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Scheduling Under Uncertainties Using Fuzzy Mathematical Model

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***Abstract*: Time and cost are the main parameters to be considered for a Project to be completed in time and within budget in the Construction industry. But the most of the projects are not in a position to complete the project in time and budget due to several reasons like uncertainties. Due to uncertainties duration of the projects was increasing that may incur losses for contractor. In those uncertainties material shortage was major uncertainty which is known from experts and previous analysis. So in order to solve material shortage problem fuzzy mathematical model was used for determining construction schedules and for evaluating the contingencies created by schedule compression and delays. Here Networks were analyzed using two methods: manual critical path method scheduling calculations, Microsoft Project. Fuzzy mathematical models that allow the multi-objective optimization of project schedules considering constraints such as time, cost, and unexpected materials shortages were used to verify commonly used methodologies for finding the minimum completion time for projects. The heuristic procedure was used for material allocation to test three cases of material shortage, which slightly increase the cost of construction and but reduce the completion time of project. From the results obtained during the dissertation study, it was determined that it is not just whether there is a shortage of a material but rather the way materials are allocated to different activities that affect project durations.**

***Keywords*: Budget, delays, fuzzy, time, cost, shortage**

1. Introduction

Construction management decisions are made based on schedules that are developed during the early planning stage of projects yet many possible scenarios need to be considered during actual construction. Decisions could be made that depends on the expertise of Decision Makers (DM) that uses commercial software such as: Microsoft Project, but sometimes the assumptions that are made during the planning stage of a project could change during actual construction processes. For instance, in a pavement facility suppose that the raw material that is coming from a particular quarry is unexpectedly insufficient, or that abnormal weather makes it too difficult to perform any task outdoors. These, and many other unpredictable events or uncertainties constantly affect project schedules. Material shortage was major uncertainty mostly occurs in every project, this problem can be overcome with the help of Fuzzy Mathematical model. Because Fuzzy mathematical models may be used to generate construction project schedules, and incorporate restrictions defined by decision makers such as materials, time, cost, etc. Time-cost tradeoffs can also be incorporated into schedules using fuzzy mathematical models, which facilitate project crashing-cost analysis. By using Fuzzy Mathematical Model time and cost reducing simultaneously. By using this Model schedule duration could be reduced by significant small increase in cost.

1) Problem statement

Construction projects are made up of many different activities. These activities are related to each other in networked systems and grouped into special categories that require different levels of expertise and resources for their completion. The main objective of a Project Manager (PM) is to determine the most efficient way to coordinate construction project activities to achieve the best possible quality and to minimize time and costs. Even though some construction companies use commercial resource allocation software like Microsoft project, so they are facing uncertain problems like material shortages in real-life situations, and that is where having a mathematical model with material constraints is useful to Project Managers.

Apart from material shortages there are many uncertainties occur in real life situations and that will effect project completion in those commonly encountered uncertainties in construction projects are Unforeseen Site or Construction Issues like material shortage, unusual atmosphere, transportation delay etc., design errors and omissions, accelerated schedules, design changes because of owners, construction coordinated issues etc.In those uncertainties the building construction industry has been experiencing a loss of benefits due to several problems which is known from experts such as: materials not available where and when they are needed, a lack of information about where materials are located, fragmented communication between different project stages, and the lack of experience of the Decision Makers (DM). These problems may cause increasing expenses and necessitate extra time to finish a project; furthermore, established schedules and budget goals may not be met. However, having a way of tracking and controlling real resource information, helps Decision Makers make better decisions.

2) Material delivery uncertainties in construction project networks

In the construction industry, experience has shown that every project manager follows a unique procedure to achieve project goals. Even though the same, or a similar, project is going to be built again in a different place the planning, controlling, and execution of each project is different. Therefore, having similar characteristics (designs, project duration, and equipment), standard conditions, and resources for two projects does not express the same procedure (techniques) and results for the projects because technical conditions, delays, and unexpected situations arise during construction. Here is where the experience of the Decision Maker and his/her subjective judgment helps achieve the goals or objectives as effectively as possible by re-planning and rescheduling projects when it is necessary. However, even though Project Managers (PMs) may have experience in construction projects, imprecision and uncertainty in their decision making practices exist in the scheduling of real-world construction processes. In other words, the efficiency of a construction project depends on many variables, conditions, and uncertainties that need to be forecast by the best approximation to a realistic construction network. However, the problem is to find the most favorable schedule that minimizes project.

3) Completion time and costs considering material constraints

A decision maker's goal is to make decisions that will result in the best utilization or allocation of resources, the highest possible profit or reduce overall increased cost for the company, and using the minimum possible time. On the other hand, traditional techniques used in the construction industry for minimizing project completion time and cost, such as Critical Path Method (CPM) scheduling and crashing procedures, assume that resources are always available. Linear Programming Methods (LPMs) have been used to minimize these objectives, but one at a time. But fuzzy Mathematical Model can be used to process multiple objectives.

2. Objectives

The objectives of the thesis include following

- To analyze construction or project network by using critical path method.
- To build optimization time and cost for the network.
- Identify most probable of occurrence of Uncertainty from expert.
- Apply that uncertainty to any one project as case study and to determine how material should be allocated.
- To build a Model that includes Cost-Time Trade-Offs, with Material Constraints.

3. Thesis organization

The thesis is summarized in the following manner: definitions and explanations used to conduct the thesis are included in Chapter Two, the literature review is in Chapter Three, the methodology is in Chapter Four, the case study and results are in Chapter five, the Summary and Conclusion in Chapter Six, the references are after Chapter Six.

A. General

In the construction industry changes to projects, and potential uncertainties, should be included in the schedule planning stage. These changes would generate extra cost and time if they are not considered during the planning stage. The ideal situation for Decision Makers (DMs) would be to find the right decision at the right moment. In order to do this, problems have to be analyzed using different approaches rather than just traditional Critical Path Method (CPM) schedules including mathematical models or optimization methods. In practice, optimization methods are not frequently used due to the time required to find optimal solutions. In contrast, most construction companies use commercial software such as Microsoft Project or Primavera Project Planner (P3) because they are easier and faster to use. Even though these generate solutions that are not optimal, they are usable solutions. Decision Makers aim to control the causes of cost overruns. The potential uncertainties which are mainly influencing the most of the projects should be identified based on expertise. So in those material constraint is taken into account. Therefore, mathematical models with material constraints would be useful for identifying and analyzing different paths and rescheduling the project in case of material shortages. This literature review discusses:(1) Project scheduling and planning (2) Construction Network Scheduling Approach and Variations with CPM; (3) related multiple objective optimization problems in construction networks; (3) Uncertainties during execution (4) Optimization Models in Construction Networks (5) the effects of applying pressure on final quality outputs in the project network; and (6) Approach of Using Optimization for Construction Management.

1) Project scheduling and planning

Project scheduling consists of deciding when tasks should be started and finished, and how many resources should be allocated to them. The project scheduling largely concentrates The generation of a precedence and resource feasible schedule that ''optimizes'' the scheduling objective(s) and that should serve as a baseline schedule for executing the project. The baseline schedule (pre schedule) serves very important functions (Aytug et al., in press; Mehta and Uzsoy, 1998); the first is to allocate resources to the different activities to optimize some measure of performance. The second, as also pointed out by Wu et al. (1993) to serve as a basis for planning external activities such as material procurement, preventive maintenance and delivery of orders to external or internal customers. Based on the baseline schedule, commitments are made to subcontractors to deliver materials, support activities are planned (setups, supporting personnel), and due dates are set for the delivery of project results. (Willy Herroelen & Roel Leus 2003).

2) Construction network scheduling approach and variations with CPM

Critical Path Method Schedules are an important technique that has been used since the 1950s and the construction industry benefits from their use in the planning and controlling of projects, when communicating plans, and when training new managers. Newer versions of CPM scheduling software make CPM techniques easier for practitioners to use them and this has increased efficiency in some construction projects. Schedules that neglect material constraints could mislead planners and affect the control of projects (Yates, 1993). Real life projects present a wide range of variables that are difficult to control due to the fact that resources are limited in construction projects; therefore, float calculated using CPM techniques will lose its significance and new critical sequences will be created (Kim and de la Garza, 2005; Wiest, 1964). Critical Path Method schedules show the critical path, or paths, of a project but resource profiles present fluctuations that are not desirable for the efficiency of projects. Project managers, or decision makers, now use commercial project management software, such as Primavera Project Planner (P3) and Microsoft Project, which are based on heuristic methods to plan and control schedules. In the article "Project-Network Analysis Using Fuzzy. Sets Theory", the authors discuss the use of different applications in project planning and control (Liberatore, Pollack-Johnson, and Smith, 2001). They found that the construction industry mainly uses critical path analysis applications and that Primavera Project used most frequently. The research showed that two out of four companies use Primavera and one out of four uses Microsoft Project for scheduling.

3) Uncertainties during execution

During project execution however, project activities are subject to considerable uncertainty that may lead to numerous schedule disruptions. The term uncertainty is used in most of scientific literature concerning risk management. Theoretically it can be defined as a lack of certainty involving variability and/or ambiguity. Like uncertainty management is concerned as managing perceived threats and opportunities and their risk implications but also managing the various sources of uncertainty which give rise to and shape risk, threat and opportunity (Chapman and Ward [2004]). This uncertainty may come from a number of possible sources: "activities may take more or less time than originally estimated, resources may become unavailable, material may arrive behind schedule, ready times and due dates may have to be changed, new activities may have to be incorporated or activities may have to be dropped due to changes in the project scope, weather conditions may cause severe delays, design omissions or errors or changes due to owner, construction coordinate issues" etc. A disrupted schedule incurs higher costs due to missed due dates and deadlines, resource idleness, higher work-in-process inventory and increased system nervousness due to frequent rescheduling. As a result, the validity of static deterministic scheduling has been questioned and/or heavily criticized (Willy Herroelen & RoelLeus 2003). So these are different type of uncertainties encountering in construction or site, these are uncertain can't do anything to stop them. So if they occur what will be the decisions that have to be taken is important. For that from these uncertainties which one is major or most probable have to be identified with the help of expertise, and apply that uncertainty to one live project and make right decision at right time to reach objective that is project should be completed within normal duration. Most decisions at construction sites are made based on the project schedules. This situation may be critical if suddenly a planned schedule has to be changed due to any type of delay due to uncertainty. Decision Makers (DM) should have enough expertise, and the availability of previous information from similar situations, that will help them to make sound decisions. Some authors have analyzed this situation and presented a modified the decision making process. For instance, in the study "Construction Decisions Support System for Delay Analysis", the author, Dr. Yates, integrates commercial project management software packages based on CPM schedules with compatible software called The Delay Analysis System (DAS). In this software, a simulated project environment is created and possible alternative situations are analyzed by the computer. This model gives decision makers valuable alternatives to prevent, or minimize, the effects of probable delays. The Delay Analysis System presents clear and detailed information that could be used during any stage in a project. In addition, the information processed is stored creating historical databases that help support future DM (Yates, 1993). This research gives practitioners an opportunity to consider historical information and have a more realistic approach to decision-making processes.

4) Optimization models in construction networks

Optimization models have been used in construction projects, but they have not been successful for large networks. Networks with more than 100 activities could not be handled due to computer hardware limitations. Critical path method techniques, with discrete information instead of continuous membership functions have proven to be more efficient and they provide not optimal, but usable solutions (Molder J., 1993). However, some optimization techniques present the opportunity to analyze more than one objective at a time and this permits a more realistic approach. On the other hand, other authors analyze the uncertainties in a project by using fuzzy sets. The principal objectives in a network project are to minimize completion time and cost. During the literature review only a few articles that concentrated on construction networks using goal programming were located. In the article "An Application of Fuzzy Goal Programming to a Multi objective Project Network Problem" an analysis of the optimization of a project network facing two constraints simultaneously is presented. Unlike other optimizing methods, the optimization is made using nontraditional mathematical modeling, called Fuzzy Goal Programming (FGP). Therefore, having two constraints and the fact that the two objectives are presented in different terms such as time and cost, make the optimization project more difficult. Subjective judgments made by the Decision Maker (DM), and the fuzziness of the objectives, are the basis of the Fuzzy Set Theory (FST). Fuzzy Goal Programming is used solution while considering two objectives at the same time and using membership functions (Arikan and Gungor, 2001). In their article "Project-Network Analysis Using Fuzzy Set Theory", Lorterapong and Moselhi (1996) present a practical network scheduling method for construction projects based on Fuzzy Set Theory (FST), which allows the consideration of uncertainties coming from diverse project settings. The authors emphasize that this method is more pragmatic than using stochastic or probabilistic techniques and does not show sophisticated computational calculations. However, the authors state that when a project consists of large networks a common spreadsheet package will facilitate the process. Consequently, taking into consideration uncertainties to decide possible completion times for each activity in a network makes this contribution a useful optimization tool for decision makers and researchers. The fuzzy set theory method is an important contribution to decision processes because it allows consideration of uncertainties coming from a diverse project setting, which is valuable because every project presents a large percentage of uncertainties. If these uncertainties are known in advance, decisions could be made with more precision. Delays are always present during construction projects; therefore, trying to avoid dealing with potential uncertainties in the planning stage of a project could lead to problems during the construction stage. Even if the delays do not occur, it would be better to be safe. In the article "Fuzzy Logic Approach for Activity Delay Analysis and Schedule Updating", the authors, Ordoñez - Oliveros and Fayek, formulate a new tool that gives Decision Makers the opportunity to have an updated schedule and to evaluate the consequences of delays in order to make adequate decisions when they are required during a project (Ordoñez- Oliveros and Fayek, 2005).

5) The effects of applying pressure to the final quality on network projects

Most schedules need to strive for optimization and earlier completion times, which sometimes results in quality being neglected. Excessive pressure to finish a project may be disadvantageous; it may generate poor quality results and rework and this could lead to an increase in the project duration. The responsibility is on managers who should understand what activities are critical and know how much pressure. In addition, some actions such as motivation and training might be taken to counteract the effects of time pressure on quality. Increasing the number of hours worked per day, or the number of days per week, does not always mean increased productivity.

6) Approach of using optimization for construction management

Considering possible material shortages in construction helps project managers to evaluate different situations and make high-quality decisions. Furthermore, traditional mathematical models may generate optimal solutions, but even if they are single objective-oriented or multi objective models they do not consider fuzziness as is possible in Fuzzy Mathematical Methods. Nowadays, powerful and fast computers can process complex fuzzy mathematical models that provide a more realistic approach to finding the optimal trade-off between cost and time for network projects in construction. In addition, some actions such as motivation and training might be taken to counteract the effects of time pressure on quality. Increasing the number of hours worked per day, or the number of days per week, does not always mean increased productivity.

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4. Thesis organization

In order to achieve the objectives of the thesis the following tasks were performed:

A. *Phase 1*

List out the number of uncertainties which will occur in real life situations and effect project duration are

- Unforeseen Site or Construction Issues like material shortage,
- Unusual atmosphere, transportation delay etc,
- Design errors and omissions,
- Accelerated schedules,
- Design changes because of owners,
- Construction coordinated issues etc

This all should identified from nearby construction sites when finding about delay problems in constructions and some could be identified with help of journals which were explained about the uncertainty problems occurs in real life situations.

B. *Phase 2*

In those uncertainties identify which is most probable uncertainty frequently occurring in constructions or site from the experts means which could know with the help of site engineers of live construction projects and previous analysis which had explained about uncertainties in real life situations.

C. *Phase 3*

A construction project was selected to demonstrate the applicability of using fuzzy mathematical programming models to verify network schedule calculations. In order to select a case study project, different origin of the information. Several construction networks were reviewed in order to find an appropriate network that could be used to validate the capabilities of the mathematical model. The network needed to take into account the availability of cost information. A construction network with real normal costs and crashing cost information was required for the project. Sample data from a 29 activity construction networks for a five-story building were obtained that included normal and crash costs and durations (GMR Brindavan, Balaji Infrastructure Pvt. Ltd, Amenities block, Waddepalli, Hanumakonda, and Warangal).

D. Phase 4

In this phase the computer software programs to be used for the case study was selected that is micro soft project for scheduling of activities and to prepare network for the schedule. Information from the case study construction project was input into Microsoft project. Although commercial scheduling software such as Microsoft project may be used to analyze and schedule project network information, the logic diagram generated is in an Activity on Node (AON) format as is shown in Figure 3.1 (Microsoft representation), but AON graphical representations cannot be used in mathematical modeling. In order to use the mathematical language, the logic for the diagram has to be drawn as an Activity on Arrow (AOA) network by hand. The representation of immediately preceding activities in the network system creates a large amount of crossing dummy lines.

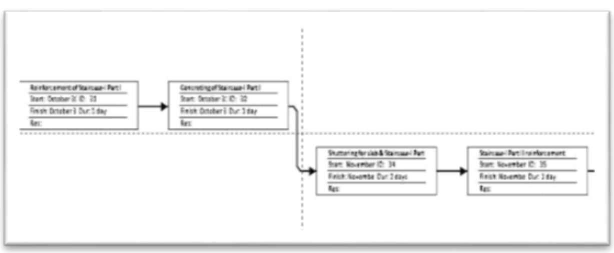

Fig. 1. Activity on node Microsoft project representation

E. Phase 5

In this phase the CPM schedule was drawn and calculations were performed in order to determine the critical paths of the project using Microsoft project. First some activities were added or modified and the logic of these activities and their logical dependencies were checked. Some relationships were simplified by eliminating lags that were in conflict in the network in this phase in order to eliminate some dummies that were considered unnecessary. Then, the Activity on Arrow (AOA) logic diagram was drawn. In Critical Path Method scheduling techniques there is a forward pass and a backward pass, and both of these were used to find the Early Start (ES), the Early Finish (EF), the Late Start (LS), the Late Finish (LF), the Free Float (FF), and the Total Float (TF). The first CPM schedule was done using standard conditions which means taking into consideration the originally estimated activity time.

F. Phase 6

The most probable uncertainty i.e. Material restrictions were applied to the selected construction project and several cases were tested to validate how the project network was affected each time.

G. Phase 7

Find optimal completion times based on the Activity-on-arrow logic diagramming method networks for several cases. The solution for the project duration as was obtained by using CPM scheduling techniques.

H. Phase 8

In this phase for above cases membership functions for time as an objective were created based on the information from the completion time. Eg. The normal completion time for the case study project was 229 days, but the objective was to reduce extra costs involved such as indirect costs; therefore, a decision was made to find the optimal amount of time that the project could be crashed. Assuming that the project needed to be crashed by 50 days, the following membership functions were generated. At this point, the objective was to finish the project 50 days ahead of the schedule, which is a satisfaction level of 1, and this is the maximum other hand, if the project is not crashed at all, the satisfaction level will be 0, which means that the satisfaction level for this objective is not satisfied or fulfilled; any value between these ranges has a weighted value of satisfaction as shown in Fig. 2.

1	=	If	$ZT = 179$
$f(XT) = (229-ZT)/50$	=	If	$179 < ZT < 229$
0	=	If	$ZT = 229$

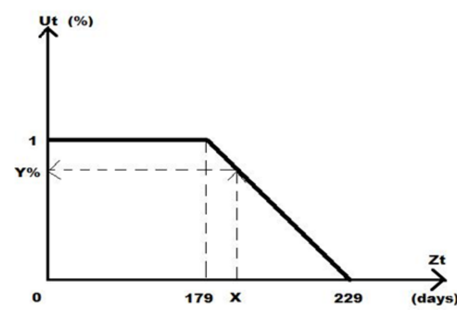

Fig. 2. Completion time (membership function)

I. Phase 9

In this phase for above cases a cost analysis based on network-crashing calculations was also performed by adding additional resources which will reduce project duration. Since Primavera Project Manager does not perform network crashing calculations, a manual calculation was used to perform this function. An analysis was performed in order to determine the minimum crashing cost for a construction network. After that cost-time trade-off curve for above cases plotted with the crashing information and reducing the maximum number of days the project could be reduced one by one.

J. Phase 10

The membership function for cost as an objective was generated by using the information from the cost analysis and the Decision Maker criteria for the above cases. For example this membership function is shown in Fig. 3 and it is one of the parameters of the fuzzy mathematical model.

1	=	If	ZC = 0
f (XC) = z (150000-ZC)/150000	=	If	0 < ZC < 150000
0	=	If	ZC = 150000

f(Zt)	=	1−
		−
		−
f(Zc)	=	−

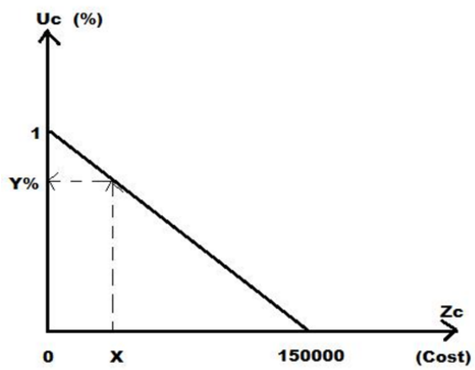

Fig. 3. Membership functions for cost

K. Phase 11

A fuzzy mathematical model was created that combined all of the results from the previous phases, including minimum completion time, minimum Crashing cost, and the membership functions. In addition, the previous objectives of time and cost were considered as constraints. The model optimized each objective individually by using membership functions and maximized the satisfaction level between them. To find satisfaction level below equations are used.

L. Phase 12

Time-cost trade-off calculations were performed using different variations of material allocations and constraints for all cases to determine the optimal duration of a sample project.

M. Phase 13

In this phase the results of the case study were summarized and included in the thesis.

5. Case study and results

A. General results

When using manual CPM calculations, and only considering time and precedence relationships as constraints, a total of 229 days was obtained for the project completion time.

Table 1
Details of case study

Name of the Project	GMR Brindavan
Construction Company	Balaji Infrastructure Pvt. Ltd
Selected block	Amenities block
Location	Waddepalli, Hanumakonda, Warangal
Actual cost of the work	Rs. 1,13, 79,066
Actual time taken to execute the work	229

Balaji Infrastructure Pvt. Ltd is one of the best companies for the construction and infrastructure. It has undertaken one of the prestigious projects in Warangal that is construction of GMR Brindavan Apartments. The premium project signifies a modern day having for inspirational living-offering apartments designed with your aspirations in mind and built with an electric ensemble of innovative architecture, free flow of space, abundant natural light and all modern amenities expertly woven into safe and secure gated enclave. In the GMR Brindavan construction project there are total 10 blocks, among them I had selected one block (amenities) for my thesis study which costs 1, 13,79,066/- for completion of project. The total time taken for construction is 229 days. The mathematical model was run a second time and the same number of days were generated although the free float was used in a different manner. The individual completion time for many activities was the earliest possible. Finally, Microsoft project was used to generate the schedule and some parameters were revised in order to obtain the same conditions. The calendar in Micro soft project was set up with 7 days as working days, 8 hours per day. For the project was set as October 1st, 2014 and the completion time was May 17, 2015 which was 229 working days. The schedule completion times are shown in Table 2. The completion time was the same number of days as was calculated manually and using the mathematical model.

Table 2
Completion time

Month	Working Days/Month
October	31
November	30
December	31
January	31
February	28
March	31
April	30
May	17

B. Time-cost trade-off calculations with material constraints

In this phase, material allocations and restrictions were analyzed for a small network in order to facilitate the process. The analysis was accomplished by creating a 29-activity sample model with its respective technological constraints. Precedence relationships, durations, and maximum crashing time for the model are listed in Table 3 and shown in Figure 1 and the cost information used in the mathematical models is presented in Figure 2 and shown in Table 3 and earliest and latest start and finish times of each activity are shown in Table .Number of labors required for each activity including helpers and mason in order to do crashing per one day and crash cost for each labor for activities is shown in Table 4.4.

C. Fuzzy mathematical model analysis fuzzy mathematical model for case planned

Using the information from the completion time and cost models, membership functions were generated. The normal completion time was 229 days and the objective was to finish 48 days early by day 170. Therefore, the time membership function is represented as:

1	=	If	ZT = 170
f (XT) = (229-ZT)/59	=	If	170 < ZT < 229
0	=	If	ZT = 229

The independent variable ZT represents the time to finish the project. The graphical representation, where the y-axis represents the satisfaction level and the x-axis represents the completion time, is:

Table 3
Single objective models (Planned)

Parameter			Minimum			
	Completion Time (days)				Cost (Rs.)	
		Z1			Z2	
	170	229		395200		0
*f*z1(%)	100	0		-		-
*f*z2(%)	-	-		0		100

D. Fuzzy mathematical model for case 1

The cost for crashing the project 48 days in Case 1 was 442200. Therefore, the membership function is

1	=	If	Zc = 0
f(Xc) = (442200- Zc)/442200	=	If	< Zc < 442200
0	=	If	= 442200

The independent variable ZC represents the crashing costs. Fig. 4, shows a graphical illustration for the Cost Membership Function. The dependent variable ZC represents the cost for the respective completion time. The single objective model that was used to define the membership function values

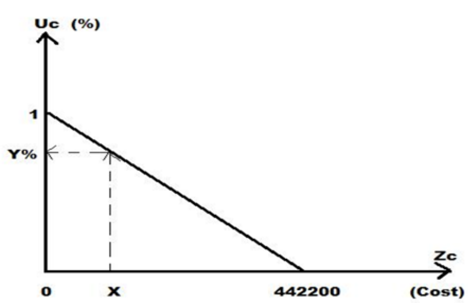

Fig. 4. Graphical illustration for the Cost Membership Function.

E. Fuzzy mathematical model for case

The cost for crashing the project 59 days in Case 2 was 463600. Therefore, the Membership function is:

1	=	If	Zc = 0
f(Xc) = (463600- Zc)/463600	=	If	0 < Zc < 463600
0	=	If	ZC = 463600

Fig. 4, shows a graphical illustration for the Cost Membership Function. The dependent variable ZC represents the cost for the respective completion time

6. Discussion, summary and conclusion

An analysis of network consisted of a five story building with 29 activities for analyzing case study. The network was analyzed using two methods: manual CPM scheduling calculations, Microsoft project. Two methods resulted in the same length of time to complete the project. In addition fuzzy mathematical methods can be used to verify other commonly used methodologies for finding the minimum completion time for projects. In addition there are different type of uncertainties encountering in construction or site, these are uncertain can't do anything to stop them. So if any uncertainty occurs solving it get the solution is important so from those different uncertainties identified one uncertainty which one is major or most probable with the help of experts, and applied that uncertainty to live project as a constraint. Material restrictions can be taken as uncertainty from expert and included as constraints that could determine more realistic solutions in analysis process for find out cost-time trade off. Microsoft project or any other software does not directly perform cost-time trade-off calculations. For crash cost comparison purposes, the baseline of a project must be first created with regular cost, and then generate the crash cost on resources, activities, etc. to compare the baseline costs with the current schedule. It then encompasses a process in which schedules are revised again and again. Finally, this information is exported to Excel to create the cost-time trade-off graphics. These processes to create the cost-time trade-off graphics make the Microsoft project not practical in terms of this aspect. Mathematical models can be used to directly perform cost-time trade-off analysis.
Membership functions are used in fuzzy mathematical methods in order to incorporate the Decision Maker's uncertainties and to serve as a tool in decision making processes. Membership functions serve as tools that can be used by researchers and practitioners in decision making processes that incorporate material constraints when planning different construction projects. The more constraints that are initially considered in construction projects, the better the results

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