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PROGRESS EVALUATION AND DIAGNOSIS INDICES FOR
CONSTRUCTION PROJECTS – OMAR’S DIAGNOSTIC
TECHNIQUE

A THESIS IN ENGINEERING SYSTEMS MANAGEMENT

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by
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PROGRESS EVALUATION AND DIAGNOSIS INDICES FOR
CONSTRUCTION PROJECTS – OMAR’S DIAGNOSTIC
TECHNIQUE

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Engineering Systems Management – Construction Management

American University of Sharjah, 2006

ABSTRACT

The construction industry constitutes a major part of the global economy. Large amounts of money are spent annually for the construction of residential, commercial, industrial, and other types of projects, including infrastructure. The control of construction projects is an essential managerial requirement to ensure on-time completion within the budget though it is a real major challenge due to the large amount of un-avoidable losses in time and cost as well as the high level of uncertainties that complicate the control process. The control process uses progress evaluation techniques that compare actual and planned progress to assess the progress status. The current evaluation techniques are based on assessing the status of the critical path and the completion percentage. However, these techniques have deficiencies which cause undesired ambiguity and trigger significant disputes. Improvements are required in the field of progress evaluation to overcome these deficiencies.

Considering the required improvements, the author proposes a new technique named “Omar’s Diagnostic Technique”. The technique is composed of several indices. It takes input data from the baseline and the updated schedules to perform some calculations then infers interpretations on the most accurate progress status. Based on the calculations the technique recommends necessary corrective action. The indices are classified into categories and each category deals with a group of related indices. The categories cover several topics such as: the overall project criticality, the commitment of the progress to the baseline schedule, the baseline float consumptions, the resources, the percentages of completions, and the repeated cycles. The research focuses mainly on the first three categories while the other categories are discussed briefly. The discussions of each index include the definitions, the calculation equations and their derivation as needed, and the interpretations of the different possible values of the indices along with what indications they give of the actual progress status.

The research shows that there is potential for great improvements in progress control concepts and techniques. The proposed indices could assist in enhancing and standardizing the progress interpretation process. The indices are able to provide the project management with valuable information such as: progress concentration, out-of-sequence works, resource shortages and inadequacy, supervision and management competency, over / under estimation of the work at the planning stage, global and local delays, level of commitment to the baseline schedule, potential future critical delays, etc. The conclusions that can be drawn from the results of the indices might be used by the different stakeholders as a tool to support the decision making process. Several discussions on how to interpret the results of the indices and what are the inferred progress interpretations are shown in the research.

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ABBREVIATIONS

AAR – Actual Average Resources
AATR – Actual Accumulated Total Resources
ABF – Allowed Baseline Total Float
ABF_F – Allowed Baseline Total Float for Finish Dates
ABF_S – Allowed Baseline Total Float for Start Dates
AC – Actual Cost
ACWP – Actual Cost of Work Performed
AD – Actual Duration of an Activity
AD – Actual Duration of an Activity
ADR_F – Advance Deviation Ratio in Finish Dates
ADR_S – Advance Deviation Ratio in Start Dates
AF – Actual or Anticipated Finish
AP – Actual Progress
APR – Actual Periodical Resources Level
ARFA – Actual Resource Fluctuation from Average
AS – Actual or Anticipated Start
BAC – Budget at Completion
BC – Budgeted Cost
BCAN – Number of Activities in the Baseline Critical Path
BCPW – Baseline Critical Path Weight
BCWP – Budgeted Cost of Work Performed
BCWS – Budgeted Cost of Work Scheduled
BEF – Baseline Early Finish Date
BES – Baseline Early Start Date
BLF – Baseline Late Finish Date of an Activity
BLS – Baseline Late Start Date of an Activity
BMTF – Baseline Mean Total Float
BOD – Baseline Original Duration
BTF – Baseline Total Float

CP – Contract Period
CPI – Cost Performance Index
CPM – Critical Path Method
CR – Critical Ratio
CV – Cost Variance
DDR_F – Delay Deviation Ratio in Finish Dates
DDR_S – Delay Deviation Ratio in Start Dates
D_F – Finish Date Difference
D_S – Start Date Difference
EAC – Estimated at Completion
ECT – Estimated Cost to Complete
ETC – Estimated Time to Complete
FCI – Float Consumption Index
MAD – Mean Actual Durations
MBD – Mean Baseline Durations
MBMTF – Moving Baseline Mean Total Float
MDOD – Mean Difference of Original Duration
MOD_F – Mean Overall Deviation for Finish Dates
MOD_S – Mean Overall Deviation for Start Dates
OCD – Original Completion Date
PAR – Planned Average Resources
PATR – Planned Accumulated Total Resources
PDCC – Percent Difference of Critical Path Completion
PDCW – Percent Difference of Critical Path Weight
PPR – Planned Periodical Resources Level
PRFA – Planned Resource Fluctuation from Average
PRGC – Progress Concentration
RDMF – Relative Difference of Mean Total Float
SP – Scheduled Progress
SPI – Schedule Performance Index
SV – Schedule Variance
UCAN – Number of Activities in the Updated Critical Path

UCD – Updated Completion Date

UCPW – Updated Critical Path Weight

UEF – Updated or Anticipated Early Finish of an Activity

UES – Updated or Anticipated Early Start of an Activity

UMTF – Updated Mean Total Float

UTF – Updated Total Float

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CHAPTER 1

1. INTRODUCTION

1.1 Preface

The construction industry plays a major role in today's highly competitive environment of the global industry [3]. Delivering projects in shorter time frames is becoming essential for contractors to win projects [17]. Most of the present construction projects could be characterized as complex, multi-participant, dynamic, and possessing a high level of uncertainty [9]. Hence, progressing on-schedule and completing on-time are considered challenging objectives that have to be achieved in order to ensure competitiveness in the industry. Many factors affect projects execution to proceed as per their original plans. Those factors could affect the on-schedule progressing, the on-time completion, or both of them [14]. Consequently, it is quite customary for any construction project to suffer from delays, lack of control, excessive wastage of resources, and unexpected costly claims that result from unforeseen obstacles to progress [17]. The progress for any construction project needs to be properly monitored and controlled to minimize the influence of the above variables.

A proper progress control should be started from the planning phase where the project requirements and the scope of work should be well understood by the project management team. The sequence of work should be discussed by the project management team and agreed upon as a prerequisite of the schedule of the work. The sequence should cover all technical requirements and should be logically correct. The schedule of work is then developed according to the approved plan and presented to all personnel involved in the project team. This schedule of work is known by the construction professionals as the "baseline" schedule. The project manager needs to ensure that the baseline schedule is adhered to by the construction people on site. Once the baseline schedule is developed and approved, then it has to be used as the "blueprint" of the construction work; i.e. all concerned personnel should prepare their work based on what the baseline schedule says.

The progress on site should be controlled and the actual work should be monitored and recorded precisely during the construction period [11]. Having current and up-to-date information to measure and analyze progress of construction projects

is an essential process [5] in order to properly evaluate its status and take prompt and appropriate action as needed [8]. Any progress evaluation should be based on some measures and indices that can provide accurate and precise results on the actual progress status. Reliable progress indicators should be identified to ensure achieving satisfactory progress evaluation [5]. These indicators should assist all project parties including the owners and contractors.

Normally, contractors' interpretations of their own progress tend to be justified yet clients tend to challenge. Consequently, disputes may break out between stakeholders on what are the most credible interpretations of available readings of the progress. For example, the contractor may allege that as long as the critical path shows favorable readings; i.e. no delay, it is of minor significance if sections of the project are running behind schedule. However, the client may assert the opposite and consider the project not progressing on schedule. Therefore, the client may ask the contractor to pay more attention in order to avoid any possible delay in the project completion. Consequently, long arguments ensue which may ultimately lead to arbitrations which cause additional expense. Accurate progress evaluation is an essential prerequisite for any proper project control to achieve the timely completion of projects. Several researchers addressed the need to improve the project control process by developing new and more reliable progress measurement concepts [2].

1.2 Background

Execution of projects should be controlled properly to ensure that the progress is as close to the baseline schedule as possible. It is impractical, if not impossible, to have a project that is progressing exactly as per its original baseline schedule. The very nature of the construction industry, as previously discussed in greater details earlier, makes deviations from the original baseline schedule inevitable. Therefore, control of the progress is an essential requirement to ensure completion of the project with minimal deviations. Some of the main objectives of progress control are to: detect any deviations, understand the causes of those deviations, investigate possible alternatives and propose whatever corrective action needs to be taken to recover from the unfavorable deviations; as well as assess the cost and time implications of the deviations.

Essentially, the progress evaluation process requires recording the actual progress of the work and comparing it with the as-planned progress, in order to achieve the most accurate evaluation of the status of execution status as of the time of the schedule update. Accordingly, necessary decisions and corrective actions are taken. The high level of uncertainty of construction projects that affect the actual progress necessitate the establishment of a reliable monitoring system that records the actual progress and alerts to any deviations. The project management team needs reliable tools and techniques that provide an acceptable measure of the current progress status.

Currently, progress of construction projects is evaluated by using some well known techniques that calculate some percentages and factors. These factors provide an assessment for the progress status as of the time of schedule update. They are mainly based on the critical path and the percentage of completion. The main contractor calculates the progress status according to the recorded actual work and includes them in his periodical progress reporting. The main measures that are of interest for most of the professionals in the construction industry are the overall percentage of completion and the calculated project completion which has resulted from any recorded delay or advance. The assessment of the actual progress status is done based on these measures. However, the two measures do not provide adequate information about the work as it is discussed in more detail in this thesis.

The “Earned Value Technique” is a well known and accepted technique by industry professionals. It depends on the use of certain percent complete variables to calculate the different parameters of the earned value to assess the progress [2]. The technique depends highly on the comparison between the actual recorded cost and budget levels for each activity. These are considered confidential data for any contractor, which makes the technique more suitable for the contractors’ internal use only while its external use is not deemed favorable in order to avoid exposing this confidential data. As a matter of fact, in most cases the main contractor is not obliged to reveal his actual recorded cost levels to stakeholders and compare them with his original budget. This is a real obstacle for the use of earned value technique.

1.3 Problem Statement

Presently, construction projects are characterized by their complexities and considered fast track projects. This requires highly reliable techniques that can provide adequate understanding of the progress and what the key progress bottlenecks are. The progress evaluation techniques currently available may not be sufficient to fulfill this requirement. More than simply the current status of the critical path and the percentage completed is required. The concept of “Progress Evaluation” may need to be replaced by the concept of “Progress Diagnosis”. The first concept deals with the assessment of some numbers and according to the result, an evaluation of the progress is achieved. The evaluation in its current implementation does not cover the progress in detail, the assessment of how the work is being executed, nor what the accurate interpretations of the recorded observations that are related to the progress are.

As an example, it is possible to have the achieved actual percentage of work at a certain time higher than the planned percentage; meanwhile the critical path shows delayed project completion. The interpretation of this case is not as easy as it may appear at first. Several progress scenarios could lead to the same status and each of them requires different treatment and action. An analysis of this situation could indicate that the contractor is giving a priority to executing higher number of non-critical activities on account of the critical activities, and therefore they suffer from delays. The reason why the contractor is concentrating on the non critical activities requires more investigation to fully comprehend it. The current progress evaluation factors could not assist in explaining the causes of such a situation. To investigate the causes, a human intervention is required to evaluate the schedule updates and assess a proper diagnosis for the status that is sufficient to justify the causes.

A different scenario for the same status is that the contractor may intentionally increased the original durations of some activities when preparing the schedule at the planning phase while it is expected to finish these activities in less duration during execution. This increase might be done to show faster actual completion of the different activities which increases the actual percentage of completion for the whole schedule and gives more favorable results than the actual status. Furthermore, it is a possibility that the contractor’s resources are not sufficient and subsequently, resource intensive and critical activities are progressing slower than planned while non

resource intensive activities are progressing faster. This is to give higher percentage of completion to cover the resource's deficiency. The same situation could result when the on-site sequence of work of the contractor does not follow the planned sequence. Consequently, the original approved schedule of works may give any arbitrary readings for the actual status because it is not representing the actual sequence on site.

On the other hand, the status example may result if the contractor's progress is generally satisfactory while the critical path delays are for some minor problems that are under control. The actual percentage of completion could be higher than the planned because the contractor is trying to utilize the available resources efficiently until the problems are resolved. Many other scenarios could explain the situation of the above progress status. The real question is, which is the most accurate scenario?

The available progress evaluation techniques do not provide an answer to such a question and the only way to get the answer is by human analysis and investigation of the issue. Such an investigation is time-consuming and the results could be subjective or biased. This time-consuming task cannot be done for every progress update if that update is done on a weekly basis as is the case in most construction projects. Furthermore, it requires additional progress status readings and measures in order to conduct such a deep investigation. In addition, not all engineers have sufficient qualifications, from a planning point of view, to conduct such an investigation. In fact, not all contractors are even able to perform proper interpretation of their actual progress status based on the readings they get from the schedule updates. This situation creates a point of deficiency in an extremely important function of the management of construction projects.

Moreover, progress deviations are quite vital when dealing with claims and disputes. Many delays could result from an improper progress evaluation because of not taking optimum corrective action on time. On the other hand, many delays could be avoided if proper evaluation is done on time and necessary corrective actions are taken. The insufficiency of the available progress evaluation techniques makes the progress evaluation process a major point of contention from which many disputes are triggered.

The second concept, i.e. the "Progress Diagnosis", is proposed instead of the concept of progress evaluation. The diagnosis is a wider concept than the evaluation.

In fact, the evaluation is only one part of the diagnosis. The diagnosis tries to achieve a proper understanding of what is going on in the project, namely: How the progress is achieved; what the priorities of the construction personnel are; if the baseline schedule is respected or a different plan is being followed on site; if there is any sign of potential, or future, critical delays; what the chance is of recovering any recorded delay; if any recorded delay is local or global; and others. All of these are some of the questions that, when answered, will provide the project management and the client with a real understanding of the current status and in addition, the interpretation of any progress reading will be more accurate. The diagnosis means that the current progress status is evaluated and an understanding of the real picture of the inside work of the project is achieved. The key points that affect the progress need to be identified. The answers to the previously mentioned questions need to be provided based on reliable tools that perform certain calculations and based on the results, the project manager can take the affirmative action.

1.4 Objectives of the Research

1. Identify important outcomes of periodical schedule updates; e.g. different variances, dates, floats, different slippages from the original baseline, etc. to provide more efficient progress interpretations and diagnosis.
2. Introduce and propose new progress indices / measures to assist in properly diagnosing the progress status and providing more reliable assessment. In addition, develop necessary calculation methodologies and algorithms for each of these indices.
3. Investigate and discuss how to diagnose and interpret the current progress status from the resulting readings of the newly proposed indices separately and/or jointly. In addition, investigate the integration of the currently available progress measures / indices with the newly proposed ones.

1.5 Why “Progress Diagnosis”

The planning and progress control are the core for feasible and effective projects in the construction industry. The success or failure to deliver projects on time depends greatly on the quality of planning and progress control. Several articles were reviewed in order to reach a valuable topic that adds to the knowledge of the industry in the same field. One of the options was with the use of “Genetic Algorithms” in

scheduling and resource allocation. The literature review revealed that many attempts have been carried out using the concept of genetic algorithms in this field, but that the results could not be considered practical every time [6, 7, 10, 15].

By examining the research and the subject of genetic algorithms, it was found that the practicality of using genetic algorithm in the field of construction scheduling and planning is questionable, at least from the author's point of view. This is due to the fact that the genetic algorithm is comprised of a searching mechanism that uses the different variables of the problems and tries to achieve close-to-optimum solution. The searching time of the genetic model increases exponentially with the increase in the number of variables. As is well known, the number of variables in construction projects is very large. Therefore, the feasibility of developing a model that is workable within the industry requirements was not assured, thus this topic was abandoned.

As a result, a search was carried out until settling on the idea of the progress diagnosis, which was studied and found to be practical. The practical experience of the author supported the idea of progress diagnosis as a requirement for the industry. Disputed situations about the accurate progress status are not infrequent between the main contractor and the client, or his representatives. In such situations the main contractors try to support their positions by analyzing the progress status to their advantage while the parties on the other side may have a different analysis. The issue here is that the different parties have different points of views for their assertion due to the fact that the available progress evaluation techniques allow for such different interpretations. The need for more advanced tools and techniques was raised some time ago as a practical requirement. However, when a recent literature review was conducted to investigate the status of knowledge in this field, it was concluded that the literature did not cover this topic. The traditional progress evaluation techniques are the only available. The need for the progress diagnosis has been observed by the author, who has worked in the same field for a long time and faced many claims and disputes, which he worked to resolve. The author therefore proposes a new technique named "Omar's Diagnostic Technique" which could add to the current knowledge in the field of project controls. The author has developed this technique to provide the project management with a reliable tool with which to properly interpret the most accurate progress status during its periodical assessments and then take the necessary

corrective actions at an early stage. In addition, “Omar’s Diagnostic Technique” provides an important tool for claims analysis since it allows better understanding of the progress during the project implementation period. A proper understanding of the progress would minimize disputes and reduce analysis efforts.

It is expected that this research will provide the construction industry with tools and techniques necessary to perform a more reliable and accurate assessment of the status of the progress and get the real picture of what is going on on the site, which might be considered as a “Closed Box”. The stakeholders of any project need to know what is inside this closed box. Sometimes the management of the main contractor does not know what is inside that closed box. It is expected that all parties at the different levels of construction projects will benefit from the results of using these progress diagnosis indices and their interpretations.

1.6 Significance of the Results

The proposed research is of high significance to the construction industry. The contractors can benefit from the results of the research since the proposed technique is expected to furnish proper diagnosis tools to accurately interpret the progress status. Accordingly, necessary decisions and corrective actions can be taken. Furthermore, the proposed indices might be used to support the contractors’ claims for extension of time against any other project participant, e.g. the owner, the consultant, or others. This can be achieved by providing more efficient tools to show the impact of any owner’s related delays. The contractors’ top management could use the proposed technique to evaluate the performance of the project management.

On the other hand, owners and consultants can benefit from the use of the proposed indices. During the practical experience of the author, it was observed that owners and consultants alike had some deficiencies in conducting proper progress evaluation and interpretation. Consequently, it was often necessary to mediate a number of dispute cases between the contractors on one side and owners and consultants on the other. The proposed technique overcomes the deficiencies of the current progress measures and resolves such disputes. Many claims for extension of time issued by the contractors to the owners are based on ambiguous conditions. The indices of the proposed technique should assist in removing these ambiguities due to their ability to provide reliable progress diagnosis.

CHAPTER 2

2. LITERATURE REVIEW

The topics of performance and progress evaluation have been considered in literature. The main trends of this literature can be categorized under two major topics [3]; (1) Company, or Construction, Performance and (2) Project Performance. The first topic deals with the overall construction performance including management, human resources, quality and safety, etc. [5]. The second topic concentrates on performance assessment at the project-level; e.g. project progress. This topic covers areas of dynamic project controls [8], cost optimization S-curves [1], Stochastic S-curves or SS-Curve [2], simulation models for construction systems [11], etc.

Construction performance measurement is originally a management tool and recently considered a project control tool. Bassioni [3] reviewed the “performance measurement frameworks” that measures the performance at the company level and addressed the insufficiency of the current measures to provide reliable performance evaluation. Cox [5] discussed the quantitative and qualitative key performance indicators that are used by construction and project managers and the management perception of these key performance indicators. The research covered under quantitative performance indicators: Units per Man hour, Cost per Unit, Cost, On-Time Completion, Resource Management, Quality Control/Rework, Percent Complete, Earned Man-Hours, Lost Time Accounting, and Punch List. The qualitative performance indicators as covered in the same research are Safety, Turnover, Absenteeism, and Motivation. The research did not investigate the schedule performance and how the project is actually progressing in comparison with the original plan. MaCabe [11] identified additional performance measurement indices for use in process automation for a computer simulation model of construction systems. In general, construction performance measurements do not cover in detail the schedule implementation and interpretations of project progress from the actually recorded data of the schedule updates.

The literature showed that the second trend; i.e. project performance, covers aspects like the dynamic control of projects which includes controlling costs, time, and resources. The main objective of the project dynamic control is to measure the

deviations of actual progress from planned in order to minimize any recorded deviation [8].

Webb [16] discussed in details the use of the Earned Value Method as a “Project Manager’s Guide”. According to Webb, the earned value principles started as an industrial engineering and accounting procedures and was introduced to the project management later on. The earned value has been considered an addition to the progress and performance measurements for project management. The earned value method uses three measures for its calculations. These are: the actual cost of work performed ACWP, the budgeted cost of work performed BCWP or the “Earned Value”, and the budgeted cost of work scheduled BCWS. The three measures should be assessed at any time of evaluation for the project status, e.g. weekly or monthly. Several helpful numerical information and calculations could be derived from the three measures. However, the most common information is the cost and schedule variances and indices. A briefing for the formulae that are used to calculate the variables of the earned value is as follows:

- Schedule variance $SV = BCWP - BCWS$, the numerical difference between the earned value and the planned expenditure at the data date. A positive value shows ahead of schedule progress while a negative value indicates behind of schedule progress.
- Schedule Performance Index $SPI = BCWP / BCWS$, or the schedule efficiency which is the ratio between the earned value and the planned expenditure. A value of SPI greater than or equal one represents ahead of schedule status while a value less than one indicates behind of schedule progress.
- Cost variance $CV = BCWP - ACWP$, the numerical difference between the earned value and the actual expenditure at the data date. A positive value shows cost saving while a negative value indicates budget overruns.
- Cost Performance Index $CPI = BCWP / ACWP$, or the cost efficiency which is the ratio between the earned value and the actual expenditure. A value of CPI greater than or equal one represents cost savings while a value less than one indicates budget overruns.

Curves can be drawn to show the progress status over the project execution period. Meredith and Mantel [12] discussed the earned value curves which are shown

in figure 1. Some predictive formulae can be used to assess the required level of schedule performance from the data date to finish on time; e.g. estimated cost to complete “ECT”, estimated cost at completion “EAC”, estimated time to complete “ETC”, budget at completion “BAC”, etc.

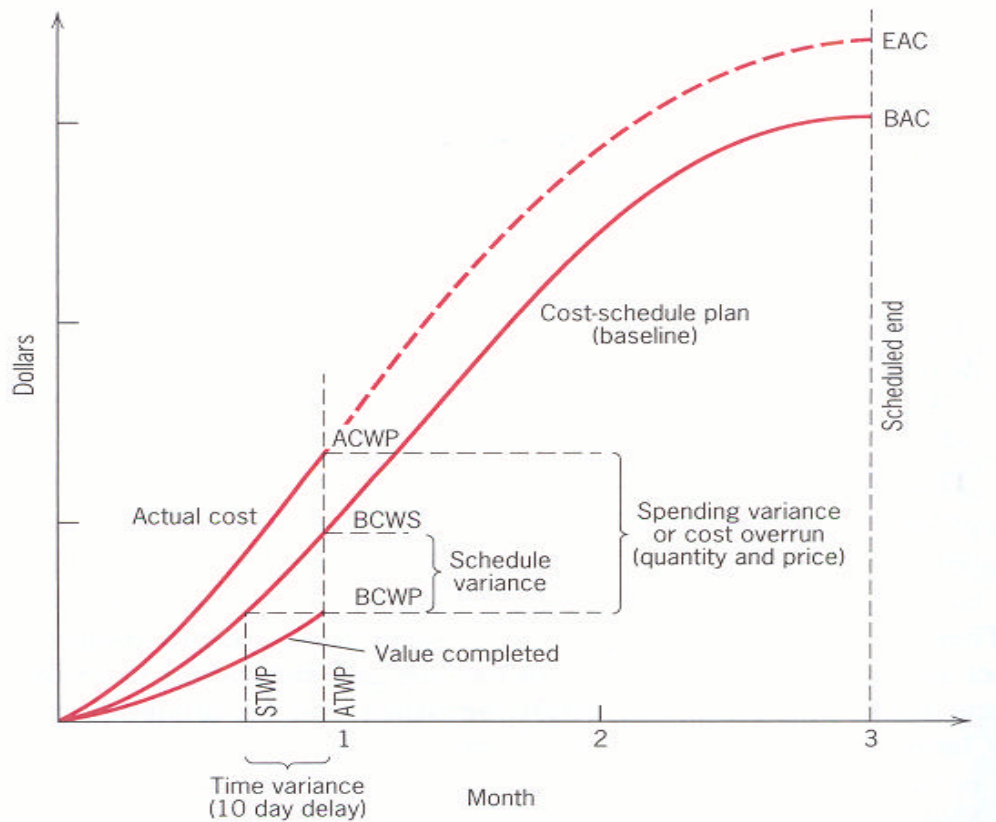


Figure 1. Earned Value Curves

The calculations of the earned value are done by assessing the earned value of each activity and then the overall project earned value is calculated. The assessment of the activity earned value is done by using some agreed scoring method for the earned value that was created by the implementation of the activity under study. The scoring method should take into consideration the required degree of accuracy, the nature of the particular activity, and the practicality of using the proposed method. The degree of accuracy of the project earned value is dependent on the degree of accuracy of the assessment method of the activity earned value, which is one of the drawbacks of the earned value method. The earned value method does not provide information about the factors or elements in the schedule that govern the progress. It

does not identify the real problems that lead to the resulting final readings. In addition, it cannot be used to sufficiently address the required or necessary corrective actions to overcome any progress problems. It is not expected that the whole picture of the project progress will be considered understood by just having the final result of the earned value given to the project manager.

Meredith and Mantel [12] discussed the use of the critical ratio measures to monitor and control the general health of the project. The critical ratio “CR” is simply calculated using the formula:

$$CR = \frac{AP}{SP} \times \frac{BC}{AC} \quad \text{Eq. (2.1)}$$

Where:

CR – Critical Ration

AP – Actual Progress

SP – Scheduled Progress

BC – Budgeted Cost

AC – Actual Cost

If the result of this critical ratio is greater than or equal one then the project progress is considered good and it is bad if the result is less than one. The first term of the formula represents, some how, the schedule performance index “SPI” while the second term represents the cost performance index “CPI”.

A chart can be developed to visually monitor and control the project during the construction period by plotting the results of the critical ratio at different periods. The multiplication of the two terms allows an offset between a bad ratio of one part and an equal good ratio of the other part. Meredith and Mantel [12] suggested action limits for the critical ratio chart and showed the chart of figure 2. If the critical ratio is between 0.9 and 1.1, then the project manager may not need to take any action. If the ratio is between 0.8 and 0.9, then the project manager needs to carefully watch the status for further actions later on. If the ratio is between 0.6 and 0.8, then an immediate investigation is required. If the ratio is less than 0.5, then the company management needs to be informed for necessary actions.

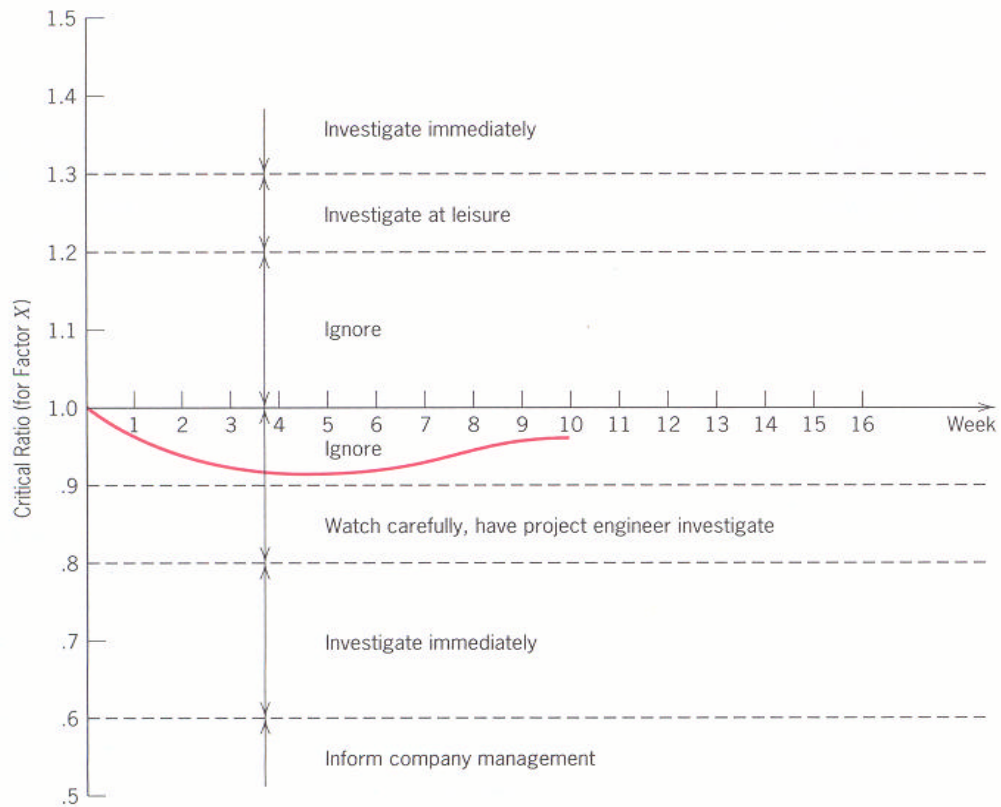


Figure 2. Critical Ratio Limits

These limits are dependent on the nature of the work and the tasks to be performed; hence the project manager may set different limits for the project and/or for some different tasks in the project. The project manager should read the results of the critical ratio carefully since the priorities in the project play a major role in determining the significance of the obtained results. If the priority of one term of the formula is higher than the other then the reading of the critical ratio should not be considered final without referring back to them. The results of the critical ratio are more reliable when the two terms of the formula have relatively equal priorities. However, it is rare to find such a situation all the time for all projects. The critical ratio measure is very close to the earned value in the sense that it is another representation of the cost and schedule performance indices. It does not provide information about the key elements that determine and govern the current progress status. Furthermore, it gives no information about the details of the schedule

performance. The result of the multiplication of the formula could not be used without referring back to the individual values.

Nassar, et al [13] introduced a method for the evaluation of cost and schedule performance using the weibull analysis technique. The weibull analysis is widely used for failure analysis and reliability engineering. The proposed method is considered an extension of the well-known earned value method. It introduces a probabilistic approach to evaluate and control projects performances through the use of the earned value indices; i.e. CPI and / or SPI, which are normally calculated during the periodical progress evaluation, as the input data set to estimate the statistical weibull distribution parameters; i.e. (α and β). A performance graph presenting the performance probability versus the performance index can be developed to evaluate the chances of achieving certain performance indices.

The method can be used to forecast the performance of the project by assessing the probability of achieving certain performance index values so that project managers can take necessary decisions or corrective actions. The method uses a probability approach to assess the future performance. This is based on the assumption that the same conditions that affected the past will appear in the future without a chance of having other different conditions that may play a major role in the performance of the progress. Most of the times this is not realistic; hence project managers may not be able to confidently rely on the results of the proposed method. The author suggests that this method needs a minimum of three actual recorded data of earned value indices so that the probability-related measures can be estimated. Therefore, the accuracy of the method depends on the number of readings. This is a deficiency since the reliability of the method at the early stage of the project is much less than that at the final stage of the project.

Hegazy and Petzold [8] discussed some project control techniques including the previously discussed “Earned Value” technique which can be used to identify project cost and time variances. Its results depend on the efficiency and quality of the project original plan and the developed schedule. The earned value technique provides a progress assessment at the project level without being able to recommend alternatives to enhance the current progress and minimize progress deficiencies [8]. Hegazy and Petzold proposed a model that adopts the principles of Genetic Algorithm to search for close-to-optimum solution to determine corrective actions during the

construction period. The model does not evaluate the actual progress in order to recommend reliable interpretations about the progress. Furthermore, the genetic algorithms may not be feasible for use in a real construction project with large numbers of activities because the amount of calculations will be huge and will take a long time for processing.

Barraza, et al [2] discussed the need for project performance measures and proposed a probabilistic monitoring using stochastic S-curve (SS-curve). Their attempt to use the stochastic approach to evaluate project performance was intended to overcome the drawbacks of using a single deterministic value of any progress evaluation factor. The proposed technique assumes availability of the probabilistic nature of the progress values and variances. This assumption could not be feasible from a practical point of view especially when considering the nature of the construction industry and the uncertainties that may affect the statistical analysis. The proposed technique does not provide recommendations on the current progress status and what the factors that affect the progress could be; nor how the progress can be interpreted so that necessary decisions can be taken.

Shi, et al [14] have proposed a computation method for construction delays that uses the contribution of activities' variations to the project delay. In their proposal they compared as-planned versus as-built schedules. The variations in the start dates, finish dates, and durations are calculated without the need for CPM calculations of schedule updates. The proposed method illuminates the need to properly analyze the different variations in the dates and durations of projects' activities. This approach requires the analyst to consider these variations as the area of analysis and not only the results of the CPM calculations. Most of currently used project control processes do not directly analyze the deviations in the dates and durations of the project activities.

The author observed a gap in the available knowledge relating the progress evaluation and diagnosis. The gap is in the part that is directly related to the diagnosis of the actual work progress from the schedule aspect. The author feels that many questions may still need to be answered for progress evaluation. The progress analyst needs to have manual investigation for both the actual progress and the schedule updates in order to achieve some understanding of the real progress status. This process is not an easy one, especially when it is required to be done for large and

complicated projects. The results of any manual investigation of the progress are subjective in nature and dependent on the investigators professional qualifications and experiences since there are no reliable techniques or indications that can be used by the progress analyst.

The current progress evaluation techniques do not provide answers to questions related to the baseline program implementation, e.g. how the original sequence of work is being respected by the project manager? Are the total floats of the activities being consumed or increased and what are the consequences of each case? Is the current critical delay significant or not and what is the difference between criticality and significance? Are there bottle-necks in the current actual progress or not and if yes what are they? If there is a delay in the schedule is it global or local and what are the consequences of each? For a delayed schedule is that delay recoverable or not and if the contractor submitted a recovery plan, how realistic would this plan be? And so forth... The gap comes from the unavailability of easy-to-use and reliable measures that assist in diagnosing and interpreting the progress status as per the latest schedule update.

CHAPTER 3

3. PREFACE FOR THE PROPOSED METHOD

3.1 Scope of the Research

The scope of this research is to introduce new techniques that add to the available knowledge in the field of progress control for construction projects. These techniques can be considered as a new concept that deals with the “Progress Diagnosis” instead of the “Progress Evaluation”. The newly proposed technique takes input values from the baseline and updated schedules every progress update, then measure some ratios and indices. The results of these ratios and indices could assist the concerned management teams of the construction project to properly perform an accurate progress interpretation which will ensure taking more efficient decisions on time. The management decisions will rely on the resulting values of the different indices separately. The integration of the readings of a group of several related indices would support some interpretations and oppose others, which is a basic requirement for the process of decision making at the managerial levels or even at lower levels. The research discusses the indices and how to calculate them. The discussion of each index covers its definition, derivation of its calculation formula, its effect on different progress conditions, and the causes. The proposed technique is expected to be calculated with assistance of some computerized tools due to the excessive amount of calculations.

It is beyond the scope of this research to perform practical case studies. The above mentioned concept has been introduced and discussed in this thesis without case studies as they need separate research efforts. Any research that might be performed in the future to validate the proposed indices and the progress interpretation from their values need to be done for some of the indices, or all of them simultaneously. However, it is recommended that the indices be separated and several practical case studies be made to validate the interpretations of the values of each individual index. The more case studies are performed the better the understanding of the “sensitivity” of each index for certain interpretations due to changes in their values. It might need accumulated effort to ensure that the final interpretations of the values for each index are achieved. It is very important to notice here that the value interpretations of the proposed indices have already been discussed in the thesis but

the recommended practical case studies are mainly to enhance the interpretations by providing better understanding of how each index shows different values for different conditions.

3.2 Important Schedule Data

The baseline schedule provides the planned early dates, late dates, total floats, and original durations for the project's different activities as they have been estimated at the planning and scheduling phase. During the execution the progress may show deviations from the baseline schedule. A schedule update should be done periodically either on a weekly basis, monthly or any other updating interval. This update records the actual progress including the actual start and finish dates, the percentage of completion for in-progress activities, etc. The progress evaluation is then done based on the recorded actual readings of the schedule updates. Normally the most important readings are the overall percent of the project completion and the calculated project completion date which reflects the status of the current critical path.

However, many other data that can provide valuable information about the progress are not given significant attention by the concerned progress control professionals. These could be the deviations of the activities' dates from their baseline dates, the way the baseline total float is being consumed, the current total floats of the updated schedule, the differences between the actual and original durations, etc. A professional investigation of these data by any experienced progress control personnel would ensure having better understanding of the progress status, or better diagnosis of the progress, how it is performed, where it is concentrating, what the future progress condition could be, and what best corrective actions should be taken, etc. The current research has investigated these things and provided the concept of how to achieve the most accurate interpretations for progress. More details are in the following chapters where the different indices of the proposed technique are discussed.

3.3 Categories of the Indices

The research has grouped the different indices in several categories. This grouping allows those indices that are related to the topic of the category to be gathered under the title of each category. The research focuses on the first three categories in detail because they have higher importance with respect to the progress control. Less focus has been given to the next three categories. Each one of the first

three categories is discussed in one of the next three chapters; i.e. chapters 4, 5, and 6, while the other three categories are discussed in chapter 7.

3.4 Some Important Research Assumptions

The research considers some assumptions when conducting the necessary calculations of the different indices. These are as follows:

- a. The baseline schedule is well studied and developed without any major or significant errors. The relationships are based on a well studied plan and the breakdown level of the activities is sufficient to conduct the necessary monitoring system which is essential to record the actual progress. The schedule is assumed to sufficiently cover the scope of work of the project.
- b. An adequate monitoring system is implemented in the project. The system is able to detect the actual progress on site at a sufficient level of control to provide the input data for the equations of the indices.
- c. A regular progress updating is carried out at certain periods. All actual data that have been collected during the last period are recorded with sufficient accuracy.
- d. Project scheduling software packages have the option to fix the project completion date or release it. The research assumes the project completion date is not fixed and moves according to the calculated critical path completion. This is to allow recording the calculated completion date which is required in some indices. In addition, this option avoids having negative total floats in the updated schedule. The fixed completion date in the software forces its calculations to show the critical delayed activities with negative total floats. The proposed indices do not consider negative total floats. However, it is possible to adjust the calculation equations of those indices to adopt the negative total floats which are not done in this research.
- e. The proposed indices are assumed to be calculated with the assistance of a computer. They are not assumed to be calculated manually due to the excessive amount of calculations that are expected by the proposed indices. However, the computer assistance in the calculation does not require complicated programming. A spread sheet can be programmed to perform these calculations.

- f. The number of activities in the updated schedule is similar to the number of activities in the working baseline schedule. In case of any revision done for the baseline schedule, it should be reflected to the updated schedule directly.
- g. Whenever the term “Baseline Schedule” is mentioned it means the “Working Baseline Schedule”, which is the last revised and approved schedule and at the same time it is the one that is used to monitor the work.

CHAPTER 4

4. CATEGORY 1 – OVERALL PROJECT CRITICALITY

4.1 Introduction

The completion date of any project is governed by its longest path, or the most critical path, in the “CPM” network of that project. This longest path reflects the shortest period of time that is required to finish the entire project’s activities. The status of the longest path is one of the major issues that needs to be continuously monitored during the project execution period. Certainly, one of the most important items of information in any progress update is the longest path completion date. Claims for extension of times that are normally resulting from critical delays depend highly on the recorded delays on project completion date, which is again the longest path completion date. The longest path may change during the progress of the project as a result of the different rates of progress for the different “CPM” network paths. This is simply due to the fact that delays may occur for any set of activities in the network and once it becomes critical, the path of that particular set of activities takes the lead for the project completion by becoming the longest path of the whole “CPM” network.

The amount of critical delay for the project completion is normally recorded in every progress report. This information shows the trend and magnitude of any recorded critical delays, or advances, in the project; e.g. increasing rapidly, decreasing, steady, etc. Necessary decisions and corrective actions can be taken based on the longest path status. Most construction professionals keep their eye on the calculated project completion date and the way it is developing from one progress reporting period to another. They consider a non-delayed critical path a favorable case while adversely, the delayed critical path is an adversarial indication on the overall project status.

The above understanding of the status of the longest path might be misleading for the industry professionals. There is a possibility of having a situation where the longest path reading is favorable, i.e. on-schedule or about-schedule, but the whole project is in serious condition of having large number of non-critical activities suffering from close-to-critical delays. The reason for this could be shortage of resources which would definitely lead to future critical delays in the project. The

longest path does not tell us how many non-critical activities are gradually becoming close to critical before they actually become critical and start to push back the project completion date. The same argument applies when the longest path is delayed. The project completion could be delayed by a longest path comprised of a few activities that are easily recoverable while at the same time all other activities could be ahead of schedule. The previous two examples show that the status of the longest path alone is not sufficient to tell us the severity of its condition.

Available knowledge lacks a reliable and easy-to-use tool or technique to provide a measure, or an index that can be used to assess the exact situation of the project's criticality or potential criticality. The proposed criticality indices try to fill this gap in the available knowledge by introducing three indices which, if used together with the longest path status, will give an extremely important interpretation of the project's criticality. These three indices are:

1. Percent Difference of Critical Path Completion "PDCC"
2. Percent Difference of Critical Path Weight "PDCW"
3. Mean Total Float Indices; "RDMF" & "PRGC"

Detailed discussions on each of the proposed indices are shown in separate sections below. However, it was found important before going into detailed discussions with the three indices to introduce and discuss two important concepts that classify the delays into two main types according to their spread over the entire schedule as shown in the next section.

4.2 Spread of Delays

Delay in any project can be classified into two main types with respect to their spread over the project's network and activities. These are:

a. Local Delay

This case is when the critical delay is located in certain spot(s) or region(s) in the network. Under local delay a relatively few critical activities are contributing in the delayed longest path while the majority of the activities are non-critical. The causes behind local delays are mainly related to the delayed set of activities themselves; e.g. delayed approvals, delayed deliveries or procurements, unavailability of necessary special resources, certain obstructive site conditions, etc. The significance of the delay depends on their causes. However, the recovery

of such a delay is simply achieved by dealing with the delaying factors. If the delay of these activities is not recoverable then the recorded delay will cause a delayed project completion. The recovery of a local delay is relatively straight forward or easy to develop. In most of the times, local delays are not related to reasons associated with the competency of project management, resource shortages, etc.

b. Global Delay

This case is when the delay is spread over the network in a way that the delay could not be considered confined to certain spot(s) or region(s) in the network. Many critical activities contribute relatively to this delay. The causes behind global delay are in the main more related to reasons at a level higher than to the activities; e.g. incompetent staff and management, improper decisions, shortage in resources, major change order(s), out-of-sequence work, schedule ignorance due to non-commitment, etc. These reasons affect the different activities all over the network without concentrating on a specific set or group of activities.

This delay may or may not be associated with excessive delays in the longest path. The significance of global delay could not necessarily be considered minor if the longest path has minor delays. This is because the globally increased criticality of the project's activities will lead to future delay in project completion if no corrective actions are taken promptly. Accordingly, the impact of the global delay is higher than that of the local delay.

There are several signs that can be used to indicate, and differentiate between, the local delays and the global delays. These signs will be mentioned in more details when discussing the indices of this category and other categories.

4.3 Overall Project Criticality Indices

The criticality indices provide fairly good signs about diagnosing the project criticality and the possible reasons of any recorded delay. The indices are discussed in details in the next sections:

4.3.1 Percent Difference of Critical Path Completion "PDCC"

This index measures the difference between the original completion date and the calculated completion date of the progress update schedule and relates this difference to the original project duration. The importance of this index is that any recorded delays, or even advances, in the longest path is converted into a percentage

of the original project duration and therefore achieve a better estimate for the significance of that delay. Although this index is quite simple, it is imperative that it be calculated and shown in every progress update and report in order to use it for the overall progress assessment and diagnosis. The formula to calculate this index is:

$$PDCC = \frac{OCD - UCD}{CP} \times 100 \quad \text{Eq. (4.1)}$$

Where:

PDCC – Percent Difference of Critical Path Completion

OCD – Original Completion Date

UCD – Updated Completion Date “Calculated”

CP – Contract Period

The significance of the value of “PDCC” could be fine tuned for each project according to the project’s conditions. However, based on the author’s experience, a significance rating is proposed as in table 1. The rating is not based on research efforts; therefore the author recommends considering these ratings as guidance only. It is recommended that practical case studies be conducted in order to reach at what could be considered an industry-accepted significance rating though it might not be considerably differing from the suggested one. It is beyond the scope of this research to conduct such case studies. It will not make any difference to the content of this thesis if the suggested significance rating is changed.

Table 1
Suggested Significance Rating for PDCC Values

Sr.	Range of <i>PDCC</i>	Progress Status	Significance Rating
1	$+4.5\% \leq PDCC$	Ahead of Schedule	Large
2	$+3.0\% \leq PDCC \leq +4.5\%$	Ahead of Schedule	Medium
3	$+1.5\% \leq PDCC \leq +3.0\%$	Ahead of Schedule	Small
4	$-1.5\% \leq PDCC \leq +1.5\%$	On/About Schedule	No Significance
5	$-3.0\% \leq PDCC \leq -1.5\%$	Behind Schedule	Small
6	$-4.5\% \leq PDCC \leq -3.0\%$	Behind Schedule	Medium
7	$PDCC \leq -4.5\%$	Behind Schedule	Large

While the project progresses, “PDCC” values can be plotted on a graph against the percent completion of the project duration to have a curve that provides a pictorial view of the movement of “PDCC” from the beginning of the project to the end of it. The “PDCC movement” graph is proposed to be as shown in figure 3.

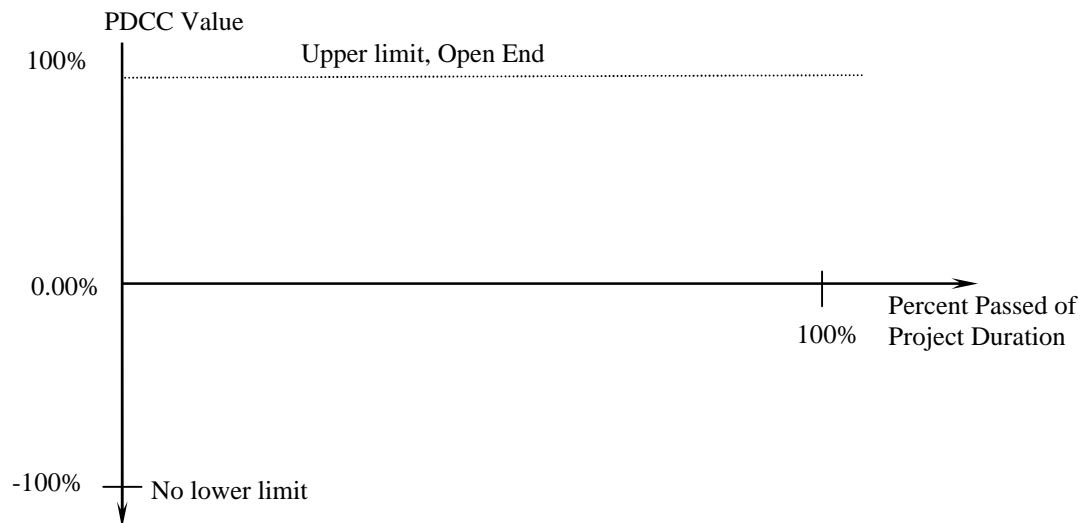


Figure 3. PDCC Movement Graph

In the above graph of figure 3, the x-axis represents the percent of project duration while the y-axis is the value of “PDCC”. The x-axis starts from zero to 100% and might be more than 100% if the project suffers from delays. The y-axis has an open ended upper limit at (+100%) which is a very theoretical case, actually it is hypothetical to have the project completed 100% ahead of its original project duration. The minimum value of the y-axis is open without any lower limit since any project might be delayed by 100% of its original duration or by even more. The ranges of the suggested significance ratings could be shown in the same graph for more clarity and easy interpretation of the progress status.

4.3.2 Percent Difference of Critical Path Weight “PDCW”

The weight of the longest path of the baseline schedule can be represented as the percentage of the activities of the baseline critical; or longest, path to the total number of activities in the whole schedule network. During the progress updates the number of activities in the critical path might change either by increasing or by decreasing. The change in the weight of the critical path provides an indication about the weight of those activities that contribute to the current, or updated, critical path

and accordingly, to the significance of the completion date that is shown by that current critical path. The proposed index tracks the changes in the weight of the critical path by calculating the difference in the percentage weight of the critical path between the baseline and the updated schedules. In this index the baseline schedule has been considered the datum where any increase or decrease in the number of activities of any updated critical path is referred to the baseline one.

The baseline schedule is originally developed as the plan that, once followed and respected, the whole project can be completed on its contractual completion date. If at any progress update a change occurred to the project completion date, say increased due to a critical delay, the information that “an updated critical path weight lower than the baseline schedule by 1% is causing the current calculated completion date” is much different than another scenario with the same delay but caused by “an updated critical path weight higher than the baseline schedule by 5%”. The interpretation of the significance of each of the two example scenarios is not the same. The first scenario is a critical delay that affects fewer number of activities than the baseline number of activities of the critical path. The recovery of such a delay then has a better chance to be easily achieved. The resources that are delayed by this critical delay are more likely to be much less than the second delay scenario. If a revision to the baseline is required, then a more cost effective revision could be achieved in the first scenario than that of the second scenario. For all these reasons the significance of the two scenarios should not be considered the same. The second scenario of 5% more weight of the critical path could be more significant than the other 1% less scenario. The second scenario should result in a higher warning sign to investigate the issue and its causes thoroughly. The importance of this index comes when dealing with a large amount of concurrent work where the paths of the network have many branches and parallel lines; e.g. finishing works on a multi-story building. The formula to calculate “PDCW” is:

$$PDCW = BCPW - UCPW \quad \text{Eq. (4.2)}$$

And from the above definition:

$$BCPW = \frac{BCAN}{N} \times 100 \quad \text{Eq. (4.3)}$$

$$UCPW = \frac{UCAN}{n} \times 100 \quad \text{Eq. (4.4)}$$

Where:

PDCW – Percent Difference of Critical Path Weight

BCPW – Baseline Critical Path Weight (Percentage Value)

UCPW – Update Critical Path Weight (Percentage Value)

BCAN – Number of Activities in the Baseline Critical Path

UCAN – Number of Activities in the Updated Critical Path

N – Total Number of Activities

n – Number of Remaining Activities

Equation 4.2 above has two parameters; the “BCPW” which is a constant value and calculated at the beginning of the project and the “UCPW” which is varying from one update to another. The ranges of values for “PDCW” are bounded from both ends; the upper limit is above zero by an amount of “BCPW”; i.e. (+BCPW), and the lower limit of (BCPW-100) which is a negative value since “BCPW” is lower than 100%. The upper limit is an open ended one that cannot be reached since it means that the current updated schedule has a critical path with zero number of activities which is an imaginary condition. The lower limit, on the other hand, is a closed ended limit and in some extremely limited conditions can be reached. These conditions are when all project activities have zero total float and hence the current updated schedule critical path is actually a group of all paths of the network. In this special case the lower limit can be reached. Table 2 shows the ranges of values for “PDCW”.

Table 2

Ranges of Percent Difference of Critical Path Weight “PDCW”

Sr.	Range of <i>PDCW</i>	Criticality Level
1	$(BCPW - 100) \leq PDCW < 0$	Higher Weight than the Baseline
2	$PDCW = 0.0$	Similar Weight to the Baseline
3	$0.0 < PDCW < BCPW$	Lower Weight than the Baseline

A graph is proposed to track the “PDCW” during the progress. The graph is given the name “Critical Path Weight” and is established in a way similar to the previous “PDCC Movement” graph. The x-axis in the Critical Path Weight graph is the same as the x-axis of the “PDCC Movement” graph while y-axis shows the

“PDCW” values during the project execution period. However, the upper and lower limits of the “PDCW” values should be shown in the graph for more clarity and a better significance interpretation. When the value of “PDCW” is positive, then the interpretation is that the current updated schedule has a critical path with a weight lower than the baseline schedule. The negative value of “PDCW” means the opposite i.e. higher weight than the baseline schedule which is a more significant situation. The proposed graph would be similar to figure 4.

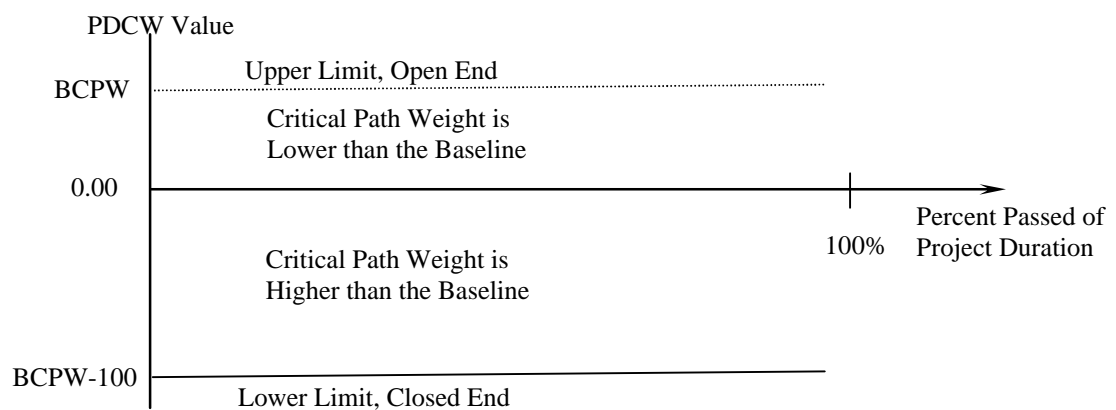


Figure 4. Percent Difference of Critical Path Weight Graph

4.3.3 Mean Total Float Indices; “RDMF” & “PRGC”

The third part in the category of “Overall Project Criticalities” is constituted by two main indices; the “Relative Difference of Mean total Float – RDMF” and the “Progress Concentration – PRGC”. Both of them use the total floats of the baseline and updated schedules but in some different ways of representation and interpretations. The first one which is the “RDMF” index deals with the changes between the mean total float per activity “MTF” of the project at any progress update and that of the baseline for the same project. Tracking the changes from one progress update to another during the project execution provides an important indication and a more reasonable understanding of the criticality status at the activity level. The indices of this category cover the overall project criticality in several aspects including; (1) the critical path length which investigates the changes in the length of the current critical path and compares it with the baseline critical path length, (2) the critical path weight which measures the difference of the weight of the current updated critical path with respect to the weight of the baseline critical path, and (3)

the mean total floats which is comprised of the two indices of this section, the relative difference of mean total float “RDMF” and the progress concentration “PRGC”. The following discussions deal with the third aspect of the overall criticality category.

The Relative Difference of Mean total Float “RDMF” calculates the relative difference in the mean total float per activity between the baseline and the updated schedules. This difference can be considered as a criticality measure at the activity level. When the mean total float of the activities of the updated schedule is less than that of the baseline schedule, then the situation indicates that more activities are approaching criticality by consuming their total floats. The higher the level of criticality the lower the value of “RDMF” and vice versa. The importance of this index becomes higher when it is read together with other related indices of this category and other categories. This is discussed in more detail in separate sections below.

The calculation of “RDMF” requires the baseline and updated values of the mean total floats for the activities in order to facilitate the comparison that will allow the investigator to accurately recognize the criticality status. Therefore more precise conclusions could be drawn. Regarding the baseline mean total float, there are two baseline-related measures. The first one is the original baseline mean total float before having had any actual progress recorded which is calculated at the beginning of the project for all activities. This measure is constant and has been given the abbreviation “BMTF”. The second one is the “Moving Baseline Mean Total Float – MBMTF” which is the mean baseline total floats of only the remaining activities as they are shown in the updated schedule at the day of progress update.

The value of “MBMTF” differs from one update to another since the remaining activities are differing and then the mean baseline total float for the activities at one updating period will not be necessarily the same as that of another updating period. From this argument two comparisons need to be carried out. The first one is the comparison between the original mean baseline total float for all activities “BMTF” and the moving baseline mean total float “MBMTF” for the remaining activities as appearing in the updated schedule. This shows which types of activities are completed and which are remaining from the view point of total float. If the progress is concentrating more on the critical activities and giving less than required concentration on the other activities, then the remaining activities will include more

non-critical activities that have higher total floats than those being implemented. Then the difference between the two will increase indicating unbalanced progress concentration at the side of these more critical activities. This has been given the name “Progress Concentration – PRGC”.

The second comparison is between the mean total floats of the updated schedule and the moving baseline mean total float “MBMTF”. This comparison shows the status of the mean total floats of the activities in the updated schedule with respect to what they should be as calculated from the “MBMTF”. If the updated mean total float “UMTF” is higher than the moving baseline mean total float “MBMTF” then there should be a local critical delay with an amount that affects the progress status and shows that most of the remaining activities are gaining additional total floats, which should not be considered genuine. The discussions and calculations of the two indices are detailed in the following paragraphs of this section starting with the Progress Concentration then the Relative Difference of Mean total Float.

The progress concentration index “PRGC” provides indications on how the progress is running and what activities are being given higher priority than what they should have, or in other words, which activities have more concentration. This can be well understood by the following example scenario: when calculating the mean baseline total floats of only the remaining activities and without considering the completed activities i.e. calculating the “MBMTF”, and it is found higher than the original baseline mean total floats of all activities “BMTF”, then it could be concluded that the progress is focusing more on the most critical activities, which is a good sign from one side, but relatively speaking ignoring non-critical activities, which is a bad sign from the other. If the progress is ahead of schedule, then it is better to have it balanced for all activities but if the progress is consuming the floats of non-critical activities by delaying them, then some problems exist. The cause of this situation could be related to shortages in the resources or to some other problems that can be addressed when integrating the readings of other indices as discussed below in more detail.

The difference between the “BMTF” and the “MBMTF” indicates what activities of the baseline schedule are now remaining, and where the progress is more concentrated with regard to the activity’s total float. For example, the progress could be concentrated mainly on the originally critical activities while the originally non-

critical activities are kept suffering delays; could be concentrated mainly on the originally non-critical activities while the originally critical activities are kept suffering delays; or could be concentrated on all activities in a balanced manner. The techniques that are currently available for progress control are not sufficient to investigate the progress concentration. If such information is needed, then it requires reviewing all remaining activities and comparing them with the baseline schedule in order to draw conclusions. This is a time-consuming process and the results might be subjective because no reliable measuring technique is available, while by calculating this difference, it could be recognized directly whether the progress concentration is balanced or not, and if not, which activities are given higher priority. The difference between the “BMTF” and the “MBMTF” has been given the name “Progress Concentration – PRGC” and can be calculated using the following equation:

$$PRGC = MBMTF - BMTF \quad \text{Eq. (4.5)}$$

From the above definition:

$$BMTF = \frac{\sum_{i=1}^N BTF_i}{N} \quad \text{Eq. (4.6)}$$

And

$$MBMTF = \frac{\sum_{i=1}^n BTF_i}{n} \quad \text{Eq. (4.7)}$$

Where:

PRGC – Progress Concentration

BMTF – Original Baseline Schedule Mean Total Float, for all activities

MBMTF – Moving Baseline Mean Total Float, for remaining activities

BTF – Total Float of Activity (*i*) as in the Baseline Schedule

N – Total Number of Activities as in the Baseline schedule

n – Number of Remaining Activities in the Last Updated Schedule

Equation 4.5 has a lower and closed end limit which is at negative “BMTF”. This case would occur if the remaining activities were purely those with zero total floats as in the baseline schedule; i.e. the most critical activities in the baseline schedule not in the updated one. The upper limit of this equation occurs in an extremely limited and very special case if the remaining activities include only one

activity and this activity is the one that has the highest total float in the baseline schedule. In this case, the value of this upper limit is equal to the amount of the baseline schedule total float of this remaining activity minus the baseline mean total float value “BMTF”. However, it is rare to reach this upper limit because the activity of the highest baseline total float could be a predecessor for other activities, and then it is not possible to have that particular activity as the only remaining activity. Reaching the upper limit is a very special case and may only occur at very limited conditions, if ever. The only use of the remaining activities is because the completed activities should not be included since they don’t have total floats in the updated schedule, and then their existence will confuse the results of the calculation of the mean total float of the updated schedule. It should be noted that the dominator of the mean total float formula is the number of activities that have total floats in the updated schedule which is actually the number of remaining activities only.

Figure 5 shows a graph for the progress concentration index. The x-axis of the “Progress Concentration” graph is the percentage passed of the original duration, or the days if needed. The y-axis shows the Progress Concentration value “PRGC” which is the difference between the moving baseline mean total float “MBMTF” and the original baseline mean total float “BMTF”.

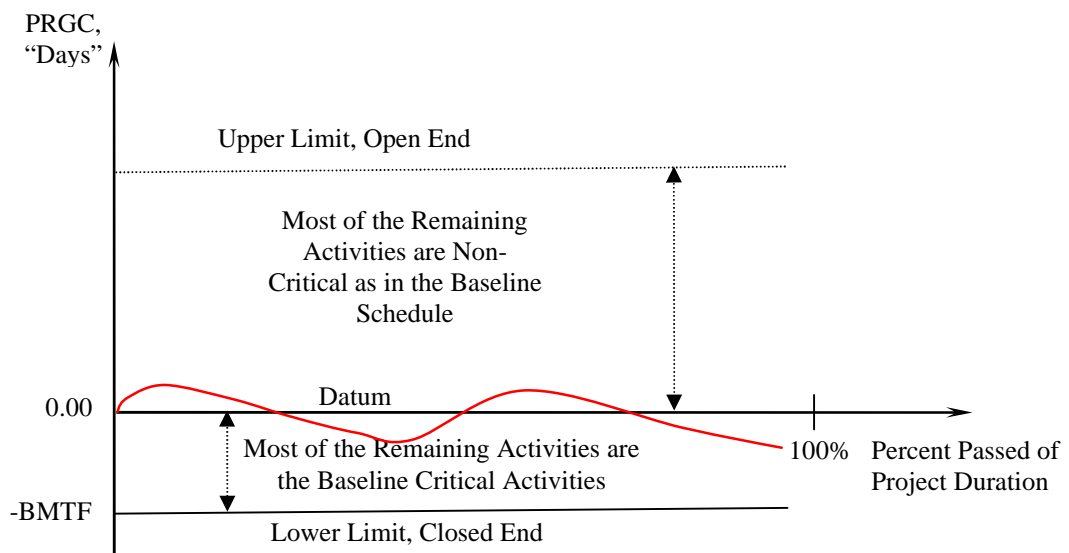


Figure 5. Progress Concentration

Figure 5 shows a hypothetical example of how the curve of the “MBMTF” could look like. The part of the curve that is above the datum; i.e. the value of “PRGC” is positive, shows that the progress is concentrating more on the baseline critical activities and gives lower priority for the baseline non-critical activities which are becoming the majority of the remaining activities. The reason could be a shortage in the resources where the project management team could not find enough resources to assign for the required activities as per the baseline schedule. Therefore, the priorities should be for the critical activities with the non-critical activities being delayed. The same case would occur as a result of some site conditions that do not allow working in some non-critical area or because of some site logistic problems. Other reasons could be: approvals, incompetent management performance, out-of-sequence work, etc. This situation might be associated with a favorable critical path reading; i.e. on-schedule or even ahead of schedule. The use of percentage of completion only could not help in determining that there is a potential resource problem, for example, since the concentration on the critical activities sufficiently compensate the other delayed non-critical activities. This index, however, shows easily and immediately that the progress is not balanced and there is a concentration on certain activities while ignoring others. The integration between the reading of this index and other indices will shorten the list of possible causes and problems which accurately diagnose the progress and address the real problems if any.

If the Progress Concentration curve is close to the datum then the concentration could be balanced or scattered and then no well defined concentration can be recognized in this case. The scattered concentration is when the progress concentrates on one part of the critical activities and ignores the other, and at the same time concentrates on one part of the non-critical activities and ignores the others. In this case the reading of other indices should be integrated to clarify the real progress condition because this index is “indifferent” in this case and cannot determine the situation. The last case is when the curve is below the datum i.e. negative “PRGC” value, then the progress is concentrating more on the non-critical activities and the baseline critical activities are given lower priority. That is why they constitute the majority of the remaining activities. The indication that comes from this sign is that serious problems exist. It is not necessarily related to resources unless very special type of equipment is required and not available on the site. The causes for such a

situation are more related to delayed approvals, delayed material deliveries, major change orders, etc.

The above discussion shows that two different values could be calculated from using the baseline total floats of the different activities. The total floats of the remaining activities in the updated schedule have not been considered by these two measures. It is required to calculate the Updated Mean Total Float “UMTF” and compare it with the baseline value in order to investigate the current updated progress. As has been detailed before, the baseline mean total float “BMTF” is a constant value and calculated at the beginning of the project and before considering any actual progress while the moving baseline mean total float “MBMTF” is the mean baseline total floats but for the remaining activities only. The updated mean total float will be compared with the “MBMTF”, not the “BMTF”, in order to have a complete picture about the overall project criticality. The “BMTF” will not be considered in the comparison since its main use is to determine what type of activities is remaining and is achieved by calculating the “Progress Concentration Index – PRGC”.

The Relative Difference of Mean total Float “RDMF” will use the moving baseline mean total float “MBMTF” as the reference for the comparison with the updated mean total float “UMTF”. If the “UMTF” is higher than the “MBMTF” then the majority of the remaining activities of the updated schedule are less critical than what the baseline schedule originally assumed for the same activities. This indicates a local critical delay in the project and it could have resulted from any of the probable causes of the local critical delays. The opposite, i.e. “UMTF” is lower than “MBMTF”, then the majority of the remaining activities are more critical than what the baseline schedule originally assumed for them, which indicates different progress situation such as: global critical delay, shortage of resources, etc. More detailed discussion about the progress interpretations from the different readings of these indices are shown in a separate section below.

Both “UMTF” and “MBMTF” could be calculated and plotted together in a graph with the percent passed of the original duration as the x-axis and the mean total float at the y-axis. The two curves of the proposed graph could be visually compared to easily interpret some conclusions about the progress status. If the curve of “UMTF” is shown above the curve of “MBMTF” then the activities’ criticalities of the updated schedule are decreasing which, is an indication for certain conditions like local critical

delay. The investigation should be directed then to the causes of this local critical delay. Some of these causes have been detailed with the discussion of the local critical delays above. The graph would look like the following figure 6 which shows hypothetical two example curves:

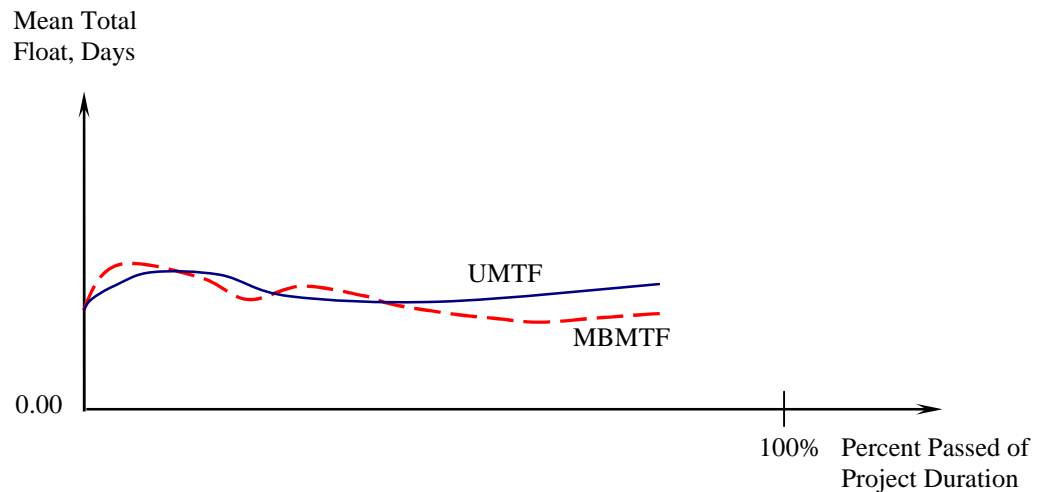


Figure 6. Mean Total Floats

The value of the updated mean total float “UMTF” of figure 6 started lower than the moving baseline mean total float “MBMTF”, which indicates increased activities’ criticalities at the beginning of the project. This means that there could be a global critical delay. But if the curve of figure 5 is assumed for the same hypothetical example then it could be observed how the comparison would be conducted by integrating both graphs. The curve of figure 5 demonstrates that the remaining activities at the first execution stage showed increased mean total float, and as per the discussion of that curve, the progress interpretation suggested an ahead of schedule performance as one of the probable causes of this case due to the additional concentration on the baseline critical activities. Even without knowing the critical path reading, which is normally easily available at any update, the two curves could be integrated to conclude that the project might be ahead of schedule, which shortened the critical path; and accordingly, the activities updated mean total float is lower. With the use of what is supposed to be available at any progress update; e.g. critical path reading, etc. the most accurate interpretation will be ensured. By using the previously discussed “PDCC” index which is related to the length of the longest path, a more precise conclusion could be reached for this situation. It is worth mentioning

here that the integration should not be carried out between two indices only. Alternatively, it should be done with all indices so that the final conclusion will be the most accurately possible conclusion about the progress status and the diagnosis of it.

The “RDMF” index is the difference between the updated mean total float “UMTF” and the moving baseline mean total float “MBMTF” divided by the “MBMTF”. The resulting value provides an important indication about the mean total float of the remaining activities and how it is compared with that of the baseline for the same activities. The calculation formula for this index is as follows:

From the definition of “RDMF”, its value is calculated as:

$$RDMF = \frac{UMTF - MBMTF}{MBMTF} \quad \text{Eq. (4.8)}$$

But again from the definition:

$$UMTF = \frac{\sum_{i=1}^n UTF_i}{n} \quad \text{Eq. (4.9)}$$

By substituting 4.7 and 4.9 in 4.8 and cancel “n” from top and bottom:

$$RDMF = \frac{\sum_{i=1}^n UTF_i - \sum_{i=1}^n BTF_i}{\sum_{i=1}^n BTF_i} \quad \text{Eq. (4.10)}$$

Equation 4.10 can be simplified as follows:

$$RDMF = \frac{\sum_{i=1}^n UTF_i}{\sum_{i=1}^n BTF_i} - 1 \quad \text{Eq. (4.11)}$$

Where:

RDMF – Relative Difference of Mean Total Float

MBMTF – Baseline Schedule Mean Total Float

UMTF – Updated Schedule Mean Total Float

BTF – Total Float of an Activity as in the Baseline Schedule

UTF – Total Float of an Activity as in the Updated Schedule

n – Number of Remaining Activities

Both equations 4.8 and 4.11 can be used to calculate the value of “RDMF” at any progress update process during the execution period. Equation 4.11 gives the

value of the “RDMF” directly while equation 4.8 requires first the values of the mean total float for the baseline and updated schedules to be calculated first. The resulting values of the “RDMF” have a lower limit of (-1) which is closed end while no upper limit for the values of it. Three main categories can be identified for the ranges of results for “RDMF” as shown in table 3.

Table 3

Ranges of Relative Difference of Mean Total Float “RDMF”

Sr.	Range of <i>RDMF</i>	Activities’ Criticality Level
1	$-1.0 \leq RDMF < 0$	Higher Than Baseline
2	$RDMF = 0.0$	Similar to the Baseline
3	$0.0 < RDMF$	Lower than the Baseline

The value of “RDMF” reaches its minimum; i.e. (-1), if the total floats of all remaining activities at any progress updating equals zero exactly where the “UMTF” and all “UTF” values equal to zero at this case. Although this case could be difficult to reach easily, it is still a possibility to have such a situation where all remaining activities in the updated schedule have zero total floats. When “RDMF” equals (-1), then the value of the previous index “PDCW” equals its maximum value which is (100-BCPW). The rationale of this situation is detailed in the discussions of the previous index when detailing the case of having all activities in the updated schedule with total floats equal to zero exactly.

As long as the “RDMF” value is below zero, then the criticality level of the updated schedule is higher than that of the baseline schedule for the set of remaining activities. In a special case, the value of “RDMF” may equal zero. The meaning of this is that the criticality level of the updated schedule equals that of the baseline schedule for the remaining activities, though it does not mean that the progress shall be considered “On-Schedule”. This condition occurs with two scenarios, the first one if all remaining activities have a total float equal to the baseline total float of the same activities, which is a very special case or even could be hypothetical, and the second scenario if there are some changes in the total floats; but these changes cancel out each other to keep the summation of all total floats of the updated schedule similar to

that of the baseline. If the value of “RDMF” is higher than zero, then the criticality level is lower than that of the baseline for those remaining activities.

To properly track the values of the “RDMF” and how they change from one progress update to another, a curve is proposed to be plotted with x-axis similar to the previous two curves i.e. percentage passed of original project duration, and the y-axis shows the “RDMF” values. Figure 7 shows the proposed graph with a hypothetical example curve.

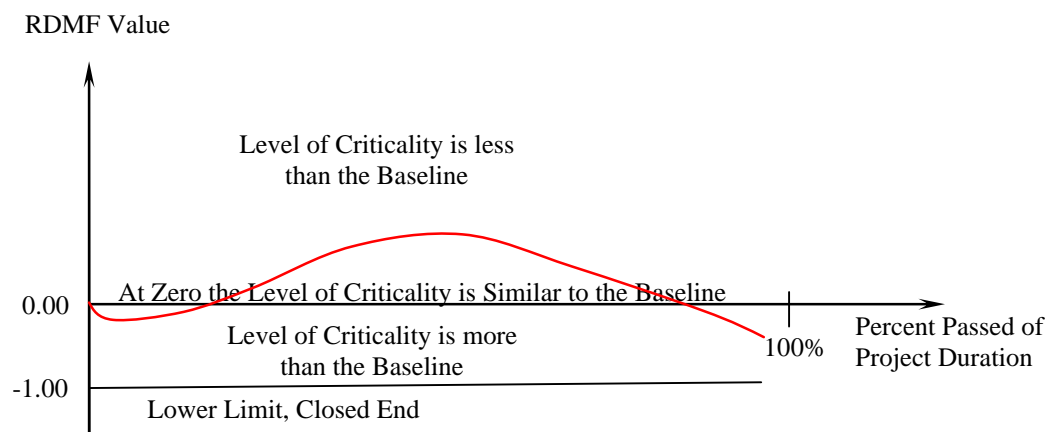


Figure 7. RDMF, Level of Criticality Curve

4.4 Comments of the Overall Project Criticality Indices

The overall project indices provide more useful and valuable information when read together. The three indices have been prepared in such a way that the interpretation of the progress status from their resulted values is easy and systematic. As is noted in the equations, some indices are calculated by deducting the values that result from the updated schedule from that of the baseline schedule. This is in the percentage difference of critical path completion index “PDCC” and the percentage different of critical path weight index “PDCW” while in the relative difference of mean total floats “RDMF” index the calculation is done by deducting the value of the baseline schedule from the value of the updated one. This is to ensure that for the three indices the sign of the value gives always the same interpretation of the progress status.

The first index; i.e. Percent Difference of Critical Path Completion “PDCC”, is considered favorable if it shows reduction in the calculated project completion date,

which means that the work is ahead of schedule or at least on schedule. This favorable indication is represented by the positive sign of the result if the calculated completion date is earlier than the original completion date and vice versa. The second index i.e. Percent Difference of Critical Path Weight “PDCW”. will show a negative value if the calculated weight of the critical path is increased. This increase might not be favorable and the negative sign indicates that. The Relative Difference of Mean total Float “RDMF” could be favorable when its value increases which is opposing the cases of the first two indices. Increased value of the mean total float of the activities at any updated schedule results when more activities in the schedule are gaining an additional float, which is a better situation than having more activities losing floats. However, this could not be a good indication all the times because it might occur when a serious critical local delay exists in the project. But the good news for the positive value of “RDMF” is that not all activities suffer the same amount of delays. The positive sign of the value of “RDMF” comes to indicate this fact. The opposite situation of having reduced mean total float indicates that activities are losing floats and then the recovery of such a situation could not be as easy as the previous one. That is why the negative sign results in this situation. Integrating the readings of the three indices ensures providing better understanding and interpretation of the exact situation of the project progress.

The curves of the three indices can be read together to draw the most accurate interpretations and conclusions about the progress. The progress analyst may prefer to show the project duration in days instead of percentages in the x-axis of each curve. This will make no difference for the curves and their readings. For any curve that has upper and / or lower limit, the value of that limit(s) should be shown in the curve in order to give more clarity on the status and easier progress interpretation.

4.5 Indices Integration and Progress Interpretation

This section discusses the integration of the criticality indices and how the progress can be interpreted based on the readings of all of them. It is worth mentioning that the integration is not limited to this group of indices; i.e. overall project criticality, should be done across the indices of all groups together. The values of some indices might support others as will be shown in the following groups of indices. The following discussion is not assumed to cover all cases. It gives guidelines

on how the indices can be used to interpret the most accurate project status. Other cases might come with the practical application of these indices. To ensure covering most of the cases, the conducting of separate researches and study cases is recommended so that more comprehensive status interpretation rules can be established and made ready for the professionals of the construction industry.

1. IF the value of the Percent Difference of Critical Path Completion “PDCC” is negative and high, and the value of the Percent Difference of Critical Path Weight “PDCW” is positive, and the value of the Relative Difference of Mean total Float “RDMF” is positive and high, THEN:
 - a. The case shows a high possibility of “Local Critical Delay” in which some parts of the network are delayed and if recovered, the project status will improve significantly. The identification of the local delay is a matter of showing a list of the most critical activities to discuss the causes of that delay. The key issue in this interpretation is that the “PDCC” has increased and is associated with additional floats added to the activities in general which has been shown in the mean total float value.
 - b. The case indicates that the current critical path might be different than the baseline critical path. This conclusion comes from the increased value of “PDCC” due to a prolongation to the updated longest path and this has been associated with the reduction in the weight of the critical path. Most likely this situation occurs when the original critical, or longest, path has been replaced by another one of different weight.
 - c. There could be out-of-sequence work or another cause for this case which cannot be supported only by the indices of this group. Other groups could assist in the investigation of other causes or additionally support one of the above causes, and then the management would immediately be directed to the most likely causes of the observed critical delay.
2. IF the value of the Percent Difference of Critical Path Weight “PDCW” is negative and high, and the value of the Relative Difference of Mean total Float “RDMF” is negative, regardless of the value of the Percent Difference of Critical Path Completion “PDCC”, THEN:

- a. An indication of a “Global Delay” is shown by this situation. This global delay could be associated with a critical delay in the longest path, or could not. However, if no critical delay is shown in the longest path at the time of this progress update, then the case forecasts a future critical delay and consequently the project management team should start the necessary corrective action to solve the causes of this situation ahead of time and before it becomes a clear critical delay. The indices provide good indications about this potential delay even before it becomes a reality, which is the great advantage of these indices.
 - b. The same situation indicates resource-related problems either shortages or other adequacy-related problems so that the overall achieved productivity is less than what the baseline calls for. Some other indices of other groups will or will not support this indication; e.g. resource indices will investigate their adequacy and if found adequate then the situation could not be related to the resources.
 - c. A deficiency in the management competency could cause this situation as well. The management could not be sufficiently qualified to meet the challenges of the project. That is why they do not prepare their work properly. Again, other indices determine whether to keep or exclude this possibility.
3. IF the value of the Percent Difference of Critical Path Completion “PDCC” is low positive or low negative, and the value of the Progress Concentration Index “PRGC” is positive and high, THEN:
- a. The case indicates that the non-critical activities are being ignored or given a priority that is lower than what they should have been given. At the same time the critical and close to critical activities are well respected. This results from a shortage or inadequacy of the productivity of the resources at the site. The situation shows that the project management team tries to overcome this shortage by concentrating mainly on the critical and close to critical activities while sacrificing the non-critical activities. The significance of the situation comes from the fact that the project is potentially under a future critical delay and if the management recognizes this problem early then the

solution could be much easier, otherwise the project will be in serious critical delay. Since this problem is normally not associated with a clear critical delay then the recognition of it well ahead of time is not assured, actually it is difficult without using these indices. However, it is associated with reduced percentage of work done in comparison with the baseline unless the weights of the critical or close-to-critical activities are relatively higher than those of the non-critical activities.

- b. The situation indicates that the site conditions could not assist the work; e.g. site logistics problems that force the work to move at a pace much slower than that of the baseline schedule and accordingly, the management team gives the priority to the critical and close to critical activities while the non-critical activities are kept suffering from delays.

The above discussion shows that the use of these indices can assist the project management team to have a better view of the status of the project well ahead of time in most cases, so that necessary corrective actions could be taken with a higher expected efficiency and lower cost implications of these actions.

CHAPTER 5

5. CATEGORY 2 – COMMITMENT TO THE BASELINE SCHEDULE

5.1 Introduction

The “Schedule Commitment Category” deals with the variations in the dates and durations of the project’s activities during the execution phase. It compares the activities’ baseline early dates with their actual dates to draw important conclusions about the progress that are mainly related to the level of commitment to the original baseline schedule; i.e. whether the actual work “follows” or “deviates from” the baseline and in what direction the deviations occur. There should be a differentiation between two concepts, the schedule “commitment” and the schedule “criticality”. The “commitment” focuses on the degree the original baseline schedule is respected without being subjected to any single day of deviation whether this deviation is in the delay direction or the advance direction. Whenever a deviation occurs, then the level of commitment to the baseline schedule should be reduced by a certain proportional amount. The more the commitment is reduced, the more the actual progress is “indifferent” from the baseline schedule and vice versa.

The second concept; i.e. the “criticality”, is concerned with the amount of critical delay for part of, or all the activities. Consequently, criticality is a special case that occurs when the reduction in the commitment, due to a deviation for certain activities, is in the direction of delay, not advance, and the amount of that delay exceeds the amount of its updated total floats, or baseline total floats, depending on the type of analysis. Criticality deals with project delayed completion due to some critical delays in certain activities. While, on the other hand, the commitment to schedule does not deal, or investigate, the project delayed completion. However, the integration between the two categories of criticality and commitment would provide valuable diagnostic conclusions on the most accurate progress interpretation.

From the above discussion, the “commitment” to the baseline schedule is affected by any single day of deviation from the “early” start or finish dates of any activity in the schedule. Therefore, the indices of this category are concerned with the comparison between the “early” baseline dates and actual dates while the “late” baseline dates of the activities are not considered in the calculations. The late start and finish dates are mainly related to the total float and criticality evaluation which is not

in the scope of the schedule commitment category. The deviations in the start dates are not necessary equal to that of the finish dates. That is why the commitment calculations should be applied for both the start and finish dates of the activities. Whenever such a difference between the start and finish deviations exists it indicates that the actual durations of some activities are more or less than what the baseline durations are. Actual durations that are larger than the baseline indicate a problem affecting the work continuation due to some interruption that prolongs the activities durations. In addition, it could be an indication for problems in the productivity and adequacy of resources, etc.

Understanding the readings of the indices of this category provide valuable information on the pattern of the deviations which in turn highlights how the original baseline sequence of work is being respected. Actually there is no available technique that provides such information directly without doing it by manual investigation which might not be reliable, or at least it could be arguable by the different parties concerned. If the majority of the deviations are in the direction of delay and even before having real recorded critical delay, then the project is under global delay that would become critical soon. However, if the dates of the activities are deviating in both directions i.e. delay and advance, and the proportion of these two directions are significant, then it indicates an out-of-sequence work or, in other words, the actual working sequence on site is different to the baseline sequence. This could result from having a different program from the approved baseline is or because the work on site is not following a well defined program due to a lack of supervision, or other reasons. This category contains four indices:

1. Advance Deviation Ratio
2. Delay Deviation Ratio
3. Mean Overall Deviation
4. Mean Difference of Original Duration

The following sections provide more details and discussions on these indices and their use and calculations formulas.

5.2 Mean Deviation Indices

This group of indices is concerned with the calculations of the mean deviations, or variances, for either the start dates, finish dates, or the original

durations of the activities. In practical life the deviations could be classified into two types of deviations, delay deviation and advance deviation. The delay deviation occurs for those activities that have their actual start or finish dates beyond, or will be beyond, their baseline early dates. This deviation has a negative value as it is shown in the equations below. The advance deviation, on the other hand, occurs for those activities that have their actual start or finish dates earlier, or anticipated to be earlier, than their baseline early start dates or finish dates. When calculating this type of deviations the resulted value is positive as it is shown in the equations below.

The delay deviation ratio is a measure for the delay-deviated activities in the schedule. The interpretation of the resulting value of this ratio and how it is progressing from one progress update to the other assists in understanding the trend in the progress and prepares a more accurate forecast for the status if the same progress remains. It also allows for taking more efficient corrective actions if they are required. The same applies for the advance deviation but this type is actually a favorable case and no corrective actions are required for them directly. However, a proper understanding of the trend of the advance deviation and comparing it with the trend of the delay deviations that are occurring in the same project would provide better progress interpretations. For example, if the advance deviation is increasing and the delay deviation is increasing simultaneously, then the interpretations could be something like “the project is running out-of-sequence” or “there is a very slow progress in some areas due to certain causes that need to be discovered”, or others. As mentioned several times before, the “integration” between the different indices and ratios provides the most accurate diagnosis for the progress in order to have the best interpretation of it.

Based on the above argument, each value of the two deviations is important but at the same time the algebraic sum of both of them would also provide additional important information by knowing which one is dominating. For example, the delay deviations could dominates other deviations in the progress and gradually increases from an updating period to another, which indicates a potential future critical delay if no prompt corrective actions are taken. If such a conclusion is reached well in advance, then the corrective actions will be more cost effective and feasible. In addition, the chance to correct the situation on time and before delaying the project

completion date would be much higher. That is why the third measure; i.e. the “Mean Overall Deviation” is needed for the calculation as it is more detailed below.

The calculations for the deviation ratios should be carried out for the start dates and finish dates separately. The difference between the two represents the mean difference between the baseline original durations for the activities and the actual durations. The derivation of the equation of the mean difference in the original duration is shown below. The importance of this measure is discussed in the related section below but in general, it gives an idea about the work continuity, work interruptions, possible resource shortages or adequacy, etc.

The following sections discuss in some details each of the four measures of this group and derives the calculation equations and some important curves that can be plotted to provide the necessary information visually.

5.3 Advance Deviation Ratios

As discussed earlier, the advance deviation ratio calculates the difference between the actual, or anticipated, dates and the baseline early dates, and divides them into the total number of activities in the schedule. The ratio should be calculated for both the start and finish dates at any progress updates. During the project execution and once a progress update is done, the start and finish dates of the activities will be different from than the baseline early dates, and some of them will be actual while others will be anticipated. Some activities are recorded as completed i.e. their start and finish dates have become actual. Other activities are in-progress i.e. start dates have become actually known while the finish dates are anticipated. The remaining non-started activities will have both start dates and finish dates anticipated. An anticipated date is the date that is calculated from running the schedule and has still not been considered actual. The anticipated date of an activity is calculated based on the recorded progress and the relationships of that activity with other activities. This date could be the same as the baseline date, which happens under very rare conditions, while most of the times it varies depending on the actual recorded progress. For simplicity purposes, both actual and anticipated dates will be given the name “actual dates” in the following discussions and equations. From the above definition the “Advance Deviation Ratios” for start and finish dates are calculated as follows:

For all activities that are actually, or anticipated to be, started ahead of their baseline early start dates, the Start dates Advance Deviation Ratio “ ADR_S ” equals:

$$ADR_S = \frac{\sum_{i=1}^k (BES_i - AS_i)}{N} \quad \text{Eq. (5.1)}$$

For all activities with $AS \leq BES$

And, for all activities that are actually, or anticipated to be, completed ahead of their baseline early finish dates, the Finish dates Advance Deviation Ratio “ ADR_F ” equals:

$$ADR_F = \frac{\sum_{j=1}^m (BEF_j - AF_j)}{N} \quad \text{Eq. (5.2)}$$

For all activities with $AF \leq BEF$

Where:

ADR_S – Start dates Advance Deviation Ration

ADR_F – Finish dates Advance Deviation Ration

BES – Baseline Early Start date for activity (i)

BEF – Baseline Early Finish date for activity (j)

AS – Actual, or Anticipated, Start date for Activity (i)

AF – Actual, or Anticipated, Finish date for Activity (j)

k – Number of All Activities that are actually, or anticipated to be, started ahead of their Baseline Early Dates

m – Number of All Activities that are actually, or anticipated to be, finished ahead of their Baseline Early Dates

N – Total Number of Activities in the Schedule

The two equations of the Advance Deviation Ratio are divided by the total number of activities in the schedule (N) rather than the number of advance activities only. This is because this ratio is not intended to find the mean value of the amount of the advance per advanced activities, which will not provide the required trend comparison to be shown when discussing the delay deviation ratio and the mean deviation. The use of (N) as the reference will help in better assessing the overall trend and tracking the periodical changes of each type of deviation. The values of the “ ADR ” are always positive because the activities that are considered in the two

equations have their actual dates always ahead of the baseline early dates and hence the result of the subtraction is always positive.

5.4 Delay Deviation Ratios

The Delay Deviation Ratios “DDR” are similar in principle to the Advance Deviation Ratios “ADR” but in the other direction which is unfavorable; i.e. delay. The same arguments of the previous ratios “ADR” apply for “DDR”. The concern that should be initiated when having continuously increasing value for “DDR” is higher than that of “ADR” because this indicates a potential future critical delay even if all other indices do not show current critical delays. The reason is that when the trend of delay deviations in a project dominates, or at least starts to dominate, advance deviations trend, the absolute amount of the “DDR” exceeds the amount of the “ADR”. If this trend increases from an update to another, then necessary corrective actions should be taken immediately in order to avoid going into real critical delay that cannot be recovered. From the above definition the Delay Deviation Ratios for start and finish dates are calculated as follows:

For all activities that are actually, or anticipated to be, started behind, or after, their baseline early start dates, the Start dates Delay Deviation Ratio “ DDR_S ” equals:

$$DDR_S = \frac{\sum_{i=1}^I (BES_i - AS_i)}{N} \quad \text{Eq. (5.3)}$$

For all activities with $AS > BES$

And, for all activities that are actually, or anticipated to be, completed behind, or after, their baseline early finish dates, the Finish dates Delay Deviation Ratio “ DDR_F ” equals:

$$DDR_F = \frac{\sum_{j=1}^n (BEF_j - AF_j)}{N} \quad \text{Eq. (5.4)}$$

For all activities with $AF > BEF$

Where:

DDR_S – Start dates Delay Deviation Ratio

DDR_F – Finish dates Delay Deviation Ratio

BES – Baseline Early Start date for activity (i)

BEF – Baseline Early Finish date for activity (j)

AS – Actual, or Anticipated, Start date for Activity (i)

AF – Actual, or Anticipated, Finish date for Activity (j)

l – Number of All Activities that are actually, or anticipated to be, Started Behind their Baseline Early Start Dates

n – Number of All Activities that are actually, or anticipated to be, Finished Behind their Baseline Early Start Dates

N – Total Number of Activities in the Schedule, $N = k + l$, and $N = m + n$

The values of “DDR” are always negative since the activities that are used in its equations have always actual dates coming after their baseline early dates and hence the result of the subtraction is always negative. It is practically possible to have activities with actual start dates status different than that of their finish dates. For example, an activity may actually starts earlier than the baseline early start date, and hence it is included in the calculation of start advance deviation ratio, while its actual finish date is behind, or anticipated to be behind, the baseline early finish date. This means that the same activity will be included in the calculation of finish delay deviation ratio.

The values of the “ADR” and the values “DDR” can be plotted together on a graph to visually allow better and easier interpretation of the progress. To avoid confusion, the proposed graph should be plotted for either the start dates or the finish dates separately. Therefore, at any progress update two graphs need to be plotted; the first one is for the start dates deviations and the second one is for the finish dates deviations. The graph consists of two sides representing the two directions of the deviations. The upper side shows the “ADR” values for either the start dates or the finish dates based on the type of the graph. The lower side shows the “DDR” values for again either the start dates or the finish dates. The x-axis shows the percentage passed of the project original duration, or it could be the number of days passed. The y-axis shows the values of the deviation ratios in days with the “ADR” in the positive side and the “DDR” in the negative side as detailed before. It should be clearly shown in the graph whether it is for the start dates or for the finish dates. It is recommended to have this clearly mentioned at the y-axis and at each curve in order to avoid any confusion. A hypothetical example is shown in figure 8.

Figure 8 shows the start dates deviation ratio for an example project. Six points have been shown in the graph. These are of concern for any analyst. Point (a) in the graph shows that the start dates advance deviation ratio “ADR_s” is relatively low while the start dates delay deviation ratio “DDR_s” is relatively high in magnitude with a negative sign. This indicates a tendency of the progress at that time to be in delay, even if the other delay indices show favorable indications. The case could be considered significant and some a corrective action should be taken in order to avoid any real critical delay, which might not be recoverable, or might be recoverable but with higher cost. Point (d) is almost similar to point (a).

Point (b) which occurs after some time of progress, shows different progress trend since the tendency is to have a higher amount of advance deviations for the start dates and lower delay deviations. This is a good indication, and if the project suffers any real critical delay, the chance to recover this delay could be higher in situations similar to point (b). If this indication is associated with any proposed recovery efforts by the main contractor, for example, then the client’s satisfaction for the results of these efforts might be relatively high. Point (f) is similar to point (b).

Point (c) shows a case which could be more significant than that of points (a) and (d). This is the case when both values of “ADR” and “DDR” are high. This is an indication of out-of-sequence work pattern since the activities are deviating in a higher randomness level due to the existence of a high amount of advance deviations and a high amount of delay deviations. If such a case occurs, then the concerned parties should not take it easily without investigating the causes and taking necessary corrective actions. The level of commitment to the schedule is very low, or in other words the level of indifference is very high. The more this two-sided divergence, is the less the schedule commitment is, or the more the schedule indifference is. An integration between the different related indices should be considered to know why the original sequence of the baseline schedule is not respected by the progress on site to discover any hidden major problems with the main contractor such as: lack of supervision or incompetent supervision; following a different undeclared program as it might happens in some cases in order to gain certain benefits; improper baseline sequence of work due to poor planning; or something else. Point (e) indicates a higher level of commitment to the baseline schedule because both values of “ADR” and “DDR” are very close to the zero. If such a situation occurs in reality, then it is the

most favorable case. However, the analysis of the readings of the other indices is still required. But at least this curve shows that the commitment to the baseline schedule is “high” for the start dates and/or finish dates of all activities.

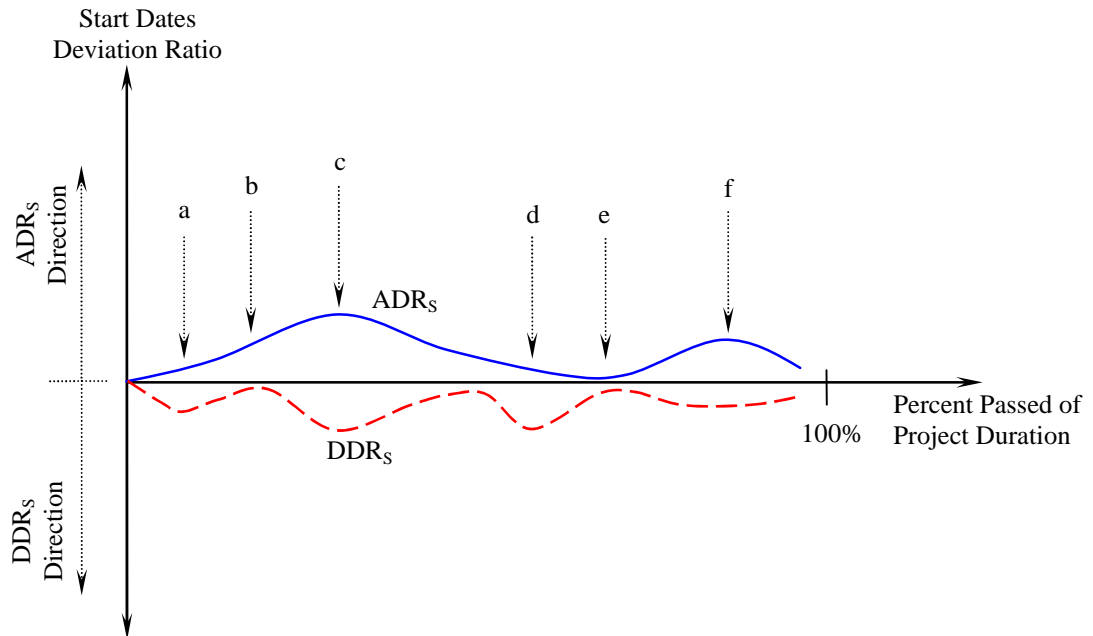


Figure 8. Start Dates Deviations Graph

5.5 Mean Overall Deviation

This ratio represents the overall deviations whether advance or delay. The importance of this ratio is its ability to directly tell the resultant trend of the progress due to the impact of both advance and delay deviations. The index calculates the mean difference between the actual and the baseline early dates of all activities. It considers all activities without separating between those advanced and delayed activities. The values of the mean overall deviation “MOD” could be positive or negative. The sign itself indicates the dominating deviation of activities. If the delay deviations dominate in the schedule, then the result of the “MOD” will be negative. The more the delay deviations are dominating, the higher the “MOD” is in its absolute value and vice versa. The same argument applies if the advance deviations are dominating where the result will be positive. The calculation of the mean overall deviations should be for the start dates and the finish dates separately as shown in the following two equations:

For all activities, the Start Mean Overall Deviation equals:

$$MOD_S = \frac{\sum_{i=1}^N (BES_i - AS_i)}{N} \quad \text{Eq. (5.5)}$$

And, for all activities, the Finish Mean Overall Deviation equals:

$$MOD_F = \frac{\sum_{i=1}^N (BEF_i - AF_i)}{N} \quad \text{Eq. (5.6)}$$

Where:

MOD_S – Start dates Mean Overall Deviation

MOD_F – Finish dates Mean Overall Deviation

BES – Baseline Early Start date for activity (i)

BEF – Baseline Early Finish date for activity (i)

AS – Actual, or Anticipated, Start date for Activity (i)

AF – Actual, or Anticipated, Finish date for Activity (i)

k – Number of All Activities that are actually, or anticipated to be, started ahead of their Baseline Early Dates

l – Number of All Activities that are actually, or anticipated to be, Started Behind their Baseline Early Start Dates

m – Number of All Activities that are actually, or anticipated to be, finished ahead of their Baseline Early Dates

n – Number of All Activities that are actually, or anticipated to be, Finished Behind their Baseline Early Start Dates

N – Total Number of Activities in the Schedule, $N = k + l$, and $N = m + n$

The summation term in the nominators of equations 5.5 & 5.6 could be split into two parts. The first one is the difference between the actual start and baseline early start dates for all advanced activities while the second part is for the delayed activities as shown below:

$$\sum_{i=1}^N (BES_i - AS_i) = \sum_{i=1}^k (BES_i - AS_i) + \sum_{i=1}^l (BES_i - AS_i) \quad \text{Eq. (5.7)}$$

The same above argument applies for the finish dates but with (m) equals number of advanced activities in their finish dates and (n) for the delayed activities in their finish dates:

$$\sum_{i=1}^N (BEF_i - AF_i) = \sum_{i=1}^m (BEF_i - AF_i) + \sum_{i=1}^n (BEF_i - AF_i) \quad \text{Eq. (5.8)}$$

Divide both sides of equations 5.7 and 5.8 by “N” and recall equations 5.3, 5.4, 5.5, and 5.6 then we get:

For the start dates:

$$MOD_S = \frac{\sum_{i=1}^k (BES_i - AS_i)}{N} + \frac{\sum_{j=1}^l (BES_j - AS_j)}{N} \quad \text{Eq. (5.9)}$$

And for finish dates:

$$MOD_F = \frac{\sum_{i=1}^m (BEF_i - AF_i)}{N} + \frac{\sum_{j=1}^n (BEF_j - AF_j)}{N} \quad \text{Eq. (5.10)}$$

Considering equations 5.1 to 5.4, the first term of the right side of equations 5.9 and 5.10 are for the activities with advanced deviation ratios for start and finish dates, and the second term of the same equations are for the activities with delay deviation ratios for start and finish dates. The two equations could be rewritten as follows:

For the start dates:

$$MOD_S = ADR_S + DDR_S \quad \text{Eq. (5.11)}$$

For the finish dates:

$$MOD_F = ADR_F + DDR_F \quad \text{Eq. (5.12)}$$

The values of “MOD” for the start dates and the finish dates are actually the summation of the values of the two previous indices, “ADR” and “DDR”, for start and finish dates of the activities respectively. For more clarity, the values of the “MOD” could be plotted in graphs similar to figure 8. The start dates and finish dates would have separate graphs and then the graph should be for either start or finish dates. The x-axis of the proposed graph is similar to that of figure 8 while the y-axis shows the “MOD” values for either the start dates or the finish dates. Figure 9 shows a hypothetical example for the curve of “MOD” start dates.

The curve in figure 9 shows two points. Point (a) in the curve is the case of positive “MOD” where the advance trend of the project dominates. This is a favorable condition even if it is showing deviation from the original baseline schedule. On the other hand, point (b) shows a different case where the delay trend of the project

dominates, which is an unfavorable condition. The delay deviations in the example project started to be observed as soon as the trend of the curve started to decline, which started after point (a) and continued until it became the dominating trend. This early observation of the delay deviation trends in any project allows the project management team to recognize it and take corrective action well in advance, and before it becomes a real significant delay in the project.

This index is important because of its ability to provide the resultant dominating trend directly. However, the previous two indices, “ADR” and “DDR”, are required because they illustrate how the trend of each deviation is progressing from a progress update period to another. Both graphs of figures 8 and 9 are needed for a better understanding and a broader view of the project’s progress deviations. In addition, the graph of figure 8 shows the different key trend points that are discussed in details above. Therefore, the three indices i.e. “ADR”, “DDR”, and “MOD”, are linked in their calculations since each of them provides part of the picture, which is required to properly understand the level of commitment to the schedule and how any recorded deviation can be interpreted.

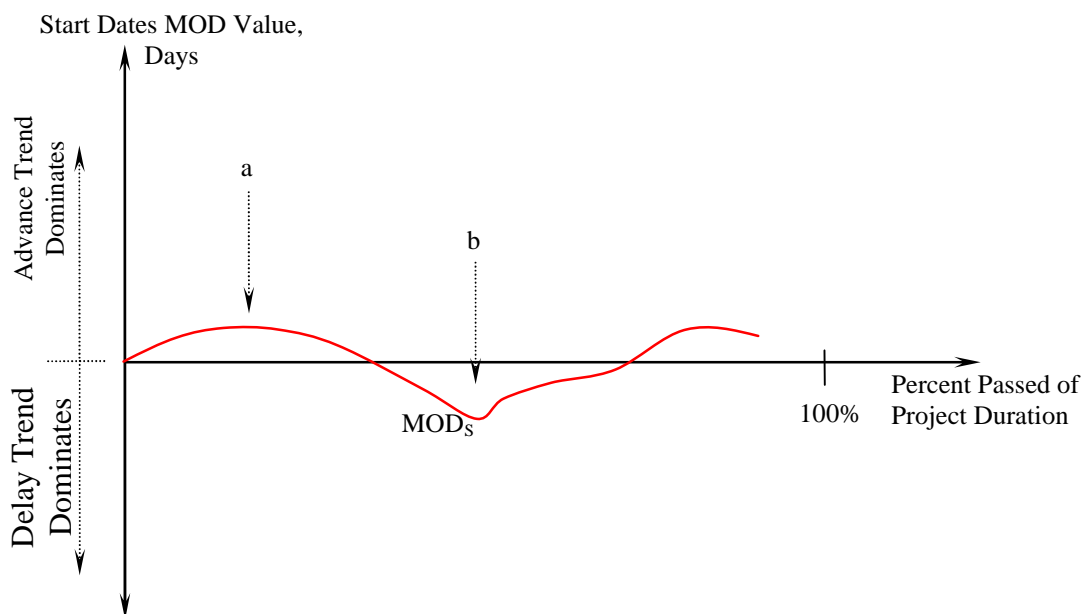


Figure 9. Start Dates Mean Overall Deviation Graph

5.6 Mean Difference of Original Duration

The actual duration of any activity may not necessarily be equal to its baseline original duration due to the different site conditions that affect its progress.

Consequently, the amount of deviation of the finish date of that activity does not equal the amount of deviation for its start date. The comparison between the actual and baseline durations of the different activities provides indications on the work patterns and how it is being performed. Excessive work interruptions for the in-progress activities and other reasons could cause their durations to be prolonged. Hence their actual durations are higher than their baseline original durations. The impacts of this could be, extra costs to perform the work than the budget, delayed learning curves establishment for certain repeated works, delaying the commencement of the activities' successors, keeping large amount of work incomplete, which consume the available supervision and thus requires additional resources to maintain the progress or suffer from critical delays, etc.

There is a need to investigate how the actual durations differ from their corresponding baseline durations in order to ensure achieving most accurate interpretation by covering an important aspect of the progress which is the work execution pattern. The calculation of the differences between the actual and baseline durations of the activities can be done using the previously discussed start and finish indices. For more illustration, figure 10 shows an example activity with a baseline original duration "BOD" and during the progress it suffered from two different deviations at its start and finish dates

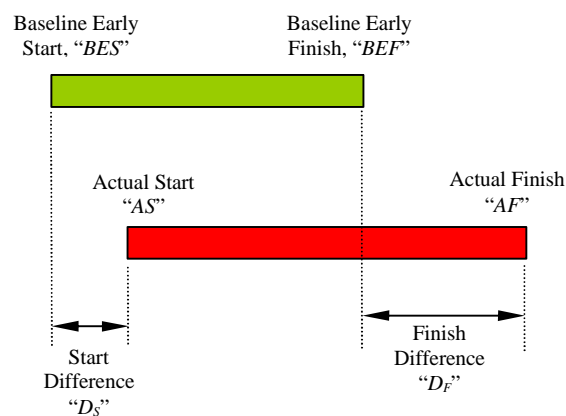


Figure 10. Relationship Between the Deviations and the Actual Duration

From the above figure the start difference " D_s " and finish difference " D_f " are calculated as follows:

The start difference equal:

$$D_S = BES - AS \quad \text{Eq. (5.13)}$$

Reordering equation 5.13:

$$AS = BES - D_S \quad \text{Eq. (5.14)}$$

The finish variance equal:

$$D_F = BEF - AF \quad \text{Eq. (5.15)}$$

Reordering equation 5.15:

$$AF = BEF - D_F \quad \text{Eq. (5.16)}$$

But from the definition of the actual duration “AD” it is the difference between the actual finish and the actual start, then the actual duration is calculated as follows:

$$AD = AF - AS \quad \text{Eq. (5.17)}$$

Substitute equations 5.14 and 5.16 in equation 5.17 and simplify:

$$AD = (BEF - D_F) - (BES - D_S) \quad \text{Eq. (5.18)}$$

$$AD = (BEF - BES) + (D_S - D_F) \quad \text{Eq. (5.19)}$$

$$AD = BOD + DOD \quad \text{Eq. (5.20)}$$

Where:

AD – Actual Duration of an Activity

BOD – Baseline Original Duration

DOD – Difference of Original Duration of an activity

D_S – Start date Difference

D_F – Finish date Difference

Since the “Actual Duration – AD” is equal to the “Baseline Original Duration, BOD” plus any recorded difference in the duration, or the “Difference of Original Duration, DOD”, then the second term of equation 5.20, which is added to the “BOD”, represents the difference in the activity’s duration. This difference could be negative or positive based on the direction the start date and finish date of the activity deviated from their baseline early dates.

The above discussion is based on one single activity. To generalize the argument, the duration variance is required to be calculated for the entire project’s activities in order to properly understand how the durations of the executed activities

are being implemented in comparison with the baseline estimated durations. The proposed index; the “Mean Difference of Original Durations, MDOD”, measures this variance. The derivation of the calculation equation of this index is as follows:

Equation 5.20 is for single activity. If we sum the actual durations of all activities then the same equation can be developed to become:

$$\sum_{i=1}^N AD_i = \sum_{i=1}^N BOD_i + \sum_{i=1}^N (D_{S_i} - D_{F_i}) \quad \text{Eq. (5.21)}$$

Divide both sides of equation 5.21 by (N) and reorder to get the following:

$$\frac{\sum_{i=1}^N AD_i}{N} = \frac{\sum_{i=1}^N BOD_i}{N} + \frac{\sum_{i=1}^N D_{S_i}}{N} - \frac{\sum_{i=1}^N D_{F_i}}{N} \quad \text{Eq. (5.22)}$$

Substitute equations 5.13 and 5.15 in 5.22

$$\frac{\sum_{i=1}^N AD_i}{N} = \frac{\sum_{i=1}^N BOD_i}{N} + \frac{\sum_{i=1}^N (BES_i - AS_i)}{N} - \frac{\sum_{i=1}^N (BEF_i - AF_i)}{N} \quad \text{Eq. (5.23)}$$

The left hand side of the above equation 5.23 is the “Mean Actual Durations, MAD”. The first term of the right hand side of the same equation represents the “Mean Baseline Durations, MBD” while the second and third terms in the right side of the previous equation are actually the “Start Dates Mean Overall Deviations, MOD_S” and “Finish Date Mean Overall Deviations, MOD_F”, which were detailed above and shown in equations 5.5 and 5.6. By substituting in equation 5.23 and rewrite it to get the final form:

$$MAD = MBD + (MOD_S - MOD_F) \quad \text{Eq. (5.24)}$$

Or

$$MAD = MBD + MDOD \quad \text{Eq. (5.25)}$$

Where:

MDOD – Mean Difference of Original Durations

MAD – Mean Actual Durations

MBD – Mean Baseline Durations

Since the concern is in the mean difference of the original durations then the second term in the last equation, the “MDOD”, could be used alone without calculating the mean baseline durations. This mean difference of the original durations “MDOD” is simply the difference between the mean overall deviations of

the start dates “MOD_S” and the mean overall deviations of the finish dates “MOD_F” as shown in the following equation:

$$MDOD = MOD_S - MOD_F \quad \text{Eq. (5.26)}$$

5.7 Indices Integration and Progress Interpretation

The following is some discussion about how to read the values of the indices of this category and what interpretations can be inferred. Additional study and research for real construction projects should be conducted in order to improve the interpretation process. This thesis does not cover such an effort. However, this section highlights some points of them as follows:

1. IF the value of the Start date Mean Overall Deviation “MOD_S” is more than zero and the value of the “MOD_F” is less than zero, THEN:
 - a. The value of the Mean Difference of Original Duration “MDOD” is more than zero since most of the activities start earlier than their baseline early start dates but complete later than their baseline early finish dates.
 - b. There is a possibility that the estimate of the baseline original durations of the activities are relatively more optimistic than what actually they require; i.e. a problem of wrong estimate.
 - c. There are a higher number of “In-Progress” activities than what the baseline assumes. The consequence of this is that the successive activities are not allowed to start on time; more open work than what is originally scheduled.
2. IF the value of the Start date Mean Overall Deviation “MOD_S” is less than zero and the value of the “MOD_F” is more than zero, THEN:
 - a. The value of the Mean Difference of Original Duration “MDOD” is less than zero since most of the activities have delayed actual start with earlier completion than the baseline dates.
 - b. They Show that the baseline original durations of the activities are estimated higher than what they actually need.
 - c. The above conclusion can be supported by investigating the project overall percentage of completion. If it is satisfactory then it indicates good progress.

3. IF the value of the Start date Mean Overall Deviation “MOD_S” is more than zero and the value of the “MOD_F” is more than zero, or if the value of the Start date Mean Overall Deviation “MOD_S” is less than zero and the value of the “MOD_F” is less than zero, THEN:
 - a. They need to check the value of the Mean Difference of Original Duration “MDOD” and according to its value the conclusion would be as in points 1 and 2 above.

CHAPTER 6

6. CATEGORY 3 – FLOAT CONSUMPTION

6.1 Introduction

The baseline schedule of any project includes interrelated activities that constitute the overall CPM network of that baseline. The logic of the baseline network and the way the different activities are linked together are based on the planned sequence of work. A primary objective of any baseline is to calculate the activities' start dates, finish dates, and total floats and presents them for the project team to properly manage the execution of the project. Theoretically speaking, any activity should start at its early start date and finish at its early finish date. In case that particular activity has a total float more than zero, then the early start can be delayed to any other start date that is less than or equal to its late start date. The same rule applies for the finish date of the activity. Whenever an activity is delayed beyond its late dates, then that particular activity becomes in a critical delay and pushes the original project completion date by an amount equivalent to the difference between the actual dates and the late dates of that activity. Figure 11 shows graphically an example of how an activity could push the project completion date, even if it is originally a non-critical activity.

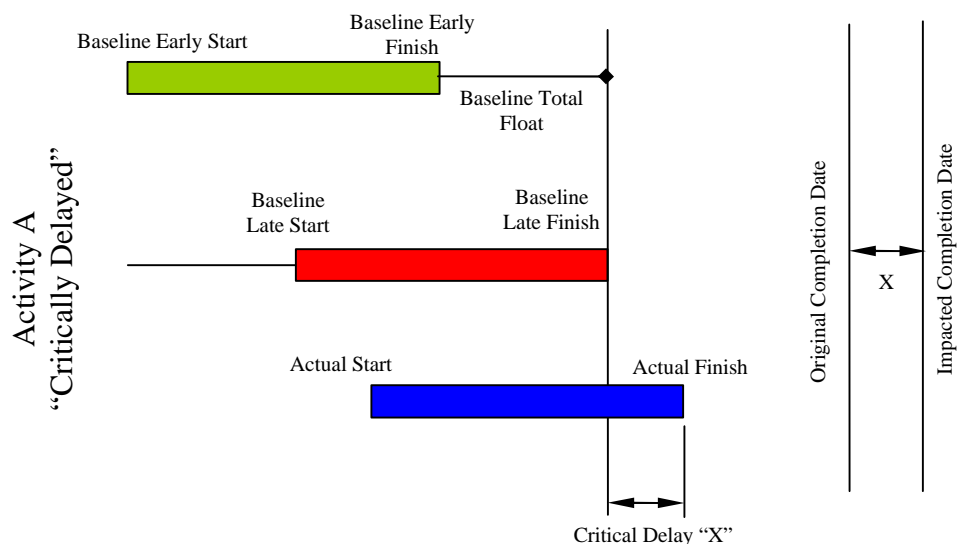


Figure 11. Baseline Start and Finish Dates and the “Critical Delays”

During the execution phase of the project, the actual progress of the work is monitored and recorded to update the baseline program and calculate the impact of the actual progress on the original project completion. Progress update is an important process since it shows how the original plan is being implemented and addresses any deviations from that plan. The project manager benefits from the progress update and takes necessary corrective actions to overcome these deviations or to use it when preparing claims, in case the initiator of the deviations, or the delays, is another party such as the client, the engineer, or another party. The result of the baseline update is another program that shows two categories of information; the first category is the actual work from the beginning of the project till the date of the update, or what is known as the “data date”; and the second category is the anticipated start dates, finish dates, and total floats of the remaining activities as a result of the recorded actual work.

The information of the second category may not be the same as the baseline information for the same remaining activities. In reality, this situation is the most common. Whenever a critical delay in any path in the CPM network occurs, the original project completion date will be impacted accordingly, as detailed above. The non-delayed or less-delayed paths of the CPM network will be shown as having additional total float on their activities. This additional float is not genuine since it comes as a result of that critical delay. The calculated late dates of the remaining activities will be affected by the additional total floats that have come due to the delays of the most critical path of the whole network.

The problem is that this additional float causes confusions to the project participants and most of them are willing to consume it as a real total float for the non-delayed or less-delayed activities and consequently push more activities to become critically delayed. This situation is similar to the chain reaction that starts with one path in a critical delay and then more paths might be pushed to be in critical delays. Moreover, an activity that is shown in the update schedule as non critical i.e. total float more than zero, could actually be in critical delay when it is compared with the baseline dates. This means that the real critical activities in the project with respect to the original baseline are not only those activities with zero total float, as shown in the updated schedule. There might be more critical activities but shown as

non-critical due to the additional total floats that come from the most delayed path in the network.

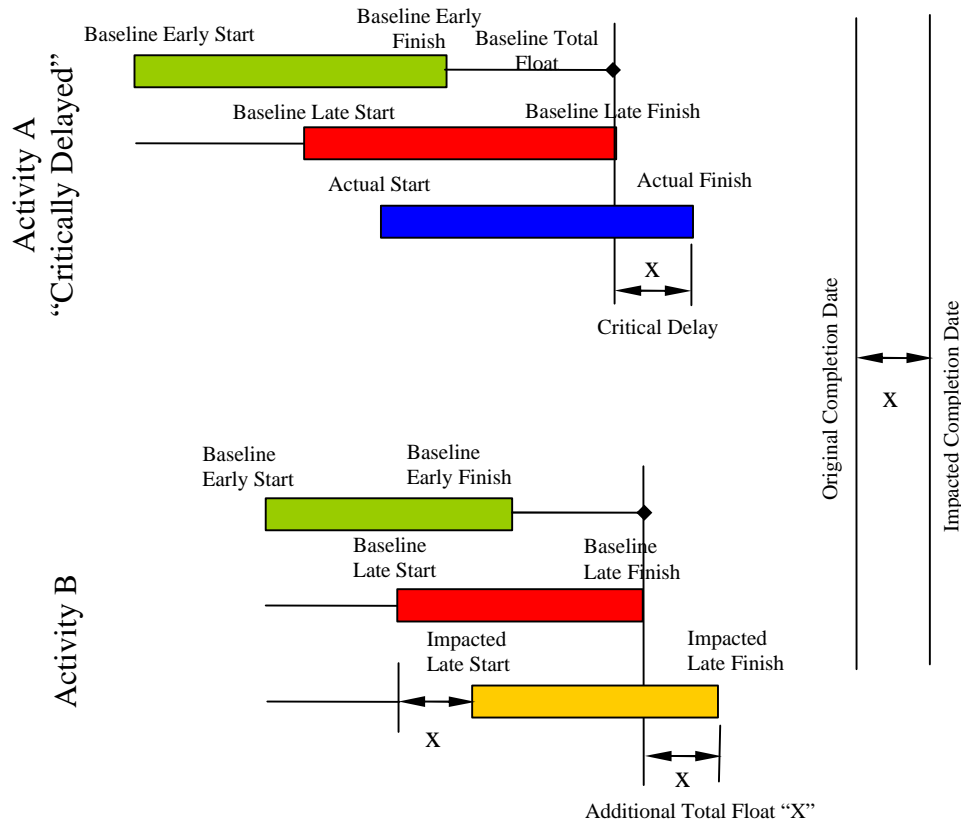


Figure 12. Additional Float Caused by Critical Delays of Other Activities

Figure 12 shows an example for this situation graphically. Activity A in the figure is critically delayed by an amount of “X” days and then the original completion date is pushed by the same “X” days. The impact of this push in the project completion date on activity B is shown as an additional total float of “X” days. If this activity is not delayed, then its late dates will be impacted by the same amount of delay; i.e. “X” days. If activity B is expected to finish on a date that is more than the baseline late finish date and less than the impacted late finish date, then this activity will be shown in the updated programs and the progress reports as non-critical while it is actually in a critical delay of an amount equal to the difference between the anticipated or actual finish date and the baseline late finish date. This information is quite valuable during the project execution because such an activity; i.e. Activity B, still requires certain corrective actions to recover its critical delays even if it is shown

as non-critical in the updated programs. The main impact of this case on the projects is the tendency to push more activities to become critically delayed without providing adequate alarming to the project management team to promptly take corrective actions.

To control this problem and its consequences and to prevent spreading any critical delay in one path over other paths in the network the project manager needs to understand that the resulting additional total floats in the non-delayed or less-delayed paths should not be considered real floats. The project manager may keep monitoring the baseline dates and total floats for all activities and shows them in the regular progress reports so that the relevant parties may take the necessary actions to recover the critical delays of those activities that are shown in the updated schedule as non-critical. However, it is still not guaranteed that all project participants are sufficiently aware of about this issue since it needs clarifications and further elaboration. Furthermore, such a report may not be easily readable and comprehensible. The Float Consumption Index “FCI” is established as a tool that project participants can rely on when reviewing and evaluating the progress without falling under the effect of these fake, and dangerously misleading, additional floats. The index links the updated dates to the baseline dates and prepares an easy to understand evaluation measure. The following section discusses an important concept that has to be introduced before going into detail to discuss the Float Consumption Index “FCI”. This concept is the “Allowed Baseline Float – ABF”.

6.2 Allowed Baseline Float “ABF”

The Allowed Baseline Float “ABF” measures the amount of float an activity has before becoming critically delayed with respect to the baseline schedule. It is the difference between the early start and/or finish dates of an activity as calculated during the regular progress updates and the corresponding baseline late dates. At the beginning of the project and before having any progress, the “ABF” equals the original baseline total float. However, the value of the “ABF” becomes different when the calculated early start and/or finish dates of an activity deviate from their original baseline dates. For example, a delayed activity will have “ABF” value less than the baseline total float while an advanced one will have “ABF” higher. The “ABF” of an activity at any progress update is not necessarily equal to the total float of the same

activity that results from the same update. The “ABF” may have negative values in case the amount of delay of the activity exceeds the baseline total float. The “ABF” subtracts activities’ early dates of the updated schedule from the corresponding activities late dates of the baseline schedule as shown in the equations below. The “ABF” is an important input in the calculation of the Float Consumption Index as will be shown later on. The following equations are used to calculate the values of the “ABF” for each activity at any progress updating:

Allowed Baseline Float for Activities’ Start dates:

$$ABF_S = BLS - UES \quad \text{Eq. (6.1)}$$

Allowed Baseline Float for Activities’ Finish dates:

$$ABF_F = BLF - UEF \quad \text{Eq. (6.2)}$$

Allowed Baseline Float for overall Activities’ dates:

$$ABF = BLF - UES + BOD \quad \text{Eq. (6.3)}$$

Where:

ABF_S – Allowed Baseline Float for an activity’s Start dates

ABF_F – Allowed Baseline Float for an activity’s Start dates

ABF – Allowed Baseline Float for an activity

BLS – Baseline Late Start date of an activity

BLF – Baseline Late Finish date of an activity

UES – Updated or anticipated Early Start date of an activity

UEF – Updated or anticipated Early Finish date of an activity

BOD – Baseline Original Duration of an Activity

Actually, in most cases the “ ABF_S ” and “ ABF_F ” are equal and either one can be used. Only in special cases are there different values for “ ABF_S ” and “ ABF_F ”. When dealing with “In-Progress” activities during the schedule updates the third equation 6.3 requires special treatment because of the existence of the Actual Start date and then the “UES” becomes an actual start. In addition, special consideration shall be taken for the remaining duration that should replace the original duration in the equation. The treatment for this special case has been kept out of the scope of this thesis. That is why the “ABF” will be considered either equal to “ ABF_S ” or “ ABF_F ”. In the following discussion the “ABF” will be used instead of “ ABF_S ” or “ ABF_F ”. It is worth mentioning that at the beginning of any project and before having any

progress the value of “ABF” for each activity equals the value of the baseline total float “BTF” of the same activity.

The “ABF” is a measure of the remaining amount of the total float an activity has before it becomes critically delayed with respect to the working baseline schedule. If an activity has a float in the baseline schedule and this activity starts to suffer from some delays i.e. consuming its baseline total float, then the measure will flag this activity as delayed but not yet in critical delay. By the time this activity consumes its entire baseline total float then it should then be considered critically delayed, even if it is not the most critically delayed activity in the updated schedule. The more this activity is critically delayed, the more it contributes to pushing the project completion date. In other words, if all other critical delays in the project are recovered, then the project completion will remain in delay with an amount equal to the critical delay of the activity under study, or the absolute value of the “ABF” which is negative in this case. The resultant value of the “ABF” will have a negative sign if the activity is in critical delay. If it is in non critical delay then the value will be positive but less than the baseline total float “BTF”. If the activity is ahead of schedule, then the value of “ABF” will be higher than the “BTF” and with positive sign. This information is of high importance for the project management team because whenever a delay recovery is required, all those critically delayed activities with respect to the baseline; i.e. whose “ABF” values are negative, shall be given the highest priority and the resources should be distributed according to these priorities.

6.3 Float Consumption Index - FCI

The Float Consumption Index “FCI” measures the status of each activity with respect to the working baseline schedule and provides a tool to show how they are distributed by classifying them under five different categories; (1) activities that are ahead of schedule, (2) activities that are on-schedule, (3) activities that are behind schedule and at the same time they are consuming their baseline total float without being in critical delays i.e. non-critically delayed, (4) activities that are just critical without pushing the project completion date i.e. having exactly consumed the baseline total float, (5) and activities that are critically delayed and pushing the original project completion date.

The objective of this index is to track the changes that occur on the value of the “ABF” of each activity. As mentioned above, the value of “ABF” at the beginning of any project equals the value of the baseline total float “BTF” for each activity in that project. While the project progresses the “ABF” of the activities may change either by increasing or decreasing. The increase in the value of “ABF” means that the activity is progressing ahead of schedule while the decrease in the value of it means that the activity is consuming its baseline total float until it becomes zero i.e. all the baseline total float has been consumed. Once the “ABF” becomes less than zero, then the activity has become in critical delay by an amount equals to the absolute value of the “ABF”. The Float Consumption Index “FCI” for each activity in the schedule is proposed to be calculated as follows:

If the activity is non-critical in the baseline schedule; i.e. baseline total float $BTF > 0$, then:

$$FCI = \frac{BTF + ABF}{BTF} \quad \text{Eq. 6.4}$$

Or

$$FCI = \frac{ABF}{BTF} + 1.0 \quad \text{Eq. 6.5}$$

In the above equations the value of the baseline total float “BTF” is constant for each activity and the only variable allowed is the baseline float “ABF”. The ratio makes some sort of standardization for the value of “ABF” to convert it from the number of days, which could be any number, to some easily understandable and meaningful ratio. The value of the float consumption index “FCI” for each activity takes one of five cases as detailed below. A classification for the activity’s status under each of the five cases can be achieved and according to each case, the activity status is inferred. The five cases of the expected values of the float consumption index “FCI” are:

1. If the activity is ahead of schedule then “ABF” is higher than “BTF”. Consequently, “FCI” value becomes higher than 2.0.
2. If the activity is non-critical and it is exactly on-schedule during the progress update, then both “ABF” and “BTF” are equal and the value of “FCI” is 2.0.

3. If the activity is behind schedule but not yet in critical delay the “ABF” is less than “BTF” but still in positive value i.e. more than zero, then the “FCI” value will be less than 2.0 and more than 1.0.
4. If the activity has consumed exactly its baseline total float without becoming in critical delay i.e. “ABF”=0, or the activity is critical in the baseline schedule i.e. “BTF”=0, and it is on-schedule during the progress update, then the value of “FCI” is equal 1.0.
5. If the activity has consumed more than its baseline total float, then “ABF” is less than zero and the value of “FCI” is less than 1.0. In this case the activity is in critical delay and contributing to the delays of the project completion. In case the amount of critical delay is similar to the activity’s baseline total float, then the value of “FCI” is equal to zero. When the “FCI” value reaches (-1.0), negative one, then the amount of critical delay has become twice its baseline total float, and so on.

If the activity in the baseline schedule is critical; i.e. “BTF” = 0, the above equation will have division by zero condition. The float consumption index “FCI” can be calculated using only the allowed baseline float “ABF” which equal to zero at the beginning of the project and may have positive or negative value according to the progress. To ensure having consistent values for “FCI” with both critical and non-critical activities an addition of the unity; i.e. 1.0, is then proposed for the calculated value of “ABF” to have a condition similar to case 4 above at the beginning and changes in a similar manner to the other activities. In this case the value of “FCI” for baseline critical activities is calculated as follows:

$$FCI = ABF + 1.0 \quad \text{Eq. 6.6}$$

A graphical representation for the float consumption index “FCI” distribution at any progress update can be plotted to easily interpret the conditions of the project’s activities. The “FCI” values are plotted on the x-axis of the graph and at any point of “FCI” the corresponding number of activities that are having this particular point are plotted on the y-axis. The resulting graph, which has been given the name “FCI Distribution Chart”, shows the distribution and concentration of the activities under each zone of the five cases that are detailed above. Figure 13 shows this graph and the zones that reflect the above five cases. At the beginning of any project its activities

are concentrated in two points on the “FCI” Distribution Chart. All non-critical activities will fall at the point of “FCI=2” or case 2 while the critical activities will fall at the point of “FCI=1” or case 4. As the project progresses, those advanced activities will have “FCI” values higher than 2.0; the non-critically delayed activities will have the values of the float consumption index “FCI” fall between 1.0 and 2.0; critically delayed activities with respect to the working baseline schedule will have “FCI” values less than 1.0; on-schedule activities will remain with “FCI” values of 2.0; and activities of fully consumed total floats will have “FCI” equal to 1.0.

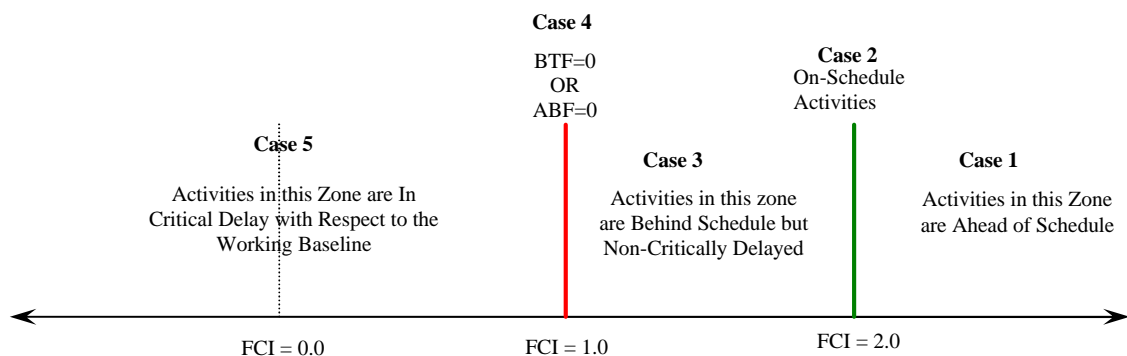


Figure 13. FCI Distribution Chart

Critical activities with respect to the working baseline schedule have a special case of BTF=0, which makes their “FCI” values more sensitive to any deviation i.e. a one day delay for a critical activity in the working baseline has higher impact on the “FCI” than a one day delay of a non-critical activity. Such a delay i.e. one day, for a critical activity changes its “FCI” value from one to zero directly while a similar delay in a non critical activity reduces its “FCI” value from two by an amount less than one but proportional to the amount of its baseline total float “BTF”. In other words, the lower the amount of “BTF”, the larger the change of the baseline float consumption index “FCI” is and vice versa. The result of this fact is that the “FCI” values of critical or close to critical activities will respond faster to any delay and then move toward the left side of the graph at a higher speed than the non critical activities. This is a beneficial result of this index as the project management will have an alarm that is responding to the critical activities in a different way than with non critical; i.e. it prioritizes the delays of different activities based on their criticalities. This enforces taking better corrective actions that correspond to the site conditions.

The activities in the three zones of cases 1, 3, and 5 are distributed in each zone according to the magnitude of their status in days. The scale of the graph can be adjusted according to the conditions of the schedule by dividing each zone into intervals. For example, the activities that fall between 1.0 and 2.0 can be grouped in intervals of 0.1, 0.2, 0.25, etc. according to the required level of details. The number of the activities in each interval could be represented by a histogram or curve.

6.4 Discussion on the Outcomes of FCI and its graph

1. “FCI” is a very useful tool to show how the delays are distributed and concentrated. The importance of this is that different delays should have different treatment and consideration. When the majority of delays are critical and in the fifth zone; i.e. “FCI” < 1.0 , then the management response and involvement should be different than if the majority of delays for the same project are in other zones, say zone 3 between 1.0 and 2.0, even if the longest path reading shows the same completion date or the same amount of delay for the whole project in the two scenarios. The more the delays are concentrated in zone 5, the more significance of the situation.
2. The proposed baseline float consumption index “FCI” provides a tool to prioritize delays of different activities based on their baseline criticality. A critical activity shows a significance of one day delay much higher than another non-critical activity. This means that the critical activities, and those close to critical, will move toward the left hand side of the “FCI” graph much faster than other non-critical activities and this reinforces taking necessary corrective actions depending on the criticality of the delayed activities. Note that in most of the situations many activities could be in delays, but only one longest path is shown in the progress updates, in which a deficiency is expected, in taking the necessary corrective actions to recover any delays. However, the proposed index overcomes this deficiency.
3. Whenever a delay recovery is required, then the emphasis should be given to those activities that have “FCI” values less than 1.0, even if they are shown as non-critical in the progress update. The understanding of this fact and the use of the information given by this index will allow the project manager to properly plan the delay recovery process. The recovery should do the necessary actions

to bring back those activities with “FCI” values < 1.0 to become in non-critical delay; i.e. “FCI” values > 1.0 .

4. Resource management can benefit from this index since the resource distribution will focus not only on the critical activities of the latest progress update schedule but on those critically delayed activities of zone 5 as well. Accordingly, resource management will have a better chance of being more efficient in achieving the objectives of any recovery by focusing on the correct activities.

CHAPTER 7

7. OTHER CATEGORIES – BRIEF DISCUSSION

7.1 Introduction

This chapter covers another three categories of progress diagnosis indices that are discussed with less focus on the details of the derivations and the integration. These categories are: the Resources Variances, the Progress Percentages, and the Cycles Status. The following is the discussion for each of them.

7.2 Resources Variances Category

The indices of this category deal with the level of resources during the execution phase and the recorded trend of the resource loadings to the project. A proper understanding of the level and trend of actual resource loadings and the comparison with the planned ones would highly benefit the project management teams in determining how the resources affect the progress status. It is common sense that the resources highly affect the progress. However, the progress could be governed in some cases by other factors. Therefore the study of the resources should not be excluded as they are one of the major factors that might have an effect on the recorded current progress status.

In many cases the resources are monitored by comparing the actual resource levels with the planned ones. This might not be sufficient to provide a clear picture of how the resources might affect the current progress. What could be available now might be not sufficient to meet the actual progress requirements even if the planned resource levels were estimated to be less than the currently available resources. The reasons could be: the estimated levels are less than what the actual production needs, which means that a mistake has been made in the original estimation; a delay has been recorded and then the recovery of this delay needs additional resources; the current resource levels are shown sufficient but a deficiency occurred at a previous period which necessitated additional resources to cover this deficiency even if it did not cause critical delay; the contractor has a fluctuating resource loading pattern which significantly affected the progress; or any other reason. The study of the resources needs to investigate all these issues and make them clear to the concerned personnel in any construction project. It is proposed that three main measures be calculated,

which are statistical-oriented measures, to infer more accurate progress interpretations. These proposed indices are:

7.2.1 The Accumulated Total Resource Hours

This index measures the actual accumulated total resource hours, or resource days, that are recorded from the project start date to the current progress update date, or what is known in the construction industry as the “Data Date”, and compare them with the planned accumulated total resource hours, or days, for the same period span. The importance of this index is that it clarifies what amount of total resources has been loaded to the project from its start to the current data date. It is only one part of the information to know whether the current actual resource level is higher or lower than the current planned resource level. Any construction project has a budget of the resources that should be spent in the project in order to complete it on time. Consequently, using only the current status of resource levels to compare between the actual and planned as an indication of the contractor’s resource availability is not a clear index. Therefore, the previous periods shall be included in any comparison of the resources to understand the contractor’s commitment to the required budgeted resources. The calculation equation for this index is quite simple as follows:

The Planned Accumulated Total Resources “PATR” is:

$$PATR = \sum_{i=1}^t PPR_i \quad \text{Eq. 7.1}$$

And the Actual Accumulated Total Resources “AATR” is

$$AATR = \sum_{i=1}^t APR_i \quad \text{Eq. 7.2}$$

Where:

PPR – Planned Periodical Resource level at time (*i*)

APR – Actual Periodical Resource level at time (*i*)

t – Total time periods passed from the project start date to the data date

Then a comparison between the “PPRT” and “PATR” should be carried out to investigate which one is higher and then how the project is loaded by its original budgeted resources.

7.2.2 The Average Resource Hours

The average resource, which is the periodical average of the resources levels for both the planned and the actual resources, should be calculated. This periodical average could be the daily, weekly or even the monthly if the project conditions dictate. Its calculation formula is simply the accumulated total resources divided by the number of periods passed from the project start to the data date.

The Planned Average Resources “PAR” is:

$$PAR = \frac{\sum_{i=1}^t PPR_i}{t} \quad \text{Eq. 7.3}$$

And the Actual Average Resources “AAR” is

$$AAR = \frac{\sum_{i=1}^t APR_i}{t} \quad \text{Eq. 7.4}$$

The importance of these indices is for the calculation of the next index of resources since it will be used as the datum for the calculations.

7.2.3 Fluctuation from Average

The amount of fluctuations in the resource loading in any construction project is important information that would allow better understanding of the resource loading in the project. This index calculates the sum of absolute differences between the periodical resource levels and the average resources for both the actual and planned resources and compare between them. At the planning phase each activity is loaded by its estimated required, or budgeted, resources. The project overall periodical resource requirements are then calculated. These planned resources are normally not constant from one period to another. They build up gradually until reaching a peak and then reduce. The build up of the actual resources is not necessarily the same as originally planned. Therefore, the comparison would help a lot in knowing the pattern of differences. The actual resources may have slower build up than the planned, or something else. If the actual accumulated total resource hours are equal or higher than the planned, then the average would be equal or higher than the planned average as well. However, if the actual resource loading has followed a slower build up than the planned, then the fluctuations from the actual average would be higher than that of the planned resources from their average planned. This is

because such a situation occurs when the resource loading at the beginning was slower than the planned while it increased rapidly later on in a higher rate than the planned until the actual accumulated total became equal or higher than the planned. Such a situation results in higher deviations of the periodical resource loading from the actual average. The comparison between the planned and the actual build up indicates how the resources are fluctuating from the average and then the consequences can be evaluated to know whether the actual resources are fluctuating more or less than the planned. The calculation formula for this index is as follows:

The Planned resource Fluctuation from Average “PRFA” is:

$$PRFA = \frac{\sum_{i=1}^t |PPR_i - PAR|}{t} \quad \text{Eq. 7.5}$$

And the Actual resource Fluctuation from Average “ARFA” is

$$ARFA = \frac{\sum_{i=1}^t |APR_i - AAR|}{t} \quad \text{Eq. 7.6}$$

If the value of the actual resource fluctuation “ARFA” is higher than the planned “PRFA” for the period from the project start to the current data date period then this can be considered an indication that the actual resource loading is more fluctuating than the planned. This could be integrated with the readings of other indices from a progress update period to another in order to investigate the impact of resource loadings on the progress.

The more actual resources are fluctuating than the planned, the more deviations in the activities are expected, which in turns means that the schedule commitment is lower than what it should be. The concentration on the baseline critical activities indicates a possibility of resource shortages. By reading the resources indices and conducting a comparison, it can be concluded whether the main contractor has, or had, a resource shortage problems or not, and if so, then what are the precise implications of these problems?. If the deviations from the baseline early dates started before the resource fluctuation, then the conclusion is that the resource fluctuation was a result of some other problems that affected the commitment to the baseline schedule. These conclusions are actually very important for any evaluation of the progress status. It gives a real diagnosis of the progress.

7.3 Cycles Status Category

This category evaluates the status of the different cycles of the project if it includes repeated cycles like the multistoried building construction where the repeated typical floors are repeated cycles. The analysis of the cycles is done on the basis that the cycle itself is considered a separate unit or module. There should be a differentiation between the criticality of a delay and the significance of that delay. The criticality is something that is related to the possibility of delaying the projects' completion dates while, on the other hand, the significance of the delay is the possible unfavorable implications that would result from this delay. If a critical delay occurs at the lower floors of a multistory building, for example, then it is considered critical because it affects the project completion date; i.e. critical delay. Furthermore, it is significant because such a delay would impact large number of activities due to its location at the beginning of the CPM network, which means that it is a predecessor for larger number of activities than those located at the end of the critical path. The amount of delayed work should be considered when evaluating the delay significance in any progress diagnosis. Based on the same argument, a critical delay at the last repeated cycles of the network might be critical but not necessarily significant. If the project consists of typical repeated cycles then any progress diagnosis for that project should address the delays in the repeated cycles and where this delay occurs in order to investigate the significance of the delay for that cycle, as well as its amount.

7.4 Progress Percentages Category

This category just talks about the widely known progress overall percentages that are normally calculated based on the activities durations, the activities budgeted costs, and the activities budget resources. The earned value is the technique that considers the budgeted costs of the activities and compares them with other costs as is mentioned earlier.

During the discussions of some indices in the thesis these percentages were considered in the evaluation of the results of those indices and the interpretation of the progress based on the integration between them and some project completion percentages. It is not part of this research to go in details in the discussions of these well known percentages because they were covered in a lot of previous researches as discussed in chapter 2; i.e. "Literature Review", of this thesis.

CHAPTER 8

8. CONCLUSION

This research has demonstrated that there is potential for great improvements in progress control concepts and techniques. This process is currently carried out by investigating two main measures. The first one is the status of the critical path which shows the calculated project completion date, or the impacted completion date. The second measure is based on the calculations of percentages such as, the overall percentage of completion of time, cost, or resources. The concept of Earned Value technique is based on the use and comparison of several percentages to conclude the overall progress status of the project. The earned value is more oriented toward the internal use rather than the external use because it requires actual data and budgets for the costs which are considered commercially and operationally confidential data. Therefore, the contractors may not accept to release this information. Consequently, the available techniques are not sufficiently adequate to ensure that all parties are able to have sufficient understanding of the actual progress.

The research discussed the complications of the present construction industry which include increased projects complexity, fast track projects, several project participants and stakeholders who belong to different parties, increased disputes between the different project parties, the high level of uncertainty of the construction industry as a characteristic of this industry, etc. Accordingly, the research showed that the construction industry currently requires more advanced techniques and tools to assess the progress status in order to minimize the increased associated disputes and complications. The need to improve in this field has become a necessity for the construction industry to ensure having reliable techniques that are accepted and easily used by all different parties of the project. The current research did not cover any practical case studies as this is not in its original scope. Such an effort requires separate studies to be conducted. This research introduces a new concept of “Progress Diagnosis” and proposed a technique named “Omar’s Diagnostic Technique” that uses several indices to diagnose the progress status. The necessary discussions and derivations of the indices have been conducted as well.

The newly introduced indices can accurately diagnose the progress status and so achieve better interpretations of the different progress reading that normally result

from any periodical progress update. The indices have been classified into several categories that cover in details the criticality, schedule commitment, and baseline float consumption. In addition, other categories have been discussed briefly. The detailed discussion showed the definitions, the derivations of the equations, the use and interpretations of the resulted values, and how an index is related to other indices where this relation may increase the efficiency of the progress interpretation by integrating the reading of several indices.

The research showed that the adoption of the proposed indices will assist in providing valuable information which allows for better progress interpretations. The term “diagnosis” has been given to this technique to describe its ability to show very detailed information about how the progress is being achieved and what the real hindrances to progress are. The research illustrated how it is not an easy task to achieve a real “Progress Diagnosis” by relying on the currently available progress evaluation techniques as they lack the provision of such details. The proposed indices, on the other hand, can provide such details clearly. Furthermore, they can be relatively easily calculated.

The details that can be provided by the indices of the proposed technique include, as an example, the significance of those activities that have deviated beyond their baseline late dates because their baseline total floats have been consumed and what this means. In addition, the meaning of the two types of delays; i.e. local and global, when and why they occur; what indices indicate for each of them; and what the significance of such an indication is. Moreover, the commitment of the work on the site to the sequence and dates of the baseline schedule; how the deviations from the baseline affect the level of commitment; when the deviations are considered an indication of the lack of commitment; the assessment whether the actual progress is running out-of-sequence or not; what the different types of deviations are and which are favorable and which are unfavorable; the overall project criticality at the time of schedule update; what different indices can be used to provide indications on that overall criticality; where the progress is more concentrated e.g. giving more priority to only the critical activities or only the non-critical activities, or to other.

Some recommendations need to be emphasized herein, including the need to ensure establishing a well studied baseline schedule that covers the entire scope of the work with a practical workable detailed breakdown. The monitoring process is vital

for reliable progress control. The progress update of the schedule should be carried out at regular periods to enable better tracking for the progress and its trend. The indices of the proposed technique could not be calculated manually, from a practical point of view, and they need to be included in some computerized calculation tools. The better understanding of the meaning of the proposed indices by the industry professionals will ensure taking more efficient decisions at the different levels, including top management level. These indices could not be considered efficient for use with projects that have numerous changes to their original scope by additions and omissions due to client's changing orders. The reason is that the baseline schedule will change more frequently and then the comparison will not be efficient.

The direct implementation of the proposed progress diagnosis technique may suffer from some limitations if the baseline schedule has logical or technical errors. These errors could affect the ability of the working schedule to provide satisfactory calculations for the actual progress. If such errors exist in the working schedule then they should be corrected.

Future research efforts could be done to improve the interpretations of the different value levels of the progress diagnosis indices and the integrations between them. Practical case studies are highly recommended since the next step of introducing a new concept is to apply it in the practical life and then fine tune its results according to the outcomes of the cases. The case studies might be carried out to investigate all indices together for certain projects or to selectively investigate some indices. The type of project may have an impact in adjusting the interpretation of the values of some indices. The interpretations that have been shown in the current research are based on the logical and technical discussions of each of them based on the engineering reasoning and understanding of the different indices. However, practical case studies would improve this and may suggest additional interpretations.

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VITA

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Directly after graduation, Mr. Mourad worked as a “Teaching and Research Assistant” for three years at Al Ain University, in the Civil Engineering Department. During his work at the University, he published two papers in the field of knowledge based expert systems for the preliminary design of high rise buildings. In 1996, Mr. Mourad moved to work as a planning engineer in a construction company engineering contracting company “ECC”, in Dubai, UAE; and three years later he was appointed as the head of the newly established “Planning and Quality” department in the same company. During his work with ECC, Mr. Mourad planned, developed schedules, and monitored more than 40 projects of different sizes and types, e.g. residential and commercial buildings, parks and leisure projects, industrial projects, etc. The overall cost of these projects exceeds AED 2,750/- millions. Mr. Mourad was also involved in many delay analysis, claims preparations and discussions, performance assessment and enhancement studies, corrective and preventive actions, etc. In 2003, Mr. Mourad began his master of science in Engineering Systems Management program at the American University of Sharjah. He is expected to earn a Master of Science in Engineering Systems Management in June 2006 with GPA 4.00/4.00.

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