Optimising the Design Process of the Injection Camshaft by Critical Path Method (CPM)

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In the present paper a series of advantages of the CPM method are presented, focusing on the optimization of design duration of an injection camshaft, by cost criteria. The minimum duration of finalizing the design of the injection camshaft will be determined, as well as the total cost associated to this project, normally, and then under crash regime. At the end, two types of sensitivity analysis will be performed: Meeting the desire completation time and Meeting the desired budget cost.

Keywords: *injection camshaft, sensitivity analysis, design, optimal solution.*

1. Introduction

The worpiece, injection camshaft is part of the motor assembly 6 L 35 MC B&W Diesel A/S and is executed in the middle precision class according to STAS 2300-88. The material from which the part is executed is 17 MoCrNi 14 and its weight is 13,7 kg.

2. Case Study

The corresponding stages of analysis and deployment of the design process, according to the technological processing flowchart of the injection camshaft, are the following:

E1. Constructive-functional elements analysis of the part;
E2. Performs analysis;
E3. Detailed design of the technological process;
E4. Economical analysis of the technological process;
E5. Elaboration of the final technological documentation.

The steps presented in fig.1, are the mix of activities which are connected to each other for which it is important to know the finishing durations, the moments

of finalizing the intermediary operations, the critical activities, the time reserves etc.

Nr. crt.	Name of step/activity	Nr. step	Activity code	Precedence	Time unit [hours]
1	Sketch of the part	E1	A	-	1
2	Material analysis		B	-	6
3	Functional role of the part		C	A	2
4	Method of obtaining	E2	D	B, C	1,5
5	The process for obtaining		E	D	2
6	The additions of processing		F	E	2
7	Technological additions		G	F	1
8	Sketch of the operation	E3	H	G	0,5
9	Steps of the operation		I	H	0,5
10	Choosing the machine tools		J	G	4
11	Establishing devices		K	I, J	1,5
12	Establishing tools		L	I, J	1
13	Establishing checkers		M	L	0,3
14	Establishing cutting regimes parameters	E4	N	K, M	8
15	Technical standardization of the processing operations		O	N	6
16	Economical analysis of the technological process	E5	P	O	4
17	Elaborating the final techno-logical documentation	E6	Q	P	4

Figure 1. Project preparation activities

Having the data presented in figure 1, we can determine the minimal duration of the design completion of the injection camshaft. To be able to calculate the total cost of design, we assign the each activity a cost. It is desired to speed up the completion of the project and calculating the total finishing cost of the injection camshaft in Crash regime. For this, the data input are entered according to fig.2.

The final cost of design of the injection camshaft will be calculated, also the total cost of this project, in normal regime, and then in Crash regime. Finally to types of sensitivity analysis will be performed: Meeting the desire completation time and meeting the desired budget cost.

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Cama CPM

Activity Number	Activity Name	Immediate Predecessor (list number/name, separated by ',')	Normal Time	Crash Time	Normal Cost	Crash Cost
1	A		1	1	10	10
2	B		6	5,2	30	38
3	C	A	2	1,9	10	12
4	D	B,C	1,5	1	5	7,5
5	E	D	2	1,5	7	9
6	F	E	2	1,5	15	19
7	G	F	1	1	6	6
8	H	G	0,5	0,4	3	3,3
9	I	H	0,5	0,5	3	3
10	J	G	4	3,5	20	24
11	K	I,J	1,5	1	10	15
12	L	I,J	1	1	5	5
13	M	L	0,3	0,3	2	2
14	N	K,M	8	6	50	66
15	O	N	6	5	30	37
16	P	O	4	3	20	25
17	Q	P	4	3,5	20	25

Figure 2. Data input of the problem

3. Solving in normal regime

From figure 3, we can observe that designing the part can be done in 40 hours. The design cost is of 246 lei and there is only one critical path whose cost is 213 lei.

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Activity Analysis for Cama CPM (Using Normal Time)

06-23-2016 08:31:44	Activity Name	On Critical Path	Activity Time	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Slack (LS-ES)
1	A	no	1	0	1	3	4	3
2	B	Yes	6	0	6	0	6	0
3	C	no	2	1	3	4	6	3
4	D	Yes	1,5	6	7,5	6	7,5	0
5	E	Yes	2	7,5	9,5	7,5	9,5	0
6	F	Yes	2	9,5	11,5	9,5	11,5	0
7	G	Yes	1	11,5	12,5	11,5	12,5	0
8	H	no	0,5	12,5	13	15,5	16	3
9	I	no	0,5	13	13,5	16	16,5	3
10	J	Yes	4	12,5	16,5	12,5	16,5	0
11	K	Yes	1,5	16,5	18	16,5	18	0
12	L	no	1	16,5	17,5	16,7	17,7	0,2
13	M	no	0,3	17,5	17,8	17,7	18	0,2
14	N	Yes	8	18	26	18	26	0
15	O	Yes	6	26	32	26	32	0
16	P	Yes	4	32	36	32	36	0
17	Q	Yes	4	36	40	36	40	0
	Project	Completion	Time	=	40	hs		
	Total	Cost of	Project	=	$246	(Cost on	CP =	$213)
	Number of	Critical	Path(s)	=	1			

Figure 3. Results in table form for normal durations.

4. Solving in CRASH regime

In the case of speeding up the design completion of the injection cam-shaft, the times of some activities will be reduced, and in exchange for this reduction, there is an increase in costs. The obtained results are presented in fig.4, where it can be noticed that the project can be done in 32,5 hours. The design cost if of 306,80 lei and there is only one critical path which has a cost of 263,50 lei.

06-23-2016 08:44:50	Activity Name	On Critical Path	Activity Time	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Slack (LS-ES)
1	A	no	1	0	1	2,3	3,3	2,3
2	B	Yes	5,2	0	5,2	0	5,2	0
3	C	no	1,9	1	2,9	3,3	5,2	2,3
4	D	Yes	1	5,2	6,2	5,2	6,2	0
5	E	Yes	1,5	6,2	7,7	6,2	7,7	0
6	F	Yes	1,5	7,7	9,2	7,7	9,2	0
7	G	Yes	1	9,2	10,2	9,2	10,2	0
8	H	no	0,4	10,2	10,6	12,8	13,2	2,6
9	I	no	0,5	10,6	11,1	13,2	13,7	2,6
10	J	Yes	3,5	10,2	13,7	10,2	13,7	0
11	K	no	1	13,7	14,7	14	15	0,3
12	L	Yes	1	13,7	14,7	13,7	14,7	0
13	M	Yes	0,3	14,7	15	14,7	15	0
14	N	Yes	6	15	21	15	21	0
15	O	Yes	5	21	26	21	26	0
16	P	Yes	3	26	29	26	29	0
17	Q	Yes	3,5	29	32,5	29	32,5	0
	Project	Completion	Time	=	32,50	hs		
	Total	Cost of	Project	=	306,80 lei	(Cost on	CP =	263,50 lei)
	Number of	Critical	Path(s)	=	1			

Figure 4. Activities analysis using CRASH durations

5. Cost analysis

The sensitivity analysis allows us to apply some restrictions regarding the duration or budget of the project and determining cost allocation so that the total cost is minimal.

There will be two types of analysis performed:
1. Meeting the desire completation time;
2. Meeting the desired budget cost.

1. Meeting the desire completation time

Case 1. For designing the injection camshaft it's desired completion time is of 37 hours. In the case in which the design ends faster, a bonus of 75 lei per hours is offered, and for each hour of delay a penalty of 50 lei is added. The obtained results are presented in figure 5.

06-23-2016 08:40:35	Activity Name	Critical Path	Normal Time	Crash Time	Suggested Time	Additional Cost	Normal Cost	Suggested Cost
1	A	no	1	1	1	0	$10	$10
2	B	Yes	6	5,2	6	0	$30	$30
3	C	no	2	1,9	2	0	$10	$10
4	D	Yes	1,5	1	1	2,50 lei	$5	7,50 lei
5	E	Yes	2	1,5	1,5	$2	$7	$9
6	F	Yes	2	1,5	2	0	$15	$15
7	G	Yes	1	1	1	0	$6	$6
8	H	no	0,5	0,4	0,5	0	$3	$3
9	I	no	0,5	0,5	0,5	0	$3	$3
10	J	Yes	4	3,5	4	0,00 lei	$20	20,00 lei
11	K	Yes	1,5	1	1,5	0	$10	$10
12	L	no	1	1	1	0	$5	$5
13	M	no	0,3	0,3	0,3	0	$2	$2
14	N	Yes	8	6	8	0	$50	$50
15	O	Yes	6	5	5	$7	$30	$37
16	P	Yes	4	3	3	$5	$20	$25
17	Q	Yes	4	3,5	4	0	$20	$20
	Penalty/	Reward:						0
	Overall	Project:			37	16,50 lei	$246	262,50 lei

Figure 5. Results obtained from the first analysis of the costs

It can be seen that the design of the part can be done in 37 hours, but with an additional cost of 16,5 lei, so a total cost of 262,5 lei.

06-23-2016 08:47:03	Activity Name	Critical Path	Normal Time	Crash Time	Suggested Time	Additional Cost	Normal Cost	Suggested Cost
1	A	no	1	1	1	0	$10	$10
2	B	Yes	6	5,2	5,2	$8	$30	$38
3	C	no	2	1,9	2	0	$10	$10
4	D	Yes	1,5	1	1	2,50 lei	$5	7,50 lei
5	E	Yes	2	1,5	1,5	$2	$7	$9
6	F	Yes	2	1,5	1,5	$4	$15	$19
7	G	Yes	1	1	1	0	$6	$6
8	H	no	0,5	0,4	0,5	0	$3	$3
9	I	no	0,5	0,5	0,5	0	$3	$3
10	J	Yes	4	3,5	3,5	$4	$20	$24
11	K	Yes	1,5	1	1,3	2,00 lei	$10	$12
12	L	Yes	1	1	1	0	$5	$5
13	M	Yes	0,3	0,3	0,3	0	$2	$2
14	N	Yes	8	6	6	$16	$50	$66
15	O	Yes	6	5	5	$7	$30	$37
16	P	Yes	4	3	3	$5	$20	$25
17	Q	Yes	4	3,5	3,5	$5	$20	$25
	Late	Penalty:						$125
	Overall	Project:			32,50	55,50 lei	$246	426,50 lei

Figure 6. Results obtained from the second analysis of the costs

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Case 2. A shorter project completion time to 30 hours is tried, this time, the penalties and bonuses remain the same.

It can be seen in figure 6 that the project can not be done faster than 32,5 hours, and to the total cost penalties are added, namely 125 lei, plus and additional cost of 55,5 lei. So the total cost in this case is 426,5 lei, with 119,2 lei more than in the Crash case and with 180,5 more than the case of normal duration times.

06-23-2016 08:52:04	Activity Name	Critical Path	Normal Time	Crash Time	Suggested Time	Additional Cost	Normal Cost	Suggested Cost
1	A	no	1	1	1	0	$10	$10
2	B	Yes	6	5,2	5,65	3,50 lei	$30	33,50 lei
3	C	no	2	1,9	2	0	$10	$10
4	D	Yes	1,5	1	1	2,50 lei	$5	7,50 lei
5	E	Yes	2	1,5	1,5	$2	$7	$9
6	F	Yes	2	1,5	1,5	$4	$15	$19
7	G	Yes	1	1	1	0	$6	$6
8	H	no	0,5	0,4	0,5	0	$3	$3
9	I	no	0,5	0,5	0,5	0	$3	$3
10	J	Yes	4	3,5	3,5	$4	$20	$24
11	K	Yes	1,5	1	1,5	0	$10	$10
12	L	no	1	1	1	0	$5	$5
13	M	no	0,3	0,3	0,3	0	$2	$2
14	N	Yes	8	6	6	$16	$50	$66
15	O	Yes	6	5	5	$7	$30	$37
16	P	Yes	4	3	3	$5	$20	$25
17	Q	Yes	4	3,5	4	0	$20	$20
	Overall	Project:			33,65	44,00 lei	$246	$290

Figure 7. Results obtained in the case of a budged of 290 lei

2. Meeting the desired budget cost

Case 1. In the case of an available budget of 290 lei, the project can be done in 33,65 hours, according to fig.7.

Case 2. In the case of a budget even smaller than 275 lei, the project can be completed in 35,44 hours.

6. Conclusion

Design in normal regime of the injection camshaft can be completed in 40 hours, with a total cost of 246 lei, and in emergency regime it is completed in 32,5 hours. In this case, the total cost of design is of 306,80 lei. It can be seen a decrease in the time of deployment of the project in the case of Crash durations of 7 hours and 30 minutes and an increase of the total cost of 60,8 lei.

Two type of sensitivity analysis have been carried out:

− Meeting the desire completation time;

▪ Case 1. Completing the design of the part in 37 hours can be achieved, but with an additional cost of 16,5 lei, so with a total cost of 262,5 lei.

▪ Case 2. Completing the design of the part in 30 hours is impossible. The camshaft can not be designed in a shorter time than 32,5 hours, and to the total cost, namely 125 lei, plus an additional cost of 55,5 lei. So the total cost in this case is 426,5 lei, with 119,2 lei more than in the Crash case and with 180,5 more than in the case of normal time durations.

− Meeting the desired budget cost.

▪ Case.1. Available budget of 290 lei, the project can be completed in 33,65 hours.

▪ Case.2. Available budget of 275 lei, the project can be completed in 35,44 hours.

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