Minimization of Failed Roads - A Hybrid Resource-Constrained Project Scheduling Problem

Patience I. Adamu, Michael C. Agarana, and Hilary I. Okagbue

***Abstract*— Causes of failed roads and the reasons why most roads stay consistently failed in some nations of the world, like Nigeria, may be attributed to many factors, salient among them may be *corruption and recession* ultimately. Corruption in the award of road construction contracts make roads not to be properly done, to meet set standards thereby failing almost immediately they are completed. So, if corruption is minimized in awarding road construction contracts, the number of failed roads maybe minimized. This paper introduces some solution methods to minimize corruption in road construction projects so that good and sustainable roads are constructed even if there is also recession. In our experiment, we formulated the construction of real life 5km asphalt road as a hybrid resource constrained project scheduling problem (HRCPSP). Using priority based project scheduling technique, our results show the number of skilled workers needed in each period which gives the idea of the amount of fund needed in each of the periods. We constructed two Gantt diagrams: when resources are unconstrained and when resources are constrained to the minimal demand of jobs in the eligible set in each period. The unconstrained Gantt diagram helps to know the maximum amount of fund that should be released to the engineers in each period. This helps to curb corruption. The constrained Gantt diagram helps to know the minimum amount that should be released to the engineers for work to go on and the project to get to completion stage even there is recession. This helps project to be completed even if there is recession.**

Index Terms*— Construction Projects, Network Analysis, Project Scheduling, Corruption, Recession

I. INTRODUCTION

TRANSPORTATION is a very important tool in the economic development and civilization of a nation. This is because it facilitates the movement of goods and passengers. In some nations of the world, like Nigeria, road transportation is the major means of movement [4]. Hence constructing good and sustainable roads is of paramount importance.

The main causes of failed roads in some nations of the world, may be attributed to many factors, the most important among them may be *corruption*. In Nigeria, for instance, corruption is a persistent phenomenon (Wikipedia [10]) and its economy slipped into recession in early 2016. In our opinion, corruption and recently recession may be the ultimate reason why, most of its roads are in deplorable states and are death traps to its citizenry [1]. What is to be done to minimize corruption in road construction projects thereby minimizing the number of failed roads is the main motivation of this paper.

This paper introduces some solution methods which seek to minimize corruption in road construction projects which is a major factor for failed roads in nations where the level of corruption is very high, like Nigeria.

- Our solution methods first of all, advocates that all the needed materials be purchased before any job execution starts when a road construction contract is awarded and a new road is to be constructed. This brings an end to the idea of reviewing contract agreements, which in our opinion is an avenue for corrupt practises.
- In awarding any road constructing contract to any constructing firm, every stakeholder should be represented: the state governors, the county (local government) chairs, the village heads, the elders, the youths, all the road transport unions and the market women in the communities. The essence of making a large crowd of people to be involved is because, not everybody is corrupt. There are still some individuals who will still prefer good roads in their communities than having some few dollars in their pockets.
- All stakeholders should know and understand in detail the terms of the contract.
- Everyone involved should know when every periodic payment is paid and how much.
- Everybody should be involved in the accountability process.
- In the quality control process all stakeholders should be represented. Everyone is involved in checking to see that the terms of the contract are adhered to in every period. That is, the right materials are used in their right quantities before going to the next period.
- Institutions should be established to make sure that there is continuity in projects even when the country's leadership changes hands. This minimizes corruption because awarding new contracts in our opinion, is an avenue for corruption.
- We then formulated the road construction problem as a hybrid resource-constrained project scheduling model (HRCPSP). In this model, the funds (resources) made available each period varies from period to period. A

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period could be a week or a month. The maximum funds (resources) given per period should not be more than the amount needed to execute the eligible jobs in that period. The minimum, be such that at least a job should be executed in that period, hence encouraging disbursement of funds (resources) in small quantities, which is what is needed if there is recession. This also helps to check corruption, since disbursing large amount of funds (resources) at once, encourages misappropriation of funds (resources) in a nation that is bed ridden with corruption, like Nigeria. This model also seeks to minimize the total completion time of the project.

- We then use priority based project scheduling technique to solve the model. The solutions which is a schedule, tells the engineers the jobs that should be processed in each period so that completion time of the project is minimized.

The main contribution of this paper is to present some methods to reduce corruption in road construction, thereby reducing the number of failed roads, in countries where corruption is the main reason why their roads are death traps to its citizenry.

II. PRELIMINARIES AND RELATED WORKS

A. *Recourses for Resource-Constrained Projects*

Slowinski [6] and Weglarz [9] categorized the resources (e. g. manpower, materials, equipment, capital etc.) needed for the execution of a project into categories, one of them is renewable resource:

Renewable Resources: These are resources that are made available per period (hourly, daily, weekly, monthly, etc). For each period, the quantity of each resource (say, manpower) made available can be constant or it can vary. In this paper the renewable resource is assumed to vary from period to period to reflect true life situations. For example, a company can decide to make available 5 skilled and 10 unskilled labourers in first day, 4 skilled and 6 unskilled labourers in second day, 10 skilled and 20 unskilled labourers in third day and so on for the execution of a particular project until it is completed.

B. *Priority Based Project Scheduling Technique*

This technique constructs precedence and resource feasible project schedules. It is made up of a priority rule and a schedule generation scheme. The priority rule lists the jobs of the project in a topological order while the schedule generation scheme finds the finished times of each job (schedule) using the activity list. There is quite a number of existing priority rules (Vanhoucke [8]). They used different information on the project as job priorities. Examples include: Shortest Processing Time (SPT) which uses the processing times of the jobs to determine the job priority, Minimum Slack (MSLK) uses the logic of the network to know which job to choose and Greatest Resource Work Content (GRWC) uses the project resource information, and so on.

There are only two Schedule Generation Scheme (SGS) available: the serial SGS and the parallel SGS [5]. In constructing their schedules, the serial SGS selects an activity and then schedules it at its earliest precedence and resource feasible finished time while the parallel SGS schedules the jobs at their schedule times.

C. *Single-Mode RCPSP Model*

The resource-constrained project scheduling problem (RCPSP) considers a single project with J number of jobs $(j = 0, 1, 2, 3, \dots, J, J+1)$ to be performed, where job j = 0 corresponds to a unique dummy source (project start) and job j = J+1 corresponds to the unique dummy sink (project end). Dummy jobs are appended only if there is no unique start and end jobs naturally. Two types of constraints exist between jobs: the precedence constraint and the resource constraint. The precedence constraint delays the performance of a job until all its immediate predecessors (P_j) are completed. That is, a job cannot start processing unless all its direct predecessors (P_j) are completed. In the resource constraint, the jobs require resources to be processed, but the availability of each resource is limited. There are K types of renewable resources $(k = 1, 2, 3, \dots, K.)$. Each resource type $k \epsilon K$ has constant per-period availability of R_{kt} and each job uses r_{jk} units of resource type k to be processed every period of time. Once job j starts processing, there is no interruption and its processing time is p_j. For both start and end jobs j = 0 and j = j+1, their processing times $d_j = 0$ and their resource usage $r_{j,k} = 0$ for all k. The objective is to find precedence and resource feasible schedule that minimizes the makespan (total completion time) of the project.

A conceptual formulation of the scheduling problem by Talbot and Patterson [7] is as follows:

$$Minimize\ F_{n+1} \quad (1)$$

Subject to:

$$\underset{n \epsilon P_j}{\mathrm{Max}}\{F_n\} + d_j \leq F_j;\ \forall j = 1, 2, \cdots n+1; n \epsilon P_j \quad (2)$$

$$\textstyle\sum_{j \epsilon A(t)} r_{j,k} \leq R_{kt};\ k \epsilon K;\ t \geq 0 \quad (3)$$

$$F_j \geq 0 \quad (4)$$

where F_j denotes the completion time of job j; a vector of finished times of the jobs, denoted by $\{F_1, F_2, \dots, F_n\}$ is called a schedule and $A(t)$, the set of jobs undergoing processing at time t.

The objective function (1): minimizes the finish time of the last job of the project, which minimizes the total completion time of the project. Constraints (2): the precedence constraint ensures that the start time of job j is greater than the finished time of all its predecessors (F_h). Constraints (3): demands that in time t, the resource constraint enforces that the total resource demands of the jobs under processing A(t), should not be greater than the limit for each resource type k. Constraint (4): ensures that the finished times of every job j, F_j is greater or equal to zero. It defines the decision variables.

Blazewicz et al. [2] showed that RCPSP belongs to the class of NP hard optimization problems. Hence, solving large problem instances owe themselves only to heuristic solution methods.

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III. SOLUTION METHOD

In this section, we describe the solution methods that seeks to reduce corruption in the awards of road construction contracts and also minimizes completion time even if there is recession.

A. All Needed Materials to be Purchased Before Job Execution Starts

Our solution method, first of all advocates that a road construction contract should be awarded on the bases that the firm, buys all the needed materials before the commencement of any work. The reason being that after some time into the commencement of the project, prices of some materials may increase and the contract agreements may have to be reviewed. In our opinion, the review of contract agreements, due to price increase is an avenue for corrupt practices which can be avoided if all the needed materials are purchased upfront before the commencement of any job.

B. Every Stakeholder to be Involved

In awarding any road constructing contract to any constructing firm, every stakeholder should be involved: the state governors, the county (local government) chairs, the village heads, the elders, the youths, the road transport unions and the market women in the communities. The essence of making a large crowd of people to be involved is because, not everybody is corrupt. There are still some individuals who will still prefer good roads in their communities than having some few dollars in their pockets. Or rather, it may be cheaper for the firm to do the right thing than to give bribe to all the crowd of people.
The stakeholders should know and understand in details the terms of the contract and when every periodic payment is made. They also should be actively involved in the accountability and quality control processes. That is. everyone should be involved in checking to see that the terms of the contract are adhered to in every period, by making sure the right materials are used in their right quantities before going to the next period.

C. Establishment of Institutions

Institutions should be established to make sure that there is continuity in projects even when the country's leadership changes hands. This will, to an extent minimize corruption when no new contracts are being awarded and will move that nation forward in terms of development even if there is recession.

D. *Formulation of the Road Construction Project as a Hybrid RCPSP*:

a) The Description of the Hybrid- Single Mode RCPSP

The hybrid single-mode RCPSP is a combination of the existing single-mode RCPSP (Talbot and Patterson [7]) and some added assumptions below. So the conceptual formulation of this problem is:

$$\text{Minimize } F_{n+1} \tag{1}$$

Subject to:

$$\max_{n\epsilon P_j}\{F_n\} + d_j \le F_j;\ \forall j = 1,2,\cdots n+1; n\epsilon P_j \tag{2}$$

$$\mathbf{\min r_{j,k} \le R_{kt};\ \forall j\epsilon E(t);\ k\epsilon K; t \ge 0} \tag{3}$$

$$\sum_{j\epsilon A(t)} r_{jk} \le R_{kt};\ k\epsilon K;\ t \ge 0 \tag{4}$$

$$F_j \ge 0 \tag{5}$$

where constraint (4) is a mathematical representation of the assumption (i) below. It demands that in time t, the resource constraint enforces that the minimum resource demand of jobs in the eligible set (E(t) is the set of jobs whose predecessors has been scheduled) be not greater than the limit of each resource type k given in that period. This ensures that in every period, the resource provided should be enough to execute at least one job.

The Added Assumptions

i) Per-Period Resource be allowed to vary

The level of the per period resource be allowed to vary from time to time, but may not be less than the minimum resource requirement of any job in the eligible set of jobs, if work will be done in that period.
This assumption is necessary to take care of the situation where there is a demand to increase or reduce the renewable resource for convenience. The effect is that anytime the available amount is changed, the remaining jobs are simply rescheduled using the recent level of renewable resource. This will only vary the completion time of the project.

ii) *The period allowed to vary from time to time.*

The need to change the period, say from weekly to monthly or vice-versa may arise. For example, the project owner may have been providing the funds monthly, and now wants it to be weekly or even quarterly (every three months), or vice versa. The effect again is the same as per period availability. The remaining jobs are simply rescheduled using the new period. Again the project completion times varies accordingly.

b) The Road Construction Project

The road construction project is formulated as a Hybrid RCPSP model by writing out the activity list and constructing the network. This model encourages dedicated periodic funding, which is expected to vary from period to period, to reflect true life situations (recession). The amount of funds (resources) to be given per period is known from the resource demands of the eligible jobs in that period and is such that at least a job will be executed in that period. This shows that available funds (resources) per period, are in small quantities, just enough to execute the eligible jobs, which is what is needed in an economy in recession and also helps to checkmate corruption, since disbursing large amount of funds (resources) at once, encourages misappropriation of funds (resources) in nations already known for corruption, like Nigeria.
We then use priority based project scheduling technique to solve the model. The solutions which is a schedule, tells us the jobs that should be processed in each period so that completion time of the project is minimized.

Below are the jobs needed to be completed in the construction of an Asphalt road:

Reconnaissance survey, Subgrade soil sampling, Subgrade bearing capacity determination, Design, Clearing of site: Demolition of buildings, relocation of services (e. g electric poles, pipes, cables, Removal of Vegetation (deforestation may be involved), Removal of Top Soil, Analyzing the Sub-grade (If the sub-grade is not okay, it should be replaced with a good soil that meets the desired standard), Compaction of Formation, Pegging/Setting out, Excavation of trenches for lined drain, Construction of lined drains (LHS and RHS), Excavation of trenches for retaining wall, Construction of retaining wall, Excavation of trenches for culverts, Construction of access and cross culverts, Construction of median separator, Spreading and Compaction of subbase, Spreading and Compaction of stone base, Priming of Stone base, Asphalting (Binder course), Asphalting (Wearing course), Surface Markings

IV. EXPERIMENTS

Experimental setup

Our experiment is a real life two-lane 5km asphalt road and 7.3m in width. The subgrade thickness is undefined. The Subbase (laterite) is 0.15m thick while the base course (crushed stones) is 0.10m thick. The binder course (asphalt) is 0.06m in thickness and the wearing course (asphalt) is 0.04m thick.

The project is formulated as a RCPSP, by writing out the activity list (Table 1) and its network (Fig. 2). Since our solution method advocates that all the materials T be purchased before the execution of any job in the site, column 2 which contains the job description shows that all the needed materials are obtained before the first job is done, which is clearing of the site.

The Constructed Network

The constructed network shows the order in which the jobs should be executed.

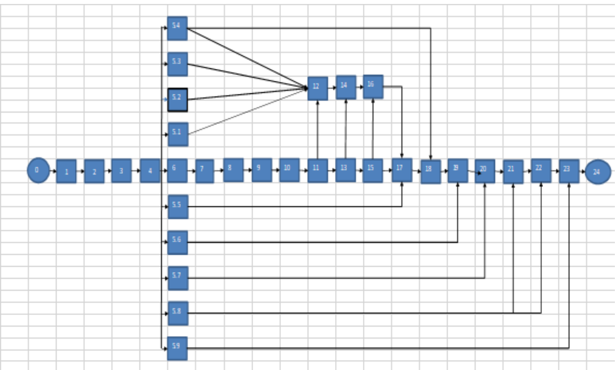

Fig. 1: The Network of the road project of Table 1

Table 1: An activity list for a 5km asphalt road. bungalow

Job No.	Job Description	Pevious Jobs	Duration/ (week)	No. of Skilled Workers
0	Start Job	0	0	0
1	Reconnaissance survey	0	1	9
2	Subgrade soil sampling	1	1	6
3	Subgrade bearing capacity determination	2	2	8
4	Design	3	1	2
5.1	Obtain Cement	4	1	1
5.2	Obtain Sharp sand	4	1	2
5.3	Obtain Reinforcement bars	4	1	2
5.4	Obtain Aggregate	4	1	3
5.5	Obtain Mortar	4	1	1
5.6	Obtain Crushed rock	4	1	3
5.7	Obtain Primer	4	1	2
5.8	Obtain Asphalt	4	1	2
5.9	Obtain Paint	4	1	1
6	Clearing of site	4	8	14
7	Removal of Vegetation (Deforestation)	6	2	7
8	Scarification of Top Soil	7	4	8
9	Compaction of Formation	5, 8	2	8
10	Pegging/Setting out	9	4	8
11	Excavation of trenches for lined drain	10	8	10
12	Construction of lined drains (LHS and RHS)	5. 11	10	17
13	Excavation of trenches for retaining wall	12	3	10
14	Construction of retaining wall	5, 13	4	17
15	Excavation of trenches for culverts	14	3	8
16	Construction of access and cross culverts	5, 15	4	13
17	Spreading and Compaction of subbase	5, 17	5	8
18	Spreading and Compaction of stone base	5, 18	10	8
19	Priming of Stone base	5, 19	2	11
20	Asphalting (Binder course)	5,20	5	8
21	Asphalting (Wearing course)	5, 21	5	8
22	Surface Markings	5, 22	3	6
23	End job	23	0	0

The fourth column has the estimated duration of each job. The last column contains the number of skilled workers needed to execute each job.

Fig. 2: Shows the number of skilled workers needed for each job.

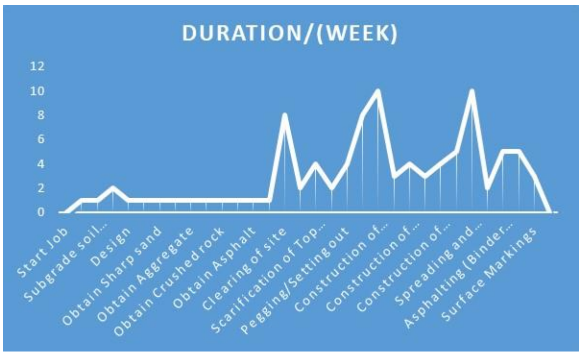

Fig. 3: Shows the duration of each job in weeks

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Results:

a) Figure 4 is the Gantt diagram of Table 1. It is constructed, in such a way to know the minimum number of skilled workers needed in each period, thereby giving the project owners a rough estimate of the least amount of funds needed every period for work to go on. For example, from the network, we observe that job1(Reconnaissance survey) comes first and the number of skilled workers needed to execute that job is 9 (Fig, 2) and it duration is 1 week (Fig. 3). So this informs the engineers the minimum amount needed for the first one week. This is done before the commencement of any job execution, which makes the project owner to plan financially before commencement. This helps project to be completed when resources are very constrained like during recession. Also in nations, like Nigeria where corruption is the order of the day, this formulation gives the knowledge of approximately the amount of funds that should be disbursed in every period, which helps to check misappropriation of funds.

b) Fig. 5 is a Gantt diagram when resources are not constrained. It is to be able to know the maximum amount of funds needed per period, so that large amounts of money will not be given out which will encourage misappropriation of funds.

c) Finding the Minimum Completion Time of the Project when resources are unconstrained:

After the formulation, we use a priority based project scheduling technique to find the minimum schedule which tells us the jobs that should be processed in each period so that completion time of the project is minimized.

Activity list of the Project

Using the Network, we use Earliest Finish Time Priority Rule to find the activity list. This is our result: {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 12, 15, 16, 17, 18, 19, 20. 21, 22, 23}. The job 5 is job 5.1 to job 5.9.

Schedule of the Project

Using the serial schedule generation scheme we got the minimal feasible schedule of the project: {1, 2, 4, 5, 6, 14, 16, 20, 22, 26, 34, 37, 41, 43, 46, 49, 55, 65, 67, 72, 77, 80}

The Completion time of the project

The completion time of the project is 80 weeks. This implies that when resources are not constrained the time of completion of the project in Table 1 is 80 weeks. Though resources are not constrained, from the model the approximate maximum amount of fund that is needed every period is known. Hence giving out more than this amount in any period may encourage misappropriation.

d) *Finding the Minimum Completion Time of the Project when resources are constrained:*

Using the same activity list, the schedule is {1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14. 22, 24, 28, 30, 34, 42, 52, 55, 59, 62. 66, 71, 81, 83, 88, 93, 96}. The completion time is 96 weeks. The completion time here is increased with 16 weeks. This is expected because the amount just enough to execute a job with the lowest resource demand in the eligible set is released every period. This shows that during recession good roads can still be constructed but with longer periods of time.

V. CONCLUSION

This paper introduces some solution methods to checkmate corruption and recession in nations of the world where these are the major reasons for a high number of failed roads in that country. Our solution method proposes that, if a new road is to be constructed: all Needed Materials Should Be Purchased Before Job Execution Starts; Every Stakeholder should be actively Involved; Institutions be established to ensure continuity in projects even when the country's leadership changes.

Finally, the Road Construction Project is formulated as a Hybrid RCPSP to know the maximum funds needed every period to checkmate corruption and the minimum funds needed every period so that project gets to completion stage even if there is recession.

In our experiment we formulated the construction of real life 5km asphalt road as a HRCPSP. Using priority based project scheduling technique, our results show the maximum and also the minimum amount of fund that should be made available each period, so that work can go on even if there is recession and also checkmates corruption. Also the solution which is a schedule, shows the jobs that should be processed
in each period so that completion time of the project is minimized.

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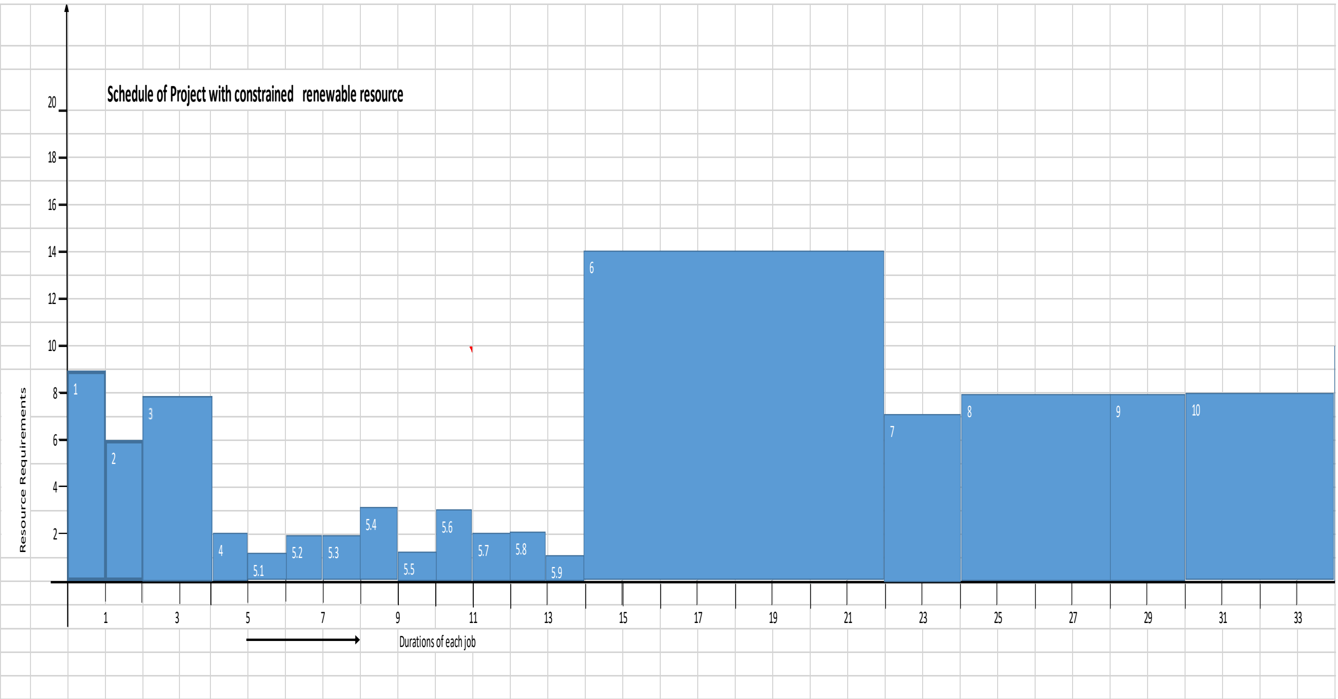

Fig. 4: Shows part of the schedule of Table 1 with constrained renewable resource

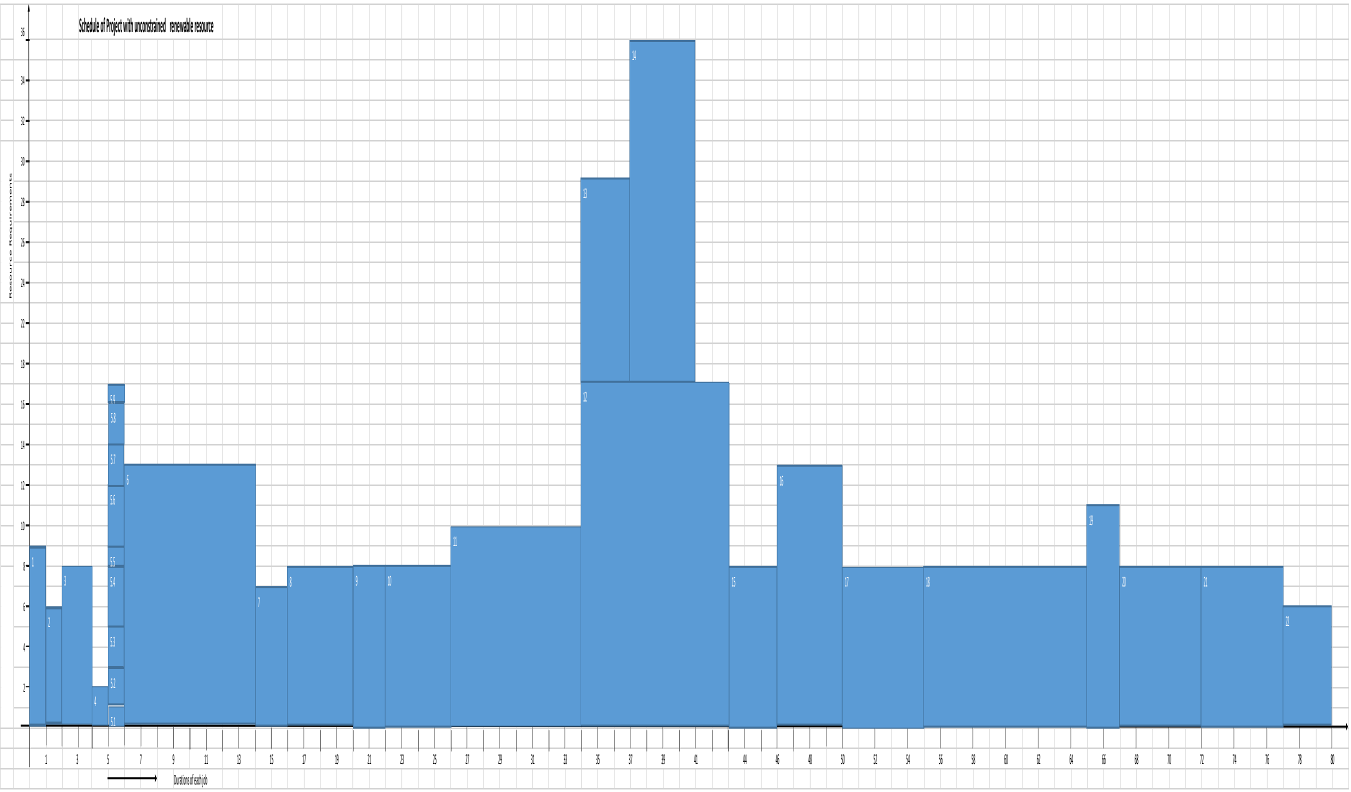

Fig. 5: Shows part of the schedule of Table 1 with unconstrained renewable resource

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