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Time-Cost-Quality Trade-Off in Project Scheduling by Using Specific Techniques of Hunting Dolphins

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ABSTRACT

Simultaneous reduction of the project cost and its performing duration was an essential necessity in today's rival environment. Quality, the effective parameter of optimization, as an effective indicator was attended by the costumers. So, due to the asymmetry between the two factors-Time and Cost and the factor of Quality it was essential to make the project decision in the best balanced conditions between the three factors. Project scheduling ,increasing the project quality level and sources limitations were unavoidable in today's environment. The accession of popularity of the project delivery system had replaced the customers. The contractors had more wariness about their benefits. The wariness about losing the opportunities, performing earlier finishing with the highest quality and reducing the cost. In this research a new model named STHD was introduced. This mechanism was inspired by the dolphin's natural behavior and living manner in hunting as clever creatures in hunting and reproduction. In this article a sample problem in discrete position and close to reality was estimated. And showed its flexibility conclusions according to ANOVA method. The high difference of this method in comparison to the others showed the most optimization, practicality and occurrence in decision making with more than 70% optimization.

KEYWORDS: The project Optimization, Quality accession, Time-Cost-Quality, Trade-off, Project Scheduling Dolphin's hunting technique , ANONA.

INTRODUCTION

By extending various systems in projects ending and by considering that Time is a determinative factor in evaluation and making processes, the projects managers do not only consider the project cost reduction. Shortening the project time gradually increases the project final cost. One of the common methods and techniques in determining the project schedule is the Critical Path Method (CPM). In this method we can't change the schedule and on the other hand, the sources unlimitation presumption is the determiner of the project time. In real world it isn't like this. Furthermore On the other hand, the investors sometimes tend to reduce the cost and time and increase the quality, therefore one of the most important conclusion of these efforts is removing the fault in Time, Cost and Quality balance and create a new and complete method for making the balance between these three factors by STHD.

Lots of mathematical methods and investigations are applied for solving the problem of time, cost and quality balance (Fondahel 1961; Azaron and Perkgoz 2005). Commonly these methods are related to the problem and don't guaranty the optimized answer (Prager 1963; Leu and Yang 1999) And on the other hand, by increasing the problem's dimensions and complication; it loses the practicality; Alternation and applying these methods that include converting the investigative methods to objective functions and etc, could occurs with a mistake. By applying these methods it is too difficult to achieve the optimized answer. it has low occurrence and it's unable to check the environment of sum of the responses completely. Given methods in related projects and time, cost and quality optimization in performing the projects are categorized into three groups: 1) investigating 2) mathematics 3) ultra-investigative. Some investigative methods are the given methods by (Fondahel 1961, Prager1963,Moslehiand1993, Siemens 1971). For mathematical methods we can mention Linear programing method (Kelly 1961), Integer programing model (Mayer 1963), Operational programing model (Robinson 1975) and The collective model of linear and integer programing(Liu & Burns 1995) . Investigative methods are related to the problem's kind for achieving the response and do not guaranty the optimizing response achieving. Even if the mathematical methods be able to solve the problem, do not guaranty the optimization of the problem's answer. But by dimension increasing and problems more complications they aren't practical any more.

In order to optimization and introduce a method which is practical, fast, and correct in decision making, we provide a new and powerful model named as ultra creative technique of hunting by dolphins. During recently decades a few methods for simultaneous optimization for time, cost and quality were given. Recently, Quality has attended seriously as a major and important criteria in choosing the project performing method. Most articles are specialized for Time, Cost and Quality optimization which shows the lack of suitable response to the costumers demand. And do not consider Quality as an important factor.

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According to dependence of investigative method to the problem's kind and do not achieving to the optimized answer ,decision making occurs with mistake. On the other hand, mathematical method's fault which are not able to solve the problem or increase the number of designing variables an its complication. During last few years the complete progress of an ultra creative algorithm in solving the complicated optimizing problems named as NP-hard , has taken lots of researchers interests. So the importance of the introduced algorithm and the three indicators_ time, cost, quality_ the necessity of a more practical algorithm is felt completely.

This article introduces a new model named as STHD. This model indicates the natural manner and real life of dolphins in dealing with nature. This mechanism is inspired by dolphin's natural behavior that by rapid swimming and excellent memory, approach to the feeding area, divide to some sub groups. Each group is guided by a leader. The leader's duty is preparing the hunting conditions with delicacy and occurrence. The leader makes the water muddy by slapping its tail and make a circle by other dolphins. It causes the feeding, surviving and reproduction.

Designing this algorithm guides us in progressing our aims, and makes the answer achievement easy by attending to the customers demand in some regions such as: 1) management, contracting decision making,national,consulting.2) decision in production, beginning and installing the projects.3)And some problems such as NP-hard which are so complicated and have to decide or optimized with high occurrence.

Problem Formulation

In this research, the project has been defined by Direct acyclic graph, G=(N,E), that V1 is the Nodes collection, and E2 is the Arcs collection. Arcs show the Activities, and Nodes indicate the Events. G(V,E) is shown as a matrix Amx3 that m is the Nodes number and n is the number of Arcs.

The Amx3 matrix is called the node - arc incidence matrix for graph G(V,E) .

According to the activities number, Matrix, A contains m rows and 3 columns. The first column includes the activities number. The second one is the network model number for each activity which the activity has exited from that, And the third column is the model number that the activity in the network has entered to that.

$$\mathbf{A} = [\mathbf{a}_{ij}]$$

$$\mathbf{a}_{ij} = \begin{cases} \mathbf{i} & \mathbf{if\ j = 1} \\ \mathbf{q} & \mathbf{if\ j = 2\ and\ q\ be\ the\ beginning\ node\ of\ Arc\ i} \\ \mathbf{q} & \mathbf{if\ j = 3\ and\ q\ be\ the\ ending\ node\ of\ Arc\ i} \end{cases} \quad \mathbf{i = 1, \dots, m} \quad \mathbf{j = l, \dots, 3} \quad \mathbf{q = 1, \dots, n} \tag{1}$$

In each activity of the project (Ej) includes a different execution mode of M_j that each $K \in M_j$ includes time t_{jk}, cost c_{jk} and quality q_{jk} of the activity j. It is presumed that if k and r be the modes for j activities and t_{jr} and c_{jk} The aim is finding out the optimized combination for each activity, in order to shorten the project networks. Somewhat that by decreasing the time of the whole project, the whole project cost (direct cost + indirect cost) reaches to the least, and the quality of the whole project doesn't be less than acceptable point. For this issue's modeling, the integer programming has been used.

$$\mathbf{Min.\ C_T = \left(\sum_{j=1}^{n} \sum_{k \in M_j} c_{jk} * y_{jk}\right) + C_{Id} * T_{cpm}^{k}} \tag{2}$$

St:

$$\mathbf{\sum_{j=1}^{n} w_j \sum_{l=1}^{L} \acute{w}_{jl} \sum_{k \in M_j} q_{jlk} * y_{jk} \geq Q_{allow}} \tag{3}$$

$$\mathbf{\sum_{k \in M_j} y_{jk} = 1 \qquad j = 1, 2, \dots, n} \tag{4}$$

$$\mathbf{\sum_{j=1}^{n} w_j = 1} \tag{5}$$

$$\mathbf{\sum_{l=1}^{L} \acute{w}_{jl} = 1 \qquad j = 1, 2, \dots, n \qquad y_{jk} = 0\ or\ 1 \qquad \forall\, j, k} \tag{6}$$

The CPM issue can be viewed as the reverse of the networks shortest way, so $\mathbf{T_{cpm}^{k}}$ according to the network matrix has been formulated as below:

$$\mathbf{T_{cpm}^{k} = Max \sum_{j=1}^{n} x_j \sum_{k \in M_j} t_{jk} * y_{jk}} \tag{7}$$

St:

$$\mathbf{\sum_{j=1}^{n} a_{ij} * x_j = b_i \qquad i = 1, 2, \dots, m \qquad x_j = 0\ or\ 1} \tag{8}$$

$$\mathbf{b_i} = \begin{cases} \mathbf{1} & \mathbf{i = 1\ if} \\ \mathbf{-1} & \mathbf{i = m\ if} \\ \mathbf{0} & \mathbf{otherwise} \end{cases} \tag{9}$$

Solution Procedure

Dolphins have high coordination in feeding activities and most of the time have group hunting. In one kind of group feeding , the fish are trapped in offshore shallow water in the balls that are made by dolphins and captured. (Norris and Dohl 1980; Wursing 1986; Tayler and Saayman 1972). By fast swimming dolphins come to the feeding zone from different directions, then they divide to some sub_ groups and surround the fish school in small balls, about 6 square meter, by their special technique.

Fig. 1. a) Hunting activity begins by mud. b) Creating a muddy ball and trap some fish in it. c) Fish flies for surviving. d) Being captured by dolphins.

Figure 1 shows some photos of dolphins hunting method. Dolphin arrangement is somehow that forces the fish to the surface of the water. some dolphins swim beneath of the fish and by “bubble bursting” run the school of fish to the surface. While a group of dolphins in a coordinated activity maintain the school of fish close the water surface, the dolphins that are out of the ball capture the fish. Sometimes some dolphins pass through the edge of the ball, rolling on their sides in an arc toward the fish and use their lighter underside of the body as a “flash” effect to scare the fish . In some cases a group of dolphins by swimming forward and backward and slapping the tail do not let the fish scape. In beach hunting method, a dolphin swim parallel the beach in a circular, and mud the water to gather the fish. The dolphin arrangement is somehow that force the fish to move to the water surface and the other dolphins move near the surface and hunt them. While a group of dolphin in a coordinated activity keep the fish in a ball the other dolphin hunt the fish. In a group activity dolphins create a circle and trap fish in it and do not let them to escape, so the fish try to run away for surviving, then the dolphins by attending to the fish escape capture them. Several dolphins rush the bank in a coordinated manner, using their bow wave to push fish onto muddy banks. The dolphins which nearly or completely strand themselves during the process, then proceed to consume fish from the mud before sliding back to the water and to continue living and reproducing. Strand feeding documented in salt marshes west of Hilton Head Island (Hoese 1971, Rigley 1983, Rigley et al 1986). In every strand feed reported by Petricing (Rigely 1983), all dolphins stranded on their right sides, Petricing postulated that this was in part because dolphin’s eyes may be oriented to focus in slightly different directions. Petricing observed that before nearly every strand feed, the dolphins pop their head out of the water, apparently to check the position of the beach. Likely the beach hunting has extended as a method of following a group of fish in mud shallow inshore (Hamilton and Nishimoto 1977; Leather Wood 1975).

This method may indicates the variety of using the barrier (for example other dolphins) and the common aspects of beaches and the weather in the hunting environment. It isn’t possible to determine whether some dolphins fed more than the others. Dolphins wait for their turn to make feeding, while waiting next to the ball to do not let the fish move downward. This feeding behavior continue by the other dolphins who feed near the zone.

Group hunting occurs more because its benefits are more than individual hunting. So dolphins follow it. In this article a new algorithm named as STHD is introduced according to the dolphins group activity in hunting, for solving the balance issue of Time, Cost and Quality. In figure 2 this algorithm steps are indicated.

By attending that dolphins at the beginning of hunting make a muddy circular by their tail to trap and capture fish, in this algorithm we account the number of first generation of fish by circle equation and a random number.

$$\mathbf{y} = \sqrt{\mathbf{x^2} - \mathbf{r^2}} \qquad (10)$$

Which in this equation “x” is the random number and “r” is the amount of radius of the assumption circle that its amount is accounted by random, too.

The project data include:
project Network matrix (Amx3=[a_{ij}])
available Execution modes for each activity j an their expected impact on the activity cost , duration and quality (M_j)and (c_{jk},t_{jk} ,q_{jk}).
Weight of activity j compared to other activities in the project. (W_j)
Project indirect cost per time unit . (C_{Id})
Lower bound for Project quality . (Q_{allow})
The required STHD Parameters include :
string size (n)
Number of generation (G).
Population size (N).
weight of EXP function.(W_{exp})
weight o Linear function. (W_{lin})
crossover Rate
Mutation Rate.
After accounting the number of first fish, the accounted number will be produced by random as the population of first generation. The amount of time, cost and quality and in consequence the amount of fitness for each one will be computed.
The project direct cost: The sum of whole project activities direct cost;

$$\mathbf{DC_{(s)}} = \sum_{j=1}^{n} \mathbf{c_{sj}} \qquad \mathbf{s = 1, 2, \dots, N} \tag{11}$$

The whole project time: The sum of the exist activities time in crisis path;

$$\mathbf{T_s^{cpm}} = \mathbf{Max} \sum_{j=1}^{n} \mathbf{x_j * t_{sj}} \tag{12}$$

St:

$$\sum_{j=1}^{n} \mathbf{a_{ij} * x_j = b_i} \qquad \mathbf{i = 1, 2, \dots, m} \qquad \mathbf{x_j = 0 \text{ or } 1} \tag{13}$$

The whole project quality: The balanced sum of the qualitative values of the activities different indicators.

$$\mathbf{Q_{(s)}} = \sum_{j=1}^{n} \mathbf{w_j * q_{sj}} \tag{14}$$

$$\mathbf{q_{sj}} = \sum_{l=1}^{L} \mathbf{\acute{w}_{jl} * q_{sjl}} \qquad \mathbf{s = 1, 2, \dots, N} \tag{15}$$

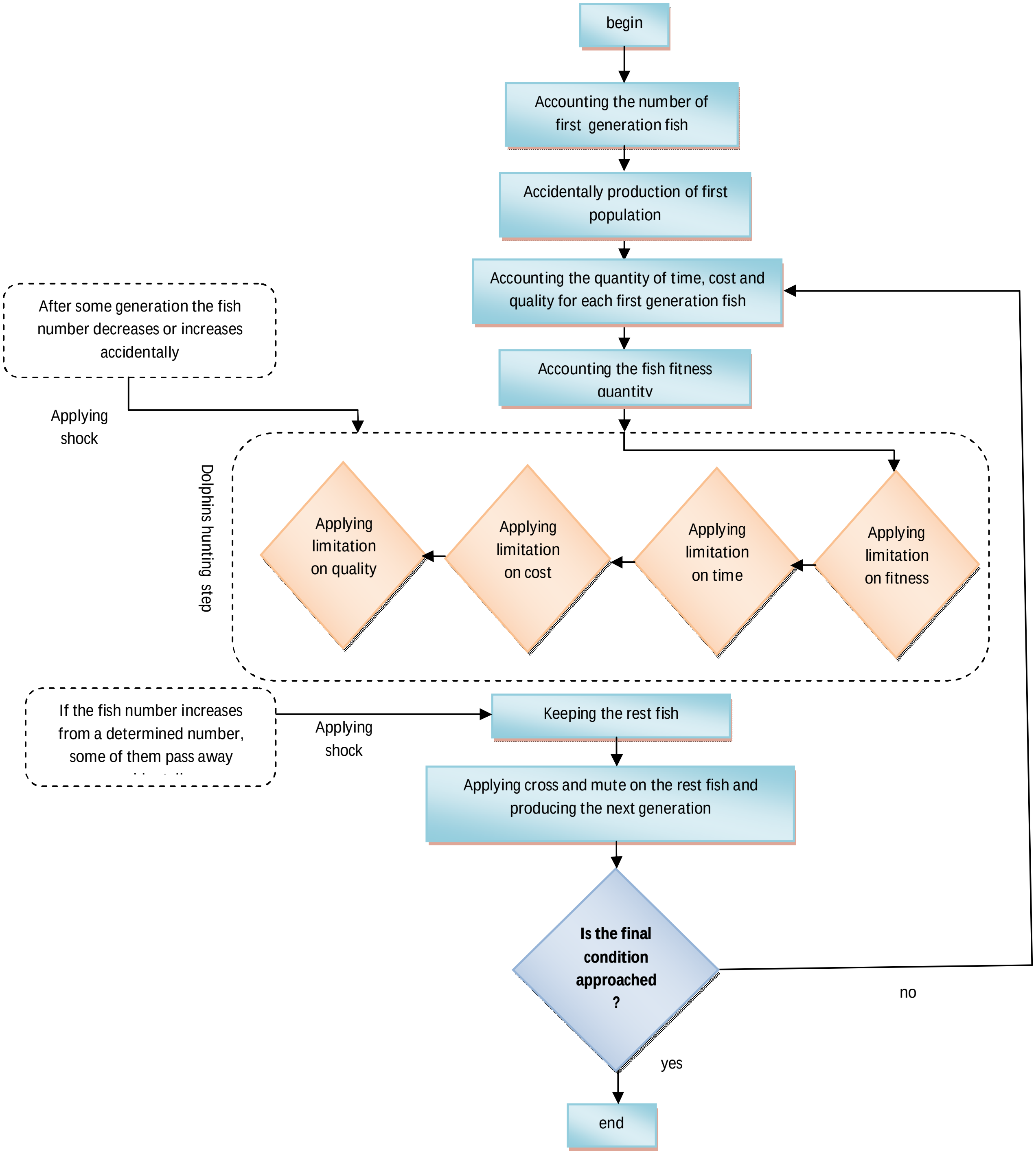

Fig 2. the proposal algorithm steps

Determining the Fitness Function and the possibility of choosing Ps for each of S seeds by using bellow formula:

$$\mathbf{F_{(s)}} = \mathbf{w_c} \times \frac{\mathbf{C_s - C_{min}}}{\mathbf{C_{max} - C_{min}}} + \mathbf{w_t} \times \frac{\mathbf{T_s - T_{min}}}{\mathbf{T_{max} - T_{min}}} + \mathbf{w_q} \times \frac{\mathbf{Q_{max} - Q_s}}{\mathbf{Q_{max} - Q_{min}}} \qquad (\mathbf{16})$$

At this step that the ball is made and the fish has trapped in it, dolphins start feeding. In this algorithm the dolphins are the determined limitation by using the equation (17) that are applied on each fish features. Each fish that passes this limitation, that is be alive and don't be eaten by dolphins can be a member of next generation.

$$\mathbf{f(x)} = \mathbf{e^{(-ax)}} \qquad (17)$$

By using (17) equation for each features of the time, cost and quality, a limitation as a dolphin will be defined and be applied on the accounted features for the fish. After ending the dolphins feeding, the rest fish reproduce and make the next generation by using the connection and mutation operators.

The reproduce operators have designed in a way that the fish is adequate after execution. Some point crossover, and steady crossover has been used in this issue. And according to the activities number, one or some point mutation has applied. For example, in a project with 9 activities, 3 random fish with right gene could be as below:

$\mathbf{Parent_1} = [\mathbf{2}, \mathbf{1}, \mathbf{5}, \mathbf{3}, \mathbf{2}, \mathbf{4}, \mathbf{1}, \mathbf{5}, \mathbf{3}]$

$\mathbf{Parent_2} = [\mathbf{4}, \mathbf{3}, \mathbf{2}, \mathbf{5}, \mathbf{4}, \mathbf{1}, \mathbf{3}, \mathbf{2}, \mathbf{5}]$

$\mathbf{Parent_3} = [\mathbf{1}, \mathbf{4}, \mathbf{3}, \mathbf{2}, \mathbf{3}, \mathbf{5}, \mathbf{4}, \mathbf{1}, \mathbf{2}]$

In this sample, the operator has used some point crossover and one, and some point mutation, because the numbers of activities are less. By the effect of operator execution, the produced fishes from the above parents are like these:

$\mathbf{Offspring_1} = [\mathbf{2}, \mathbf{3}, \mathbf{3}, \mathbf{3}, \mathbf{4}, \mathbf{5}, \mathbf{1}, \mathbf{2}, \mathbf{2}]$

One – two & three point mutation with Random point (**E=6**)

$\mathbf{Offspring_1} = [\mathbf{2}, \mathbf{3}, \mathbf{3}, \mathbf{3}, \mathbf{4}, \mathbf{3}, \mathbf{1}, \mathbf{2}, \mathbf{2}]$

It should be mentioned that using one, two or three-point mutation depends on the fish fitness, somehow that a fish with high fitness takes fewer mutation (one point) and a fish with lower fitness takes more mutation (three points).

As well that, the mutation rate is digressive and use function (18). Somehow that it reaches to zero in the last generation

$$\mathbf{F_{MuRate}} = \mathbf{1} - \frac{\mathbf{n_G}}{\mathbf{G}} \qquad (18)$$

Since the dolphins ability and power isn't similar in each hunting, a shock is applied on them accidentally to decrease or increase the amount of their power. And since all of the first fish or their offspring do not transfer to the next generation or it is possible to die, a shock is defined for this occurrence and accidentally some fish die and do not transfer to the next generation.

These steps repeat in defined numbers until there won't be any changes on fish from one generation to the next. The rest fishes are the answers of the issue.

Application Example

The applied example in this article includes 9 activities. Each activity contains different modes that have the time, cost and quality of the activity which are shown in table2. Also the effective weight of each activity is indicated in the table2. Figure 3 shows related network of the example, and the network matrix has been distinguished in the table1 for achieving the time and critical path.

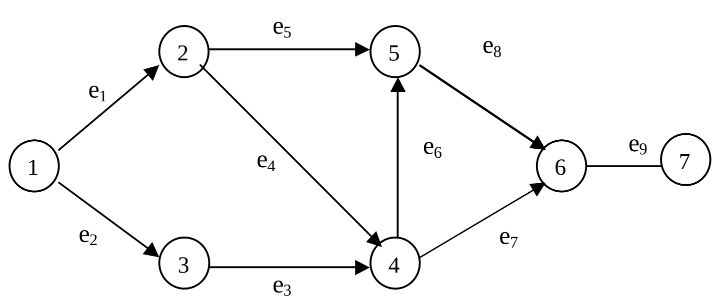

Fig. 3. Project network

Table 1. Network matrix

$$\begin{array}{c}e_1\\e_2\\e_3\\e_4\\e_5\\e_6\\e_7\\e_8\\e_9\end{array}\begin{bmatrix}1 & 1 & 2\\2 & 1 & 3\\3 & 3 & 4\\4 & 2 & 4\\5 & 2 & 5\\6 & 4 & 5\\7 & 5 & 6\\8 & 5 & 6\\9 & 6 & 7\end{bmatrix}$$

Table 2. Activities executions modes

		Modes																	
		1			2			3			4			5			6		
		T	C	Q	T	C	Q	T	C	Q	T	C	Q	T	C	Q	T	C	Q	W_d
Activities	e_1	7	160	90	6	180	85	5	190	80	4	200	70	3	230	85				0.1
	e_2	8	140	85	7	150	82	6	179	80	5	180	75	4	200	80				0.1
	e_3	8	110	90	7	120	85	6	140	84	5	150	80	4	170	90				0.14
	e_4	10	100	88	9	130	90	8	140	85	7	150	75	6	165	80				0.11
	e_5	14	160	92	13	170	90	12	180	86	11	200	70	10	230	80	9	240	90	0.12
	e_6	8	130	85	7	140	82	6	150	80	5	170	85	4	190	90				0.15
	e_7	11	150	87	10	180	90	9	190	85	8	200	90							0.08
	e_8	11	140	91	10	150	88	9	160	85	8	170	75	7	265	85				0.12
	e_9	11	150	90	10	170	88	9	180	85	8	200	90							0.08

IWO Parameters Are Set as Following

The introduced model has done in Microsoft Excel by using the visual basic application programming, and the used parameters are as below:

G=100, mutation rate: 0.2, crossover rate: 0.8. The program was run on a Pentium 4 PCs with CPU 2.8 GHz.

The table 3 includes some of the achieved responses by applying the algorithm. It is possible to make another balance between time, cost and quality by changing the related weight of them and achieves other responses.

For showing the practicality of the introduced algorithm, the achieved responses from the GA and NHGA (Shahsavari Pour et al 2012; Shahsavari Pour et al 2010) is compared. The GA, NHGA and DOLPHIN are implemented with same parameters for thirty times. Their results are analyzed via the analysis of variance (ANOVA) method.

The below parameter has been used for the variance analysis and the conclusions of variance analysis are shown in Figure 4.

$$\mathbf{WRD} = \left(w_c \times \frac{C_{alg}-C_{min}}{C_{min}} + w_t \times \frac{T_{alg}-T_{min}}{T_{min}} + w_q \times \frac{Q_{max}-Q_{alg}}{Q_{max}}\right) \qquad (19)$$

where, C_{alg} and T_{alg} and Q_{alg} are the total project cost, duration and quality for a given algorithm, respectively. C_{min} and T_{min} and Q_{max} are the best solutions obtained by each algorithm for a given instance. Whatever WRD be much less, the difference between the achieved response and optimized relative response will be less.

As it is shown in the graphs of figure 3, it can be concluded that the scatter of the introduced algorithm is less than the GA and NHGA and thereby is more optimized.

Since that the duration of program execution, that is the result achieving time is an important factor, and we are tended to achieve the optimized response in the least time, this factor could be added after normalizing in comparison parameter and according to their importance, rate gives a weight to each one and be compared by that. Related graphs are shown in figure 5:

$$\mathbf{WRD\&Run\_Time = W_{WRD} * WRD + Wrun\_time * Runtime} \qquad (20)$$

$\mathbf{W_{WRD}}$ and $\mathbf{W_{run\_time}}$ are the specialized weights for the criterions of WRD and Execution Time, which indicate these two parameters importance. According to the importance of the space degree and also the response achieving time, the amount of WRD is considered 0.9 and the Execution Time is considered 0.1. Less amount in this answer shows the optimizing being of the response in the least time.

Figure 4 Analysis Graphs based on WRD and Execution time. As it is shown in the graphs of figure 4, all the responses are optimized as well as having less been scattering the introduced method and much few times has spent for computing the responses.

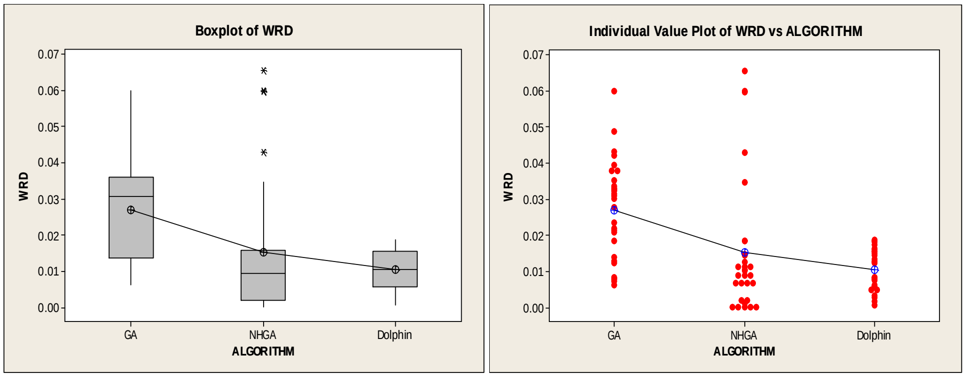

Fig. 4. Variance Analysis Graph based on WRD

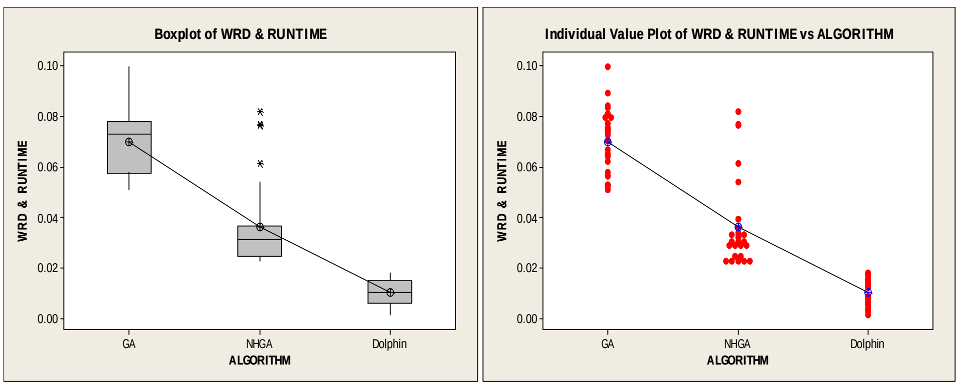

Fig 5. Analysis Graphs based on WRD and Execution time

Table 3. Final outputs of the DOLPHIN

W_t	W_c	W_q	T	C	Q	*Solution*
0.5	0.2	0.3	31	1685	87.35	*5 5 1 3 2 5 2 5 4*
0.5	0.3	0.2	34	1510	87.94	*5 1 5 1 2 5 1 3 4*
0.4	0.3	0.3	41	1330	89	*1 1 1 1 1 5 1 1 3*
0.3	0.3	0.4	41	1330	88.88	*1 1 1 1 1 5 1 2 2*
0.3	0.4	0.3	40	1340	88.52	*1 1 1 1 1 5 1 3 2*
0.2	0.3	0.5	42	1320	89.24	*1 1 1 1 1 5 1 1 2*
0.2	0.4	0.4	42	1370	88.9	*5 1 1 1 1 5 1 1 1*
0.2	0.5	0.3	40	1350	88.4	*1 1 1 1 2 5 1 2 3*
0.1	0.6	0.3	44	1300	87.95	*1 1 2 1 1 1 1 1 4*

Conclusion

The introduced model in the new algorithm was inspired from the dolphins specific hunting method which was the dolphins natural living manner in a special hunting technique, and solved the problem of time, cost and quality balance in discrete position and was close to reality. Quality is the most effective factor in projects. This study indicated how quality as an effective factor was able to change the answers of a time, cost balance problem in relation to a time, cost and quality balance problem. By studying and comparing the previous done searches about the balance time, cost and quality problem, the ability of the suggested algorithm in finding out accurate, fast and approaching the answers in least time and the set of optimized responses was proved and by having the optimized points decision making become much easier in comparison to the time that they just had the Pareto responses. Applying the algorithm of the dolphins specific hunting technique in this model increased the speed of achieving the problem's set of answers. As it was stated in the example in average less than 12 seconds spent for achieving the answer. High speed, the responses fast converging, attending to decision makers preferences about time, cost and quality balance indicators, giving the graphs of the whole project and its flexibility in comparison to other algorithm and ability and practicality of the model for bigger projects about time, cost and quality balance issue by assumption that the required sources be changeable at time for doing the activities were suggested.

Totally, the suggested model can help the managers, decision-makers and programmers in stimulating ,the effects of different consuming programs in the project process.

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Notation

The following symbols are used in this paper:

$\mathbf{C_T}$= Total Cost of Project (Direct costs+ Indirect Costs)
$\mathbf{C_{Id}}$= Project indirect cost per time unit
$\mathbf{c_{jk}}$= Direct cost of activity j when performed the Kth execution mode.
$\mathbf{t_{jk}}$= Duration of activity j when performed the Kth execution mode
$\mathbf{q_{jlk}}$= Performance of quality indicator (l) in activity j performed the Kth execution mode
$\mathbf{y_{jk}}$= Stands for the index variable of activity j when performed the Kth execution mode . If y_{jk}=1 then the activity j performed the Kth mode . while y_{jk}=0 means not.
$\mathbf{x_j}$= The index variable of activity j that of flow on the arc j . if xj = 1 the activity j is in the path. While x_j = 0 means not.
$\mathbf{a_{ij}}$ **= The entry of incidence matrix, as defined before**
$\mathbf{b_i}$= the available supply in ith node
$\mathbf{M_j}$= Set of available execution modes for each activity j
$\mathbf{w_j}$= Weight of activity j compared to other activities in the project
$\mathbf{\acute{w}_{jl}}$= Weight of Quality indicator (L) compared to other(L) indicator , in activity j
$\mathbf{Q_{allow}}$= Lower bound for Project quality
$\mathbf{DC_{min}}$ = minimum direct cost of population
$\mathbf{T_{min}^{cpm}}$= minimum time of population