Model and Problem Generation Tool of Project Scheduling Problem with Spatial Resources

Daoguang ZHANG, Lanshun NIE, Jintao JIN, Dechen Zhan, Xiaofei Xu

School of Computer Science and Technology, Harbin Institute of Technology
92 West Dazhi Street, Nangang District, Harbin 15001, China

daogzhang@gamil.com
nls@hit.edu.cn
jintaojin@gmail.com
dechen@hit.edu.cn
xiaofei@hit.edu.cn

Abstract**—**Spatial resources such as slipway, platform, and mould are key and bottleneck resources for OKP (One-of-a-Kind Production) and construction industries. However, researches focusing on RCPSP (Resource Constrained Project Scheduling Problem) with spatial resource are still rare and there is a large gap between academic research and practical requirement. In this study, characteristics of spatial resource are systematically investigated. Activities are well classified into types, *i.e.* call, release, and interval activity based on their behaviours in utilizing spatial resources. Then, mechanisms of utilizing spatial resources are proposed according to two dimensions, *i.e.* quantity and position. A reference problem formulation of RCPSP with spatial resource is provided. We design a problem generation tool taking spatial resources into account, and explain the design method in detail.

Key words Project Scheduling, spatial resource, activity group, generation tool

I. INTRODUCTION

There is usually a kind of special resource, *i.e.* Space or Fixed facilities in OKP (one-of-a-kind production) and construction enterprises. Some typical examples are slipway, erection platform, crane in shipbuilding enterprises, assembling workshop in aircraft manufacturers and moulds in construction enterprises. These resources are generally named spatial resource [1]. Spatial resources usually belong to strategic resources of OKP and construction enterprises because of high investment. They are also usually bottlenecks which restrict output and efficiency of enterprises. For example, the utilization rate of slipway directly affects the output of ship manufacturing enterprise. As a result, the question arises of how to efficiently utilize spatial resources and schedule activities in projects with limited capacity of spatial resources and other resources in order to shorten the make-span of projects and increase the output of enterprise in OKP and/or construction enterprises.

According to the well-known resource classification in project scheduling field [2], spatial resource belongs to renewable resource. However, spatial resource is so different from labour, machine, and other ordinal renewable resources that Resource-Constrained Project Scheduling Problem (RCPSP) with Spatial resources, entitled as sRCPSP, is more complex. Firstly, because of the “spatiality” of spatial resources, project scheduling should answer not only “when to start activities”, but also “where the activities is carried out”. *i.e.* decision on the partition of resources and the position that activities happen . Secondly, the objects processed on spatial resources, for example a ship or a wall, usually are immovable, or nearly immovable. Thus, spatial resource is continuously occupied by a group of activities (i.e. activity group), not by single activity. So, when scheduling activity groups with spatial resource, we should be careful to simplify them as single task in sRCPSP because this will lead to less optimal solution or failure to obtain feasible solution caused by deadlock[3]. Because of the distinguished characteristics, sRCPSP is very different from and more complex than RCPSP without spatial resources. It is necessary to study spatial resources and sRCPSP, which will not only enrich project scheduling theory in academic, but also address the practical requirements in industry.

Based on our comprehensive review in project scheduling research field, we find that researches on spatial resource and sRCPSP is still limited. Lee et al[6] studied spatial scheduling method and software system, and successfully applied them in curve blocks manufacturing scheduling of shipbuilding enterprises (Daewoo Shipbuilding). Koh et al[7] studied a problem similar to Lee’s. They divided the block assembly scheduling problem into two stages, namely activity scheduling and spatial layout. The former schedules activities and load balancing by genetic algorithm. The latter treats spatial layout problem which is constrained by scheduling result. The problem studied by Park K. et al[8] can be regarded as a special case of Lee’s. They deal with one-dimensional spatial resource, and use tabu-search and genetic algorithms to determine the order of layout. Park C. et al[9] studied for block painting shop in shipbuilding industry, and the algorithm are applied in the HYUNDAI Company. Koh S. etal[10] improved layout algorithm for spatial scheduling problem based on research work of above several scholars. Koh S. et al[11][12] studied the big block assembly spatial scheduling problem in which 1-dimensional and divisible spatial resource is utilized in fixed and constant mode.

Based on our knowledge on typical industry and existing literatures, this study investigated concepts, mechanisms and models of project scheduling problems with spatial resources. Firstly, characteristics of spatial resources and activity group are analysed. Then we proposed several spatial resources utilization mechanisms by activity group. After that, we established concepts, classification, symbols and model of sRCPSP. We need lots of problem instances when research project scheduling problems, but instances from the actual are few and difficult to control. Kolisch. et al[11][12] designed a tool called PROGEN as project scheduling problem builder, and used this tool to generate a standard problem library PSPLIB, which is a great convenience for resource-constrained project scheduling problem. But it just considered three types of resources: renewable, non-renewable and dual nature resources. Research about spatial resource-constrained project scheduling problem also requires a lot of problem instances, but there is no corresponding problem generation tool. So this paper will design such a problem generation tool.

II. CONCEPTS，FEATURES AND CLASSIFICATION OF SRCPSP

Firstly, we present a definition for spatial resource and activity group from two views.

Definition 1 Spatial resource is a kind of renewable resource with spatiality, which plays a role of holding or accommodating some objects in process. It is required by a group of activities, rather than a single activity. Accordingly, the group of activities is called a spatial resource activity group (or just activity group)[1],[4].

A. Characters of Spatial Resource

Besides occupation by activity group, spatial resource has following characters.

Character 1 Spatiality: There are two meaning concerning the spatiality of spatial resources. One is its space dimensions and the measure in each dimension; another is its geometric shape.

Character 2 Divisibility: Some kinds of spatial resources can be dynamically divided into smaller spatial resources during utilized. A smaller piece of this resource is named as a *Resource Block*.

Character 3 Directivity: Some spatial resource is directional, for example, a slipway. Respectively use σ_1、σ_2 and σ_3 represent spatiality、divisibility and directivity，then one kind of spatial resource can be described as ($\sigma_1, \sigma_2, \sigma_3$)， such as ($1, d, o$) represent 1-dimensional、can be divided and single-ended release space resource, it can be further simplified as $1do$.

B. Characters of Activity Group and Classification of the Task in Group

From the perspective of utilization, spatial resource is occupied by activity group while not single activity. We call it as the group characteristics of spatial resource. There are three kinds of activity in the activity group: call activity、movable activity and release activity. Call activity is responsible for applying space resources needed by activity group, movable activity may have the condition that spatial resources are movably occupied, release activity is the last activity of the activity group, is responsible for releasing the space occupied by the activity group.

G_g is the g^{th} activity group. Call activity set J_g^c consists of all call activities, and these call activities are numbered according to their precedence constraints. $j_{g,n}^c$ is the n^{th} call activity of activity group g, and $j_{g,1}^c$ is its beginning activity. j_g^r is the only release or ending activity of G_g . The beginning time and ending time of G_g can be calculated by $s_g = \{s_i \mid j_i = j_{g,1}^c\}$ and $f_g = \{s_i + d_i \mid j_i = j_g^r\}$ respectively. All non-call activities and non-release activities of G_g constitute intermediate activity set J_g^i . Removable activities of G_g constitute removable activity set J_g^m , and $j_{g,n}^m$ is n^{th} removable activity of G_g . $\delta_{g,n}^m = (\delta_{g,n,1}^m, ..., \delta_{g,n,D_l}^m)$ is the moving direction of movable activities, where $\delta_{g,n,k}^m \in \{1, -1\}$ represent the positive or negative on n^{th} dimensional.The requirement on spatial resource l of call activity $j_{g,n}^c$ is described as requirement vector $r_{g,n,l}^\sigma$ =($r_{g,n,l,1}^\sigma$,..., r_{g,n,l,D_l}^σ), where $r_{g,n,l,d}^\sigma$ means $r_{g,n,l,d}^\sigma$ units resource is required on the d^{th} dimension.To simplify, we assume that 2-D and 3-D spatial resource are rectangle and polyhedron, respectively.

C. Formulation of SRCPSP

AON network of the project consists of {*1*,…,*N*} activities, where the only start activity (j_0) and finish activity(j_{N+1}) are introduced, and their resource requirement and duration are all zero. Set P_i consists of immediate precedence activities of activity i whose duration is d_i . R^ρ is the “plain” renewable resource set, where $R_k^\rho \in R^\rho$ represents k^{th} renewable resource whose availability is a_k^ρ on each time unit within plan horizon T. Activity j_i requires r_{ik}^ρ units per time unit for renewable resource R_k^ρ . R^σ is the spatial resource set, where $R_l^\sigma \in R^\sigma$ represents l^{th} spatial resource whose availability is D_l -Dimension vector a_l^σ =($a_{l,1}^\sigma$, $a_{l,2}^\sigma$,…, a_{l,D_l}^σ) on each time unit within plan horizon T. I_t is a set including all the in-processing groups. Given that the planning horizon starts from 0.

There are three kinds of constraints. First is *precedence constraints*, which force activity j_i can not start unless all its precedence activities $j_z \in P_i$ are finished. Second one is the *"plain" renewable resource related constraints*, i.e. all requirements within one time unit must be less than a_k^ρ. Last one is *spatial resource related constraints* which restrict the concurrent activity groups not to occupy spatial resource blocks overlapped.

Decision variables are formulated in this paragraph. s_i denotes the start time of activity j_i. Use $S_{g,l}$ to present the spatial resources allocated to activity group G_g. Here we assume that the layout of spatial resource and its resource blocks occupied by activity groups are all orthogonal with *x* and *y* axis. At time *t*, ($CurS_{g,l,t}$, $CurC_{g,l,t}$) denotes the spatial resource block occupied by G_g, where $CurS_{g,l,t}$ =($CurS_{g,l,t,1},...,CurS_{g,l,t,D_l}$) and $CurC_{g,l,t}$ =($CurC_{g,l,t,1},...,CurC_{g,l,t,D_l}$) represents the start position and the end position respectively. $CG_{g,t}$ denotes the specific shape of spatial resource blocks(1-Dimensional resource blocks is a segment, 2-Dimensional resource blocks is a rectangle, and 3-Dimensional resource blocks is a polyhedron). The formulation of sRCPSP with objective minimizing make-span is as following:

$$\min s_{N+1} - s_0 \tag{1}$$

s.t.

$$\sum_{j_i \in I_t} r_{i,k}^\rho \le a_k^\rho \,, \quad \forall R_k \in R^\rho ; \forall t ; \tag{2}$$

$$s_l \ge s_i + d_i \,, \quad j_i \in P_l ; \tag{3}$$

$$s_i \ge 0 ; \tag{4}$$

$$C_{g,n,l} - S_{g,n,l} \ge r_{g,n,l}^\sigma \,, G_g \in G, R_l^\sigma \in R^\sigma \tag{5}$$

$$CG_g \cap CG_h = \phi \;\; G_g, G_h \in G, R_l^\sigma \in R^\sigma \tag{6}$$

$$CurC_{g,l,t} = CurS_{g,l,t} = 0, t \in [0..s_g] \cup [f_g..T]; \tag{7}$$

$$CurC_{g,l,t} \le a_l^\sigma, \forall t \in [1..T] \tag{8}$$

The objective function (1) minimizes the make-span of the project. (2) denotes the renewable resource related constraints. (3) forces activities to start after its immediately precedes. (4) forces every activity to start not before zero. (5) means that the requirement of every activity group should be satisfied. (6) ensures that spatial resource blocks allocated to concurrent activity groups are not overlapped. (7) denotes that activity group does not occupy spatial resource before starting or after ending. (8) denotes the constraints of spatial resource availability.

If the spatial resource related constraints are released, sRCPSP deduces to RCPSP who is *NP-hard*, so sRCPSP is also *NP-hard*.

III. PROBLEM GENERATION TOOL FOR SRCPSP

In the field of project scheduling, researchers need to test the algorithm that they design, which requires a lot of data. So far, several existing resource- constrained project scheduling problem generation tools only consider renewable resources, non-renewable resources, and the dual nature of resources, none of which consider spatial resources. Therefore, developing a problem generation tool of spatial resources is necessary, which will enrich the tool set in the field of project scheduling.

A. Definition For Input And Output

The tool that this paper designs is based on PROGEN but adds spatial resource constraint. First we need to define the format for input (base files) and output file (example file).

(1)Base file

Base file describes the constraints for project scheduling problem, the base file of PROGEN contains many parameters , you can refer to the relevant literature. This paper extends the spatial resource constraints, so we need to add some parameters.

①Parameters about activity group

MinNofTaskG(MaxNofTaskG)：the min(max)number of activity groups in every subproject.

MinNofJobTask(MaxNofJobTask)：the min(max) number of activities in every activity group.

MinNofQJob(MaxNofQJob)：the min(max)number of request activities in every activity group.

MinNofMJob(MaxNofMJob)：the min(max)number of movable activities in every activity group.

②Parameters about spatial resources

NofSR：the number of spatial-resource types;

SRAmin(SRAmax)：the min(max)kinds of the spatial resources of SRA type;

SRAminDemand(SRAmaxDemand)：the min(max) needs of SRA type;

SRARmin(SRARmax):the min(max)kinds of needs of activity group for SRA type;

SRAF：the resource factor of SRA type;

SRAS：the resource intensity of SRA type.

(2)Example file

Example file is used to describe a specific space resource project scheduling problem instance. The example file of PROGEN includes projects and the information of subprojects etc. The example file of this paper designs is based on PROGEN, and takes activity group information, the spatial-resource needs of every activity group, the spatial-resource division of request activity, the amount of available spatial resources, and the direction of spatial resources.

B. The Tool's Generation Method

The generation process can be divided into five parts, as follows.

1) Generation of specific parameters

Specific parameters include: the number of activities of every subproject, the number of activities of all projects, the number of modes of activity j, the duration of each mode, the start time of each subproject, The time span of the project, the critical path length of each subproject, the number of kinds of certain spatial resource, the number of activity groups of each subproject.

2) Generation of project network

The generation of the project network is very complex, you can refer to relevant literature[13].

3) Generation of activity group

Firstly, according to the activity group information defined in the base file, generate the number of tasks, request tasks and movable tasks randomly. After that, the generation of activity group is as follows:

①Add the activity which is not in any activity group to the candidate set, and choose an activity randomly as the first activity of current activity group.

②Add the direct precursor and direct successor of the just selected activity to the extension set, randomly select an activity and add it to the current activity group, at last remove it from the extension set.

③Repeat ②, until the number of activities reach the specified value.

④Generate request activities of the activity group.

⑤Generate movable activities of the activity group.

4) Generation of resource requirements

Due to spatial-resource's particularity, the method is different from the general resource. The generation of spatial-resource requirements this paper designs includes two parts: generate resource's type and generate resource's level. The main idea of the generating resource's type is similar with PROGEN, so this paper mainly describes how to generate resource's level.

① For each activity group, if it needs some spatial resource, randomly generate the resource demand on various dimensions between the minimum and maximum demand.

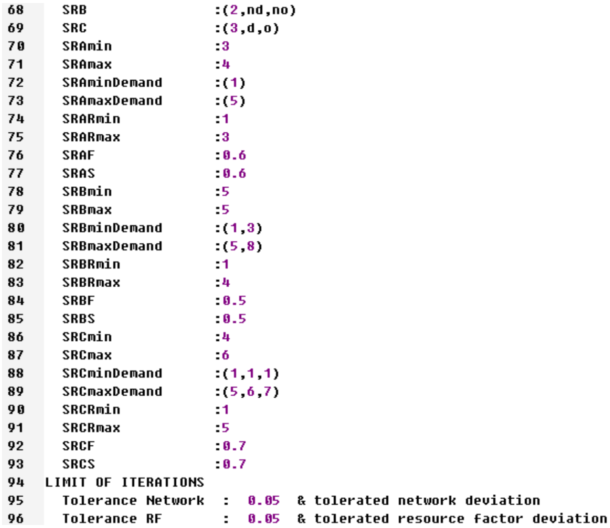
②For each activity group, divides its spatial-resource's requirements to every request activity.

5) Generation of available resources

According to the project scheduling problem model, we have generated the amount of resource requirements, and resource intensity is designated in the base file. So we can calculate the amount of available resources following the formula.

IV. DEMONSTRATION OF THE TOOL

This paper designs a project scheduling problem generation tool containing spatial resources, which can generate scheduling problem considering renewable resources、non-renewable resources、dual nature resources and spatial-resource constrained problem. The tool is based on PROGEN, and adopted JAVA for programming to achieve a new project scheduling problem generation tool which contains spatial-resource constrained , called SRPROGEN.



```
68    SRB                :(2,nd,no)
69    SRC                :(3,d,o)
70    SRAmin             :3
71    SRAmax             :4
72    SRAminDemand       :(1)
73    SRAmaxDemand       :(5)
74    SRARmin            :1
75    SRARmax            :3
76    SRAF               :0.6
77    SRAS               :0.6
78    SRBmin             :5
79    SRBmax             :5
80    SRBminDemand       :(1,3)
81    SRBmaxDemand       :(5,8)
82    SRBRmin            :1
83    SRBRmax            :4
84    SRBF               :0.5
85    SRBS               :0.5
86    SRCmin             :4
87    SRCmax             :6
88    SRCminDemand       :(1,1,1)
89    SRCmaxDemand       :(5,6,7)
90    SRCRmin            :1
91    SRCRmax            :5
92    SRCF               :0.7
93    SRCS               :0.7
94  LIMIT OF ITERATIONS
95    Tolerance Network  :  0.05  & tolerated network deviation
96    Tolerance RF       :  0.05  & tolerated resource factor deviation
```

Fig.1. Instance of base file

Fig.1. shows an instance of base file. In accordance with the prescribed format, the base file gives all the constraints for target problem to generate. Because there are too many parameters , fig.1. only shows part shots. For example, sixty-ninth row represents the third kind of spatial resources, and from eighty-sixth row to ninety-first row shows specific definition of SRC, as SRCRmin represents the min kinds of needs of activity group for SRC type.

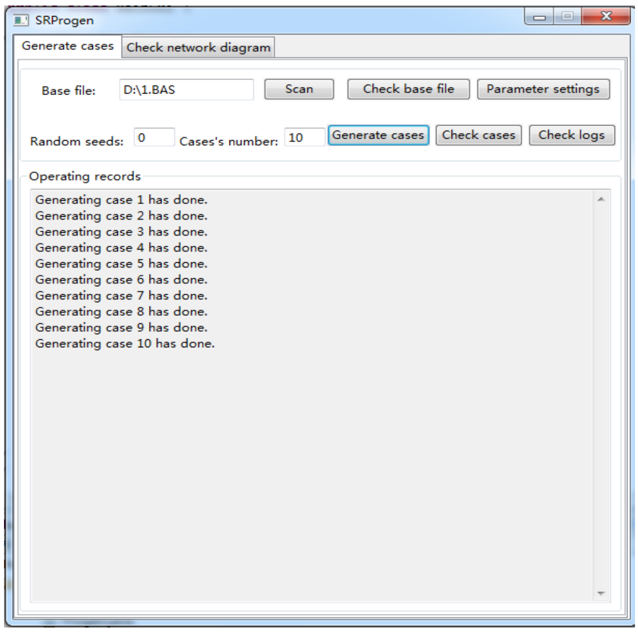


Fig.2. Main interface of the tool

Fig.2. shows the main interface of the tool, it can use the "Scan" button to choose base file to generate the example file. The bottom of fig.2. shows the result after clicking "Generate cases" button, as shows, it generates ten cases.

```
538 100                 (4,5)
539             40      (4,5)
540 ************************************************************************
541 SPATIAL  RESOURCE AVAILABILITIES:
542 SRA1
543 (26,27)
544 ************************************************************************
545 SPATIAL RESOURCE ORIENTATION:
546 SRA1
547 (0,0)
548 ************************************************************************
549 POLYGON STYLE 2-DIMENSIONAL SPATIAL  RESOURCE REQUESTS:
550 jobnr. mode duration  EST   LST  REQSP   VertexNr  SHAPE
551 ------------------------------------------------------------------------
552  1     1     0     1   1  (0,0)     0   null
553  2     1     1     1   1  (3,8)     4   (0.00,0.00)(0.00,8.00)(-3.00,4.68)(-3.00,1.95)
554  3     1     3     2  32  (2,7)     3   (0.00,0.00)(2.00,5.11)(0.00,7.00)
555  4     1     9     2   2  (9,9)     3   (0.00,0.00)(4.86,9.00)(-4.14,9.00)
556  5     1     4     2  11  (3,9)     4   (0.00,0.00)(6.93,2.39)(-2.03,3.00)(-2.07,2.05)
557  6     1     1    11  11  (7,3)     4   (0.00,0.00)(4.43,2.97)(2.02,3.00)(-2.57,1.72)
558  7     1     4    11  13  (6,5)     3   (0.00,0.00)(6.00,0.00)(5.67,5.00)
559  8     1     2     2   9  (7,4)     6   (0.00,0.00)(1.05,1.30)(1.05,2.59)(-1.71,7.00)(-2.95,2.89)(-2.95,1.22)
560  9     1     5     6  15  (9,8)     5   (0.00,0.00)(1.18,6.39)(-2.35,9.00)(-6.82,3.58)(-6.82,0.61)
561 10     1     2    15  17  (4,4)     4   (0.00,0.00)(2.61,3.50)(1.97,4.00)(-1.39,2.09)
562 11     1     6    12  35  (3,8)     4   (0.00,0.00)(3.00,0.00)(3.00,8.00)(0.00,8.00)
563 12     1     5     4  11  (9,8)     6   (0.00,0.00)(0.95,4.52)(0.95,5.98)(0.92,9.00)(-7.05,2.00)(-2.31,0.00)
564 13     1     4    11  20  (6,6)     4   (0.00,0.00)(4.12,0.72)(-0.29,6.00)(-1.88,2.66)
```

Fig.3. Instance of example file

Fig.3. shows an instance of example file. It describes the number of subproject、the information of activities、the information of activity groups、the resource demands and available resources etc. Because when there are too many activities ,there will be a lot of information in the example file, so fig.3. only shows part shots. For example, Line 554 first gives the number of this activity is three, there is one mode and it's duration is three; Then is gives its earliest start time and last start time, which is two and thirty-two respectively; At last, it shows it's a triangle with coordinates of the three vertices are (0.00, 0.00)、(2.00, 5.11) and (0.00, 7.00) respectively.

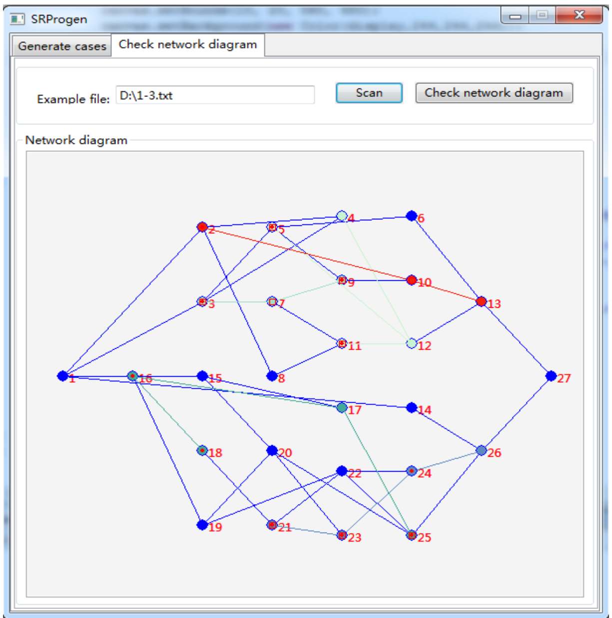


Fig.4. View of the project network

Fig.4. shows a view of the project network. The use of designing this function is to see the information having generated about project network structure and activity groups clearly. From fig.4. we can draw that there are two subproject of this project which is composed by twenty-seven activities, and the activities connected by the line of same color are in one activity group.

V. INTRODUCTION OF SCHEDULING ALGORITHM ABOUT SPATIAL RESOURCES

We have implemented some algorithms about resource-constrained project scheduling problem. First, we proposed a method based on configuration space theory for solving the problem about where to place the segmentation, and the following we will introduce the main idea.

From the beginning, it calculates the venue configuration space of the segmentation; Then it calculates the obstacle space produced by the segmentation will be placed with others have placed; Then it calculates configuration point set which can be used now, if the point set is empty then turns to conflict management, otherwise it will choose one point from the point set; Finally, it will place the segmentation on this point.

After we have known where to place the segmentation, we also need to know when to place the segmentation. For this reason, we propose an algorithm based on artificial bee colony ABC. Because limited to the paper space, we only give the main idea. We take the food resource position vector as a feasible scheduling scheme so the goal is turned to find the best food resource, then we can use artificial bee colony algorithm to solve the resource-constrained project scheduling problem. When we calculate the better food resource, it will invoke the layout algorithm proposed above. By this, we mainly have solved the resource-constrained project scheduling problem in an acceptable time.

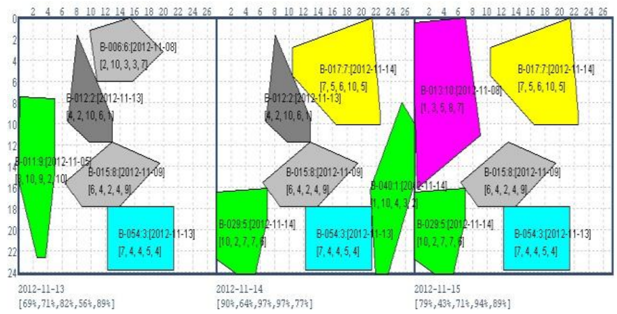


Fig.5. An example of configuration result

Fig.5. shows an example of configuration result. It shows the configuration results from November 13, 2012 to November 15, 2012, and it gives the use of spatial resources and the regular resources needed by activities. The centre of spatial resources occupied by activities shows the name of activities and their start time.

By fig.5 we can see that the algorithm proposed this paper has a good performance to solve the resource-constrained project scheduling problem.

VI. CONCLUSION

Based on the analysis of typical spatial resources in typical industry, we propose some concepts and properties of spatial resources, such as spatiality, divisibility, directivity and group characteristics. We propose a problem generation tool for sRCPSP and explain the design method of the tool in detail, by which we can have rich test data for further studies about spatial resources. Then, we give the demonstration of the tool. Finally, we give the algorithm to solve the resource-constrained project scheduling problem.

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