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PRODUCTIVITY ASSESSMENT AND SCHEDULE COMPRESSION INDEX (PASCI) FOR PROJECT PLANNING

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Abstract. *Planning and scheduling of construction projects are very much affected by its resource productivity and influenced by various other factors. An increase in construction time and cost is usually related to inefficiency or low productivity, which can be reduced by employing effective planning and monitoring. Schedule compression or work acceleration whether it is planned or unplanned, is normally required to recover projects from delay and inefficient works. It is not easy to perform schedule compression for people who do not have good knowledge and experience on construction processes. The situation can become very difficult and discouraging for many small contractors, especially during economic downturns. There is a need for a simple way to assess productivity and apply schedule compression by using simplified tools such as an index. This paper discusses an on-going research, which objective is to produce a project assessment tool called the Productivity Assessment and Schedule Compression Index (PASCI). This index utilizes a combination of weighted scores from key elements that affect labour productivity and schedule compression methods. It predicts the capability of completing a construction project by comparing the index score to its given contract period at a certain stage of a project. Using the index as a guide, further actions can be taken by contractors and clients, which could produce savings in terms of time and cost.*

1. Introduction

Previous researchers on project management have often measured the effect that specific inputs have on project success. However, the concept of project success is often complicated and there is no clear method as to how it should be measured. Research into project management frequently involves a comparison of two elements: an input or independent variable and an outcome or dependent variable [1].

The usual research objective is to measure the effect that changes in the independent variable have on the dependent variable. Examples of independent variables that have been used for project management research in the past include project manager experience, level of communication, level of pre-project planning effort, and project team integration [1]. The outcome or dependent variable often used in this type of research is project success.

Obviously, researchers want to identify the effect that different inputs have on the ultimate success of projects. A greater deal of effort is normally expended on developing accurate measurements of the input variable, but the measurement of the output is often based on a far less developed ground. In actuality, project success is a very complex concept that actually changes over time and may be drastically different for different project. Despite the complexities involved, project management researchers and practitioners are in need of a method of measuring project success based on factual project data that enables the results from different projects to be compared and used as forecasting or estimating tool for future projects. There is also the same concern in the Malaysian construction industry.

This is an on-going research project investigating project planning, which used the results of questionnaire surveys (mail and electronic) from several Malaysian general building projects, discussions and interviews with experienced project team members to develop an assessment index that is based strictly on quantified subjective project productivity measurements. This paper presents the development of this index along with some findings regarding the input and output variables.

2. Background

From review of literature, it was found that project success has been the focus of many published articles. For the most part, the reviewed articles have divided project success into two conceptual areas: success factors and success criteria. Success factors are those factors, procedures, preconditions, and determinants that effect project outcomes, and success criteria are the standards on which a judgment or decision regarding project success are based [2].

2.1. Project Success

A successful construction project is typically defined as a project that finishes according to planned schedule, within the allocated budget and meets the client specifications and needs [3]. There are many articles regarding project success that focus on the area of success factors [1]. Various authors have developed lists of issues, practices, or factors that either positively or negatively affect project outcomes. These factors were identified by using various methods, such as formally structured research investigations at one extreme, to simply drawing on extensive years of work experience at the other. There are not as many articles, however, identified in the literature review that addressed the concept of success criteria.

3. Research

3.1. Project Planning

The construction industry is well known for its traditional characteristics. It is well known for its fragmentation, complexity and uniqueness, which make it quite difficult to plan, monitor and control [3]. The environment is open and dynamic, instead of close and repetitive like it is in the operational or manufacturing industry. It is considered as a vital industry in Malaysia as many other industries are dependent on the performance of this industry [4]. There is still opportunity for improvement if problems associated with the industry are properly identified and monitored [5].

According to Wang [6], amongst the weaknesses of the construction industry in Malaysia are poor records, lack of systematic education, skill training, recognition, teamwork, sense of belonging to the industry, financiers confidence, in-depth study before implementation of projects and also the difference in attitude of various parties. In order to ensure that improvement could be made, these weaknesses should be seriously considered and analyzed. One way to start this is by identifying the main elements that can influence the development of the construction industry and its performance. The main elements normally considered are labour, materials, equipment, finance, contractors capability, teamwork, practices, traditions, education, training, research, prevailing social, political and economic conditions, among others.

Problems related to the elements mentioned above have to be analyzed before any measures can be taken. Every participants of the construction industry must play its role to ensure that solutions to the problems are total. Research and development activities, especially in the area of management are very important in assisting to solve those problems. However, according to IRPA report for Seventh Malaysia Plan [7], majority of the research and development activities did not concentrate on construction management field but more towards design and performance of building materials. This pattern has to change since many problems in the construction industry are related to construction management. Therefore, to ensure future growth of the construction industry, it is recommended that research and development activities should also include construction management field.

Construction project planning has a significant impact on the ability of construction companies to achieve success in the implementation of construction projects [8], [9], [10]. The difficulties faced in planning, monitoring and controlling construction projects are contributed by many factors, varying from management, resources and environment, to the nature of the work itself. These factors must be identified and understood before any effective action can really be taken. The way the project is progressing is considered very much related to its level of productivity. This is because construction projects are usually resource-driven, which rate of progress is mainly determined by the productivity and utilization of resources. All of these must be taken into account during planning and construction stages if a project has to go well [11], [12].

The research domain for this investigation was limited to general construction projects and the basic hypothesis was as follows: The successful completion of a general construction project can be predicted by the correlation between the level of factors affecting productivity, the selection and the level of effort expended during the schedule compression phase of the project. For the purposes of the study, project productivity and schedule compression methods were defined in the following subsections.

3.1.1. Project Productivity

Low level of productivity output has been the reason of many project delays in construction [13]. Productivity is difficult to measure, but is frequently discussed by many parties because productivity improvement translates directly to labour cost savings [14]. Thus, measuring and monitoring productivity are essential steps to managing and improving productivity.

Productivity is usually defined as the unit rate of performing a specific task in a construction process, or as total productivity if the unit rate was obtained after the completion of the whole process [15]. In order to get the productivity of certain tasks, productivity measurement has to be performed on individual activities, but to get the total productivity, the outcome of the whole process must be taken into account. Some of the techniques commonly used in the construction industry are [16], [17], [18]:

- Time study.
- Activity sampling.
- Synthesis.
- Analytical estimating.
- Comparative estimating.
- Index measurement.

In this study, productivity is defined as the capability of achieving the time target or ability to complete a project on the contract due date. Low productivity means low capability of finishing on time and high possibility of facing delays. In order to get back on track or on schedule, certain action must be taken to accelerate work and compress the work schedule. The degree of schedule recovery can be assessed by the effectiveness of methods of schedule compression being implemented. The whole process adopts some previous techniques, before coming up with the assessment index.

3.1.2. Schedule Compression Methods

Schedule compression was defined as '*a reduction from the normal experienced time or optimal time typical for the type and size project being planned within a given set of circumstances*' [14]. Schedule compression can be thought of as the shortening, squeezing or compaction of the project schedule. "Planned" schedule compression is the one that was anticipated and planned for before the start of a construction phase of a project. On the other hand, "unplanned" schedule compression is the one that was not anticipated and planned for before the start of construction. Unplanned schedule compression is commonly a result of some form of unanticipated events or problems that change the original planned scope of the work or construction schedule.

The common primary reasons for compressing or accelerating the schedule of a construction project can be attributed to the following reasons [19]:

1. Monetary considerations (i.e. project financing, lost of production during construction, or stockholder pressure).
2. Development of a new product or service by the client's organization that needs to go into the market as soon as possible (due to rising loss-of-opportunity costs).
3. Planning and design phases of the project delivery cycle have fallen behind the required schedule, forcing the construction phase to make up the lost time.

In other words, a project will easily require schedule compression whenever it has fallen behind schedule and does not have a chance to recover the lost time (i.e. being denied an extension-of-time).

However, the effects or results produced by different methods or techniques are found different [20]. Some of the techniques will produce shorter schedule time and others will simply prevent needless loss of time. It must also be strongly emphasized at the outset that the various techniques will not necessarily save time at the same or reduced cost. There are many instances that it will be a time-cost trade-off. It must be emphasized that the applicability of each method depends on the situation and plenty methods are available as possibilities for consideration by an open-minded project manager.

3.2. Research Effort

The Malaysian construction industry (building projects) is in need of a simple and user-friendly tool that can assist clients and contractors in maximizing the chance of seeking project success. This can be done by performing productivity assessment and schedule compression effectiveness study, which will help to forecast the probability that certain construction activity will finish on time by focusing on productivity problems and the capability of compressing the project schedule.

Early planning is typically not conducted very well in building projects because of the complexity and extra costs that almost always associate with it. A quantitative assessment for pre-project planning and during construction can be very helpful and is not readily available, especially the one that is simple but relatively reliable.

This research should significantly enhance the project environment by improving predictability of labour productivity and the capability of compressing the schedule in the events of delay or work acceleration. Although there are many research and models being used to analyze project-planning efforts, there is still not a publicly applicable tool for determining the adequacy of preparation in terms of productivity and construction methods, let alone one that is locally customized for Malaysian building projects.

The study is focused on developing a productivity assessment and schedule compression index (PASCI) for general building projects in public and private sectors. The findings from this research will be applicable to the following facilities construction:

- Offices
- Banks
- Hospitals
- Schools
- Hotels
- Light Factories
- Mosques
- Sports club
- Transportation Terminals
- Apartments

The projects being studied must be completed within 2 years of this study. PASCI for general building projects cannot be applied to infrastructure projects since infrastructure projects involve different scope and thus should remain as a possible subsequent research topic.

4. Development Of PASCI

Initial development work on the PASCI began in June 2000, which effort included input and review from approximately 30 industry experts, as well as extensive use of literature sources for identifying the appropriate scope, terminology and key element definition. The complete list of the sections and categories is given in Table 1. There are two parts involved; Part 1 contains "Factors Affecting Productivity" (FAP) and Part 2 contains "Schedule Compression Methods" (SCM). There are 77 elements in Part 1 and 28 elements in Part 2, which are arranged in a score-sheet format. Due to limitations of space, the entire list of detailed element descriptions is not included in this paper.

4.1. PASCI Element Weighting

It is understandable that the elements stated above were not equally important with respect to their potential impact on overall project duration or completion. Therefore, the elements would need to be weighted relative to each other to enhance their usefulness as an assessment tool. The method chosen to develop reasonable and credible weights for the elements was to rely on the expertise of construction industry practitioners.

Table 1 PASCI Parts and Categories

PART 1: FACTORS AFFECTING PRODUCTIVITY
FAP-O: Client Related Factors
FAP-A: Consultant Related Factors
FAP-B: Contractor Related Factors
FAP-C: Materials Related Factors
FAP-D: Labour Related Factors
FAP-E: Tools & Equipment Related Factors
FAP-F: Contractual Related Factors
FAP-G: External Factors
PART 2: SCHEDULE COMPRESSION METHODS
SCM-A: Labour Related Factors
SCM-B: Materials Related Factors
SCM-C: Construction Methods Related Factors
SCM-D: Tools & Equipment Related Factors
SCM-E: Organization Related Factors
SCM-F: Information Related Factors

The weighting sheet was developed based on literature review, direct feedback from the industry's experts, and also from mail questionnaires. The method used for developing Project Definition and Rating Index for building projects [21] was chosen to be adapted to form the weighting sheet. From July 2001 to October 2002, one weighting workshop, several interviews and discussions were held for this purpose. The efforts involved a total of about 30 experienced contractors, consultants, clients, academicians, engineers and project managers to help evaluate and weight the elements. The weighting development was an inductive process in nature that incorporated expert input into developing final weights. The workshop concluded with critiques of the scoring methodology and the tool itself. These comments were subsequently evaluated and several minor corrections were made to the score-sheet, instructions for use, and element descriptions. Any unnecessary element was eliminated during this process. The resulting weighted score-sheet was re-analyzed using box-plots to identify extremes and outliers, which were far different from the overall sample.

An example of the weighting sheet is shown in Figure 1. Experts were asked to share their experience on how much each factor that affect productivity compiled from literatures and experience would influence the completion time of a project. They were also asked to identify the schedule compression methods that would be effective in compressing schedule when delay is imminent. The minimum and maximum values of both criteria were collected. The extremes and outliers were identified and thrown away to preserve the precision of the data. Using the means of the minimum and maximum values, the values were converted to values with a maximum of 1000 points. The values in between the two extremes were then interpolated equally. An example of the final score-sheet is shown in Figure 2 and 3.

FAP-B	Contractor Related Factors	N/A	Effect on Time (%)				
			Min	Low	Med	High	Max
1	Selection of Subcontractors		5				16
2	Overcrowded Work Area		2				13
3	Level of Supervision		5				16

Fig. 1 An Example of A Weighting Sheet

Q I: How Much Do These Factors Affect Work Productivity in this project? (*Please tick*)							
FAP-O	Client Related Factors	N/A	Level of Effect (1 = Minimum)				
			1	2	3	4	5
1	Approval of Drawings						
2	Long Waiting Time when requiring Test or Inspection						
3	Payment of Completed Work						

Fig. 2 An Example of An Empty Score-Sheet

PART I: Factors Affecting Productivity							
FAP-O	Client Related Factors	N/A	Effect on Time (%)				
			Min	Low	Med	High	Max
1	Approval of Drawings		1	4	7	9	12
2	Long Waiting Time when requiring Test or Inspection		1	4	7	10	13
3	Payment of Completed Work		1	4	7	10	13

Fig. 3 An Example of A Weighted Score-Sheet

The score-sheet was then used to evaluate the level of FAP and SCM at a point in time. Each of the element in Part 1 and 2 was subjectively evaluated by any key project member during pre-project planning or during project construction. This was done based on its level of effect on the subject of the element. For example, in Part 1, the level of effect in interfering or slowing down construction progress is measured. In Part 2, the level of implementations of various schedule compression methods is assessed.

The six levels of definition are listed across the top of the score sheet, creating a matrix with the 105 elements. These six definition levels, including one level for not applicable, ranged from minimum impact or implementation to maximum impact or implementation. By adding up the individual element evaluations and their corresponding weights, a total score for each part, which can range from 78 to 1000 for Part 1 and 0 to 1000 for Part 2 can be obtained. The lower the total score in Part 1, the lower the level of problems affecting project progress. Higher weight in any element in Part 2 signifies that the element was implemented at higher level or being used frequently in the project.

5. Analyses

5.1. Analyzing the Weighted Score-sheets

The two parts and their categories were sorted in hierarchical order of importance as shown in Table 2. The weight column corresponds to a summation of all level 5 values for that category or section. In other words, if all elements in that section or category were at their maximum, these would be the scores. Human related factors, which are represented in Part 1, FAP-O, FAP-A and FAP-B, comprise 611 points or approximately 61% of a potential 1000 points, as identified by the experts. This indicates the significance of having a very good commitment from the clients, consultants and contractors. Client's input and active participation is critical as stakeholders during the planning stage of a project. However, the impact from contractor would be higher since the contractor is the party that has direct and physical input to the project. Organization related factors receiving 394 of the 1000 points, contained the most number of methods for reducing project duration. A list of highest weighted elements in descending order is shown in Table 3.

The highest weighted FAP elements are related to contractors. The highest weighted SCM elements are those methods believed to be effective in accelerating work or reducing project duration. This means, if a project schedule needs to be compressed, the priority should be given to the implementation of these high weighted elements. This is especially important during those trouble times, since there would not be enough time to really analyze the effectiveness of certain methods. Therefore, at least those elements defined in Table 3 should be given the priority.

Table 2 PASCI Category Weights

Part 1 – Factors Affecting Productivity		Part 2 – Schedule Compression Methods	
Category	Weight	Category	Weight
FAP-B: Contractor	239	SCM-E: Organization	394
FAP-O: Client	190	SCM-A: Labour	194
FAP-A: Consultant	182	SCM-C: Construction Methods	162
FAP-D: Labour	106	SCM-B: Material	159
FAP-G: External	97	SCM-D: Equipment And Tools	60
FAP-E: Tools & Equipment	68	SCM-F: Information	31
FAP-F: Contractual	64		
FAP-C: Materials	54		

6. PASCI Validation

Although the weights obtained for PASCI elements were based on professional expertise, the tool needed to be tested on actual projects to verify its capabilities and usefulness. In order to establish an unbiased and reliable validation data sample from an analytical and statistical standpoint, a number of both successful and unsuccessful projects were used for the validation. The primary goal of the validation process was to correlate the scores with projects outcome, in terms of finishing the project within the given contract period.

Table 3 Highest Weighted PASCI Elements

Part 1 – Factors Affecting Productivity		Part 2 – Schedule Compression Methods	
Element	Weight	Element	Weight
FAP-B: Complexity of Construction	17	SCM-C: Look for Process Shortcuts	45
FAP-B: Scheduling	16	SCM-C: Use Modular/Pre-Assembled Components	45
		SCM-E: Provide Employees with Incentives	45
		SCM-E: Staff Project with Most Efficient Crews	45

Mail, electronic survey and industrial visit were used to collect quantitative and historical project data as well as any critique regarding the practicality of the developed score-sheet. The data were used to build profiles of the samples and to assess the projects with regard to their schedule performance. The index was tested on a total of 64 completed projects varying in size. The sample was a nonrandom sample from organizations in the state of Johor, Selangor, Federal Territory, Perak, Kedah, Penang, Kelantan and Trengganu. These projects represented the general building construction, which types are shown in Table 4.

Table 4 Types of Validation Projects

Types of Project	Number of Projects
Office	18
School	12
Shop-house	9
Residential	7
Other	19

Using empty score-sheets, the respondents were asked to rate how severe their project were affected with regard to productivity and their action in selecting appropriate methods to recover from possible delay. The use of empty score-sheets would minimize the tendency of being influenced by element weights during the evaluation process. Respondents indicated their choice for each element by placing a check mark in the box corresponding to the appropriate level. When the questionnaire was returned, the check marks were converted to their appropriate scores.

The FAP scores for the sample projects ranged from 110 to 717 (from a possible range of 78 to 1,000) with a mean value of 392 and a median of 333. The SCM scores ranged from 0 to 796 with a mean value of 313 and a median of 343. The survey questionnaire also captured detailed project information such as schedule (SV) and cost variance (CV). SV varies from –1 to +58 weeks with a mean of +9.6 weeks and a median of 5 weeks (with a mean contract duration of 26 working weeks and a median of 24 working weeks). The project cost ranged from RM 400,000 to RM 235 millions. However, it was very unfortunate that the details of the project cost were mostly unavailable, since they were considered “private and confidential” by most participants. When CV was considered, the total number of projects schedule and cost data available dropped down to only 24. Therefore, the CV was not used for discussion in this paper.

Even though the data used in the study were collected by relying on the respondent’s subjective intuitions and recollections, which could be biased, the level of industry input in developing the index and the number of the sample size are considered adequate to justify the results and to provide an initial tool for project assessment, pending further study in the future.

6.1. Regressions

SV from the validation questionnaire was converted to appropriate schedule variance index (SVI) values using the criteria shown in Table 5, which were adopted from previous research [2]. Each variable was assigned a value of 1 for over-run, 3 for on target and 5 for under-run, depending on project performance in the area. With PASCI scores as dependent variables, the corresponding multiple-R and the adjusted-R^2 were calculated as shown in Table 6. The multiple-R of 0.793 indicates that there is a moderately strong correlation between SVI and the PASCI scores. Adjusted-R^2 of 0.616 was significantly different from zero, which indicates that

PASCI explains about 62 percent of the SVI. This shows the ability of PASCI as a predictor of SVI, which is based on the given project contract duration.

Table 5 Scoring Criteria

Variable	Range	Value
SVI	Under-run On Target Over-run	5 3 1

Table 6 Regression Table

Multiple-R = 0.793		Adjusted-R^2 = 0.616	
Model	Sum of Squares	Degree of Freedom	Significance
Regression Residual Total	134.15 79.39 213.54	2 62 64	4.77E-14

The Predicted SVI calculated from the sample ranged from -1 to 4. The predicted and actual values of SVI were plotted as shown in Figure 4.

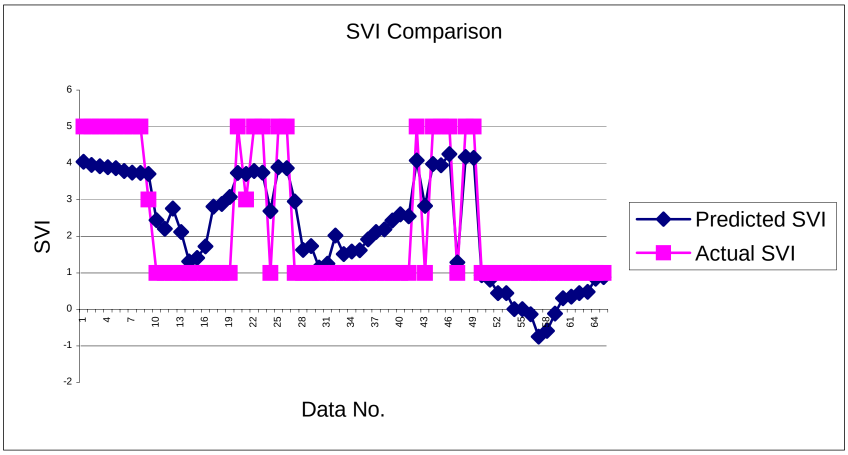

Fig. 4 Predicted vs. Actual SV Plot

The equation of the multiple regressions is:

$$SVI = 5.06 - 0.00374\ FAP - 0.00445\ SCM \qquad (1)$$

7. Conclusions

PASCI is a project assessment tool that applies to general building projects such as institutional, offices, light manufacturing, medical facilities, etc. It consists of two scores namely FAP and SCM. FAP are elements that should be monitored well by parties working on a construction site, so that the overall productivity of a project or its progress is not affected greatly, which usually results in delay. Amongst the highly rated FAP elements identified were the contractor's scheduling effort and the complexity of construction to the contractor. SCM are methods of action to be taken when problems, especially delays, were foreseen or unavoidable, so that the project schedule can be compressed and the project can be brought back on target. Amongst the more effective action identified from this research were staffing the project with most efficient crews, using short cuts whenever possible, providing employees with incentives and using pre-assembled components for quick set-ups. Based on the validation projects, it was found that the PASCI was able to explain quite well the SVI values. High SVI means a project is progressing well in terms of schedule progress, which was based on the project's contract duration. Low SVI indicates potential risk of having the project behind schedule and corrective action is needed.

The index could become an effective tool that would allow a planning team to assess the probability of avoiding delay based the contract period if it can be applied during pre-project planning and during construction phase. If the PASCI scores were monitored closely, overall project productivity could be improved, or at least maintained at the desired level. The index can also be used as an assessment tool for establishing a comfort level against risk, at which clients and contractors are willing to proceed with certain project conditions. Clients, consultants and contractors can also use it as a means of discussion and negotiating in project meetings. Since planning process is inherently iterative in nature and any changes that occur need to be resolved as soon as possible, the index would provide a forum for all project participants to communicate and reconcile differences using a simple written tool that can be evaluated individually by all parties. However, it should be noted that the index, like any other tool, does not ensure project success, but should be coupled with sound business planning and good project execution to greatly improve the probability of achieving our project objectives.

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