic links. In general repetitive scheduling methods are more concerned with movement of resources through locations or places than with repetition of activities, so they introduced the Location-Based Management System (LBMS) which shifts the focus from individual discrete activities to managing the progress of repetitive activities as performed by crews moving through a building and completing all their work location by location.

Location Based Scheduling

A repetitive project is a multi-unit project where resources move through the various similar location of the project (e.g. multi – storey building, housing projects, highway projects), while a non-repetitive project is a building project that has a complex location breakdown structure and is mostly a set of one-off activities.

Construction process modeling, for repetitive projects in particular, needs a more detailed model regarding resource flows through project activities. Location Based Scheduling is a resource oriented construction process model. Location Based Scheduling produces schedule that achieve a continuous workflow by considering the relationship between the work to be done and the location of the work (Firat et al, 2010). In a repetitive construction project locations require the establishment of a hierarchical Location Breakdown Structure (LBS), where a higher level location logically includes all the lower level locations (Kenley and Seppanen, 2010).

In Location Based Scheduling working tasks, set of repetitive activities, are plotted on time / space chart using general principles of the Line of Balance (LOB). The essence of location based resource scheduling is the view of the movement of construction resources through the various project locations as a key to improve project performance.

Location Based Scheduling recognize that networking techniques like Precedence Diagramming Method does not well match the character of construction projects, which consists of large amounts of one site fabrication involving continuous or repetitive work. The character of a repetitive construction project can be defined as (Kenley and Seppanen, 2010):

- multiple working places;
- one site and continuous assembly of components;
- repetitive activities performed in different locations, but in which the amount or context changes;
- equally parallel and sequential paths;
- resource management is a flow-optimization problem, designed to achieve smooth flow and continuity in the use of resources.

So at least three basic item of construction project scheduling with precedence diagramming method must be implemented for repetitive project scheduling: resource – driven scheduling, work area or space definition and resource flow tracking. In the resource driven scheduling process resources must be committed on a specific range of time for one job, assuring maximum efficiency of committed resources. In fact any task or activity requires a specific work space, termed “Space demand” for its execution. This space demand is based on the space requirements of each resource allocated to the activity. If the required space becomes limited or unavailable, the activity or task can not be executed or performed with the required

productivity rate. Often critical path method ignore requirements of activities for work space or work area for specialized resources (Thabet W. Y., Beliveau Y. J. 1994).

Birrell (1980) highlighted that basically construction process is a set of construction operations performed by specialized resources who moves through the various locations of the project. Starting from the building to be done basic concept is to define the sequence of trades on every construction item, and to set the route of the work crews that will be moving through the various project locations or space units. Buffer space or time are needed to prevent crews from interfering. Once the first crew has started, the following crews will be added in the same sequence. This creates a flow of crews or a trade parade (Tommelein, Riley and Howell, 1999) moving through the space units of the project.

In summary, construction site space is an important concept and viewpoint for understanding characteristics of repetitive construction projects. The earlier research has covered already several important methodological characteristics of construction planning and scheduling with the site space on focus. Although not covered explicitly here some research has covered also computerized assistance for the generation of alternative plans and schedules – for example (Kahkonen, 1994; Märki et al, 2007). The research to be presented in the following chapters is also targeting to produce such a solution that would incorporate characteristics of repetitive construction operations and to present this together with computerized assistant that would enable efficient high quality scheduling.

REPETITIVE NETWORKING TECHNIQUE (REPNET): BASIC PRINCIPLES

With the aim of improving resource scheduling in repetitive construction projects with Precedence Diagramming Method, an heuristic algorithm for repetitive activity scheduling process called REPNET is presented, based on a precedence network plotted on a resource–space chart (Bragadin, 2010). In repetitive-unit projects it is important that repetitive activities are planned in such a way as to enable timely movement of crews from one repetitive unit to the next, avoiding crew idle time. This is known as the “work continuity constraint” and its application during project planning can provide an effective resource utilization strategy that can lead to: maximization of the benefits from the learning curve effect for each crew; minimization of idle time of each crew; minimization of the off-on movement of crews on a project once work as begun.

Resource-flow tracking

A Precedence Diagram Network of the repetitive project is plotted on a resource – space chart, with the x-axis representing resources and the y – axis representing space units of the project. So the network node representing the activity is identified by two coordinates: the main resource performing the activity and the work space in which the activity is to be performed. The procedure of plotting the network on a resource – space coordinates has been used by many researchers in the past. In particular Yi, Lee and Choi (2002) presented an heuristic method for network construction and development for repetitive units project, with the aim of minimizing total project duration by reducing idle time of resources and spaces. Actually the heuristic changes the sequence with which crews complete the scope of work encompassed in each repetitive activity. About this procedure Moselhi and Hassanein (2004) observed that this approach and general formulation has been applied in earlier and more accurate models (e.g. El Rayes and Moselhi, 1998) and that the Yi, Lee and Choi method does not guarantee a global optimum solution.

Resources in the x-axis of the chart are generally the work crews or the equipments that perform activities. When the activities are completed the crews are released to the next activities in the successor space units. Resources are grouped by work item i.e. masonry, plastering, floor concrete slab etc. Multiple resources, i.e. crews, are allowed for the same work item in order to perform parallel repetitive activities in different locations for the same task. In this way in every column of the chart activities are grouped by resources.

Space units of the projects are plotted on the y-axis. Space units are the locations where only one crew can perform one activity at a time. The Location Breakdown Structure is represented on the y-axis. The location breakdown structure (LBS) consists of an higher level of locations where it is possible to perform construction process independently of the other locations. The middle level should consists of locations where the flow of work can be planned across middle level locations. The lowest level are the space units of the project (Kenley and Seppanen, 2010). Space Units on the y – axis should be small, only one crew can work in that area and are identified by the k - code.

Activity is defined as the set of construction operation performed by a specialized crew or equipment in a space unit of the construction project. In a repetitive construction project a set of activities, performed by the same crew in more than one space unit is defined repetitive activity. Resources that perform a repetitive activity are identified by a j code. Task is defined as a set of repetitive activities performed by one or more than one crew for a work item, and is identified by the i code. So a resource path is completely identified as a repetitive activity by the ij code and a single activity is identified by the ij-k code (figure 1) where i identifies the work item or task, j identifies the repetitive activity or the single crew (i.e. resource path) and k identifies the space unit where the activity is performed (i.e. space path).

Plotting the PDM network on a Resource – Space chart makes easier resource tracking, in fact columns of the chart identify resource path through the project and the logical relationships between activities of the same task or repetitive activity represent resource flow tracking, while k rows of the chart identify space units of the project and make possible to detect unit path where the relationships between activities performed by different trades represent physical or technological dependencies (figure 1).

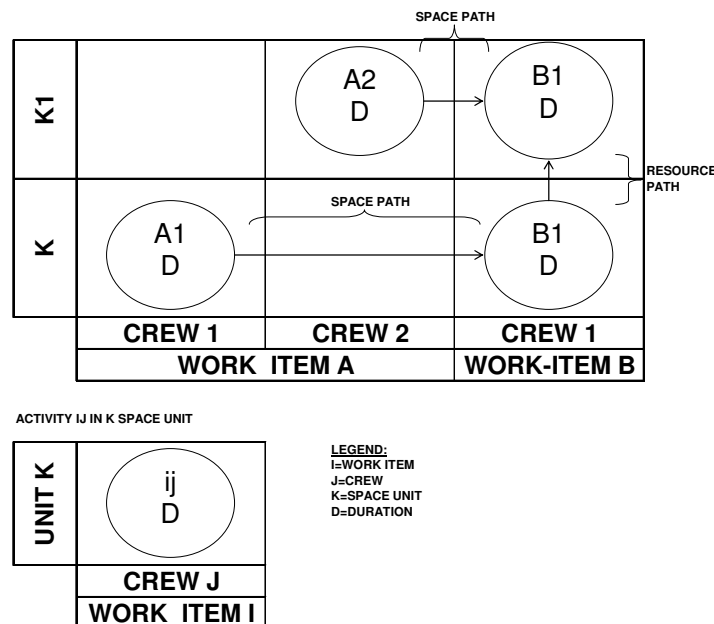


Figure 1: Network Diagram plotted on a Resource-Space Chart (adapted from Yi, Lee and Choi, 2002).

Work continuity requirement

After PDM critical path analysis, minimum construction project duration is found and as soon as possible project schedule is detected (ASAP) with Early Start (ES) and Early Finish (EF) of activities. Critical Path is detected and Free Float (FF) and Total Float (TF) for every activity can be found. In general non-zero link lags due to early time position of activities belonging to the same resource path prevent the ASAP schedule from satisfying the work continuity requirement. The proposed method aims at minimizing idle time of crews by activity shifting. Since that the optimization algorithm does not modify total project duration (TPD) as computed by traditional forward pass of Precedence Diagramming and resource flow continuity can be obtained only if made possible by network logic and activity float. If the work continuity requirement is satisfied for every activity of a resource path, the resource path is defined critical (figure 1).

The idle time of crew j on a resource path ij between the k' predecessor space unit and the k successor space unit, is computed as the difference between the early start of the successor $ij-k$ activity and the early finish of the predecessor $ij-k'$ activity:

$$\text{Idle } ij (k',k) = \text{ES}_{ij-k} - \text{EF}_{ij-k'} \quad (\text{eq.1})$$

Work interruption can be detected in the same way between activities of different tasks in the same space unit. If there are not any work interruptions between all the activities of the various task on a space unit, the space unit is defined critical.

The idle time of work on a space unit k , between activities belonging to the ij' predecessor task and the ij successor task is computed as the difference between the early start of the successor activity $ij-k$ and early finish of the predecessor activity $ij'-k$:

$$\text{Idle } k (ij',ij) = \text{ES}_{ij-k} - \text{EF}_{ij'-k} \quad (\text{eq.2})$$

Rule 1: Critical Resource Path

If, for every k',k couple of space units of a resource path ij the idle time $\text{Idle } ij (k',k)$ value is equal to 0, or for every single activity $ij-k$ of the same resource path ij the Total float TF_{ij-k} value is equal to 0, the resource path ij is defined critical, although sub-critical.

Rule 2: Critical Space Unit

If, for every ij',ij couple of the resource paths of a space unit k the idle time $\text{Idle } k (ij',ij)$ value is equal to 0, or for every single activity $ij-k$ of the same space unit k the Total float TF_{ij-k} value is equal to 0, the space unit k is defined critical, although sub-critical.

Time Critical Path

Note that a critical resource path or a critical space unit are not critical path in the original CPM sense, because they are defined by the idle time (eq.1 and 2) which does not mean the absence of Total Float of the activities, but only the absence of a part or the entire Free Float (with the exception of the cases of rule 1 and rule 2, where actually the Total Float TF_{ij-k} is equal to 0). In fact the chain of critical tasks or of critical space units can still have float time in the CPM sense.

To highlight this difference the original CPM critical path can be called "Time Critical Path".

Also note that critical tasks are desirable, because of work continuity constraint, while critical space units are not desirable, because of the risk of interference between various tasks in the same space unit.

Contingency Buffer

The resource- space chart enhances Location Based Scheduling. The activities itself are defined as a set of work operations on a single space unit. The focus is on the process performed on a sequence of locations by resources. So the flow of resources must be protected with buffers to allow for variability (Kenley and Seppanen, 2009). Buffer is a time allowance provided to absorb any disturbance between two activities or tasks.

Contingency Buffers (CB) are placed at the end of every sub critical task (i.e. resource path ij) to protect Time Critical Path from overruns, and to maintain the minimum project total duration.

REPETITIVE NETWORKING TECHNIQUE: SCHEDULING PROCESS

The Repetitive Networking Technique (REPNET) is an heuristic solution for resource scheduling for repetitive projects. The proposed method is a PDM based optimization of resource constrained project scheduling. The project solution can be sub-optima, but it is a simple method, easy to perform by researchers and practitioners.

The heuristics of REPNET carry out resource timing in two phases: in the first phase traditional PDM as soon as possible project schedule is performed; in the second phase the REPNET algorithm search for resource scheduling optimization by minimization of resource idle time in repetitive activity performance. The work continuity constraint is relaxed in order to maintain the PDM minimum project duration. In this way, besides the classic time critical path, a resource critical path is detected. Space critical path can be highlighted if useful.

Phase 1 – Resource – Space Chart Network

In the first phase the resource – space chart is plotted. In the x – axis resources are grouped by construction item and work crews are identified. In the y – axis space units are plotted. Then PDM network is drawn on the chart. Activities on the same k row show the work flow in the k space unit (i.e. space path), activities on the same j column show the work flow performed by the same crew j on a work item i (i.e. resource path).

Note that network plotting on the chart is an important phase. In fact by means of ordering PDM network by resources and space units the sequence of work is set.

The traditional forward pass and backward pass are performed and early activity times (ES and EF) and late activity times (LS and LF) are detected. Free Floats and Total Floats for every activity are found. Time Critical Path is found ($TF_{ij-k} = 0$).

Phase 2 – Schedule optimization

Resource paths ij are analyzed and critical resource paths are found. Then every sub – critical resource path is processed, starting from the last one. A contingency buffer is inserted at the end of resource path. Then, starting from the last activity of the resource path, every predecessor activity with idle time of crew is shifted forward by the shift S. The shift S is equal to the minimum between the Free Float of the activity and the Idle Time of crew. By addition of early times (ES and EF) and shift (S) Planned Start (PS) and Planned Finish (PF)

are found for every activity. The optimization process goes on until all the resource path is optimized, then goes to the earlier resource path and it is repeated starting from the last activity. The scheduling process is performed for every sub-critical resource path until all paths are optimized. The flow charts of figure 2 and 3 show this process.

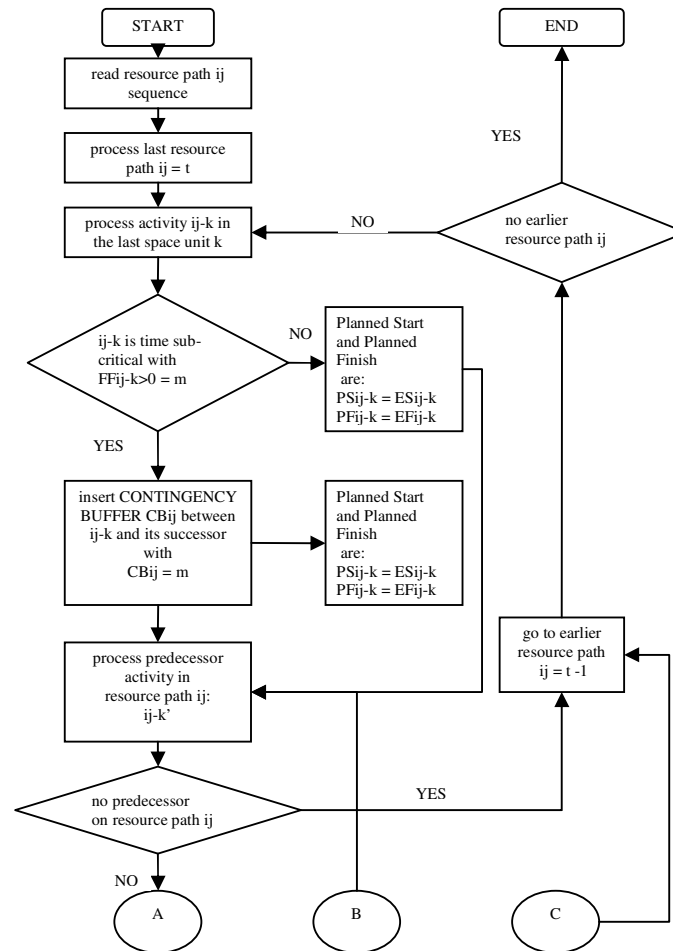


Figure 2: Flowchart of REPNET – part 1

CASE STUDY AND DISCUSSION

The REPNET optimization algorithm is tested using a case study from pertinent literature. The case study used for REPNET was presented by El Rayes and Moselhi (1998) and is a construction project which involves the construction of a three-lane highway for a stretch of 15 Km., and consists of five consecutive tasks: “A – cut and chip trees”, “B – grub and remove stumps”, “C – earthmoving”, “D – base” and “E – paving”. The space units are 15 segments of 1 Km each. The precedence relationships among these repetitive activities are Finish to Start with no lead time. For every task multiple crews are allowed. In the table of figure 4 activity data are presented. For simplicity activity data has been synthesized in crews allocated for each space unit k and the corresponding activity duration. The scope of the case study is to test the proposed heuristic solution with a simple but feasible project, which involves multiple crews in a multi-unit repetitive project.

The resource space chart with the PDM network is plotted in figure 5. The original ASAP schedule does not assure the work continuity requirement in 6 resource paths out of 13 (B1, B2, C1, E1, E2, E3). The flow line chart or production lines (Selinger, 1980, Kenley and Seppanen 2010) of figure 6 shows activities represented by lines on a time / space chart, where time (days) is plotted on the x-axis and space units are plotted on the y-axis. Activities are the lines starting from the lower left corner (start of location, start of duration) to the upper right corner (end of location, end of duration). In general, since activities are performed by a single crew, the lines represent crews passing through locations. The activities of a same resource path are linked each other by arrows representing the Finish To Start (FTS) relationships. Solid arrows are FTS links with no lag, dashed arrows are FTS links with non-zero lag, i.e. with crew work interruption. The flow line of the ASAP schedule shows work flow discontinuity between predecessor and successor space units in the afore mentioned sub-critical paths. Note that crew idle time, generally speaking, is more common in the last group of resource paths, due to network complexity.

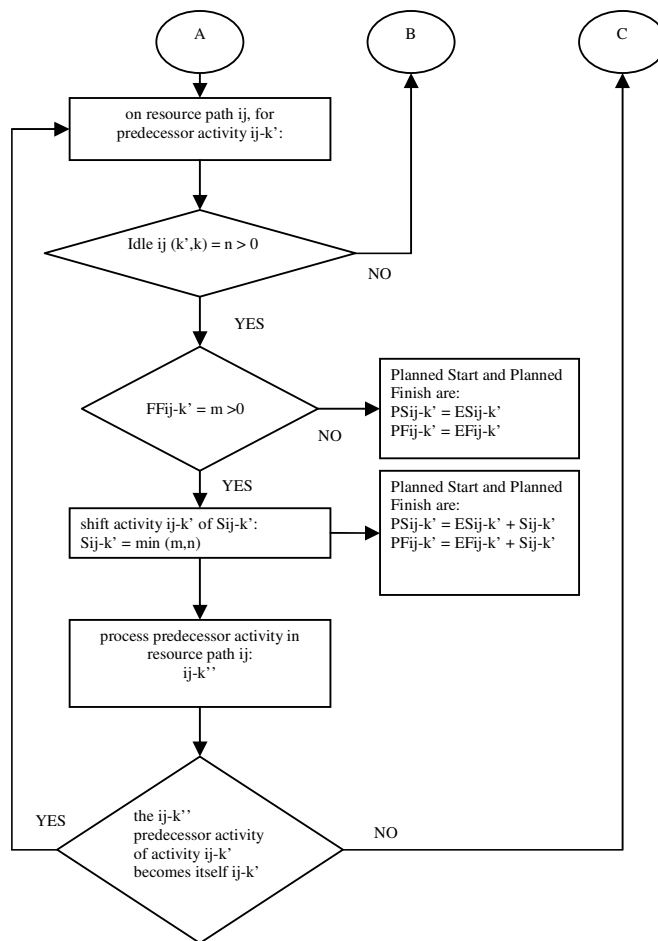


Figure 3: Flowchart of REPNET – part 2

The application of the REPNET heuristic solution reduces these non – optimized paths to 3, and the work continuity is not assured only in 3 resource path and in four cases (resource path B1: between unit 1 and 3; resource path B2: between unit 2 and 4; resource path C1: between unit 1 and 3, 3 and 5). Also, in the found solution all resource paths except B2 and C1 are

resource critical. The REPNET optimized schedule flow line of figure 7 shows resource path compression due to activity shifting, and at the same time work continuity requirement satisfaction in most paths.

Further optimization of the REPNET schedule can be made by hand manipulation of the network. Nevertheless the semi/automatic found solution seems ready for building site execution without further in depth study. This could be very helpful in real life project where the time for the scheduling phase itself is often very short.

The REPNET found solution is different from the solution found in the original case of El Rayes and Moselhi, because the objective of the REPNET is to implement a simple semi/automatic optimization that maintains PDM total project duration without changing activity sequencing imposed by the project planner. With this aim the REPNET keeps the PDM project duration of 100 days as a data of the problem, which is the result of the activity duration and sequencing imposed by the planner, and critical path calculation. On the other hand El Rayes and Moselhi found 83 or 87 days respectively with or without the satisfaction of the requirement of crew work continuity in every resource path, but this with semi/automatic activity sequencing. Scope of the REPNET is not to automate crew work sequencing, but to automate work idle time reduction, thinking that crew work sequencing is a strategic objective of site managers due to context, productive and contingency requirements.

Work item i	A		B		C		D		E	
Space Unit	Crew Number	activity duration	Crew Number	activity duration	Crew Number	activity duration	Crew Number	activity duration	Crew Number	activity duration
k	j	D	j	D	j	D	j	D	j	D
1	1	4	1	3	1	5	1	10	1	8
2	2	4	2	3	2	8	2	10	2	8
3	3	6	1	5	1	5	3	10	3	8
4	4	4	2	3	2	9	4	10	1	8
5	1	6	1	5	1	7	1	10	2	8
6	2	10	2	8	2	9	2	10	3	8
7	3	12	1	9	1	6	3	10	1	8
8	4	10	2	8	2	8	4	10	2	8
9	1	8	1	6	1	5	1	10	3	8
10	2	8	2	6	2	8	2	10	1	8
11	3	6	1	5	1	5	3	10	2	8
12	4	4	2	3	2	8	4	10	3	8
13	1	4	1	3	1	5	1	10	1	8
14	2	4	2	3	2	8	2	10	2	8
15	3	4	1	3	1	5	3	10	3	8

Figure 4: table of activity input data

CONCLUSION

The REPNET heuristic procedure for resource based construction process preparation is presented. The REPNET is a semi/automatic procedure that can help inexperienced planner in repetitive construction project scheduling. The optimization process carry out resource timing in two phases: resource – space network implementation and schedule optimization. In the first phase a traditional PDM network is plotted on a resource – space chart and the as soon as possible project schedule is performed. In the second phase the REPNET algorithm search for resource scheduling optimization by minimization of resource idle time in every

resource path on repetitive space units. The work continuity constraint is relaxed in order to maintain the PDM minimum project duration. In this way, besides the classic time critical path, a resource critical path is detected. Space critical path can be highlighted if useful. Some of the critical elements of traditional Network Scheduling for repetitive projects are tackled by implementing Location Based-Scheduling in the proposed method. In particular the resource driven scheduling is implemented by network definition and activity sequencing on the resource paths plotted on the resource – space chart. The work space definition is implemented by location based scheduling due to allocation of activities on specific space units. These two features make possible to implement resource flow tracking, i.e. the movement of resources through the construction project. Thus resource flow can be easily optimized reducing idle time of resources as much as possible. Also the resource - space chart shows the workflow and the use of resources (e.g. crews and equipment) on the same graph, thus providing an easy-to-control schedule, improving the control phase during project execution.

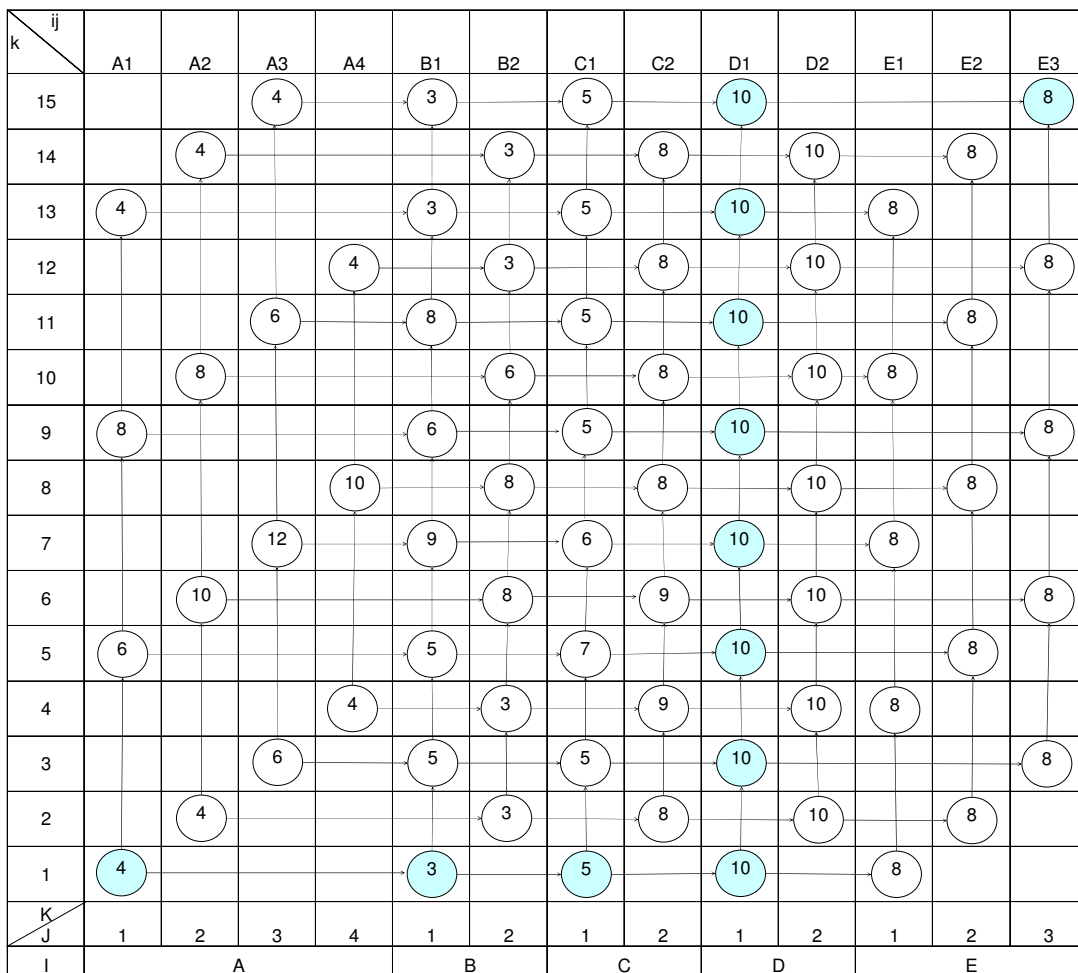


Figure 5: REPNET: resource – space network

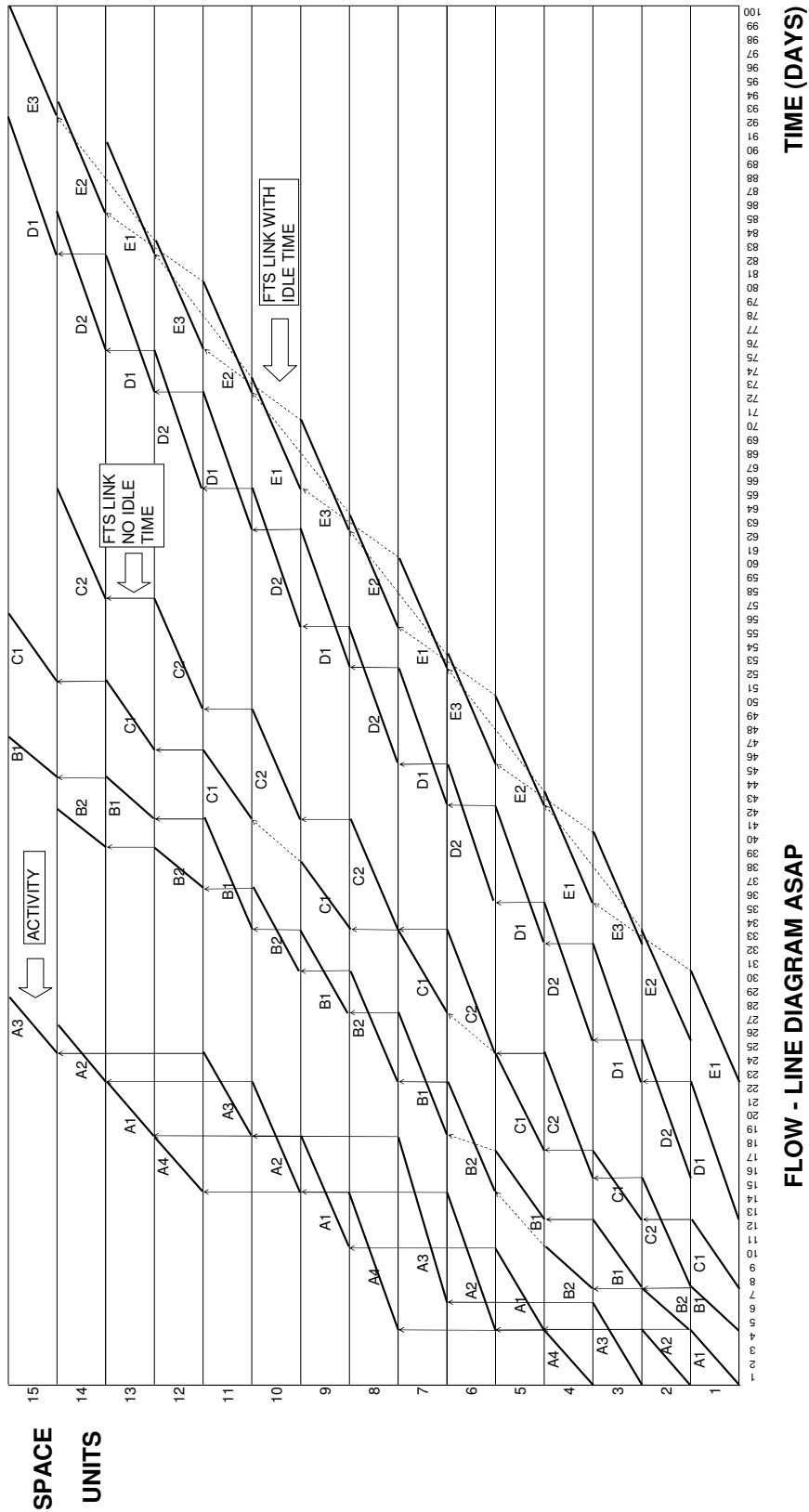


Figure 6: REPNET: Flow line of ASAP scheduling showing work idle time on six resource paths. Lines are the activities performed by specialized crews on every space unit. Arrows are FTS link between activities of the same resource path (Solid line arrow is a link without idle time, dashed line arrow is a link with idle time).

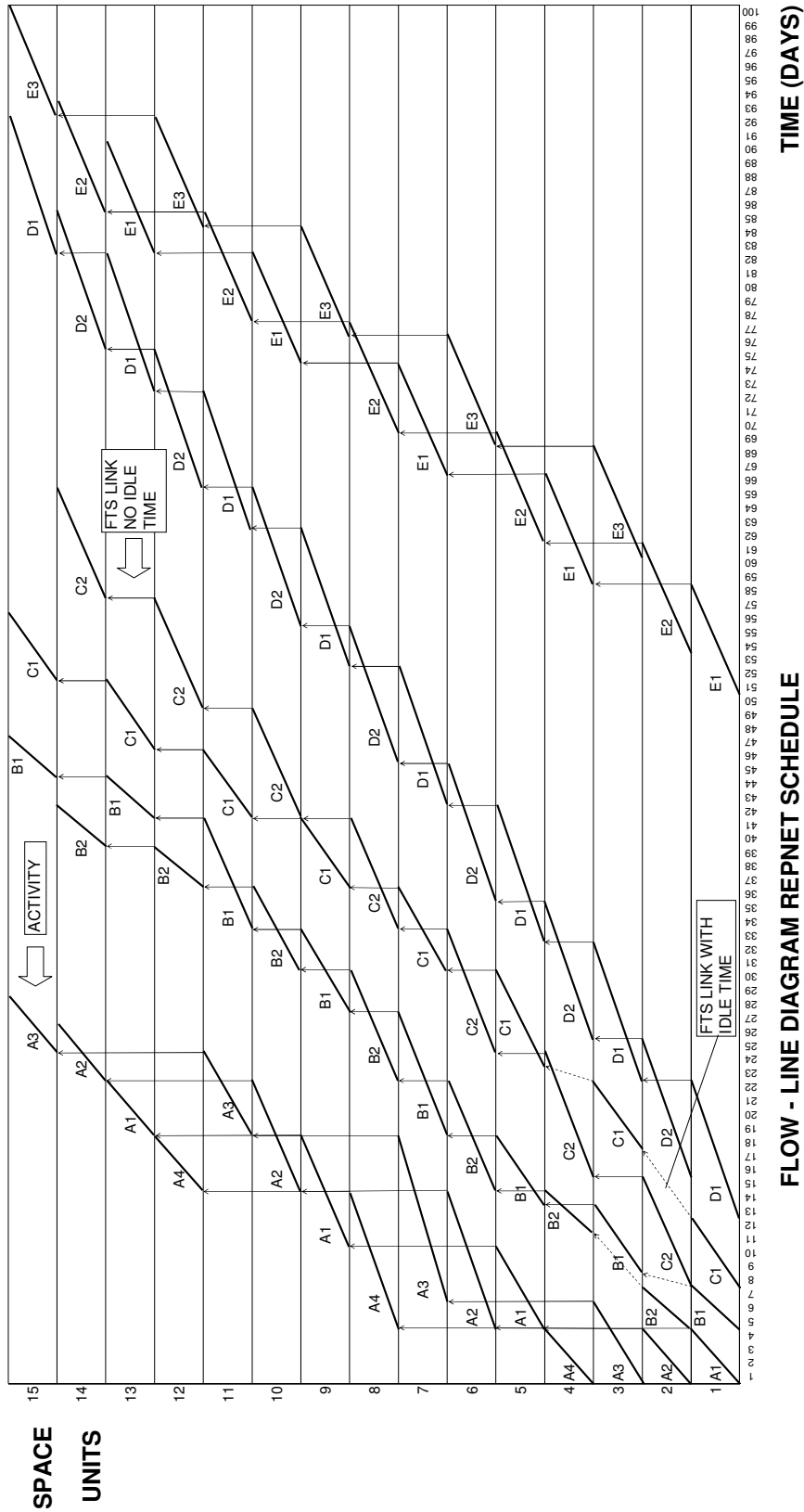


Figure 7: REPNET- flow line of optimized schedule showing work continuity requirement satisfied on most resource paths. Lines are the activities performed by specialized crews on every space unit. Arrows are FTS link between activities of the same resource path (Solid line arrow is a link without idle time, dashed line arrow is a link with idle time).

LITERATURE

Arditi D., Tokdemir O. B., Suh K. (2001) Scheduling System for repetitive unit construction using line-of-balance technology. *Engineering, Construction and Architectural Management* 8(2), 90 – 103.

Arditi D., Tokdemir O. B., Suh K. (2001) Challenges in Line-of-Balance Scheduling. *Journal of Construction Engineering and Management*, vol 128(6), 545-556.

Birrell G. S. (1980) Construction Planning – Beyond the Critical Path *Journal of the Construction Division American Society Civil Engineers*, 106(3), 389-407.

Bragadin M. A. (2010). Heuristic Repetitive Activity Scheduling Process for Networking Techniques. *Proceedings of the CIB 2010 World Building Congress, Salford Quays, U.K.* 1-12.

El Rayes K., Moselhi O. (1998) Resource-driven scheduling of repetitive activities *Construction Management and Economics*, 16, 433-446.

Firat C.E., Arditi D., Seppanen O., Kahkonen K., Kiiras J (2010) Comparative Study of Location-Based Scheduling (LBS) and Critical Path Method (CPM) in Non-Repetitive Building Construction Projects, Working paper.

Harris R. B., Ioannou P. G. (1998) Scheduling Projects with repeating activities. *Journal of Construction Engineering and Management*, vol 124(4), 269-278.

Kähkönen, K. (1994) Interactive Decision Support System for Building Construction Scheduling, *Journal of Computing in Civil Engineering*, 8(4), pp. 519-535

Kenley R., Seppänen O. (2009) Location-Based Management for Construction Projects: part of a new Typology for Project Scheduling Methodologies. *Proceedings of the 2009 Winter Simulation Conference*, 2563-2570

Kenley R., Seppänen O. (2010) *Location-Based Management for Construction*, Spon Press, U.K.

Kang L.S., Park I.C. and Lee B. H. (2001) Optimal Schedule Planning for Multiple, Repetitive Construction Process, *Journal of Construction Engineering and Management*, 127(5), 382-390.

Märki, F., Fischer, M., Kunz; J. and Haymaker, J. (2007) *Decision Making for Schedule Optimization*, Stanford University, CIFE Technical Report #169.

Moselhi O., Hassanein A. (2004) Discussion of Network Creation and development for Repetitive-Unit Projects *Journal of Construction Engineering and Management*, 130(4), 613-614.

Russell A. D., Caselton W. F. (1988) Extensions to linear scheduling optimization *Journal of Construction Engineering and Management*, 114(1), 36-52.

Russell A. D., Wong W. C. M. (1993) New generation of planning structures. *Journal of Construction Engineering and Management*, 119(2), 196-214.

Selinger S. (1980) Construction planning for linear projects *Journal of Construction Division American Society Civil Engineers*, 106(2), 195-205.

Thabet W. Y., Beliveau Y. J. (1994). Modeling Work Space to Schedule Repetitive Floors in Multistory Buildings. *Journal of Construction Engineering and Management*, 120(1), 96-116.

Tommelein I. D., Riley D. R. Howell G.A. (1999) Parade Game: Impact of work flow variability on trade performance. *Journal of Construction Engineering and Management*, vol 125, n.5/1999

Vanhoucke M. (2006) Work Continuity Constraints in Project Scheduling *Journal of Construction Engineering and Management*, 132 (1), 14-25.

Yang I. T., Ioannou P. G. (2001) Resource-driven scheduling for repetitive projects: a pull-system approach, *Proceedings of the 9th International Group for Lean Construction Conference*, Singapore, 6-8 August, 365-377.

Yi K.J., Lee H. and Choi Y.K. (2002) Network Creation and development for Repetitive-Unit Projects *Journal of Construction Engineering and Management*, 128(3), 257-264.