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Research Paper

A Goal Programming Linear Model for Simultaneous Project Scheduling and Resource Leveling - a Huge Civil Project as a Case Study

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Abstract We have a huge civic project, includes several sub-projects, which are divided into activities. This project is a project to rehabilitate 550,000 hectares of agricultural land in the provinces of Khuzestan and Ilam. The project has been divided according to the plots of land. The Jehad in Tehran is managing the projects. They need project scheduling as well as resource levelling and "lot-sizing". Levelling and lot sizing are the most important issues in utilizing the limited resources. For determining the scope and the size of those sub-projects as well as their parallel activities, so far, many models have been proposed. However, the models are weak either in higher resource utilization or in solving numerically the problems. In this paper, our effort has been concentrated on developing scheduling, resource levelling, and lot sizing model, based on balancing utilization of resources, so that the real size civil project could be solved within an acceptable duration time. This paper proposes a goal programming linear model for simultaneous project scheduling and resource levelling. This model determines the best schedule of sub-activities (optimal "lot size" of each sub-activity) to reach the minimum amount of diversion of resources consumed from the number of resources available for the entire periods of the planning horizon. In fact, if the best "lot sizes" have been taken, then minimum fluctuation of the active resources is reached. The proposed model has been used to schedule a project with 87 activities. This project has been scheduled and, accordingly, the optimal volume (the "lot size") of sub-activities have been determined for each activity at any period of time. In this way, only 4 resources

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out of a total of 32 resources are in shortage. In contrast, the scheduling of this project, using the CPM, results in a shortage of 13 resources.

Keywords *Scheduling, Resource Leveling, Lot Sizing, Goal Programming*

Introduction

We have a huge civic project that includes several sub-projects, each of which is divided into several activities. This project is a project to rehabilitate 550,000 hectares of agricultural land in the provinces of Khuzestan and Ilam, southwestern Iran. The Jihad Organization is officially responsible for its implementation. The people in charge have divided this project into several sub-projects according to the plots of land. The Jehad in Tehran is managing the projects. They need project scheduling as well as resource levelling and "lot sizing". Levelling and lot sizing are the most important issues in utilizing the limited resources. For example, too small lot sizes cause too many parallel activities and end up us with a crowded environment and shortage of resources. On the other hand, too large lot sizes could cause costs of idle resources, despite easier scheduling and no sign of crowded environment. For determining the scope and the size of those sub-projects as well as their parallel activities, so far, many models have been proposed. However, the models are weak either in higher resource utilization or in solving numerically the problems. For example, in the project approach, in order to overcome a resource shortage, it is necessary to attempt to change the planning of the activities by a trial-and-error method, which will not guarantee finding the optimal solution. But we need a model that guarantees an optimal solution. moreover, we need a proposal for using a linear model with no integer variables, the variables whose existence makes it difficult to solve the model or, even if the model size is big, they make it impossible. In this paper, our effort has been concentrated on developing a scheduling, resource levelling, and lot sizing model, based on balancing utilization of resources, so that the real size civil project could be solved within an acceptable duration time. Generally five stages of activity should be planned and implemented in the rehabilitation plan for a few hectares of agricultural lands, namely: resource acquiring, land acquisition, land leveling, and canalization. Doing each of the activities needs time and resources. We suppose that those needs have already been determined. Moreover, we assume that the activities are splitable and we could break them down into sub-activities. These are the research limitations. Therefore, our job is to split and schedule the activities so that the available resource and their needs are balanced. Figure1 shows the initial Gantt chart.

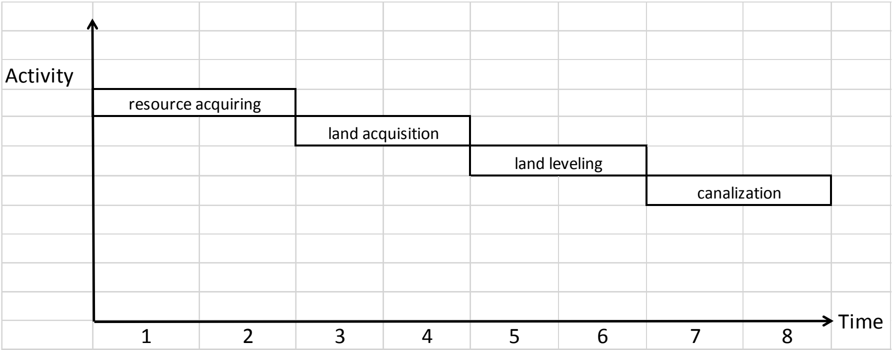

Figure1

The Initial Gantt Chart

In the figure1 the size of lots is considered equal to the whole activity. But the project’s make-span is too long. Moreover, while an activity like "resource acquiring" is in progress, the resources of other activities are idle. If, the lot sizes become smaller, for instance if each lot becomes half of its initial size, then there will be parallel activities and the make-span will become half. Instead, the active resources will be doubled and, therefore more resource utilization will happen. The Gantt chart of this process is shown in figure2.

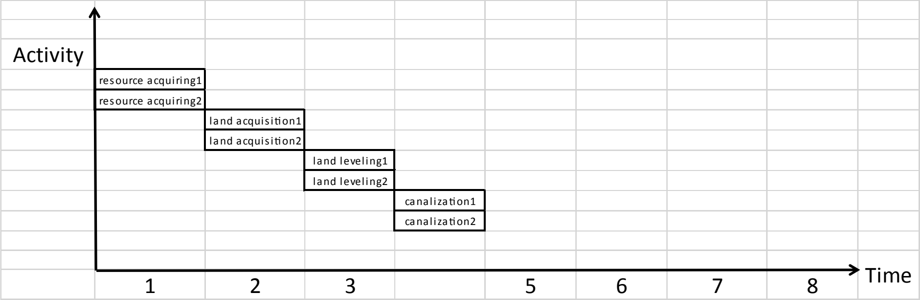

Figure 2

Gantt Chart with Half Size Lots

If there are different available number of resources, for instance, if there is a large number of resources available for the "land levelling" activity, but less resources are available for the "canalization" activity, the "lot size" for each activity should be commensurate with the resources at hand for the same activity. As a result, the problem can be defined in this way: What portion of each activity could be scheduled at any time (time period) in order to balance the number of resources required throughout the project period with the available resources? Moreover, if it is applicable, how many parallel sub-activities for each activity should be determined? The purpose of this article is to answer these questions. We introduce a new model that has the ability to allocate resources optimally by splitting down the activities and optimally scheduling them. This model can be solved with the simplex method, so it will be very efficient.

Background

Production and project scheduling, including resource levelling and "lot sizing" problem, have a history of over 100 years. Bahl et al., (1987); Cfieline et al., (2008); Tomotani and Mesquita., (2018); Lin and Gen, 2018; Christoph and Grosse, (2021); Hartmann and Briskorn, (2021); Shadrack , (2021) have reviewed the literature. Borna et al., (2021) have conducted a Survey on Integration of Optimization and Project Management Tools for Sustainable Construction Scheduling as well.

Critical path method (CPM) is commonly used in scheduling of construction projects (Kastor and Sirakoulis, 2009; Abbasi Iranagh and Sonmez, 2012; Fahmy et al., 2020). Moreover, Line Of Balance (LOB) has emerged as an alternative for scheduling repetitive projects (Ammar, 2020). Project scheduling and materials lot sizing decisions need to be concurrently (Almatroushi et al., 2020; Ammar, 2020; Eirgash, 2020; Ntardas, 2020). In some cases, resource levelling is needed for higher productivity rather than additional resources (Donner, 2012). Resource levelling problem (RLP) aims to obtain a feasible schedule to minimise the resource usage fluctuations during project execution (Kastor and Sirakoulis, 2009; Hongbo et al., 2018; He and Zhang, 2013; Hongbo et al., 2020; Rieck and Zimmermann, 2015; Mohibullah, 2021). Petersohn et al., (2013) presented a case study of resource leveling for a mass digitization project in an academic library. Details on the use of resource leveling through deconstructing activities, smoothing and alternative scheduling are described in relation to this project (Petersohn et al. 2013). Celkevicius and Russo, (2018) proposed a model and actions for resource levelling implementation. The study explains that the granularity of analysis of resource allocation increases by decomposition of the duration of each activity in fixed time segments. It is suggested to use the mathematical concept of the allocation factor (Celkevicius and Russo 2018). Hongbo et al. (2020) extend the uncertain RLP by simultaneously considering uncertainties in activity durations, activity overlaps and resource availabilities. They formulated the RLP as a Markov decision process model. An objective for RLP is called “alliance portfolio (AP)” which has a multidimensional nature (Bolivar et al.,2021). Construction scheduling, in practice, commonly relies on the usage of commercial project management tools (PMT) without specific optimization features (Borna et al., 2021). However, commercial scheduling software has very limited capabilities for solving the resource levelling problem (Abbasi Iranagh and Sonmez, 2012). To obtain optimal schedules, planners often need to develop separate optimization models with special tools, which, however, demand further processing and editing of optimization results by PMT into forms expected for project management (Borna et al., 2021). Recently, meta-heuristic algorithms have made remarkable progress in solving types of complex and NP-hard problems. One of the nature-inspired meta-heuristic algorithms is symbiotic organisms search (SOS), which has been able to solve the majority of engineering issues to date (Gharehchopogh et al. 2020). SOS algorithm has been proposed to create an optimization model for construction of project resource levelling (Gharehchopogh et al. 2020). Gharehchopogh et al., (2020) introduced SOS as the best to date. Genetic algorithm (GA) is the other meta-heuristic method that has been adapted for solving the RLP (Li et al., 2002; Abbasi Iranagh and Sonmez, 2012; Hongbo et al., 2018; Mohibullah, 2021). Experiments indicate that GA enhanced resource levelling method performs better than the traditional methods in MS Project (Li et al., 2002). It is able to obtain near optimal solutions with less than 2% optimality gap for small instances in fractions of a second. It outperforms or is competitive with the state-of-the-art algorithms for large benchmark instances with size up to 1000 activities (Hongbo et al., 2018). Fuzzy-Logic based Resource Levelling Optimization tool has been suggested by some authors (Iyer et al.,2015; Abdel-Basset and Atef, 2020). Fuzzy resource leveling models assume only truth-membership functions to deal uncertainties conditions surrounded by the projects and their activities duration (Abdel-Basset and Atef, 2020). A study applies a nature-inspired intelligent algorithm, i.e. Sonar Inspired Optimization (SIO), to face the RLP of a real-world project (Ntardas, 2020). The specific application domain is a NP-hard optimization problem. A hybrid scheme of this algorithm with Simulated Annealing (SIO-SA) is used to improve the performance of SIO. Comparative results show that both approaches (SIO and SIO-SA) perform almost equally well (Ntardas, 2020). Almatroushi et al., (2020) proposed A hybrid metaheuristic procedure. They suggest that for real life projects with complex network topology, practitioners are advised to make use of the developed metaheuristic procedure due to its superior time efficiency as compared to exact solution methods (Almatroushi et al., 2020). Three global meta-heuristic methods; Simulated Annealing, Tabu Search and a Perturbation algorithm have been presented (Mushi,1997). Also, these algorithms are feasible and good approaches to the RLP, the perturbation algorithm was found to perform better than the rest (Mushi, 1997). Heuristic methods and optimization techniques have been traditionally used to solve RLP (Mushi,1997; Ammar, 2020). Although heuristic methods can handle large-size projects, they do not guarantee optimal solutions (Ammar, 2020). A straightforward scheduling technique called resource histogram is utilized to allocate and level the available resources (Eirgash, 2020). He and Zhang, (2013) proposed a dynamic priority rule-based forward-backward heuristic algorithm (FBHA) that optimizes resource allocation by shifting non-critical activities within their forward free float (FFF), forward total float (FTF) and backward free float (BFF), successively (He and Zhang, 2013). Zohrehvandi et al., (2020) introduced a project buffer and resource management (PBRM) model for RLP. Exact methods for the resource levelling problem by many authors. For example, exact solutions were obtained for the sample problems using linear-integer programming technique (Abbasi Iranagh and Sonmez, 2012). Ammar (2020) modeled the resource levelling and allocation problems under LOB scheme as an optimization problem that guarantees optimal solutions (Ammar, 2020). Resource continuity and logical dependency between activities are maintained where constant activity progress rate is assumed (Ammar, 2020). In order to solve medium-scale instances of the problem, an enumeration scheme that uses problem structures was presented and, a mixed-integer (linear) programming models was introduced, and resource leveling instances were solved using CPLEX 12 (Rieck and Zimmermann, 2015). Gather et al., (2011) presented a project scheduling problem subject to general temporal constraints where the utilization of a set of renewable resources has to be smoothed over time. For solving the NP-hard optimization problem, they point out some important structural properties and introduced an enumeration scheme. Combining this enumeration scheme with some branch-and-bound techniques, they proposed an appropriate solution procedure for the project scheduling problem at hand. (Gather et al. 2011). A mixed integer linear programming model was devised, which utilizes the splitting of noncritical activities as a mean toward leveling the renewable resources (Almatroushi et al., 2020). The developed model minimizes renewable resources leveling costs along with consumable resources related costs, and it is solved using IBM ILOG CPLEX optimization package. Objective of the RLP is to minimise the maximum resource peaks by moving jobs within their slack times. RLP is an NP-Hard combinatorial optimization problem and therefore, no optimal algorithm is known (Mushi,1997). Mushi, (1997) developed four Mixed Integer Programming (MIP) formulations for the RLP. Kong and Dong , (2021) introduced a new practical scheduling problem called the resource-constrained project scheduling problem under multiple time constraints, which involves a duration constraint of activity, temporal constraint, and resource calendar constraint. They developed a constraint programming optimization model for the new problem and used the IBM ILOG CPLEX-CP version 12.9.0 optimizer to solve it. Computational experiments were carried out to show that the CP optimizer is fast and provides a near-optimum solution to the new problem for projects with hundreds of activities within minutes compared to other metaheuristic methods (Kong and Dong , 2021). A Dynamic Scheduling (DS) model has been proposed that utilizes multi-objective optimization of cost, time, resources and cash flow, throughout project construction (Fahmy et al., 2020). Dynamic planning and scheduling forms a widely adopted smart strategy for solving real-world problems in diverse business systems (Okechukwu et al. 2021). Hafeez and Aburawi, (2013) described how system dynamics modeling allows management to plan to hire and develop right level of resources to meet desired service level targets (Hafeez and Aburawi 2013). Hongbo et al., (2020) developed a hybrid open–closed-loop approximate dynamic programming algorithm (HOC-ADP) to solve the RLP. Moreover, they developed a simulation algorithm to evaluate the resource levelling performance of the HOC-ADP. The comparison experimental results indicated that the HOC-ADP outperforms the state-of-the-art meta-heuristics (Hongbo et al., 2020). Sameh, (2018) proposed a Non-Linear Integer Programming (NLIP) model that solves the resource leveling problem while reducing the negative effect of the total float loss on risk. The proposed model was implemented using “What’s Best solver” for Excel. The results confirmed that resource leveling reduces the available float of non-critical activities; decreases schedule flexibility and reduces the probability of project completion. In conclusion, project scheduling, materials lot sizing, and resource levelling decisions need to be concurrently to minimise the resource usage fluctuations during project execution. To obtain optimal schedules, we need to develop an optimization model. The models in this area are NP-hard and could not be solved easily within time and using exact methods. So, linear and non-linear models, as well as exact, heuristic, meta-heuristic, and other algorithms to solve them, are being developed at the time. As a result, there is still room for introducing new models in this area, which improve the project scheduling and resource levelling. Developing a new model, is the aim of this paper. A model that does not need too much optimization efforts. A model that easily could be solved. A model with no need to heuristic or meta-heuristic methods. A model that has the ability to allocate resources optimally by splitting down the activities and optimally scheduling them. A model that can be solved efficiently.

The Proposed Model

This paper proposes a goal programming linear model for simultaneous project scheduling, and resource levelling. This model determines the best schedule of sub-activities (the volume of optimal "lot size" of each sub-activity in different time periods) to reach the minimum amount of diversion of resources consumed from the number of resources available for the entire periods of the planning horizon. In fact, if the best "lot sizes" have been taken, then minimum fluctuation of the active resources is reached. To develop the model, it is assumed that each activity has its own duration but it can be spitted down into several sub-activities. However, this activity splitting must be in line with its prerequisites. In each period, parts of all activities can be performed that either do not have prerequisites or their prerequisites have already been done. This is a partially activity allocation. So, the decision variable is either a partial activity allocation or a partial reserve allocation for being done in the next period. The objective function is to minimize the weighted amount of positive and negative deviations from the number of resources used with the number of resources in the hands of each period. This function is applied to reduce excessive fluctuations in the resource usage. The model has been denoted here:

- Decision variables

Definition	**Variable**
The partial amount of activity i which is scheduled in the period t	X(i , 0 , t)
The partial amount of activity i which is continued for processing in the period t	X(i , 1 , t)
The amount of activity i which has been done and is passed on to be continued for processing in the period t	I(i , 0 , t)
Positive deviation from the number of source k required with the number of source k available for period t (The shortage of source k during the period t)	YP(k,t)
negative deviation from the number of source k required with the number of source k available for period t (The idleness of source k during the period t)	YN(k,t)

- **The parameters**

Notation	**Parameter definition**	**Notation**	**Parameter definition**
I	Total number of activities	t(i)	Duration of the activity i
K	Total number of resources	NORM(k)	Number of available resources (any time)
T	Total number of periods	N(k)	The importance of resource k
$\varphi(i)$	Set of all activities which are predecessor for i	M(i,k)	Number of resource k which is used in activity i

- **The model:**

$\text{MIN } Z=\sum_{t=1}^{T}\sum_{k=1}^{K} N(k)\times[YP(k,t)+YN(k,t)]$		(1)
$X(i,0,t)+I(i,0,t)=X(i,1,t)+I(i,0,t+1)$	$\forall\ i, t$	(2)
$I(i,0,1)=0$	$\forall\ i$	(3)
$X(i,0,t)\leq 1/t(i)$	$\forall\ i, t$	(4)
$\sum_{t=2}^{k} X(i,0,t)\leq\sum_{t=1}^{k-1} X(j,0,t)$	$\forall\ i,\ j \mid j\in\{\varphi(i)\}$, $k=2,3,\ldots,T-1$	(5)
$\sum_{t=1}^{T} X(i,0,t)=1$	$\forall\ i$	(6)
$\sum_{i=1}^{I} X(i,0,t)\times M(i,k)\times t(i) - NORM(k)=YP(k,t)-YN(k,t)$	$\forall\ k, t$	(7)

Definition of the model's constraints

Constraint (1): is the objective function. The objective function is to minimize the weighted amount of positive and negative deviations from the number of resources used with the number of resources in the hands of each period. This function is applied to reduce excessive fluctuations in the resource usage.

Constraint (2): determines the flow balance between two successive periods. This equation balances the volume of the activity i planned for this period with the amount reserved for the next period.

Constraint (3): determines that zero amount of activity i has been done before starting the project.

Constraint (4): restricts the amount of scheduled activity i at each period to proportion to the number of its period.

Constraint (5): determines the predecessors for each activity in each period. This constraint ensures that all the prerequisites for the part of activity i that is to be scheduled in period t are planned in previous periods.

Constraint (6): determines that summation of partial activities (the lots) should be equal to the total activity.

Constraint (7): determines the fluctuations in the resource usage, the number of source k required with the number of source k available (NORM) for period t.

Case Study

To illustrate the effectiveness of this modeling technique, the real project of Jehad, the rehabilitation plan for 550,000 hectares, is considered. The WBS (work breakdown structure) of the project is given in Figure 3. Which must be scheduled within a year.

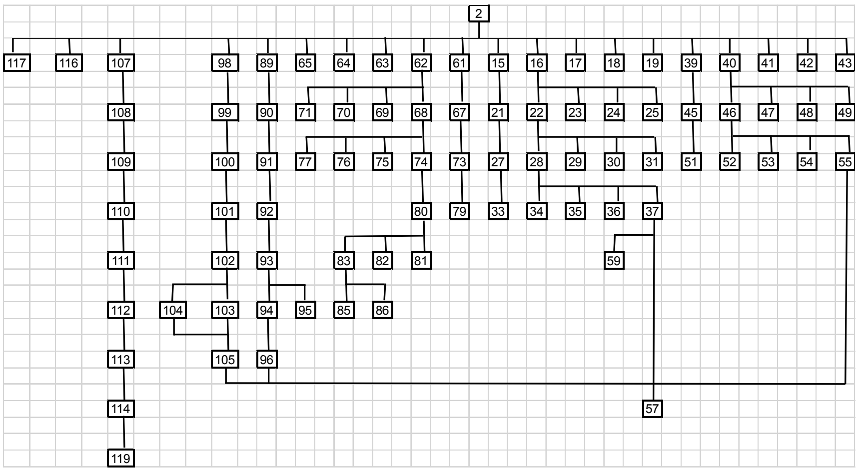

Figure 3

The Product Assembly Process Chart

In figure 1, the numbers represent the activities and the lines represent the pre-requisites. The resources required for activities and the time required to complete the total volume of each activity are given in Table 1.

Table 1.

List of the Project's Activities with their Time and Resources

Activity number	Resource number																																Time (M)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
2																																	1.00
15														1							1									1			1.00
16							1													2													2.00
17								1	1											3							1		1				2.00
18					1															1													2.00
19	1			1															1	2			1										1.00
21														1							1									1			1.00
22							1													2													1.00
23								1	1											3							1		1				1.00
24					1															1													1.00
25	1			1															1	2			1										1.00
27														1							1									1			1.00
28							1													2													2.00
29								1	1											3							1		1				2.00
30					1															1													2.00
31	1			1															1	2			1										1.00
33														1							1									1			1.00
34							1													2													2.00
35								1	1											3							1		1				2.00
36					1															1													2.00
37	1			1															1	2			1										1.00
39														1							1									1			1.00
40							1													2													2.00
41								1	1											3							1		1				2.00
42					1															1													2.00
43	1			1															1	2			1										1.00
45														1							1									1			1.00
46							1													2													2.00
47								1	1											3							1		1				2.00
48					1															1													2.00
49	1			1															1	2			1										1.00
51														1							1									1			1.00
52							1													2													2.00
53								1	1											3							1		1				2.00
54					1															1													2.00
55	1			1															1	2			1										1.00
57										1										4													1.00
58					1															1						1							2.00
61														1							1									1			1.00
62							1													2													2.00
63								1	1											3							1		1				2.00
64					1															1													2.00
65	1			1															1	2			1										1.00
67														1							1									1			1.00

Table 1. continued

List of the Project's Activities with their Time and Resources

Activity number	Resource number																																Time (M)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
68							1													2													1.00
69								1	1											3							1		1				1.00
70					1															1													1.00
71	1			1															1	2			1										1.00
73														1							1									1			1.00
74							1													2													2.00
75								1	1											3							1		1				2.00
76					1															1													2.00
77	1			1															1	2			1										2.00
79														1							1									1			1.00
80							1													2													2.00
81								1	1											3							1		1				2.00
82					1															1													2.00
83	1			1															1	2			1										1.00
85										1										4													1.00
86					1															1						1							1.00
89							1													2													1.00
90	1			1																2			1										1.00
91				1															1	3													1.00
92																				3													1.00
93						1														5													1.00
94											1	1	1							2													2.00
95	1																			2													1.00
96																				3													1.00
98							1													2													1.00
99	1			1																2			1										1.00
100				1															1	3													1.00
101																				3													1.00
102						2														5													1.00
103											1	1	1							2													2.00
104	1																			2													1.00
105																				3													1.00
107							1													2													1.00
108	1			1																2			1										1.00
109				1															1	3													1.00
110																				3													1.00
111						1														5													1.00
112											1	1	1							2													2.00
113	1																			2													1.00
114																				3													1.00
116		1																1				2			1								3.00
117		1																1				2			1								3.00
119																				5													1.00

The proposed model was used to determine the "lot sizes" during a year (12 months). The model reached to the optimal solution in one minute and fifty seconds with an ordinary linear problem solver software on a Core-i3 CPU 2.4 GHz computer. The number of restrictions and variables is about five thousand each. The total number of shortage (shortage - month) of all sources is 127 over the entire period of time and the resource number 5, 11, 12, and 20 are faced with shortage. However, if we used MS-Project to schedule this project, its critical path was one year, and thirteen sources have been faced with a shortage. The optimal solution of this model is given in Table 2.

Table 2

The Optimal Solution (the Activity Lot Sizes for Each Activity within 12 Months)

Volume percentage of doing each activity in planning horizon periods												
X12	**X11**	**X10**	**X9**	**X8**	**X7**	**X6**	**X5**	**X4**	**X3**	**X2**	**X1**	**Activity**
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19
0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	21
0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.2	0.0	0.0	0.0	22
0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.2	0.0	0.0	0.0	23
0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.2	0.0	0.0	0.0	24
0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.2	0.0	0.0	0.0	25
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.7	0.0	0.0	0.0	27
0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.1	0.2	0.0	0.0	28
0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.1	0.2	0.0	0.0	29
0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.1	0.2	0.0	0.0	30
0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.1	0.2	0.0	0.0	31
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.7	0.0	33
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.2	0.0	34
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.2	0.0	35
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.2	0.0	36

Volume percentage of doing each activity in planning horizon periods												
X12	**X11**	**X10**	**X9**	**X8**	**X7**	**X6**	**X5**	**X4**	**X3**	**X2**	**X1**	**Activity**
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.2	0.0	37
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	45
0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0	0.3	0.0	0.0	46
0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0	0.3	0.0	0.0	47
0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0	0.3	0.0	0.0	48
0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0	0.3	0.0	0.0	49
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	51
0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.0	0.3	0.0	52
0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.0	0.3	0.0	53
0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.0	0.3	0.0	54
0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.0	0.3	0.0	55
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.5	57
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.5	58
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63
0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64

Table 2. continued

The Optimal Solution (the Activity lot Sizes for Each Activity Within 12 Months)

For example, the total volume of the activity 2 is scheduled in the month 12 (no split), while the activity 21 is divided into two portions, the first portion consists of 70% in the month 5 and the second portion is planned to be 30% in the month 10 (splitting this activity into 2 sub-activities).

Conclusion and Suggestion

This paper proposed and examined a goal programming model, without using integer variables, for scheduling and resource levelling. The model is usable whenever a project is to be planned or scheduled. Using this model, the activities of the project are broken down into sub activities, each of which, determining an optimal size of an activity (optimal lot size). The model determines optimum number and size of sub activities (lot sizes), based on activity splitting and resource leveling. This model is quickly solvable, using the Simplex method. Moreover, it could determine the optimum schedule and lot sizes in case the planning horizon is being extended or compacted. A real case with 87 activities and their WBS, has been solved on a Core-i3 CPU 2.4 GHz computer in less than 2 minutes. This is showing the power of the model. This project has been scheduled and, accordingly, the optimal volume (the "lot size") of sub-activities have been determined for each activity at any period of time. The planning horizon is one year, and monthly periods have been considered. In this way, only 4 resources out of a total of 32 resources are in shortage. In contrast, the scheduling of this project, using the CPM and project length of one year, results in a shortage of 13 resources. So, this model could reduce the resource shortage from 40% into 12.5% which is a huge improvement. In addition, in the project approach, in order to overcome a resource shortage, it is necessary to attempt to change the planning of the activities by a trial-and-error method, which will not guarantee finding the optimal solution. But the proposed model guarantees an optimal solution. However, this is a preliminary proposal for using a linear model with no integer variables, the variables whose existence makes it difficult to solve the model or, even if the model size is big, they make it impossible. But as the number of time periods increases, the dimensions of the problem are increased and the problem is going to solve at longer time. For example, the problem of this study has been solved for the number of periods 19 and 24 per year, and the information is given in Table 3.

Table 3

Problem Solving Information for Different Time Periods

number of periods annually	period's length (days)	number of variables	number of constraints	Solving time (min)	number of Shortage-month	resources with shortage
12	30	5000	4500	2	127	5,11,12,20
19	20	8500	7700	4	106	20
24	15	10100	9300	6	77.5	20

In addition, the proposed model also has the ability to be improved. Because only the restriction number 5 increases the number of model constraints by increasing the number of time periods, this model can be improved by limiting the number of time periods, by increasing the length of the time period. But, further improvement of the model has been left for research in the future.

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