SCHEDULING NATURAL GAS PROJECTS IN CAIRO USING CPM AND TIME/COST TRADE-OFF

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ABSTRACT

Scheduling projects can be studied as a multicriteria decision problem, where as previously many developed techniques for minimizing project duration had been used. It is quite often true that the performance of some or all project activities can be accelerated by the allocation of more resources, at the expense of higher activity direct cost. When this is so, there are many combinations of activity durations which will yield some desired schedule duration. However, each combination will yield a different value of total project cost. Time/cost trade-off procedures are directed for determining the least cost schedule for a given project duration, usually under assumption of unlimited resources. In this paper, the scheduling of natural gas projects in Cairo is studied. The construction of natural gas lines is divided into different specific jobs and sectors, then the CPM network structure is constructed. The time cost trade-off relation of the studied cases determined considering four relations for activity time cost function. The problem is solved using a mixed integer linear programming model (MILP). The recommendations and conclusions are presented.

1. INTRODUCTION

As a consequence of the continuous development and the request of high efficient performance all over the real life aspects in Egypt, it is decided to replace the use of petroleum gas bottles by the use of natural gas lines. In this strategy the gas flows from the pumping source(s) to consumers (houses, hotels, industrial plants, ... etc.) throughout the main pipes, subsidiary pipes, flexible joints, meter, and many other joints. The construction of this system is scheduled before as a bar chart. These bar charts are not oriented to schedule the job specifically but they are just keeping the specific crew occupied all the time. So, this paper introduces the CPM technique as a procedure for constructing the natural gas project in Cairo. The devised technique provide an arrangement of the jobs according to their priority. The bar chart for each crew can be attained after relating all jobs in one schedule. This will provide an overall view of the project, and then the task of each crew can be defined. It is obvious that there is a good advantage when it is treated by the CPM technique over the current method for scheduling. Also this paper provides the construction of the time cost trade-off for the considered project. Hence, it is a good advantage to overcome any reduction of the project normal duration when it is requested. The time cost trade-off is used to find the overall optimum schedule corresponding to the project duration of minimum total (direct and indirect) cost. In this study four different relations for time cost function are considered. These different relations represent the actual conditions that exist in real life problems considering that the nonlinear relation is approximated to a multistage piecewise relation. In this study two stepwise are considered. However, the time cost function of an activity may be one of the following:

- One point for dummies or incompressible activities.
- Linear function.
- Multistage piecewise linear function.
- Discrete function.

The time cost trade-off is rendered by solving this problem using a mixed integer linear programming model (MILP). This model was developed by the authors [1] and [6] to solve such simulated case of the time cost trade-off problem.

2. THE MAIN OPERATIONS AND CREWS

In order that the natural gas lines will be well established in a specific section, the following main operations must be made:

2.1. Survey and Drawing Preparation

This is the first step and should be completed before the following steps. In this step, the number of customers, the pipe lengths and the demanded quantity of gas are calculated. Also, the complete detailed drawings are made for the connection lines.

2.2. *Distribution Lines Construction*

In which the on ground pipes are constructed on both the main ways and the subsidiary ways. The construction of distribution line is composed from main line, services line on the subsidiary ways, regulators and valves.

2.3. *Installation*

In which the on book pipes are installed. On each block, there is one riser, lateral pipes for each department, and the internal installation for each department.

2.4. *Conversion*

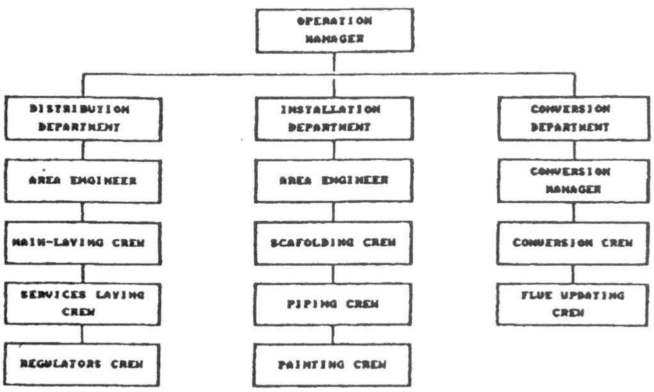

Figure 1. Organization chart for field operation.

Converting the appliance (cooker, water heater, ...) from operating with petroleum gas bottles to be operated with natural gas. This is the last step and cannot be performed before reaching the gas to the internal pipes. The organization chart for field operation is exhibited in Figure (1). As a consequence of the study, every section "under execution phase" should be divided into sectors each of which can be performed in a series or in a parallel. In each phase, six crews are available for performing the responsible jobs in parallel execution. The operating cres may be on the same sector or in different sectors. However, these crews are as follows:

1. Survey crew.
2. Distribution crew.
3. Distribution commissioning crew.
4. Installation crew.
5. Installation commissioning crew.
6. Conversion crew.

3. CALCULATIONS STRUCTURE

Referring to the data attained from natural gas proje company "EGYPT GAS" in Cairo and considering t specified two sectors 03 and 04 (3) at west Nile Cairo, is required to supply customers through pipelines with t following data:

Item	Sector 03	Sector 04
No. of customers	4114	2689
Distribution lines [m]		
- Mains	8405	6875
- Service	7324	4269
- Regulators	38	179
Installation [m]	68759	43833
Conversion [App.]	5025	3308

The estimation of normal durations is based on the average productivity per each crew. This productivity is obtained by the weekly progress report and was as follows:

Survey	806	customer/week
Distribution		
- Main line	1230	m/week
- Service	3050	m/week
- Regulators	122	m/week
Installation	6500	m/week
Conversion	466	appliance/week

The estimation of the normal cost is based on the stud carried out by Metwally [1] and was follows:

Survey	LE	12.0/customer
Distribution		
- Main	LE	88.5/customer
- Service	LE	57.5/customer
- Regulators and valves		as required
Installation	LE	422.0/customer
Conversion	LE	80.0/customer

The activity execution can be accelerated by operati the responsible crew overtime. The crash duration studied and the crash cost is reasonably address considering also, the extra overtime costs per each activi This is presented in the project description tables (1) a (3).

4. PROJECT NETWORK

The logical precedence of the considered case can be structured according to the following rules:

- The sector survey must be completed before starting any other operation.
- The distribution and installation can be made in parallel at a specified sector.
- The conversion of each sector cannot be started before the distribution and installation phases before the distribution and installation phases are completely finished.
- Any crew cannot work in two sectors at the same time.

Taking these rules into consideration and dividing each main operation into specified jobs, the network arrow diagrams built up and visualized in Figure (2).

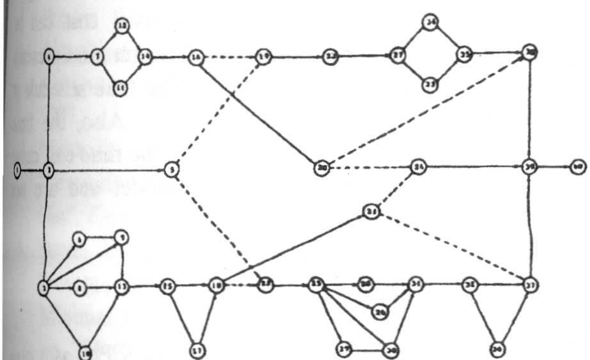

Figure 2. The network arrow diagram of the studied project.

The list of the activities with their normal durations is tabulated in table (1). The calculation method of the early late times and floats is known. The scheduling with all normal times is exhibited in table (2). As a consequence of this schedule, the installation and the conversion are critical while the distribution is not critical. So, it is recommended to reduce the size of the distribution crew or increase the size of installation and conversion crews.

5. *TIME/COST TRADE-OFF*

In this work the time cost relation of an activity is one of the four categories mentioned above. So, the activities can be classified into four sets as follows:

Set S1 ... for dummies and incompressible activities.

Set S2 ... for the activities of linear time cost function.

Set S3 ... for the activities of multistage time cost function.

Set S4 ... for the activities of discrete time cost function.

To find the activities durations at a completion time (t) of the project, the following mixed integer linear programming model (MILP) must be solved:

Maximize $CS(i,j) * X(i,j)\ \forall\ i,j\ S2 \cup S4$

$+\ [CS1(i,j) * A(i,j) + CS2(i,j) * B(i,j)]\ \forall\ i,j\ S3$

Subjected to:

$T(j) - T(i) - X(i,j) >= CT(i,j) \forall\ i,j$

$X(i,j) = 0 \qquad \forall\ i,j\ S1$

$X(i,j) <= [NT(i,j) - CT(i,j)] \forall\ i,j\ S2$

$A(i,j) <= [NT(i,j) - CT1(i,j)]$

$B(i,j) <= [CT1(i,j) - CT(i,j)] \forall\ i,j\ S3$

$X(i,j) - A(i,j) - B(i,j) = 0$

$X(i,j) - [NT(i,j) - CT(i,j)] * I(i,j) = 0 \qquad \forall\ i,j\ S4$

$T(n) - T(1) = t$

Where:

T ... is the occurrence time of event.

X ... is a variable represents the duration of an activity over its crash duration. i.e. duration = X + crash time.

CT ... is the crash time of the activity.

NT ... is the normal time of the activity.

A ... is a variable represents the duration of the activity in the first stage of the multistage activities.

B ... is a variable represents the duration of the activity in the second stage of the multistage activities.

CT1... is the intermediate crash time of a multistage activity.

1 ... is the integer zero one variable.

CS ... is the cost slope of a single stage activity.

$$CS = (\text{crash cost} - \text{normal cost})/(NT - CT).$$

CS1... is the cost slope of the first stage of a multistage activity.

CS2... is the cost slope of the second stage of a multistage activity.

The time cost trade-off can be determined by solving the MILP model over both the normal and the crash durations. In fact, the model is solved once at the first point and then the solution is considered as an initial solution for the next point. This can be continued till all the required points are attained. This is performed throughout the computer program which its outline is exhibited in Figure (3) and Figure (4).

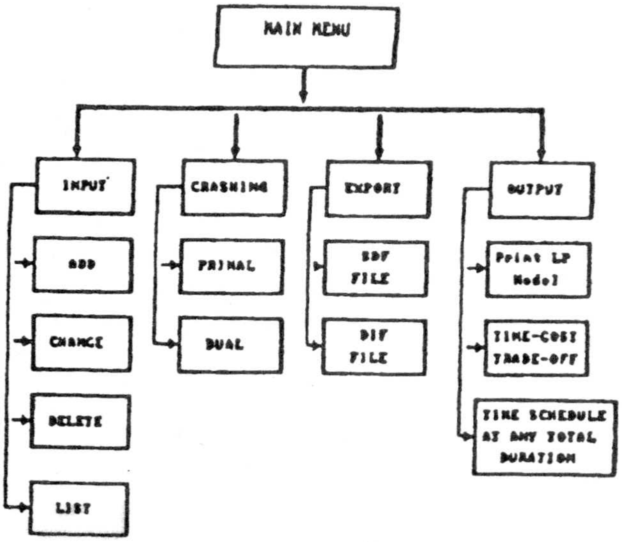

Figure 3. Program layout.

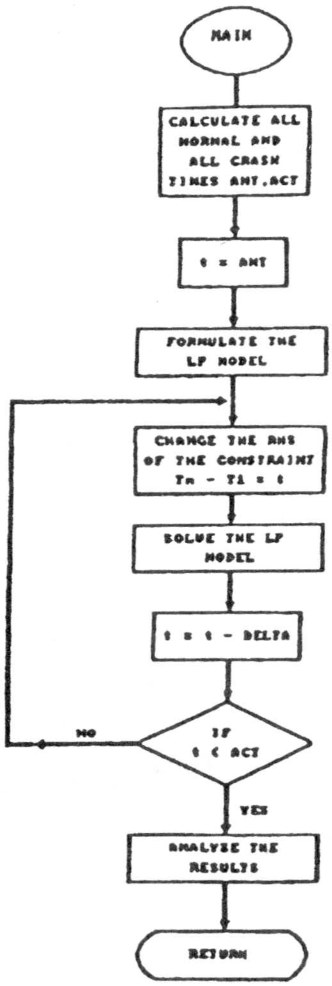

Figure 4. Calculation processes of crashing progam.

The program input data is *composed* (

* Activity identification (i,j).
* Normal time NT.
* Crash time CT.
* Normal cost NC.
* Crash cost CC.
* First crash time CT1.
* First crash cost CC1.
* Activity category L or M or D.

The input data of the considered case table (3). All the normal project duration i all the crash duration is 109 days. The mo(times with an increment of 4 days. The di rendered by the solution is shown in Fi indirect cost is considered throughout the experience to be LE 6500/day, so, the tim project are tabulated in table (4) and plo (6). It is found that the minimum total achieved at a duration of 125 days. This dur the overall optimum of the project. The tim this duration is presented in table (5). A schedules for all the available points of the ti are in hand by solving the MILP model presented here for the space limitation.

6. RECOMMENDED AND CONCLUSIOI

1. The responsible company can use the CP policy for its projects instead of the w(using bar charts. The working program fo can be produced after scheduling all the o CPM and the available crews can be ut efficiently.
2. From all the normal schedule, it is fou distribution crew is so advanced. The recommended to reduce its size or increa number of the installation crew to equ durations in performing a sector under circumstances.
3. For some reasons (such as traffic or loca constraints), the start of a project may be the scheduled start and it must be finisl scheduled finished date. In this case, cras activities is addressed to reduce the projec The direct cost curve of Figure (5) can problem to choose the minimum cost corresponding to the required duration.

overall optimum is achieved. In this project it was 125 days. By applying this study, the company can gain LE 221950 as a saving budget.

4. Finally, the company would consider this study as an example for planning, scheduling and optimizing the next projects by CPM and its time cost trade-off.

7. ACKNOWLEDGMENT

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Table 1. Project Description

ACTIVITY I -- j	DESCRIPTION	NORMAL DURATION
1 -- 2	Survey and drawings of sector 03	30
2 -- 3	Moving distribution crew onto sector 03	4
2 -- 4	Moving installation crew onto sector 03	2
2 -- 5	Survey and drawings of sector 04	20
3 -- 6	Obtaining main pipes of sector 03	3
3 -- 8	Excavation of services sector 03	3
3 -- 9	Excavation of main line sector 03	10
3 -- 10	Obtaining valves and regulators sector 03	1
4 -- 7	Scaffolding sector 03	4
5 -- 19	Dummy	0
5 -- 22	Dummy	0
6 -- 9	Joining main pipes of sector 03	4
7 -- 11	Laterals installation sector 03	20
7 -- 12	Risers installation sector 03	15
8 -- 13	Laying services pipes sector 03	3
9 -- 13	Laying main pipes sector 03	8
10 -- 13	Preparing chambers for regulators sec.03	1
11 -- 14	Testing laterals sector 03	5
12 -- 14	Testing risers sector 03	3
13 -- 15	Connecting all elements of distribution lines sector 03	4
14 -- 16	Installation and testing of internal pipes sector 03	23
15 -- 17	Backfilling of sector 03	4
15 -- 18	Air test of distribution lines sector 03	6
16 -- 19	Dummy	0
16 -- 20	Commissioning of installations sec.03	15
17 -- 18	Repaving sector 03	4
18 -- 21	Commissioning of distribution lines sec.03	10
18 -- 22	Dummy	0
19 -- 23	Moving installation crew onto sector 04	1
20 -- 24	Repaving sector 03	0
20 -- 38	Commissioning of distribution lines sec.03	0
21 -- 24	Dummy	0
21 -- 37	Dummy	0
22 -- 25	Move distribution crew onto sector 04	2
23 -- 27	Scaffolding sector 04	3
24 -- 39	Conversion of sector 03	54
25 -- 26	Obtain valves and regulators sector 04	2
25 -- 28	Excavation of services line sector 04	4
25 -- 29	Obtain main pipes of sector 04	2
25 -- 30	Excavation of main lines sector 04	8
26 -- 31	Prepare chambers for valves and regulators sector 04	5
27 -- 33	Laterals installation sector 04	10
27 -- 34	Risers installation sector 04	8
28 -- 31	Laying services pipes sector 04	3
29 -- 30	Joining main pipes sector 04	5
30 -- 31	Laying main pipes sector 04	7
31 -- 32	Connecting all elements of distribution lines sector 04	2
32 -- 36	Backfilling sector 04	4
32 -- 37	Air test of distribution lines sector 04	6
33 -- 35	Test of laterals sector 04	3
34 -- 35	Test of risers sector 04	2
35 -- 38	Installing and testing of internal pipes sector 04	11
36 -- 37	Repaving of sector 04	5
37 -- 39	Commissioning of distribution lines sec.04	7
38 -- 39	Commissioning of installations sector 04	10
39 -- 40	Conversion of sector 04	36

Table 2. Time Schedule at Project Duration = 189

Activity I	Activity J	Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float	Free Float
1	2	30	0	30	0	30	0	0
2	3	4	30	34	55	59	25	0
2	4	2	30	32	30	32	0	0
2	5	20	30	50	95	115	65	0
3	6	3	34	37	62	65	28	0
3	8	4	34	38	70	74	36	0
3	9	10	34	44	59	69	25	0
3	10	1	34	35	75	76	41	0
4	7	4	32	36	32	36	0	0
5	19	0	50	50	115	115	65	34
5	22	0	50	50	118	118	68	14
6	9	4	37	41	65	69	28	3
7	11	20	36	56	36	56	0	0
7	12	15	36	51	43	58	7	0
8	13	3	38	41	74	77	36	11
9	13	8	44	52	69	77	25	0
10	13	1	35	36	76	77	41	16
11	14	5	56	61	56	61	0	0
12	14	3	51	54	58	61	7	7
13	15	4	52	56	77	81	25	0
14	16	23	61	84	61	84	0	0
15	17	4	56	60	81	85	25	0
15	18	6	56	62	83	89	27	2
16	19	0	84	84	115	115	31	0
16	20	15	84	99	84	99	0	0
17	18	4	60	64	85	89	25	0
18	21	10	64	74	89	99	25	0
18	22	0	64	64	118	118	54	0
19	23	1	84	85	115	116	31	0
20	24	0	99	99	99	99	0	0
20	38	0	99	99	143	143	44	13
21	24	0	74	74	99	99	25	25
21	37	0	74	74	146	146	72	18
22	25	2	64	66	118	120	54	0
23	27	3	85	88	116	119	31	0
24	39	54	99	153	99	153	0	0
25	26	2	66	68	128	130	62	0
25	28	4	66	70	128	132	62	0
25	29	2	66	68	121	123	55	0
25	30	8	66	74	120	128	54	0
26	31	5	68	73	130	135	62	8
27	33	10	88	98	119	129	31	0
27	34	8	88	96	122	130	34	0
28	31	3	70	73	132	135	62	8
29	30	5	68	73	123	128	55	1
30	31	7	74	81	128	135	54	0
31	32	2	81	83	135	137	54	0
32	36	4	83	87	137	141	54	0
32	37	6	83	89	140	146	57	3
33	35	3	98	101	129	132	31	0
34	35	2	96	98	130	132	34	3
35	38	11	101	112	132	143	31	0
36	37	5	87	92	141	146	54	0
37	39	7	92	99	146	153	54	54
38	39	10	112	122	143	153	31	31
39	40	36	153	189	153	189	0	0

Table 3. Project Data "Input to The Program"

I	J	NT	NC	CT1	CC1	CT	CC	TYPE
1	2	30	49300	0	0	20	56450	L
2	3	4	10000	0	0	4	10000	L
2	4	2	90900	0	0	2	90900	L
2	5	20	32000	0	0	14	36000	L
3	6	3	266000	0	0	3	266000	L
3	8	4	59000	0	0	2	60300	L
3	9	10	18000	0	0	5	22000	D
3	10	1	8200	0	0	1	8200	L
4	7	4	90900	0	0	2	92600	L
5	19	0	0	0	0	0	0	L
5	22	0	0	0	0	0	0	L
6	9	4	18200	0	0	2	22500	L
7	11	20	454600	15	473100	10	510100	M
7	12	15	363700	0	0	10	382400	L
8	13	3	178000	0	0	2	180000	L
9	13	8	18000	0	0	3	24000	D
10	13	1	5000	0	0	1	5000	L
11	14	5	90900	0	0	3	95000	L
12	14	3	80000	0	0	2	83000	L
13	15	4	18000	0	0	2	19000	L
14	16	23	636000	18	673500	12	733500	M
15	17	4	3640	0	0	2	4200	L
15	18	6	7280	0	0	3	10280	D
16	19	0	0	0	0	0	0	L
16	20	15	5500	0	0	8	11100	L
17	18	4	15000	0	0	3	18000	L
18	21	10	4700	0	0	5	8900	L
18	22	0	0	0	0	0	0	L
19	23	1	10000	0	0	1	10000	L
20	24	0	0	0	0	0	0	L
20	38	0	0	0	0	0	0	L
21	24	0	0	0	0	0	0	L
21	37	0	0	0	0	0	0	L
22	25	2	8000	0	0	2	8000	L
23	27	3	60000	0	0	2	61000	L
24	39	54	402000	45	434000	35	479000	M
25	26	2	20000	0	0	2	20000	L
25	28	4	32000	0	0	2	33000	L
25	29	2	167000	0	0	2	167000	L
25	30	8	11900	0	0	3	15900	D
26	31	5	8600	0	0	2	11300	L
27	33	10	298000	0	0	5	335000	L
27	34	8	238000	0	0	5	256000	L
28	31	3	120000	0	0	2	122000	L
29	30	5	23000	0	0	3	26000	L
30	31	7	12000	0	0	3	17200	D
31	32	2	5000	0	0	2	5000	L
32	36	4	2500	0	0	2	3100	L
32	37	6	5000	0	0	3	9000	D
33	35	3	72000	0	0	2	75000	L
34	35	2	60000	0	0	2	60000	L
35	38	11	453000	8	475500	5	511500	M
36	37	5	15000	0	0	3	16000	L
37	39	7	3000	0	0	4	5500	L
38	39	10	3700	0	0	6	6900	L
39	40	36	264000	26	295000	17	344000	M