

Table 3. Options for 63-Activities Project with Five Modes

	Description	Option 1		Option 2		Option 3		Option 4		Option 5	
No	Precedent	Dur (day)	Cost \$	Dur	Cost \$	Dur	Cost \$	Dur	Cost \$	Dur	Cost \$
1	-	14	3700	12	4250	10	5400	9	6250	-	-
2	-	21	11250	18	14800	17	16200	15	19650	-	-
3	-	24	22450	22	24900	19	27950	17	31650	-	-
4	-	19	17800	17	19400	15	21600	-	-	-	-
5	-	28	31180	26	34200	23	38250	21	41400	-	-
6	1	44	54260	42	58450	38	63,225	35	68150	-	-
7	1	39	47600	36	50750	33	54800	30	59750	-	-
8	2	52	62140	47	69700	44	72600	39	81750	-	-
9	3	63	72750	59	79450	55	86250	51	91500	49	99500
10	4	57	66500	53	70250	50	75800	46	80750	41	86450
11	5	63	83100	59	89450	55	97800	50	104250	45	112400
12	6	68	75500	62	82000	58	87500	53	91800	49	965500
13	7	40	34250	37	38500	33	43950	31	48750	-	-
14	8	33	52750	30	58450	27	63400	25	66250	-	-
15	9	47	38140	40	41500	35	47650	32	54100	-	-
16	9, 10	75	94600	70	101250	66	112750	61	124500	57	132,850
17	10	60	78450	55	84500	49	91250	47	94640	-	-
18	10, 11	81	127150	73	143250	66	154600	47	161900	-	-
19	11	36	82500	34	94800	30	101700	-	-	-	-
20	12	41	48350	37	53250	34	59450	32	66800	-	-
21	13	64	85250	60	92600	57	99800	53	107500	49	113750
22	14	58	74250	53	79100	50	86700	47	91500	42	97400
23	15	43	66450	41	69800	37	75800	33	81400	30	88450
24	16	66	72500	62	78500	58	83700	53	89350	49	96400
25	17	54	66650	50	70100	47	74800	43	79500	40	86800
26	18	84	93500	79	102500	73	111250	68	119750	62	128500
27	20	67	78500	60	86450	57	89100	56	91500	53	94750
28	21	66	85000	63	89750	60	92500	58	96800	54	100500
29	22	76	92700	71	98500	67	104600	64	109900	60	115600
30	23	34	27500	32	29800	29	31750	27	33800	26	36200
31	19, 25	96	145000	89	154800	83	168650	77	179500	72	189100
32	26	43	43150	40	48300	37	51450	35	54600	33	61450
33	26	52	61250	49	64350	44	68750	41	74500	38	79500
34	28, 30	74	89250	71	93800	66	99750	62	105100	57	114250
35	24, 27, 29	138	183000	126	201500	115	238000	103	283750	98	297500
36	24	54	47500	49	50750	42	56800	38	62750	33	68250
37	31	34	22500	32	24100	29	26750	27	29800	24	31600
38	32	51	61250	47	65800	44	71250	41	76500	38	80400
39	33	67	81150	61	87600	57	92100	52	97450	49	102800
40	34	41	45250	39	48400	36	51200	33	54700	31	58200
41	35	37	17500	31	21200	27	26850	23	32300	-	-

42	36	44	36400	41	39750	38	42800	32	48300	30	50250
43	36	75	66800	69	71200	63	76400	59	81300	54	86200
44	37	82	102750	76	109500	70	127000	66	136800	63	146000
45	39	59	847500	55	91400	51	101300	47	126500	43	142750
46	39	66	94250	63	99500	59	108250	55	118500	50	136000
47	40	54	73500	51	78500	47	83600	44	88700	41	9400
48	42	41	36750	39	39800	37	43800	34	48500	31	53950
49	38, 41, 44	173	267500	159	289700	147	312000	138	352500	121	397750
50	45	101	47800	74	61300	63	76800	49	91500	-	-
51	46	83	84600	77	93650	72	98500	65	104,600	61	113200
52	47	31	23150	28	27600	26	29800	24	32,750	21	35,200
53	43, 48	39	31500	36	34250	33	37,800	29	41,250	26	44,600
54	49	23	16,500	22	17,800	21	19,750	20	21,200	18	24,300
55	52, 53	29	23,400	27	25,250	26	26,900	24	29,400	22	32,500
56	50, 53	38	41,250	35	44,650	33	47,800	31	51,400	29	55,450
57	51, 54	41	37,800	38	41,250	35	45,600	32	49,750	30	53,400
58	52	24	12,500	22	13,600	20	15,250	18	16,800	16	19,450
59	55	27	34,600	24	37,500	22	41,250	19	46,750	17	50,750
60	56	31	28,500	29	30,500	27	33,250	25	38,000	21	43,800
61	56, 57	29	22,500	27	24,750	25	27,250	22	29,800	20	33,500
62	60	25	38,750	23	41,200	21	44,750	19	49,800	17	51,100
63	61	27	9,500	26	9,700	25	10,100	24	10,800	22	12,700

Table 4. Pareto front solutions of 63 activity TCTP problem (Case 1: ICR = \$2300)

Sr. No	Sonmez and Bettemir, (2012)		Aminbakhsh and Sonmez (2016)		Togan and Eirgash, (2019)		Sulub et al. (2024)		(This paper)	
	HGA		D-PSO		TLBO		NDS-AOA		Oppositional MAWA-AOA	
	PCT	PCC	PCT	PCC	PCT	PCC	PCT	PCC	PCT	PCC
1	633	5421320	630	5421120	629	5613820	629	5445770	537	5912280
2	633	5421320	630	5422420	614	5644640	638	5445020	540	5878050
3	633	5421620	630	5421120	630	5600190	648	5440170	541	5823440
4	633	5421320	630	5421120	616	5623260	632	5443370	543	5864505
5	633	5421620	633	5421320	630	5642405	637	5450870	544	5873940
6	633	5421620	636	5422970	637	5637290	652	5444660	547	5888800
7	633	5421620	631	5424420	639	5503940	643	5437370	549	5939710
8	633	5421620	633	5421320	630	5696820	666	5446720	553	5773850
9	633	5421620	633	5421320	627	5588485	658	5455720	563	5824655
10	629	5450065	629	5423270	632	5625310	639	5418320	570	5885705
NOP	500		200		180		250		250	
NOI	500		250		450		130		130	
NFE	250000		50000		162180		65250		65250	

List of Abbreviations

AOA: Arithmetic Optimization Algorithm

CPM: Critical Path Method

GA – Genetic Algorithm

HHMH – Hybrid Heuristic–Metaheuristic

HOL – Hybrid Opposition-Based Learning

MAWA: Modified Adaptive Weighting Approach

AOA: Arithmetic Optimization Algorithm

NDSII: Non-Dominated Sorting II

AO: Aquila Optimization

NDSII-AOA: Non-Dominated Sorting II Arithmetic Optimization Algorithm

NDSII-TLBO: Non-Dominated Sorting II Teaching–Learning-Based Optimization

NFE: Number of Function Evaluations

NOP: Number of Population

NSGA-II: Non-Dominated Sorting Genetic Algorithm II

OBL: Opposition-Based Learning

QOBL: Quasi-Opposition-Based Learning

QRBL: Quasi-Reflection-Based Learning

RL: Reinforcement Learning

TCQP: Time–Cost–Quality Problem

TCQRP: Time–Cost–Quality–Risk Problem

TCTP: Time–Cost Trade-Off Problem

TCQETP: Time–Cost–Quality–Environmental Trade-Off Problem