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STUDIES ON PRODUCTION PLANNING OF IPEN FUEL-ELEMENT PLANT IN ORDER TO MEET RMB DEMAND

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ABSTRACT

The plant of the Nuclear Fuel Center (CCN) will have to change its current laboratorial production level to an industrial level in order to meet the fuel demand of RMB and of IEA-R1. CCN's production process is based on the hydrolysis of UF_6, which is not a frequent production route for nuclear fuel. The optimization of the production capacity of such a production route is a new field of studies. Two different approaches from the area of Operations Research (OR) were used in this paper. The first one was the PERT/CPM technique and the second one was the creation of a mathematical linear model for minimization of the production time. PERT/CPM's results reflect the current situation and disclose which production activities may not be critical. The results of the second approach show a new average time of 3.57 days to produce one Fuel Element and set the need of inventory. The mathematical model is dynamic, so that it issues better results if performed monthly. CCN's management team will therefore have a clearer view of the process times and production and inventory levels. That may help to shape the decisions that need to be taken for the enlargement of the plant's production capacity.

1. INTRODUCTION

The fuel for the Brazilian Multipurpose Reactor (RMB) will be produced by the factory of the Nuclear Fuel Center (CCN) belonging to the Institute for Nuclear and Energy Research (IPEN) of the National Commission for Nuclear Energy (CNEN), in Sao Paulo, Brazil. Currently CCN produces 10 Fuel Elements (FE) per year for IPEN's IEA-R1 reactor. RMB's demand is forecasted in 60 FE per year, thus meaning that the plant will have to change its current laboratorial production level to an industrial level. Besides, a new type of FE will be produced, since RMB's FE has small differences in dimensions and structural parts when compared to IEA-R1's FE.

Such challenges faced by CCN are typical of the area of Operations Research (OR), which is a scientific approach for problem solving of complex systems management with few resources. Nowadays OR is used in activity fields as different as agriculture, education, industry, transportation and finance [1–3]. OR looks for a deeper understanding of the problem in order to support decision making and policy definition in a scientific way [4,5]. Among various analytical instruments available in OR, in this study the option was made for the PERT/CPM technique and for the linear optimization.

A new issue of this work is that the optimization of the production of nuclear fuel for research reactors is a little studied field, as it can be perceived from the scarce literature on it. This point adds to the fact that CCN's currently used production route is one of the few in the world using the conversion of UF_6 by means of the liquid form of UF_4, after UF_6 hydrolysis and applying tin chloride as a catalyst [6–8]. This production route for nuclear fuel will not be changed in the new setting of CCN's plant.

2. PERT/CPM

The Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) are extensively studied in the OR literature [2,5,9–17]. The same happens to the many uses of the combination of the two techniques, known as PERT/CPM [11,18,19]. For that reason only their main concepts are presented in this study. CPM's variables are:

- Earliest Start Time (EST) for each activity with no delay in the end of the process;
- Earliest Finish Time (EFT) for each activity with no delay in the end of the process;
- Latest Start Time (LST) for each activity with no delay for next activities and also no delay in the end of the process;
- Latest Finish Time (LFT) for each activity with no delay for next activities and also no delay in the end of the process;

The difference between the times contained in the mentioned variables is called Slack (S), as shown in Equation 1.

$$S = LST - EST = LFT - EFT \quad . \tag{1}$$

Activities whose slack value is zero are called critical activities and the path binding those activities is known as the Critical Path.

CPM was applied to all processes of every productive area of CCN`s Nuclear Fuel Plant which were operating in the year 2014. Areas, sectors and processes of that plant are described in details in reference [20]. The large extension of reference [20] shows that several divisions are possible to represent CCN`s production processes. The process division adopted in this work is presented in Table 1. Below are the explanations of the codes adopted in Table 1, according to reference [21].

- Codes RC refer to the area CCR, where UF_6 reconversion is made;
- Codes RF refer to the area CCL, which makes the melting and reduction of alloys;
- Codes PB refer to the sector PPB, the one that processes powders and fuel cores and
- Codes PM refer to the sector FPM, responsible for assembling fuel plates.

It is important to point out that Table 1 does not include all details of the activities, as it is just an instrument for understanding the current processes and for applying CPM. Activity PM3 in that table includes all activities from "cladding and framing stripping" until "plaques identification", according to the references [20,21]. The precedency of each process in Table 1 leads to the conclusion that all processes are critical, except for activities PM1 and PM2. That means slack values are zero for all activities, except PM1 and PM2. So only activities PM1 and PM2 are not critical and will have positive slack values.

Data contained in Table 1 allow the building of CPM's simplified graph presented in Fig. 1. The dashed line between activities RC1 and PB5 of the figure means that all activities between RC1 and PB5 are critical. The same happens for the dashed line from activity PM3 until PM12.

Table 1: CCN's processes

Nr.	Code	Activity	Predecessor
1	RC1	Reception of the 5A cylinder containing UF_6	-
2	RC2	Preparation for UF_6 transfer	RC1
3	RC3	UF_6 transfer from the cylinder to the ampoule	RC2
4	RC4	Preparation to UF_6 hydrolysis	RC3
5	RC5	UF_6 hydrolysis	RC4
6	RC6	Preparation to UF_4 precipitation	RC5
7	RC7	UF_4 precipitation	RC6
8	RC8	UF_4 washing and filtration	RC7
9	RC9	UF_4 drying	RC8
10	RC10	UF_4 dehydration	RC9
11	RF1	Crucible load with UF_4-Mg	RC10
12	RF2	UF_4 reduction to metallic uranium	RF1
13	RF3	Crucible disassembly and density measurement	RF2
14	RF4	Stripping of metallic uranium	RF3
15	RF5	Crucible load with metallic uranium and Si	RF4
16	RF6	Melting of the intermetallic alloy U_3Si_2	RF5
17	RF7	Density measurement of the U_3Si_2 ingot	RF6
18	PB1	Grinding of U_3Si_2 and classification of its powder	RF7
19	PB2	U_3Si_2 homogenization with Al	PB1
20	PB3	Cold press of the mix U_3Si_2-Al for fuel core production	PB2
21	PB4	Fuel core dimensional control	PB3
22	PB5	Fuel core degassing	PB4
23	PM1	Reception of aluminum boards	-
24	PM2	Cladding and framing preparation	-
25	PM3	Please refer to the text of this section 2.2.	PM1, PM2
26	PM4	Quality control	PM3
27	PM5	Scratching test	PM4
28	PM6	Stripping of fuel plates and FE components	PM5
29	PM7	FE assembly	PM6
30	PM8	Quality control	PM7
31	PM9	Nozzle fixation	PM8
32	PM10	Handling pin fixation	PM9
33	PM11	FE dimensional control	PM10
34	PM12	FE cleaning and packing	PM11

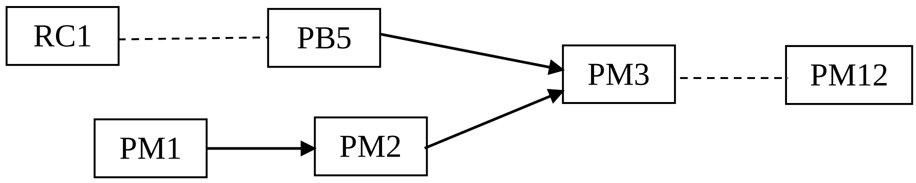

Figure 1: Simplified CPM network for CCN's processes

On the other hand, the times needed to perform the activities are not known with certainty in PERT [15,17]. Thus PERT uses following variables:

a = activity duration in the best conditions;
b = activity duration in the worst conditions;
m = most probable duration of the activity.

After calculating or measuring the values of the mentioned variables, slack usually appears in activities indicated as critical by CPM. Thus several paths may be identified as more or less critical, according to the slack values [15,17]. This fact generates doubts about which activities are really critical. Simulation is an efficient way of solving these doubts.

2.1. Simulation Methodology

In the references [10,12,15,17] there are a number of simulation methods for a process network that has been studied by PERT/CPM. Such methods give the finishing time of the process with good certainty and they calculate the slack with great precision. In this way, they help to improve the results from the PERT/CPM technique (12). In this work an adaptation of the methodologies from [12,15,17] was made to simulate CCN`s PERT/CPM network. Our simulation methodology uses two more variables, as follows:

$d = b - a$, i.e., the time gap between *b* and *a*. *d* is always positive, because $b > a$.
$ED = [(\text{random value between 0 and 1}) \times d] + a$

ED is an estimate of the time necessary to perform each activity. It will never be smaller than *a* and also never bigger than *b*. *ED* is a possible value of the duration of each activity because its value is located between *a* and. *b*.

Table 2 presents the main procedures of this simulation methodology. In this table, *n* is the number of the last activity of the PERT/CPM network. Step 16 of Table 2 is an estimate of the finishing time of the whole process with relevant certainty. That time is calculated applying all results from Step 13, using a normal probability distribution and assuming 99% of probability of the process to be finished by that time.

Table 3 was made using data from Table 1 and Fig. 1, but showing only critical activities. All data in Table 3 are expressed in continuous production hours. The contents of all columns of Table 3 are explained as follows:

- Column 1 contains all activities of Table 1, except PM1 and PM2;
- Columns 2 to 4 correspond to step 1 of the simulation methodology. For that purpose, all processes of Table 1 had their execution times measured by means of their direct

watching and accompaniment at CCN's plant during the year of 2014, which generated the values of *"a"* in column 2;

- In the same year of 2014 an estimate was made of the most probable time needed to perform each activity according to technical records from CCN, issuing values of *"m"* in column 3;
- Finally an estimate of the longest possible times was made, which is represented by *"b"* in column 4;
- Values of *"d"* in column 5 correspond to step 2 of the simulation methodology
- *"ED"* values in column 3 result from step 3;
- Steps 4 to 7 generate columns 7 and 8;
- Steps 8 to 11 generate columns 9 and 10 and
- Column 11 shows slack values from simulation step 12.

Table 2: Simulation methodology

Step	Procedure
1	Setting of *a, b* and *m*.
2	Calculation of $d = b – a$
3	Setting of values for $ED = [(random\ value\ between\ 0\ and\ 1)\ x\ d] + a$
4	$EST1 = LST1 = 0$
5	$EFT1 = LFT1 = ED1$
6	$EST_n = EFT_{n-1}$ $n = 2, 3,..., n$
7	$EFT_n = EST_n + ED_n$ $n = 2, 3,..., n$
8	$LFT_n = EFT_n$
9	$LST_n = EST_n$
10	$LFT_{n-1} = LST_n$ $n = n, n-1,..., 2$
11	$LST_{n-1} = LFT_{n-1} – ED_{n-1}$ $n = n, n-1,..., 2$
12	Calculation of the slack for each activity according to Equation 1
13	Repetition of steps 1 to 12 for a relevant number of times
14	Calculation of the average slack for each activity
15	Calculation of the average and standard deviation of the total processing time
16	Estimation of the finishing time

In order to perform step 13 the simulation was run for one hundred times. This is a relevant number of reiterations because it simulates the execution of all processes for one hundred times, which would be the same as to produce approximately 130 FE.

Results from step 14 are presented in Table 4, where the average slacks for one hundred repetitions of all activities are presented.

Table 4 shows positive slack values for activities RC2 until RC9 and zero for all other activities. The value of the slack for RC2 until RC9 is approximately 10^{-15}, which does not set those activities as not critical, although it is not zero. The low value of those slacks is an indication that those activities may not be critical. Taking into consideration the processes observed in the area CCR in the year 2014, the results of Table 4 make sense only for processes of preparation, i.e., RC2, RC4 and RC6. The nature of all other CCR's activities shows that it is not possible to consider them as not critical.

Table 3: Initial simulation of all CCN's processes in processing hours

1	2	3	4	5	6	7	8	9	10	11
	a	*m*	*b*	*d*	*ED*	*EST*	*EFT*	*LST*	*LFT*	*S*
RC1	1,0	2,0	3,0	2,0	2,1	0,0	2,1	0,0	2,1	0
RC2	4,0	6,0	8,0	4,0	5,2	2,1	7,3	2,1	7,3	10^{-14}
RC3	2,0	3,0	5,0	3,0	3,7	7,3	11,0	7,3	11,0	10^{-14}
RC4	2,0	3,0	4,0	2,0	2,7	11,0	13,7	11,0	13,7	10^{-14}
RC5	2,0	3,0	5,0	3,0	2,4	13,7	16,0	13,7	16,0	10^{-14}
RC6	1,0	1,3	3,0	2,0	1,7	16,0	17,8	16,0	17,8	0
RC7	2,0	3,0	4,0	2,0	3,7	17,8	21,4	17,8	21,4	0
RC8	1,0	1,3	2,0	1,0	1,3	21,4	22,7	21,4	22,7	0
RC9	12,0	18,0	20,0	8,0	19,5	22,7	42,2	22,7	42,2	0
RC10	5,0	6,0	8,0	3,0	7,3	42,2	49,6	42,2	49,6	0
RF1	1,5	2,0	2,5	1,0	1,7	49,6	51,2	49,6	51,2	0
RF2	6,0	8,0	10,0	4,0	7,2	51,2	58,4	51,2	58,4	0
RF3	0,6	1,0	1,5	0,9	0,6	58,4	59,1	58,4	59,1	0
RF4	0,3	0,5	1,0	0,8	0,3	59,1	59,4	59,1	59,4	0
RF5	0,2	1,0	1,5	1,3	1,2	59,4	60,6	59,4	60,6	0
RF6	6,0	8,0	10,0	4,0	6,7	60,6	67,3	60,6	67,3	0
RF7	0,2	0,3	0,5	0,3	0,2	67,3	67,5	67,3	67,5	0
PB1	1,0	2,0	3,0	2,0	2,0	67,5	69,5	67,5	69,5	0
PB2	4,0	6,0	8,0	4,0	5,4	69,5	74,9	69,5	74,9	0
PB3	2,0	3,0	5,0	3,0	3,1	74,9	78,0	74,9	78,0	0
PB4	2,0	3,0	4,0	2,0	3,8	78,0	81,8	78,0	81,8	0
PB5	2,0	3,0	5,0	3,0	3,3	81,8	85,1	81,8	85,1	0
PM3	15,0	20,3	22,5	7,5	18,4	96,2	100,8	96,2	100,8	0
PM4	5,0	6,8	8,0	3,0	5,6	100,8	106,4	100,8	106,4	0
PM5	1,0	2,0	2,5	1,5	2,0	106,4	108,4	106,4	108,4	0
PM6	10,0	13,5	15,0	5,0	10,2	108,4	118,6	108,4	118,6	0
PM7	4,0	6,0	8,0	4,0	7,7	118,6	126,2	118,6	126,2	0
PM8	1,0	3,0	4,0	3,0	2,5	126,2	128,8	126,2	128,8	0
PM9	1,0	1,5	2,0	1,0	1,4	128,8	130,2	128,8	130,2	0
PM10	1,0	1,5	2,0	1,0	1,9	130,2	132,1	130,2	132,1	0
PM11	1,0	1,5	2,0	1,0	1,1	132,1	133,2	132,1	133,2	0
PM12	1,0	1,5	2,0	1,0	1,7	133,2	134,9	133,2	134,9	0
Total	97,8	142	182	84,3	137,6	-	-	-	-	-

Step 15 results in a total processing time average of 139.8 hours and standard deviation of 4.3 hours. Step 16 results in a probability of 99% that the process will be finished in 149.8 hours. This value equals 25 working days, if the working time is considered to be 6 hours per day. And this value equals 18.7 working days for a production time of 8 hours per day.

Table 4: Average slack values

Activity Code	Average Slack	Activity Code	Average Slack	Activity Code	Average Slack
RC1	0	RF2	0	PM3	0
RC2	$4x10^{-15}$	RF3	0	PM4	0
RC3	$4x10^{-15}$	RF4	0	PM5	0
RC4	$4x10^{-15}$	RF5	0	PM6	0
RC5	$3x10^{-15}$	RF6	0	PM7	0
RC6	$2x10^{-15}$	RF7	0	PM8	0
RC7	$1x10^{-15}$	PB1	0	PM9	0
RC8	$9x10^{-15}$	PB2	0	PM10	0
RC9	$1x10^{-15}$	PB3	0	PM11	0
RC10	0	PB4	0	PM12	0
RF1	0	PB5	0	-	-

3. OPTIMIZATION MODEL

Mathematical models for linear optimization have wide use in agriculture, planning of industrial production, logistics, telecommunications, finance, transportation and many other areas, as mentioned by [1–3,5,11,12,14,15,17,19,22,23]. The same references present such models and some of them were used as a basis for the model developed in this study. The following model was adapted from [5,12,15–17,23] and represents the production of CCN's plant in its new setting. The model looks for the monthly production level, which will minimize the total annual production time. For that reason, the unknown variables are the monthly production quantities for each of the two types of FE. The unknown variables are called decision variables, according to [5,12,15–17,23], because they are the key data for production planning. CCN's plant will produce FE for RMB and for IEA-R1, thus $n = 2$. We set $i = 1$ for RMB and $i = 2$ for IEA-R1. For those reasons, our decision variables are:

$x1t$ = quantity of FE for RMB to be produced in month t and
$x2t$ = quantity of FE for IEA-R1 to be produced in month t.

The boundary conditions of the model are presented below.

- The plant produces n different products;
- It is desired to plan its production for T periods of time;
- The time period was set as one month;
- The model was made for one year of planning, so that $T = 12$ months;
- Demand of each product is known every month;
- Production time is limited, renewable and there is enough availability of it in the beginning of each month;
- There is the possibility of keeping inventory from one month to the other and
- There is no production stops due to vacations or maintenance.

The model's goal is to minimize the production time. Thus, production time is the only production resource considered in the model. Table 5 presents the definitions of the input variables, their symbols, and the values adopted to run the model. In the same Table, we considered that one year has in average 250 working days. Since the plant will produce 70 FE per year, so the time to produce one FE is $z_i = 250/70 = 3.57$ working days.

Table 5: Input variables

Symbol	Definition	Value
d_{it}	Demand of item i in the period t	Tables 6 and 7
D_1	RMB's yearly demand	60 FE
D_2	IEA-R1's yearly demand	10 FE
D	Total demand = $D_1 + D_2 = \sum dit$	70 FE
c_{it}	Production capacity allocated to item i in month t	Tables 6 and 7
Ct	Production capacity in month t ($C_t = c_{1t} + c_{2t}$)	8 FE
Wt	Production time available in month t	22 working days
z_i	Time needed to produce one FE	3.57 working days
I_{10}	RMB's inventory in the beginning of the first month	4 FE
I_{20}	IEA-R1's inventory in the beginning of the first month	1 FE
$Imax_{1t}$	RMB's maximum inventory in the end of month t	10 FE
$Imin_{1t}$	RMB's minimum inventory in the end of month t	4 FE
$Imax_{2t}$	IEA-R1's maximum inventory in the end of month t	3 FE
$Imin_{2t}$	IEA-R1's minimum inventory in the end of month t	1 FE

Given the goal of the model and the definitions of all variables, the Objective Function becomes to minimize the total annual production time, which is the product of the time needed to produce one FE and the total production, i.e.:

$$\text{Minimize} \qquad f(x) = \sum_{i=1}^{2} \sum_{t=1}^{12} x_{it} z_i$$

The Objective Function must obey following constraints:

Inventory constraints

Let I_{it} be the inventory of type i items in the end of month t. Thus:

$I_{it} = I_{i,t-1} + x_{it} - d_{it}$ $\quad i = 1, 2, ..., n, t = 1, 2, ..., T$ and

$Imin_{it} \leq l_{it} \leq lmax_{it}$ $\quad i = 1, 2, ..., n, t = 1, 2, ..., T$

Replacing the adopted values:

For RMB

$I_{1t} = I_{1t} + x_{1t} - d_{1t}$ $\quad t = 1, ..., 12$

$4 \leq l_{1t} \leq 10$ $\quad t = 1, ..., 12;$

For IEA-R1

$I_{2t} = I_{2t} + x_{2t} - d_{2t}$ $\quad t = 1, ..., 12$

$1 \leq l_{2t} \leq 3$ $\quad t = 1, ..., 12;$

Production capacity constraints

Production yield cannot be bigger than production capacity, i.e.:

$\sum_{i=1}^{n} x_{it} \leq C_t \quad t = 1, 2, ..., T$

Replacing the adopted values:

For any month $\quad \sum_{i=1}^{n} x_{it} \leq 8$

For one year $\quad \sum_{i=1}^{n} x_{it} \leq 8\, x\, 12 = 96$

Resources constraints
The amount of resources required for production cannot be bigger than the available quantity of those resources in the beginning of each month. Since only the production time is considered in this model:

$\sum_{i=1}^{n} x_{it} z_i \leq Z_t \qquad t = 1, ..., 12;$

Replacing the adopted values:

$3{,}57 \sum_{i=1}^{n} x_{it} \leq 22 \qquad t = 1, ..., 12;$

Demand meeting constraints

$x_{it} + I_{i,t-1} \geq d_{it}$ or $x_{it} + I_{i,t-1} - d_{it} \geq 0.$

But we defined $x_{it} + I_{i,t-1} - d_{it} = I_{it}$.

Thus to guarantee that the demand will be met, it is enough to impose:

$l_{it} \geq 0 \qquad i = 1, 2, ..., n, t = 1, 2, ..., T$

Other constraints

$x_{it} \geq 0 \qquad i = 1, 2, ..., n, t = 1, 2, ..., T$

$c_{it} \geq 0 \qquad i = 1, 2, ..., n, t = 1, 2, ..., T$

Therefore the complete model has the following formulation:

Minimize $f(x) = \sum_{i=1}^{2} \sum_{t=1}^{12} x_{it} z_i$

Subject to:

$I_{1t} = I_{1t} + x_{1t} - d_{1t} \qquad t = 1, ..., 12$

$4 \leq l_{1t} \leq 10 \qquad t = 1, ..., 12;$

$I_{2t} = I_{2t} + x_{2t} - d_{2t} \qquad t = 1, ..., 12$

$1 \leq l_{2t} \leq 3 \qquad t = 1, ..., 12;$

$\sum_{i=1}^{n} x_{it} \leq 8 \qquad t = 1, ..., 12;$

$3{,}57 \sum_{i=1}^{n} x_{it} \leq 22 \qquad t = 1, ..., 12$

$I_{it}, x_{it}, c_{it} \geq 0 \qquad i = 1, 2, ..., n;\ t = 1, 2, ..., T$

The model is linear and has more equations than unknown variables, thus having many possible solutions. The most common way of finding the optimal solution is the Simplex Method, which is widely studied in the literature [2,4,5,9,10,12,14–17].

Data from Tables 5, 6 and 7 were used as input for the model. The output of the model are the monthly levels of production and inventory of FE for RMB and of FE for IEA-R1, as well as the minimized annual production time. Such outputs are calculated at the same time that the monthly and yearly demands of both types of FE are met. The model was run in two different scenarios, as follows:

Scenario 1: Both types of FE are produced every month. Table 6 presents the input values of monthly demand and allocated production capacity to RMB and IEA-R1. The same table presents the output of the model, i.e., monthly production and inventory levels. All values of Table 6 are expressed in number of FE. In this case, the result for the minimized annual production time is 249.9 working days.

Scenario 2: All FE demanded by IEA-R1 in one year are produced separately from the production for RMB. Table 7 presents the input values of monthly demand and allocated production capacity to RMB and IEA-R1. The same table presents the output of the model, i.e., monthly production and inventory levels. All values of Table 7 are expressed in number of FE. The resulting minimized annual production time is also 249.9 working days for this scenario

Table 6: Alternating production (number of FE)

Months	Demand		Production Capacity		Production		Inventory	
	RMB	IEA-R1	RMB	IEA-R1	RMB	IEA-R1	RMB	IEA-R1
1	5	0	7	1	6	0	5	1
2	5	0	7	1	6	0	6	1
3	5	1	7	1	5	1	6	1
4	5	1	7	1	5	1	7	1
5	5	1	7	1	5	1	7	1
6	5	1	7	1	5	1	7	1
7	5	1	7	1	5	1	7	1
8	5	1	7	1	5	1	7	1
9	5	1	7	1	5	1	7	1
10	5	1	7	1	5	1	8	1
11	5	1	6	2	4	2	7	2
12	5	1	7	1	4	0	4	1
Total	60	10	83	13	60	10	-	-

Table 7: Continuous production (number of FE)

Months	Demand		Production Capacity		Production		Inventory	
	RMB	IEA-R1	RMB	IEA-R1	RMB	IEA-R1	RMB	IEA-R1
1	0	5	2	6	0	6	4	2
2	0	5	3	5	2	4	6	1
3	6	0	8	0	6	0	6	1
4	6	0	8	0	6	0	7	1
5	6	0	8	0	6	0	7	1
6	5	0	8	0	6	0	8	1
7	5	0	8	0	6	0	9	1
8	5	0	8	0	6	0	10	1
9	6	0	8	0	6	0	10	1
10	6	0	8	0	6	0	10	1
11	7	0	8	0	6	0	9	1
12	8	0	8	0	4	0	4	1
Total	60	10	85	11	60	10	-	-

The different suppositions adopted for scenarios 1 and 2 imply different transition times from the production of one type of FE to the other. Let the time to change the production from one type of FE to the other be one hour. In this way, scenario 1 will have an increase of 24 hours per year in the total annual production time, because it will be necessary to change processes twice a month. Similarly, scenario 2 will have an addition of two hours in its total annual

production time, since scenario 2 does it only twice a year. Therefore, the new minimized annual production times will have following values:
Scenario 1: 249.9 days + 24 hours = 249.9 + 3 = 252.9 working days per year
Scenario 2: 249.9 days + 2 hours ≈ 250.0 working days per year

4. CONCLUSIONS

Activities RC2, RC4 and RC6 may be executed as not critical in the new setting of the plant, if such processes are carried out before RC3, RC5 and RC7 respectively. For that purpose, some new resources will be needed in the new plant. Such resources may be different man power distribution or new equipment. These facts may be taken into consideration by CCN's management team in the decision making process for the enlargement of the plant.

The value of 25 working days for the production of one FE with 6 working hours per day reflects the accuracy of the PERT/CPM technique and of the applied simulation. This is so because that time is the one that actually happens as an average in the plant today.

Regarding the mathematical model, the time of 3.57 working days for the production of one FE may be seen as a goal to be reached in the new configuration of the plant. The same applies to the required inventory capabilities. The fastest way to reach 70 EC per year is the production of FE for IEA-R1 before and separately from the production to RMB. Such results come from one single run of the model for each postulated scenario. However, the model is dynamic, so that it should be executed in the beginning of every month using data of the new month. By doing so, CCN's management team will be able of fine tuning the model's responses for the next twelve months.

For future studies it is possible to build the PERT/CPM network of the new setting of the plant. The simulation of that new network will cast some light about which new activities may not be critical, before the final plant layout is decided.

Improvements to the optimization model can be made by addition of different data, like cost or other production resources besides time. The model can also be replaced by one of integer programming, if more precision is desired in its output.

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