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A STUDY ON THE APPLICATION OF LOCATION-BASED MANAGEMENT AND AUTOMATED PROGRESS MONITORING FOR LINEAR INFRASTRUCTURE PROJECTS

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Abstract

Monitoring and controlling linear infrastructure projects is a complex and time consuming task. This demands detailed planning and controlling of schedule tasks at the macro and micro level. This research aims to explore and evaluate the application of location-based management (LBM) theory and an automated progress monitoring system as two micro and macro level solutions for progress monitoring of linear infrastructure projects. The research methodology adopts a qualitative approach for data collection and analysis on an elevated railway project as a linear project in order to implement and evaluate the automated system and LBM progress monitoring framework. The location-based management components were implemented using a location-based software program to implement and evaluate LBM for progress monitoring and also reporting. This thesis also introduced an automated system for progress measurement of large scale linear projects using satellite remote sensing technology. A prototype model was implemented in a small section of an elevated railway project using multi-temporal satellite images. The results and discussion reveal that LBM is an effective tool for implementation of lean construction theory as well as for clear visualization and communication on progress deviations and hence maintaining continuous workflow between locations and crews. The results also demonstrate the application of remote sensing techniques for automatic detection of construction activities in the case study project. The accuracy assessment shows the high accuracy of feature extraction used. The research concludes that the proposed tools are effective for monitoring linear projects. The benefits include implementation of lean philosophy as well as automated progress measurement and improved communication between project participants.

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Chapter 1

Introduction

1.1 Background

Urbanization in Malaysia has rapidly increased the development of large infrastructure projects such as roadways, railways, tunnels and pipelines in the country (Renaud, 1979). Large construction firms like Prasarana Malaysia Berhad implement critical path method (CPM) to control and manage their projects including Light Rapid Transit (LRT) extension project and mass rapid transit (MRT) project (Group, 2013). During the past few decades, despite the success of activity based methods such as CPM, there has been a doubt about their suitability for monitoring and controlling large construction projects. Many researchers have realized that activity based methods fail to recognize significance of work overflow and continuity in projects particularly for linear projects (Carr & Meyer, 1974; Charzanowski & Johnson, 1986; Selinger, 1980). In addition, it has been noted that CPM network methods add little to solving the planning problem of the projects where there is repetition. The activity-based methods are also ineffective in visualization of progress and project deviations in such projects.

In the past few decades, concepts such as line of balance (LOB) technology and linear scheduling methods (LSM) have been introduced as more effective techniques to not only schedule but also to monitor and control the progress of projects in particular those which are linear and repetitive in nature (Lutz & Hijazi, 1993). Location-based management system (LBMS) has emerged as a combination of traditional scheduling techniques as well as line of balance and linear scheduling methods (Kenley & Seppanen , 2010). The LBMS approach focuses on “location” to schedule, monitor and control the workflow rather than “activity” in CPM methodology. In addition, the methodology is based on the tracking the flow of resources through project locations or units and hence the ability to maintain a continuous workflow between locations and crews in projects. Moreover, the system offers a better visualization compared to CPM in order to observe the flow of resources and the effects of any deviation on other tasks and locations.

Despite the early adoption of location-based management (LBM) in Europe in the past two decades, there has been a resistance to this approach in many countries particularly in South East Asia. In addition, academic community has not given much attention about the analytical aspects of location-based methodology in the past decade. Nevertheless, considering the recent development of commercial location-based software programs and a great deal of publications about this approach, the popularity of LBM has been significantly growing (Kenley & Seppanen, 2010).

On the other hand, rapid emergence of large scale infrastructure projects and location-based planning techniques in construction industry has also encouraged the use of geographic information system (GIS) and other automated data acquisition technologies to enhance visualization and communication on construction efficiency (Sonmez & Uysal, 2008; El-Omari & Moselhi, 2011). Among these systems and technologies, GIS system has high capability to store, analyze and present geographical information, associated attribute data and time information. However, the collection, analytics and management of such data to support the construction management for a large-scale linear project remains a big challenge (Blaschke, 2014). Top-view image providing a pictorial overview over the entire construction site in addition to possibly derived spatiotemporal information using satellite remote sensing would be helpful to automate the progress monitoring and enhance the visualization for monitoring large infrastructure projects.

1.2 Problem Statement

Any experienced project managers involved in construction understands that deviations and project problems are not isolated to one particular location or unit in the project. There is also significant correlation and relationship between locations in linear projects. Activity-based management system neglects the correlations between locations in planning and controlling the project while work in many locations is usually performed by same resources or crews. The first problem is that the focus of activity-based methods such as CPM is to primarily to optimize project duration only rather than dealing adequately with the special resource constraints that would ensure smooth procession of crews from one unit to unit with no conflict and no idle time for workers and resources. This is because the unit of analysis in CPM is involved in monitoring and controlling each activity in the project to ideally optimize their duration. The second problem is that, for a repetitive project with large number of units, the CPM network designed for a unit has to be repeated to other units (Arditi, *et al*., 2002). This results in a complex scheduling network which is inefficient to monitor and also control since progress reporting is not clear enough and also the optimization is not necessarily performed based on the continuity of resources and crews. In particular, it is burdensome to update any deviations from the original schedule and visually see the effects of the deviation on other activities or locations. In contrast, LBM system plans for productivity and manages the continuity of workflow for resources and hence optimizes the production through using location as the unit of analysis. The location-based approach also offers a clear visualization on the construction deviations and hence is a better communication tool for project participants both on and off site (Kenley & Seppanen , 2010).

This alternative management system is a better tool in monitoring and controlling the repetitive nature of linear projects. However, manual data collection of actual progress for each location and the generation of regular progress reports for such large-scale projects is still a big challenge due to large amount of data required to be collected. In these types of projects, site engineers frequently need to visit construction sites to measure the actual progress of each location and detect deviations from the baseline schedule. In the conventional monitoring and control approach, actual progress information is usually acquired manually and documented in monthly/weekly progress reports in the form of Gantt chart or construction site photos. In some large projects, these monthly reports may include few hundred pages of long Gantts charts or descriptions which are difficult to store, read and analyze (Group, 2012). The preparation of these progress reports from data collected through on-site monitoring is a difficult, time-consuming and costly for these types of projects. The manual collection of actual progress information from numerous work locations and the preparation of progress reports are often delayed and subject to inaccuracies (Davidson & Skibniewski, 1995). It is common in very large projects the contractors submit the progress information to the client a month or two after the collection of the data (Group, 2012). The potential delays in the preparation of progress data and its delivery to decision makers cause inefficiency in the communication process on construction progress. Many studies highlight the importance of improved communication on efficiency and effectiveness of the construction process (Dikbas & Scherer, 2004; Dainty, *et al*., 2006; Emmerson, 1962; Higgin & Jessop, 1965). It is common that lack of knowledge regarding the current status and progress of project at head office lead to problems remaining unsolved that could have been dealt by senior engineering staff. Moreover, providing too much detail in the progress reports can also lead to confusion and misunderstanding, hence delay in decision making (Dainty, *et al*., 2006). On top of that, in large scale projects with numerous work locations or units, progress data could be subject to inaccuracy due to the time-consuming and expensive practice of manual data collection (Davidson & Skibniewshi, 1995). This issue is more common in large scale projects due to large number of activities and locations in such projects.

The importance of communication and visualization of progress data has also encouraged many researchers and practitioners to introduce several automated data acquisition technologies (El-Omari & Moselhi, 2011). Some of these technologies include bar-coding, 3D laser scanning, computer vision technology, photogrammetry; Radio Frequency Identification (RFID), multimedia and pen based computers (El-Omari & Moselhi, 2011). For instance, the integration of 3D laser scanning and 4D Building Information Modeling (BIM) has been employed as an automated progress measurement tool (Kim, *et al*., 2013). In addition; other researchers developed an automated real time monitoring system which links the time-lapse digital movies of construction activities, critical path method and visual progress control techniques (Abeid & Arditi, 2002).

While the technologies proposed in these studies have many advantages in progress monitoring, there are certain limitations for their applications on the progress monitoring of large scale repetitive and linear projects (Kim, *et al*., 2013; Bosche, 2010; Golparvar-

Fard *et al*., 2015). An example of these projects is a few kilometers long elevated railway project with the hundreds of identical locations which involve a specific sequence of activities. The primary limitation of using the above mentioned technologies is the large number of laser sensors or digital cameras required to capture the progress data for the whole length of project. Furthermore, the progress data collection may only be limited for the objects or components which are in the range of laser sensor or camera. Progress data collection would also be limited because of the objects that may be hidden or blocked by large machineries such as piling rig or crane (Kim, *et al*., 2013).

The large amount of data in large linear projects and the importance of location-based management encourage the new project management approach that can benefit from digital technologies such as geographic information system (GIS), building information modeling (BIM) and other disruptive technologies such as cloud computing, robotics, internet of things (IOT) and many others. In particular, GIS has a great potential to be used as a macro tool to reduce data handling waste and improve visualization and documentation of progress data for a very large area (Sonmez & Uysal, 2008). GIS has high capability to store, analyze and present geographical information, associated attribute data (location) and time information. However, collection, analytics and management of such data to support the requirements of monitoring a large scale project remains a big challenge (Blaschke, *et al*., 2014). Satellite images as a top-view image providing a pictorial overview of the entire construction site in addition to possibly derived spatiotemporal information would be helpful to develop an automated monitoring system based on planned and actual progress. In addition, the development of a web-based platform can enhance the process of data handling between the project participants through the communication and visualization of progress data. A similar concept has been presented by Sonmez and Uysal's (Sonmez & Uysal, 2008) work which introduces a GIS-based visualization system for planning and monitoring a pipeline project using Google earth. The system provides the project participants with enhanced visualization of schedule, actual progress and work sequence in the project. However, the proposed system does not benefit from automated measurement of construction progress.

1.3 Aim and Objectives

The aim of this research is to explore and evaluate the effectiveness of LBM and an automated progress monitoring system using satellite remote sensing for progress monitoring of large linear infrastructure projects. To achieve this aim, following objectives were attained:

1. Implementation of location-based management (LBM) components for progress monitoring of linear infrastructure projects.

2. To evaluate and discuss the application of LBM for effective monitoring and controlling of such projects.

3. Investigation on application of geographic information system (GIS) and satellite remote sensing techniques for progress monitoring of linear infrastructure projects.

4. Development of a web-based system for automated progress measurement, data collection and online progress reporting through satellite remote sensing techniques and GIS.

1.4 Research Scope and Limitations

Linear infrastructure projects are usually two types: 1) Discrete linear projects consisting of several or many similar or identical units for example, houses in multi-family housing developments. 2) Continuous linear projects where there are no distinguishable units such as highways, mining, railways, tunnels and pipelines. However, the repetitive construction units of such projects can also be considered as meters in pipelines or stations in highways. The scope of this research is to implement and evaluate location-based monitoring techniques and automated progress monitoring for discrete linear projects which consist of multiple units for the whole length of project. The focus of this dissertation is on the application of monitoring and progress reporting of LBM and proposed monitoring system. Therefore, there will be less emphasis on the process of location-based planning (e.g. derivation of quantities including durations and resources). However, the study focuses on introduction of a monitoring framework which can help better controlling process and hence increase productivity in linear infrastructure projects. The study evaluates the benefits of location-based methodology and techniques for modeling and tracking the flow of resources and project deviations through an optimized schedule and based on clearer visualization and progress reporting. The analysis does not concentrate on the aspects of resource leveling and optimization based on the actual progress information. In addition, although LBM is widely used for planning and controlling both linear and non-linear projects (such as buildings), evaluation of LBMS in this study is limited to only a relatively small linear segment of the case study project and non-linear sections of the case study project such as buildings are not discussed and analyzed.

Furthermore, satellite remote sensing images are utilized to evaluate the feasibility for automatic detection of progress status in different locations/units in the research case study. The study also presents and evaluates a framework for development of a web-based progress monitoring and reporting system using satellite remote sensing images and location-based reporting tools such as line of balance technology. The application of satellite remote sensing is limited to progress detection of repetitive tasks in a linear project on monthly basis. . Although the system does not provide sufficient information about the exact start dates of each repetitive tasks and potential problems in each location, it provides an accurate snapshot of progress in each individual location. Therefore, the automated system can be used to quickly and automatically generate and display the overall progress of the project

1.5 Layout of the Thesis

This dissertation consists of five chapters. Chapter1- Introduction that introduces the research background and an overview of the problem statement as well as the aim and objectives of this dissertation. Furthermore, it discusses the background of activity-based methods in comparison to location-based approach for monitoring and control linear projects as well as application of GIS, satellite remote sensing and other automated technologies.

Chapter 2- Literature Review gives an extensive review of the previous researches regarding the benefits and disadvantages of activity-based scheduling methods. In addition, it introduces linear scheduling methods, line of balance technology and the principles of location-based monitoring and control system. Furthermore, current applications of satellite remote sensing and image processing techniques for construction progress monitoring are extensively discussed.

Chapter 3- Research Methodology explains the methodology and framework for implementation and analysis of LBM system on linear projects using Vico control software. Moreover, the chapter describes the methods and steps used for development of an automated system for progress monitoring of large infrastructure projects using satellite remote sensing. The description of an elevated railway project is presented as the research case study.

Chapter 4- Results and Discussion uses the research case study to illustrate the implementation and evaluation of location-based monitoring technique for the research case study. The chapter also presents the results for application of satellite remote sensing and image processing techniques for automated progress detection and online progress reporting on a web-based platform.

Chapter 5- Conclusions and Recommendations summarizes conclusions and recommendations for future researchers.

Chapter 2

Literature Review

2.1 Introduction

The literature review evaluates and discusses the benefits and weaknesses of activity-based techniques such as CPM and PERT for monitoring and controlling linear projects. Afterwards, this chapter focuses on the history of LOB technology as the origin of LBM system. The literature review also broadly previews the principles and methodology of location-based monitoring and controlling system compared to activity-based methods. Finally, this chapter overviews the current application of automated data acquisition technologies in particular, satellite remote sensing technology for automated progress monitoring. In literature review, the following key topics will be discussed in details:

1. Challenges and weaknesses of CPM for planning and controlling linear projects
2. Basic concepts of LOB technology and its benefits and weaknesses
3. The methodology of location-based monitoring and control (to some extent) techniques and further approaches for linear projects in addition to their benefits
4. Current automated data acquisition technologies as well as the application of satellite remote sensing for construction progress monitoring

As long as there have been projects, the process of planning and control has always been inseparable part of construction projects. This process has changed from simple bar charts to the sophisticated analytical and graphical approaches such as CPM and PERT implemented by large projects such as Hoover dam or Empire state building project in the past century. Despite the early success of these methods in construction industry, some researchers and practitioner pointed out the ineffectiveness of these conventional methods in modeling and visualizing the repetitive nature of linear construction projects (Arditi & Albulak, 1986; Carr & Meyer, 1974; Kenley & Seppanen, 2010; Suhail & Neale, 1994). This chapter explores the past studies on the development of traditional techniques and location-based techniques for monitoring and control of linear construction projects. Most of the studies focus on the weakness of activity-based methods due to their inability to recognize the significance of workflow, continuity and visualization of deviations in linear projects (Kenley & Seppanen , 2010). This chapter describes the common practice of progress data acquisition and reporting in most of large-scale linear projects. In addition, it explores the recent technologies for automating collection of progress data in construction projects. Later, satellite remote sensing and its applications for construction monitoring are also addressed.

2.2 The Development of Activity Based Methods

2.2.1 Gantts Chart

In the early 19th century, the universal bar chart was developed by Henry L. Gantts and Frederick W. Taylor (O'Brien & Poltnick, 1999). This was mainly a graphical technique without any basic analytical methods. Nevertheless, the Gantts charts were universally employed to represent the organization of production and soon were dominantly common in the construction industry for communication of a time schedule. While these methods and techniques have become relatively complex, they mostly remain dependent on representation of a project schedule. The fundamental characteristic of a Gantts charts is to represent the production of series of activities respect to the time (Kenley & Seppanen , 2010).

As the basic method of project planning, this was introduced in the format of a chart which graphically plots several activities against time with activities being listed vertically and usually in sequential order. The period of execution for each activity is shown as bar on the time graph corresponding to the planned times of occurrence. Parallel to the planned period, the actual period of execution is plotted. Despite of bar chart's simplicity as an advantage, it fails to illustrate the interrelationships of the activity. Therefore, the consequence of variations in duration and sequencing of an activity cannot be identified (Charzanowski & Johnson, 1986).

2.2.2 Critical Path Method (CPM)

With the growing complexity of construction projects and increased focus on management as a discipline, it was crucial to introduce an analytical method to the construction industry. Since, computers were available to automate complex analysis in 1950's; companies, governments and academia got together in the market to help the development of an analytical method. The necessity for an accurate planning and control of complex military projects particularly the early stages of Cold War, directed the researches to develop effective solutions. In 1960's the combined efforts of few research groups and Remington Rand (American business machines manufacturer), encouraged James E. Kelly and Morgan Walker to develop a new technique called Kelly-Walker method and the first commercial program RAMPS (O'Brien & Poltnick, 1999). Later James E. Kelley and Morgan R. Walker introduced a method now commonly known as critical path method or CPM.

As it was mentioned before, one of bar chart's disadvantages was its failure to determine the activity interrelationships and interdependencies. CPM method was introduced as a tool to show the logical sequence of activities in a project. The fundamental principle of this method is that sequences can be illustrated graphically where each task in the project is represented by an arrow. The arrows are then interconnected to show graphically the sequence in which the jobs in the project must be performed (Kelley, 1963). The result is a topological representation of a project. CPM uses an activity-based methodology, a term first proposed by Russell Kenley to differentiate between the emphasis on activities and locations in planning (Kenley & Seppanen, 2010).

2.2.3 Derivers for Location Based Planning

Activity based methods were a wonderful development and have enhanced the construction industry enormously. A concentration on the critical path method in the early publication record and a corresponding dominance in commercial software applications indicates, on a face of it, a remarkable degree of success for CPM. However, despite the success of activity based methods, there has remained an undercurrent of doubt about their suitability for real construction projects particularly linear construction project (Rahbar & Rowing,1992;Selinger,1980). Some researchers have realized that activity based systems were insufficient and were failing to recognize the significance of work overflow and continuity, and were essentially unreliable in their application. Over the years researchers have noted that network methods add little to solving the planning problem where there is repetition (Reda, 1990; Russell & Wong, 1993;Arditi & Albulak, 1986). The case is best made by Arditi *et al* (2002):

"The first problem is the sheer size of the network. In a repetitive project of *n* units, the network prepared for one unit has to be repeated *n* times and linked to the others; this result in a huge network that is difficult to manage. This may cause difficulties in communicating among the members of the construction management team. The second problem is that the CPM algorithm is designed primarily for optimizing project duration rather than dealing adequately with the special resource constraints of repetitive projects. Indeed, the CPM algorithm has no capability that would ensure smooth procession of crews from unit to unit with no conflict and no idle time for workers and equipment. This leads to hiring and procurement problems in the flow of labor and materials during construction" (p. 353)

Birrell can be considered as the first researcher who emphasized on the significance of location as an important part of project analysis. Based on this location-based approach, he found CPM methods inappropriate for construction scheduling and control. He mentioned that in construction the resource allocation problem is compounded by the largely non fungible nature of construction resources. This is a fundamental characteristic of construction resources which has been further rigidified by the construction unions. In addition, productivity in construction tends to be from a squad made up from various resources rather than individual resources working in isolation from each other (Birell, 1980).

2.3 Location Based Management Systems (LBMS)

2.3.1 Founding Fathers

As it was discussed before, the location-based planning methods are based on the relationship between location and the unit of work. In order to find out the origins of these methods, it is important to look for the methods which graphically and analytically consider the relationship between work and location. The origin of such methods can be traced back to over a century ago. The earliest theorist of such techniques was a Polish professor, Karol Adamiecki, specialized in engineering, economics and management. It is believed that his techniques were foundations of location-based scheduling (Kenley & Seppanen, 2010). He developed graphical techniques as well as production management and complex interaction between the engineering of production and the efficiency of production. In his researches, a more sophisticated technique was presented independently when Henry Gantt and Frederick Winslow Taylor developed Gantt chart. In his diagrammatic schedule called Harmonograms, he included location as a key feature. While his techniques provide data such as bill of quantities, duration of work and its associated dates, they also give information about location and charted movement of work through processes, improving efficiency by aligning production rates.

2.3.2 Location-Based Scheduling Techniques

Since researchers realized the weakness of CPM and importance of location in the process of planning and controlling, there have been many attempts to find an effective scheduling technique for linear construction projects. These include but not limited to, the line of balance (Lumsden, 1968; Arditi & Albulak, 1986), flowline (Gorman, 1972; Carr & Meyer, 1974; Perera, 1982), linear scheduling method (Charzanowski & Johnson, 1986), LBM (Kenley & Seppanen , 2010) and many others (Kavanagh, 1985; Lutz & Hijazi, 1993; O'Brien & Poltnick, 1999; Sarraj, 1990).

2.4 Line of Balance (LOB)

Line of Balance (LOB) was introduced as an alternative method to CPM in order to facilitate the balancing of repetitive operations based on a production scheduling technique. The main advantage of the method was its simple graphical format to obtain necessary information on production rate and duration of the tasks (Arditi & Albulak, 1986). The objective of the LOB technique was to ensure that components or subassemblies are available at the time they are required to meet the production schedule of the final assembly. Therefore, the technique was originally originated to be a way to handle repetitive construction such as highway, tunnels, railways and high rise buildings.

2.4.1 Brief History

In early 1940, a company called" Good Year" introduced Line of Balance (LOB) method before US Navy developed the method as a tool for monitoring the progress of its military and industrial processes (Kenley & Seppanen, 2010). Line of balance was presented in a naval material in department of US navy as a technique for assembling and interpreting the progress data (stages of industrial processes) in a graphic form against time. US navy in its report on line of balance described this technique as below:

According to Navy (1962), "It is essentially a management-type tool, utilizing the principle of execution to show only the most important components into manufacture of end items in accordance with phased delivery requirements." (p.3)

2.4.2 The LOB Components

Fundamentally, the basic concept of this technique is defined to determine the production rate of finished products in an operation line (Sarraj, 1990).This technique has three components output shown in Figure 2.1:

(1) *A unit network*, illustrates the relationships and duration of activities

(2) *An objective chart* which shows the commulative calender of units completion

(3) *A progress chart* depicting the detailed completion of each unit (Carr & Meyer, 1974)

Unit network or production chart

The unit network (usually called production chart) as shown in Figure 2.1 (a) consists of the set of operations for a single unit of the projec. It also shows the duration and some production measure of the operations. The main objective of this chart is similar to activity on-arrow network (O'Brien, 1969). The production diagram places primary emphasis on the event ending each assembly task.This approach might be used in planning the construction of a multi-story building; for example, the single unit may be a hotel room or an entire floor.

Progress diagram

The prime purpose of preparing progress diagram is to develop a comparison of current progress with planned objectives. Therefore, the paramount observation to be made is whether or not progress is in phase with the objective. The progress diagram in the Line of Balance technique is prepared as a bar chart. The bar represents the units produced on a particular day, which is compared to the Line of Balance to determine if the process is on, behind or ahead of schedule. The bars which are below the balance line are the elements of the endeavor which can be picked up by top management as requiring remedial action (Navy, 1962).

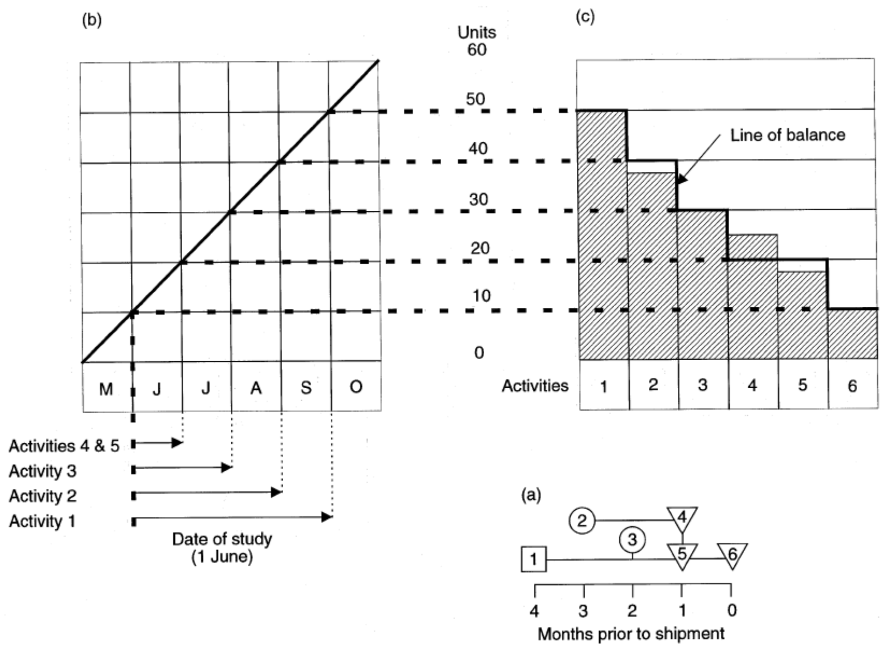


Figure 2.1: Line of Balance Diagrams (Mattila & Abraham, 1998)

A progress diagram is prepared for any particular date of interest during the production process. As shown in Figure 2.1 (c), the progress diagram shows the number of units for which each of the subassembly operations has been completed.

Objective chart

On the other hand, the objective diagrams as shown in Figure 2.1 (b) is to record the planned status of units completion in project. Another line can also show the actual progress. A comparison of the slopes of two curves indicates whether or not current lead or lag of deliveries may be expected to continue. Horizontal difference in the two curves indicate lead or lag in terms of time; whereas the vertical difference indicates lead or lag in terms of delivered units (Navy, 1962).

Based on the nature of this technique, the application of LOB can be primarily useful for any repetitive projects containing multiple units such as floors in high rise building, piers in elevated railways and etc. One of the first applications of LOB in construction was by Lumsden (1968) who presented the application of the technique on housing projects and utilized progress chart and objective diagram to determine the completion status of houses, and track the location of resources in the project. Based on his findings, the following can be determined using LOB methodology at any time:

1) Shortage of delivered resources impacts the production process
2) The production tasks which are behind schedule require higher rate of production
3) The processes or tasks which are ahead of schedule may have higher production rate than necessary.
4) The excess materials which are being delivered which may require additional material handling
5) The forecast for units or work locations which are partially completed (Lumsden, 1968).

Carr & Meyer (1974) similarly adopted LOB on a repetitive housing project with 50 identical units. They defined line of balance schedules for each repetitive task on a diagram representing number of units vs. time. In addition, buffers or lags were introduced to allow variations for production rate of the tasks. Figure 2.2 depicts a usual production curves for two random tasks B and C. In a repetitive housing project, stages characterize number of units completed during a specific time. Using the slope of tasks, it is possible to determine the production rate in terms of completed units per time. The horizontal distance between the production curves for two consecutive tasks at a particular stage represents the lag or time buffer between those tasks at that stage. The vertical distance between production curves at any given time represents the stage buffers (i.e. number of units in queue between tasks) at that time.

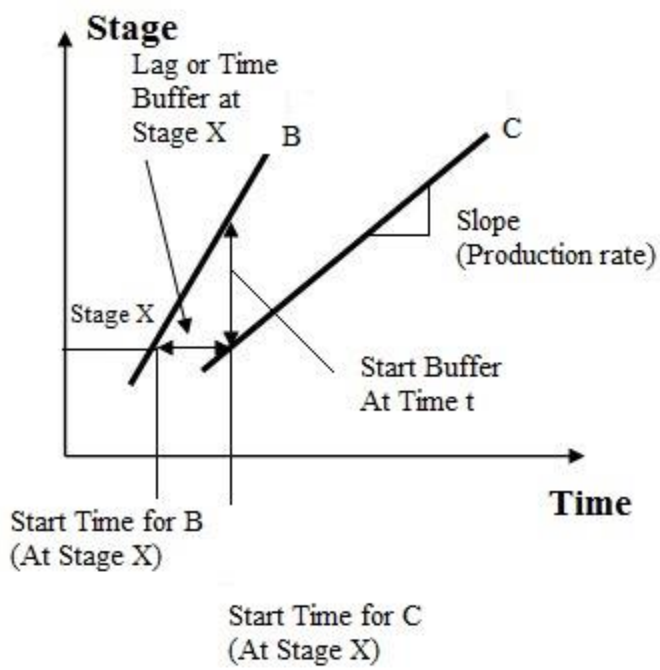


Figure 2.2: Production Curves for Two Tasks B and C (Carr & Meyer, 1974)

2.4.3 The Challenges of Line of Balance (LOB) Method

Many researchers stated the disadvantages of LOB method in projects scheduling and controlling. For example, Neale & Neale (1989) outlined that the LOB technique can only show a limited degree of complexity of the project specifically while monitoring the progress of the construction. In this relation, Kavanagh (1985) acknowledged that LOB method is only effective for simple repetitive production processes rather than complex repetitive construction. On top of all, Lutz & Hijazi (1993) mentioned that a limitation of the LOB is that its assumption that production rates are linear. Arditi, *et al* (2002) also described several scopes as challenges of LOB including:

1) Calculation of quantity in line of balance method
2) Development of a formula which manages production rate in an efficient manner
3) Recognition of the potential nonlinear and discrete activities
4) Development of an optimum plan to decrease overall duration of project through increase of production rate for some activities.
5) Performing cost optimization and enhancement of visualization in LOB diagrams.

2.4.4 Challenges of CPM in Repetitive Construction

Besides the discussions on limitations of LOB, many researchers also expressed their dissatisfaction with the application of traditional techniques such as CPM on repetitive projects. One of the main reasons is that CPM algorithm is vulnerable to potential changes of sequence between the repetitive units as result of unpredicted matters and strategic choices (Rahbar & Rowing, 1992). In CPM algorithm, there is pure logic and sequence between activities of repetitive units. Any progress out of this sequence is termed as “out of sequence”. The other challenge associated with CPM schedule is evident during monitoring and control stage of project where a huge network has to be updated (Pilcher, 1976). Carr & Meyer (1974) criticized this matter from another approach and mentioned that the sequence of progress from one unit to another should be formulated during the project by management rather than dependencies of the activities required in the schedule.

Several researchers also indicated that CPM is primarily formulated to achieve the minimum duration for an activity rather than providing work continuity for the crews of repetitive activities which is essential for repetitive construction projects (Suhail & Neale,1994; Russell & Wong, 1993). Furthermore, Rahbar & Rowing (1992) stated that CPM is not capable to determine progress rate of activities.

2.4.5 Combination of CPM and LOB Methods

As disadvantages of both methods were investigated through many studies, another alternative appeared to be the combination of CPM and line of balance method. Therefore, these two techniques became complementary in the new approach (Carr and Meyer 1974).

One of the first attempts to implement this approach was done by Schoderbek & Digman (1967) where PERT method was combined with Line of balance technique. This involved in analysis of uncertainty on linear activities. In addition, studies performed by Perera (1982) contained a resource oriented method to calculate the duration of the project as well as the float time.

Another issue raised was the possibility of project progress in out-of-sequence manner. This approach reflected in the method designed by Rahbar & Rowing (1992). They designed a method without sensitivity of out of sequence progress. Therefore, CPM was employed for non-repetitive activities while LOB was used at the summary level of repetitive activities. This avoided a complex network with out of space progress errors.

The most important method for integrating CPM and LOB was introduced by Suhail & Neale (1994). The fundamental aspect of this integration is on leveling of resource and the utilization of float times to streamline the scheduling process. The method enables the continuous revision on resources and crew production and hence can generate float times using capacity of CPM software. As a result, this technique reduces the drawbacks and challenges caused by sequence change of the work. In addition, it clearly identifies the impact of these changes on the completion date of the project. Furthermore, continuity of work for the crews is maintained while the method respects the logical relationships of the typical unit networks in CPM (Suhail & Neale, 1994).

Besides the application of line of balance methodology on repetitive construction, researchers were encouraged to develop a method to emphasize on linear projects with repetitive tasks over a distance. Linear scheduling, flowline methods were the main products of these attempts by many researchers such as Gorman (1972), Selinger (1980) and Peer (1974).

2.5 Linear Scheduling Method (LSM) & Flowline Method

The linear scheduling method utilizes a diagram to graphically illustrate the location and time of each activity in the project. This scheduling method is the most suitable method for linear projects as repetitive activities are completed over a distance. In this graphical representation, continuous activities completed over the distance are illustrated by lines consisting of a continuous set of points. Therefore, the location of work in progress can be determined at any point in time

2.5.1 Flowline Method

The earlier representation of the LSM was the time versus distance diagram (Gorman, 1972). Using this technique for linear projects, the work progress of activities in the project can be illustrated with better presentation of information. The production rate of an activity can also be determined by the slope of the plotted line on the time-distance diagram.

There have been several popular representations for flow of work through locations. The most important one called flowline method is derived from Selinger (1980) and his supervisor Peer (1974) .The focus of the Peer's representation is mainly on movement of crews which perform a set of activities in a fixed sequence. The flowline method is a graphical representation which is similar to the line of balance method. However, there are significant differences between these two methods. The main difference is that the vertical axis of line of balance represents the line of balance quantity while, the flowline representation presents the location on the vertical axis. Figure 2.3 shows the flowline method designed for five activities performed through A-D location.

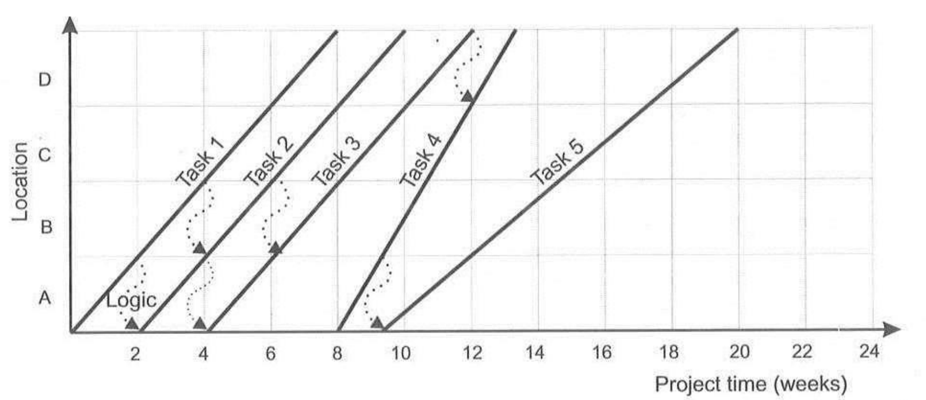


Figure 2.3: Flowline for Tasks 1-5 in Locations A-D, (Kenley & Seppanen, 2010)

The activities with slowest production rate (lowest slope) are considered as critical activities. Besides, other critical activities include those which control the start time of the slowest activity or are required to complete the project (Perera, 1982). When the process is unbalanced, construction time is determined by the slowest production lie, which is then critical. The other activities are those determining the earliest possible start of this production line, and after its completion the finish of the whole project. All other activities have free floats, changing from section to section, depending on their distance from the critical path (Peer, 1974). Peer (1974) also investigated the impact of resources on production rates and consequently on critical activities. He mentioned that techniques for the resource allocation usually do not consider the possibility of altering the crew size at various phases of the project (Mattila & Abraham, 1998). He argued that:

"Limitations are imposed on the use of network analysis for planning the production process by its fundamental unrealistic assumptions of unlimited resources and independent activities of fixed duration that can be shifted freely between earliest start and latest finish. The need for creating working continuity and balancing the while process into an integrated production system is completely neglected"

2.5.2 Birrell's Matrix Model

As it was mentioned before, Birrell (1980) is another and one of the first notable researchers who developed a model for flow of work through location. He emphasized on consideration of work crew as a continuous flow along the locations of the project. This would minimize the complexity of construction process and the confusion of the participants as the work passes through various locations in a consistent sequence. This single sequence will also enable the project manager's or general contractor's site superintendent to build a “rhythm” of work and movements of work squads through projects.

Birrel’s model of repetitive construction considers three different physical locations in the project including vertical segmentation, horizontal segmentation and the space available within the site, but outside the building, for material storage and handling.

Birrell (1980) constructed a matrix of work packages with work locations on the vertical axis and time period on horizontal axis. Birrell clearly used queuing theory to prepare the work for the construction crew. He identified that the construction process is made up of many flow lines (queues) each consisting of a work squad moving through a series of locations.

2.5.3 Further Approaches to LSM

Selinger (1980) introduced a LSM method based on the requirements of labor and possible size of the crew instead of on activity durations determined in advance. It was found that the method is more appropriate approach for practical needs of a construction site. In addition it eases the continuity between activities. The findings were proved in a simplified bridge-construction project.

Perera (1982) introduced a linear programming approach for resource sharing in linear construction. In this approach, the required resource hour to finish an activity was determined rather than required resource for a day. This resulted in more flexibility in resource allocation and sharing between several activities. The maximum rate of production and resource-hour required were determined in the linear programming. The product of this approach was that all activities had the same production rate.

Russell & Caselton (1988) employed a dynamic programming to optimize the project duration of linear projects. The variables of the model were the activity duration and potential idle time of an activity. In addition, few other variables were taken into considerations such as learning curve effects and general precedence relationships. Thabet & Beliveau (1994) introduced a method of work-space scheduling for linear construction projects and particularly multi-story buildings. In the method, physical space requirements for material storage and the movement of the manpower and equipment were considered.

2.6 Monitoring and Control of Activity-Based Planning

2.6.1 Background

Although activity based planning methods were designed for purpose of planning and control, the emphasis of these methods remained on planning and scheduling aspects. This concentration seemed to assume that focusing on one could cover the other. However, in real life monitoring and control aspects play very important role in managing projects. Kelly and Walker (1959) primarily were concerned about control aspects for construction projects by introducing a system for management by exception. In such system, management need only act when deviations from the plan occur. The program evaluation and review technique (PERT) was a control system which emphasizes on forecasting the likelihood of success. During early development of this method, US Navy reports acknowledge the necessity of control information to enhance the management system.

There were distinct differences in the philosophies between CPM and PERT. In summary, that PERT was network schedule “from time now” to the end of the project and which gave an estimate of the likelihood of achieving the project completion date or any other milestones. On the other hand, CPM was always a complete schedule from the beginning to the end, and all milestones and end dates were dictated by the schedule. This difference was reflected into different control strategies and approaches.

2.6.2 Strategies in PERT

In comparison to CPM, PERT focuses on control strategies of construction projects earlier. Fazar (1959) mentioned about failure of management practices in obtaining control objectives including: assessment of the validity of schedule, measurement of actual progress against planned progress, measurement of the current forecast. In fact the first point is a planning objective, but the other two relate to CPM and PERT objectives for controlling projects.

Fazar’s team, when designing PERT, argued that time was the only practical way to control a project since cost, resources, and technical progress were too difficult to measure the progress of the work. Therefore, PERT-Time was developed particularly to control projects to meet planned milestones. The process of control consisted of recording the progress of activities and assessing the probability of achieving milestones. Apart from the focus on reporting the probability of achieving milestones, the process of control in PERT and CPM were largely the same.

2.6.3 Strategies in CPM

Kelly and Walker also established the control concept in CPM by introducing "management by exception". This approach emphasizes on examining the critical path to correct deviations which impact the project duration. Additionally, Glaser & Young (1961) mentioned about the establishment of management by exception through measuring actual progress against predicted or planned progress. As the start of a job approaches the latest start time, or as the completion begins to come perilously close to the latest possible date, those concerned know that they have slippage on their hands of which management should be notified. Management therefore is truly enabled to act by exception only (Maunchly, 1962). One of the advantages widely perceived was the ability to give early warning of trouble, so that on-time control action may be taken. Thus the concept of an early warning system has been a component of control since the design of CPM.

Updating the status of a project

The nature and process of progress monitoring of a project has not significantly changed in the past decades. This process initiated by Woodgate was "including progress data into a scheduling network" can be considered as updating progress status in the project. Therefore, this updating requires a contract schedule as a baseline schedule. Dates from milestones in this schedule are applied to the current schedule and the updated schedule then indicates progress against the baseline (Woodgate, 1964). The implementation of actual progress reporting varies in different scheduling software programs. Therefore different planners may have different approach when applying this method depending on their own needs.

Presentation techniques for monitoring and control

The presentation of progress in CPM method is usually limited to the use of Gantt charts or network. The chart includes a vertical line showing the current progress status of each task in the project. S-curve is an alternative method to show planned and actual progress in a simple representation although it does not include the criticality of the project activities.

Effectiveness of controlling project using CPM

An effective control system for a project requires a frequent updating on actual progress data. It is usually recommended to update at least every two weeks to follow the basic principle of management by exception. However literature views significant flaws in this approach besides its strength. Meredith & Mantel (1995) considered CPM control system as an " after the fact" approach where control actions are taken only after deviations are monitored. However an efficient project management is more concerned and interested in identifying potential deviations which may affect the project in future. Therefore the monitoring system should develop progress data that indicate deviations to come. O'Brien & Poltnick (1999) also pointed out that activity based management only depends on fixing a baseline schedule and then updating the schedule using actual dates. Kenley & Seppanen (2010) explains this limitation:

"This is problematic in an activity-based management system, as the duration of each future activity is unrelated to past activities of the same type. The CPM system does not have the capacity to make forecast of future action without intervention by the project manager in the form of variation of future estimates of duration- perhaps based on probability and certainly based on experience"

2.7 Development of Location-Based Monitoring and Control

The location-based control system obviously again focuses on location rather than activity to take necessary control actions based on visualization of any deviations before they occur. Consequently, forecasts are also used to inform the management about problems which are not solved yet. Unlike CPM, LBM has a proactive control system which enables management to react to problems earlier and with better control actions. These data include the flow of resources between locations, location-based quantity data, production logic and learning experience from a location to location.

2.7.1 LBM in Finland

Research on location-based production monitoring and control began 30 years ago and resulted in more in-depth discussions about planning systems. The main derivers for this research were rapid increase of cost and low profit margins for general contractors. As a result, three construction companies established a large research collaboration attempting to identify the main causes of this economic crisis in construction industry (Seppänen, 2009). The first phases of research started by Helsinki University of technology involved in analyzing the causes for failure considering both good and bad results of construction project

The main outcomes for this research argued that project suffered from cost overruns although the original cost estimations were considered good. The causes of these overruns were discovered to be inefficient planning for quality as well as absence of production control. The main factors were poor procurement, inappropriate use of resources and failures to completion of works.

Planning problems included inaccurate estimation of tasks durations, incorrect logic between tasks, planning multiple tasks to begin at the same time, or in discontinuous manner. As a result, the research identified the most important strategies to be enhancement of planning and control system (Kolhonen , *et al*., 2003).

The theoretical foundation of the research effort was goal management:

- The most important focus for production control is to make production happen according to plans
- The prerequisites for successful production control are continuous monitoring and planning good schedules
- Location based planning is the best way to measure the quality of plans
- Location based management allows planner to visually see the effects of deviations on other tasks

Considering the goal management, location based planning was chosen to be the scheduling method with good experience resulted from utilization of linear scheduling method in highway projects. Planning and controlling was done manually, while drafting the schedules was able to be done using computer software. Benefits and advantages of location-based planning was enhanced visualization of works sequences, free locations and total impacts of deviations based on the progress stage as well as visual risk evaluations of schedules.

Following these researches, case research was followed by two professors and researchers were generally students who were completing their masters' theses. Over 30 case studies were carried out and each brought some improvements to the scheduling or production control techniques (Kiiras, 1989).

The main results of case studies:

- Production control is more important than planning
- Controlling requires good schedules, continuous monitoring and immediate reactions to deviations to decrease their effects.
- The quality of plans needs to be checked to ensure the schedules are feasible and controllable and that resource requirements are the same as allowed in the cost estimate or budget.
- The project should be divided into sections and zones for planning and controlling
- A continuous production is the key for good implementation of plans.

2.7.2 Principles of Location-Based Monitoring and Control System

In LBM, control system strongly relies on forecast information. When forecasts data are acceptable for production, project can go on based on the plan. On the other hand, when forecast predicts a potential problem, control actions have to bring the forecast data back to the plan (Kenley & Seppanen, 2010). In location-based reporting system, management should be aware of both adjusted and unadjusted forecast as well as previous and planned control actions. This allows project participants to get more confident about the beneficial control actions which have corrected previous problems and adjusted deviations.

The location-based control model needs to provide accurate information sufficient to differentiate performance deviations from changes in circumstances. The sources of deviation may include: quantity changes, startup delays, and production rate deviations, discontinuities, working out of sequence and production perquisites.

Tracking this more accurate information, and having a system with sufficient flexibility to manage changes to implement production plans will lead to better management of the perquisites for production, the availability of suitable resources and more detailed look-ahead planning during construction. As an example, in the early stages of the research in Finnish construction industry, production control in the production control system was based on weekly planning. However, weekly planning resulted in the shifting of work, and hence problems towards the end of the project (Kenley, 2003). As a result, research began on task planning as a production control method to ensure that production would be implemented according to the master schedule, and that the starting perquisites of tasks would be fulfilled.

2.7.3 Task Planning

Task planning is based on dividing production control into mutually-interacting parts and securing the implementation of each task from the different aspects: scheduling, costs, quality and safety. The master plan defines what should be done, but it is often too rigid and general to be of use to the site manager and superintendents in the planning and controlling of individual project tasks. Task planning differs from weekly or look-ahead planning in that the implementation of a whole task is planned as one entity. The definition of a task is the same as in location-based planning, i.e. the related scope of work which can be done by one subcontractor at the same time (Junnonen & Sepanen, 2004).

2.7.4 Location-Based Production Information

Kenley and Sepannen (2010) described a new location-based control model which utilizes four stages of production information, each stage having its own schedule views, information and properties. The stages are baseline, current, progress and forecasts

Baseline

The location-based baseline schedule is the same as baseline in CPM as a committed plan for the project. The location-based baseline is made based on location-based quantities and schedule tasks which cannot be altered unless a new baseline is introduced.

Current

The current stage data is similar to baseline schedule with consideration of new information which was not available in the beginning of the project including both changed data and more detailed information of quantities (current quantities) and current stage tasks (called detailed tasks) from subcontractors or project consultants. The current schedule is updated with new information such as availability of crews and resources or quantity and logic changes. In location-based control system, both current and baseline schedule are maintained and original baseline places sort of constraints for finished dates of each location in the project. These constraints are in the form of alarms to warn the project if they are not followed.

Progress

The progress stage in location-based control system tracks the actual time productivity of detailed tasks. In this stage, start and finished dates or completion rates of detailed tasks are recorded. In addition, actual resources consumptions are also measured if the information about actual resources is available.

Forecast

The current stage data and progress information are the tools for calculating forecast measures. If not control action is introduced, the forecast stage assumes that production goes on with the previous actual productivity rather than planned rate in CPM scheduling. Furthermore, the impacts of deviation are evaluated using the planned logic network. At the end, this information would be useful for project participants and managers to take required control actions to bring back the production to the planned one. Alarms play important role to signal the management before interference has taken place. The process of updating and forecasting encourages timely control actions rather than only recording the variances and updating like in CPM.

2.8 Automated Progress Monitoring

This section gives an understanding about satellite remote sensing images, image processing techniques as well as recent automated technologies applied in construction management. Primarily, it is important to know the nature of remote sensing and satellite images.

2.8.1 Remote Sensing Images

Remote sensing images have been widely applied in the spatial data extraction and GIS database updating (Smits & Annoni, 1999; Holland, *et al*. 2006; Sirmacek & Unsalan, 2009). Remote sensing images are top view snapshots of the earth surface taken from sensors mounted on space-borne or air-borne vehicle. Features on earth surface are interpreted from these top view images. The amount of information contained in remote sensing images depends on the spatial, spectral and temporal resolutions (Xie, *et al*., 2008). Spatial resolution denotes size of the smallest possible feature that can be detected from image. Spectral resolution relates to number of spectral bands and spectral width of each band. Temporal resolution of satellite gives an idea about frequency of acquiring a new measurement for the same area. According to the lighting source, remote sensing sensors are categorized as passive or active. When passive sensors measure reflected solar light from earth surface; active sensors capture its own emitted energy (Aggarwal, 2004; Pisharoty, 1983). Current passive remote sensing technology enables the capture of daily images with sub meter spatial resolution and multispectral bands. The cloud penetration ability of active satellite image and its independence from weather condition and day light are the great advantages and help to obtain the Earth surface images when and where the passive sensor cannot. Active sensor can also provide comparable high spatial resolution images as its passive counterparts do (Kuntz, 2010).

Information extraction from remote sensing image is the main target of remote sensing image processing. Recently, with the improvement of spatial resolutions of images, object-based image classification is proved to be more suitable for feature extraction. (Blaschke, 2014).The higher the spatial resolution is, the more complexity in processing. Detection of an object of interest from a classified image is usually uneasy. It is noted that existing remote sensing classification techniques are unable to fulfill the requirement of modern geospatial community (Zhang & Zhou, 2004). On the other hand, small object detection can be done using object recognition techniques, which have been well developed in the fields of image processing and computer vision. They are usually applied for the ground-based camera images with very high spatial resolution. Object recognition is commonly used to find the similar structure object distributed over the image automatically (Cole & Austin, 2004).

2.8.2 Applications of Remote Sensing

In the last decade, numerous researches have adopted several computer vision recognition technologies for remote sensing image processing (Amsaveni, 2013). Examples include detection of tree in urban area, cars in parking area and counting system for harbor boats (Craciun & Zerubia, 2013). Moranduzzo & Melgani (2014) proposed novel car detection and counting method from 2-cm resolution images. The method used scalar invariant feature transform (SIFT) for key points extraction. Grabner Grabner *et al*. (2008) also incorporated boost techniques for the car detection from large scale aerial images. Adaboost machine learning algorithm was used for efficient training of the developed system which did not rely on any prior knowledge about the image. Zhou (2005) proposed a method for extraction of particular objects in remote sensing images based on feature template correlation. The method included three parts: building the template, image match and template correlations, and object recognition. In their study, it was attempted to establish a hierarchical template to recognize the objects from common features to particular features. This was a time-saving method since it avoided searching whole input image for complex features.

Template matching technique is widely used to find the conjugated points in stereo image analysis. Originally developed object recognition techniques in computer vision cannot be simply applied for remotely sensed images. The spatial resolution of remote sensing images is relatively low although much improved. Such images may consist of several other images acquired with different view angles and climate condition. In addition, object of interest is normally very small in comparison with image size and multiple objects of interest presented in the image. Therefore, this encourages researchers to pay more attention on development of algorithms for recognition of small objects from remote sensing images.

2.8.3 Current Automated Technologies for Construction Progress Monitoring

Many researchers have introduced several automated data acquisition technologies including bar-coding, 3D laser scanning, computer vision technology, Photogrammetry; Radio Frequency Identification (RFID), multimedia and pen based computers (El-Omari & Moselhi, 2011). For instance, the integration of 3D laser scanning and 4D Building Information Modeling (BIM) has been employed as an automated progress measurement tool (Kim, *et al*., 2013). In addition; other researchers developed an automated real time monitoring system which links time-lapse digital movies of construction activities, critical path method and visual progress control techniques (Abeid & Arditi, 2002). Zhang et al also investigated the development of computer vision technology to determine the progress of construction from digital images captured on site in order to semi-automate the work in progress measurement (Zhang, *et al*., 2009).

Sun & Hasell (2002) developed a prototype system that suggests that instant spatial data capture provides fast and accurate visual information about the progress on the construction site. Integration of spatial database with the project management functions provides a powerful and effective management control system. In the mass rapid transit (MRT) construction project in Singapore, construction data was handled using GIS-based geotechnical data management system (Kimmance, *et al*., 1999).

Sonmez & Uysal (2008) presented a visualization system using Google earth based on a geographic information system (GIS) to monitor the progress of a pipeline construction project. A prototype was developed for combination of the linear scheduling method with GIS to identify the progress level of the construction along the pipeline project. Marchionni & Guglielmetti (2007) reported a web-based tunnel monitoring system that has been applied in the Bologna high-speed railway tunnel project.

Chapter 3

Research Methodology

3.1 Background

The aim of this research is to explore and evaluate the application of LBM and an automated progress monitoring system for linear infrastructure projects. The information in this research is based on two sources; a literature review and a case study. The literature review has been extensively performed to investigate the interested areas of study and underpinning of LBM theory and satellite remote sensing techniques as well as theories related to research analysis. The case study is on an elevated railway project as an ideal example of linear infrastructure project (with discrete repetitive units) providing the information related to current practice of progress monitoring and also its challenges. Moreover, secondary data collection and few interviews assisted the research on how LBM and automated progress monitoring system can be implemented in linear projects.

In particular, literature review introduced the theory of LBM and its benefits for progress monitoring and controlling linear projects in comparison to activity-based management techniques. As it was discussed, LBMS methodology is basically tracking continuous flow of crews on the project task. This scheduling system emphasizes the defining specific locations in the project in order to plan, monitor and control the workflow. LBM also minimizes the risk of delay through monitoring and maintaining a continuous work for resources, reducing the interferences of crews in the same or near location. Furthermore, the LBMS progress reporting components can assist project participants to get informed of deviations and their total effects. With respect to automated progress monitoring, the previous chapter discussed the application of automated data acquisition technologies and satellite remote sensing for construction monitoring.

3.2 Research Design and Reasoning

The research design usually consists of a framework for data collection and analysis to fulfill the research objectives through empirical and theoretical research. The research design is usually three types; exploratory, descriptive and explanatory depending on the research problems and objectives (Zikmund, 1984). The exploratory research involves in the extensive review of literature or case study group when the research problem is not completely pre-defined and hence the flexibility needs to be maintained. On the other hand, the descriptive approach aims to present a detailed description of observations or phenomena when the research problem is fully understood and defined. Furthermore, explanatory research design focuses on the explanations of the key variables, relationships and cause-and-effect problems in phenomena in where the aim and research problem are fully structured and understood.

This research is based on a semi-structured research problem which aims to explore and evaluate the effectiveness of location-based management and an automated progress monitoring after their implementations in a case study project. Thus, this research is considered as an exploratory nature and accordingly an exploratory research design has been chosen. The case study approach is used to generate an in-depth understanding of complex issue of progress monitoring in such projects (Crowe, *et al*., 2011).

With respect to research reasoning, it is possible to categorize it into two approaches; inductive and deductive (Heit & Rotello, 2010). In deductive reasoning, top to bottom approach is conducted in which observations are used to process general information to a specific conclusion. Oppositely, inductive reasoning is bottom-top approach which uses limited information to process it to a broader theories and generalization. This research aims to develop general conclusions and findings through specific observations and theory. Therefore, the reasoning approach in this thesis is inductive which uses literature review and case study findings.

3.3 Research Method

3.3.1 Data Collection

There are two main methods for data collection in research; qualitative and quantitative. These are considered as two different approaches for collection and capturing of information related to research questions. Quantitative approach contains the quantified data which is tested and analyzed to reach a conclusion. In qualitative method, data is usually interpreted to explore, explain or describe phenomena depending on the research design. The research in this thesis aims to collect the research data using secondary data from a case study project to obtain a conclusion after interpretation of data. The secondary data is based on literature review (including books, articles and reports) as well as companies' reports and documents. Give that the aim of this research is to explore and evaluate the effectiveness of LBM and an automated progress monitoring system, therefore, the research method used in this research has a qualitative nature.

3.3.2 Case Study

The case study method excels at gaining a deep understanding of a complex phenomenon or object which can expand the experience or strengthen our knowledge through previous research. In another word, case studies are appropriate for research in which existing theory is limited or the case can introduce us new important insights (Ghauri & Gonhaug, 2010). The civil engineering department at the University of Nottingham, Malaysia campus has been in research collaboration and partnership with Prasarana Malaysia Berhad in the past few years. Prasarana is the asset owner and operator of rail network and bus services in Kuala Lumpur. One of the on-going constructions of railway project managed by this firm is Kelana Jaya and Ampang Line LRT extension project which extends the previous LRT lines in the city of Kula Lumpur. This study selected a segment from the construction of elevated guideway of Kelana Jaya line as a discrete linear project. There were few reasons which derived this research to select this case study. First of all, data collection was alleviated due to strong collaboration and previous contacts with the company personnel. More importantly, this case study represents an ideal example of linear discrete projects where distinct locations and units can be defined through the whole length of the project. These distinct locations were also suitable for utilization of GIS and satellite remote sensing tool to automate and store the location-based information.

The Kelana Jaya extension project is an elevated rail line running through the highly dense urban area; and consists of 510 piers, and 240 spans of precast box girder segments through the 17.4 kilometers and 13 stations. Based on the project method statement which was collected from the company, the main scope of construction works for the elevated guide way of the project covers four main stages (shown in Figure 3.1):

Stage 1- Bored pile platform and activities (Figure 3.1, top left)

Stage 2- Pilecap construction (Figure 3.1, top right)

Stage 3- Pier works and pier head construction (Figure 3.1, below left)

Stage4- SBG launching and post-tensioning activities (Figure 3.1, below right)

Figure 3.1: Main Construction Scope of Elevated Guideway in Kelana Jaya Extension Project

In the progress reporting implementation of the project, progress reports are generated in soft and hard copy every month by two main contractors and distributed to the main client and consultants for approval and submission. The reports include the work program based on CPM schedule in the form the Gantt chart which shows actual progress against baseline schedule for 510 units in the project and more than 4000 repetitive and non-repetitive activities. In addition, the summary of progress for each station and segment is included in terms of percentage of actual and scheduled progress. Based on the CPM of the latest approved work program, project delays and current projected completion date are reported. In addition, the report contains detailed description for significant development and achievement of each segment based on the project scope of work. To enhance visualization of progress, contractors include site photographs for on-going tasks in several locations. Yet, photos are not taken on a specific day in a month and not classified into locations.

To conduct the experiment, several piers under construction were selected between two stations with the length of over 660 meter. The study collected the secondary data for planned and actual progress of each pier based on the monthly progress. The updated work program based on CPM schedule was collected in the form of Gantts charts containing the actual progress data and the baseline schedule for only five main repetitive tasks including piling, Pilecap, column, pier head and launching works. This collected include the planned and actual start/finish dates for each repetitive task of the linear project. Furthermore, the construction site photos in some selected project segments were gathered to validate/compare with the data collected from satellite remote sensing images. In addition, the overall progress of project, work done for the previous month and planned/forecasted for next month, critical/outstanding issues were collected to identify the sources of deviations.

3.3.3 Analysis

In particular, this chapter extends the theoretical discussion of LBM by implementing and evaluating the application of LBM for monitoring linear projects through qualitative analysis based on literature review and case study findings. The qualitative analysis involves summarizing the collected data to presents the results and discussion for exploring and description of the most important features of phenomena (Hancock, *et al*., 2007). The chapter introduces the research case study and current practice and challenges of conventional progress monitoring in that specific project. With respect to development of automated progress monitoring, the methodology discusses the methods investigated from literature to facilitate automatic detection of progress and then development of a web-based system for progress monitoring and reporting of a linear projects.

3.3.4 Location-Based Management (LBM) Methodology and Techniques

The implementation of LBMS on a case study can provide us with practical solutions for monitoring and controlling linear projects at the micro level and site management. Therefore, the first part of methodology provides the steps for implementation of LBMS monitoring components using location-based planning software called Vico control which is the only location-based software to schedule, monitor and control a project based on the LBM methodology. Therefore, this specific software program was chosen to explore and evaluate the application of location-based theory on the case study project. At the basic level, the resultant project plan is able to control the flow of work production to further empower productivity improvements in production. Planning is also improved with the innovative risk management of projects in progress. Flowline diagram provided in the software helps the project decision makers to monitor the planned and actual progress of tasks within time and locations. More importantly, the flowline visualization of existing CPM schedule (for activity-based planners) in a linear project helps us identify the CPM schedule errors as it was discussed in literature review. The CPM schedule activities should be combined into one task for each type using location-based layered logic to reduce the number of required links between tasks and locations (Arditi & Psarros, 1987). After identification of schedule errors and combining the activities, the flowline view enables the process of optimization of the schedule for duration (as early as possible) and continuity (Pull system). In addition to schedule optimization and use of buffers, it is also necessary to perform a Monte Carlo’s risk analysis to evaluate the risk level based on four different factors and hence estimate the expected completion date of the project and predict the variability in the project. As for the progress stage of LBM, it is possible to differentiate and visualize between deviation types based on the actual progress information exposed in both flowline and control charts. Once deviations are detected and measured, it is also necessary to visualize and forecast the total impact of deviations in the flowline view.

This study attempts to implement the location-based scheduling methods to convert the existing CPM schedule in the case study to a location-based schedule using flowline diagram. This implementation results in an optimized schedule that almost matches with CPM schedule which can be monitored and controlled as LBM schedule. Afterwards, the methodology uses the qualitative and an empirical analysis to evaluate the progress and deviations of repetitive tasks in project locations using LBM techniques. The study also discusses the location-based forecasting process in which the total impacts of deviations are visually measured and evaluated.

Based on the LBM methodology explained above and in literature review, the research methodology implements the following steps using Vico control software:

1) Flowline visualization of existing CPM schedule from a linear project
2) Converting CPM schedule to location-based schedule
3) To perform a risk analysis using Monte Carlo's simulations using Vico software
4) Actual progress monitoring and reporting using flowline and control charts
5) Evaluate the total effect of deviations and possible control actions

Flowline Visualization

The flowline method is the most important location-based tool to visualize project tasks within locations and time (Gorman, 1972; Carr & Meyer, 1974; Perera, 1982). Therefore, the first step is to visualize and represent the CPM schedule into a flowline diagram. The logical relationship and duration of tasks are based on original schedule which can be found in the Gantt chart of monthly progress reports. Locations should be well-defined in the location breakdown structure. This structure has a hierarchy which consists of different levels of location. For example, the elevated guideway of Kelana Jaya line can be broken down by number of segments or packages then further broken into number of stations which can be sub-divided to number of piers. The planned start and finished dates of repetitive tasks are also found in the Gantt chart.

Conversion of CPM to Location-Based Schedule

The existing CPM schedule includes work break down structure, start and finish planned and actual dates of each activity per location. Therefore, it is possible to derive a comprehensive CPM schedule from the heuristics which form the location-based model and can be monitored and controlled in LBM system (Kenley, 2009). The resulting CPM involves in normal CPM logics in addition to as pulled start dates ensuring continuity of work sequencing based on location-based tasks requirements and lean concepts. In another word, location-based schedule methodology forces continuous flow of resources and suggests aligning the schedule through optimization for duration and continuity. In this process, empty spaces between tasks and locations are eliminated by pull based system. Pull based systems changes the production rates so that slope of preceding and succeeding tasks becomes similar. As result of this constraint, sometimes the start of a task may be delayed so the workflow would be continuous through various locations. Based on this methodology, the activities for each type are combined into one task and one crew and then are split into the locations which the crews are assigned to. This encourages the tasks to be finished continuously according to the lean concepts. In addition, using the flowline view of the schedule, schedule waste, idle time and other CPM errors can be revealed. The improvements should be made by removing or reducing the empty space between tasks. It is important to keep in mind that, in location-based scheduling methodology, the schedule is aligned by changing the production rates of the tasks in such a way that slope of preceding and succeeding tasks becomes as close as possible.

As early as possible and continuous

Underlying a location-based scheduling methodology, start dates of locations are usually fixed based on “as early as possible and continuous” condition in order to protect production efficiency. Thus, in CPM schedule, for those tasks which are found continuous (between preceding and succeeding location), it is necessary to use the as soon as possible dates. Similarly, the tasks with as early as possible dates need to be continuous. The resulting plan is always continuous and as early as possible.

Monte Carlo's Risk Simulation Using Vico Software

The study presents a risk analysis using Vico software to evaluate the risk effects on production system such as startup delay, a production rate deviation, and interruption of the work or incomplete locations in a linear project. The proposed location-based planning model utilizes Monte Carlo simulation based on pessimistic, expected and optimistic estimation of duration for each task (Kenley & Seppanen, 2010) . Using this estimation, a planner is able to estimate the impact of variations of schedule and hence provide probability of outcomes. The risk analysis is done by the software using an analysis of schedule iteration to anticipate the impact using the probability input. The iteration process is usually repeated up to 1000 times to make a form of probability distribution based on different scenarios. The risk allocation and simulation covers the following items:

- Start of Schedule: The delay that occurs before the task starts
- Schedule task duration (as percentage): The estimation of task duration to measure it is going faster or slower than the planned
- Come-back delay (hours): The possible delay before the crew return the task after an interruption
- Beginning risk (hours): The possible delay before the crew continues the task in a location after returning to the site

The risk levels are estimated based on the history of actual duration, startup delay, come-back and beginning risk from case study. This involves the estimation of average values of these four parametters from previous months.

Actual Progress Monitoring

In the progress stage, a deviation for each location is measured to examine the quality of baseline schedule and calculate forecast data. In this process, it is important to know the start and finish dates of each individual location in order to plot this information in the flowline diagram. Interruptions should also be recorded as well as actual production rates to provide better forecast information. The current and progress data can be used to calculate forecasts to predict the total effect of schedule deviations and variation and therefore gives an early warning. Forecast makes the assumptions that production continues according to actual productivity rate in the absence of control actions.

The most important tools for visualization of current status of the project is flowline diagram and control charts. If there are too many tasks and locations per flowline, it is difficult to read and benefit from the information. Therefore, there can be defined filtered for visualization of both actual and progress. These filters include: baseline view showing critical tasks, view of detail tasks currently in progress, location or time-based views and subcontractors views. Control charts are also used for illustrating locations which are delayed in comparison to baseline or detail schedules. Later on, the detected deviations can be evaluated based on an empirical research in order to measure and classify them for every project unit.

The first step in planning control action is to classify the deviations into certain groups to identify the potential causes. Deviations can be often categorized into following groups (Kenley & Seppanen , 2010):

- Startup delay or starting too early
- Unplanned splitting of the crew into multiple locations
- Production rate deviation
- Change of work sequence
- Interruption of work

After this step, it is essential to know the reasons why these deviations occurred. This analysis usually demands deep investigation and efficient data collection as well as effective communication by project participants. The explanation and classification can help developing strategies to react to these problems. Therefore, this research aims to briefly explore and discuss such strategies and techniques.

Location-Based Forecasting

The next necessary element is to measure or predict the total effect of these identified deviations depending on the time buffers, production rates of preceding and succeeding tasks and some other factors. The total effect of deviations can be measured and visualized on the flowline diagram.

After deviations and their total effect have been identified, all possible control actions should be considered depending on the resource availability, legal restrictions and other contract limitations. Control actions include the strategies and measures taken to mitigate or eliminate the impact the deviations or recover from such variances to prevent from further delays in project. Possible control actions are classified as following:

- Changing the production rate
- Changing the location sequence
- Breaking the flow of work
- Changing shift length or working overtime

After the control actions plan has been finalized with contractor and subcontractors, the adjusted forecast plays the role of plan which needs to be followed.

3.3.5 Automated Progress Monitoring Methods

This research adopts a qualitative approach where the proposed system is developed using data collected from a case study project. This section describes the overall method for progress measurement of a linear project and representation of the baseline and actual progress in these types of projects. Firstly, the tools and techniques for the automated data acquisition from multi-temporal satellite images, populating and updating of database for actual progress data are explained in detail. This consists of five steps: 1) image co-registration; 2) CAD design alignment; 3) automated detection of repetitive construction stages using several image recognition methods; 4) updating a spatiotemporal database consisting of the geographical coordinates of project locations, the current construction stage and time (date) of data acquisition; and 5) validation process. In addition, the steps for the collection of planned and actual progress data, data integration/query and finally the progress reporting on a web-interface is clearly described. To improve communication, the interface is designed to visualize and report the LOB diagrams and a progress map as well as construction site photos taken by the project contractor. Lastly, the case study project is introduced to validate the progress measurement and reporting practice used in the project. The detailed methods for each step mentioned above are explained in detail. Figure 3.2 shows the overall process for development of the proposed monitoring system.

The methodology also describes the methods used to introduce a framework for automated data acquisition and integration of actual progress with baseline schedule in a linear project to generate progress reports on a web-based platform. The framework of a prototype model is shown in Figure 3.2. The main components of the methodology include the following steps:

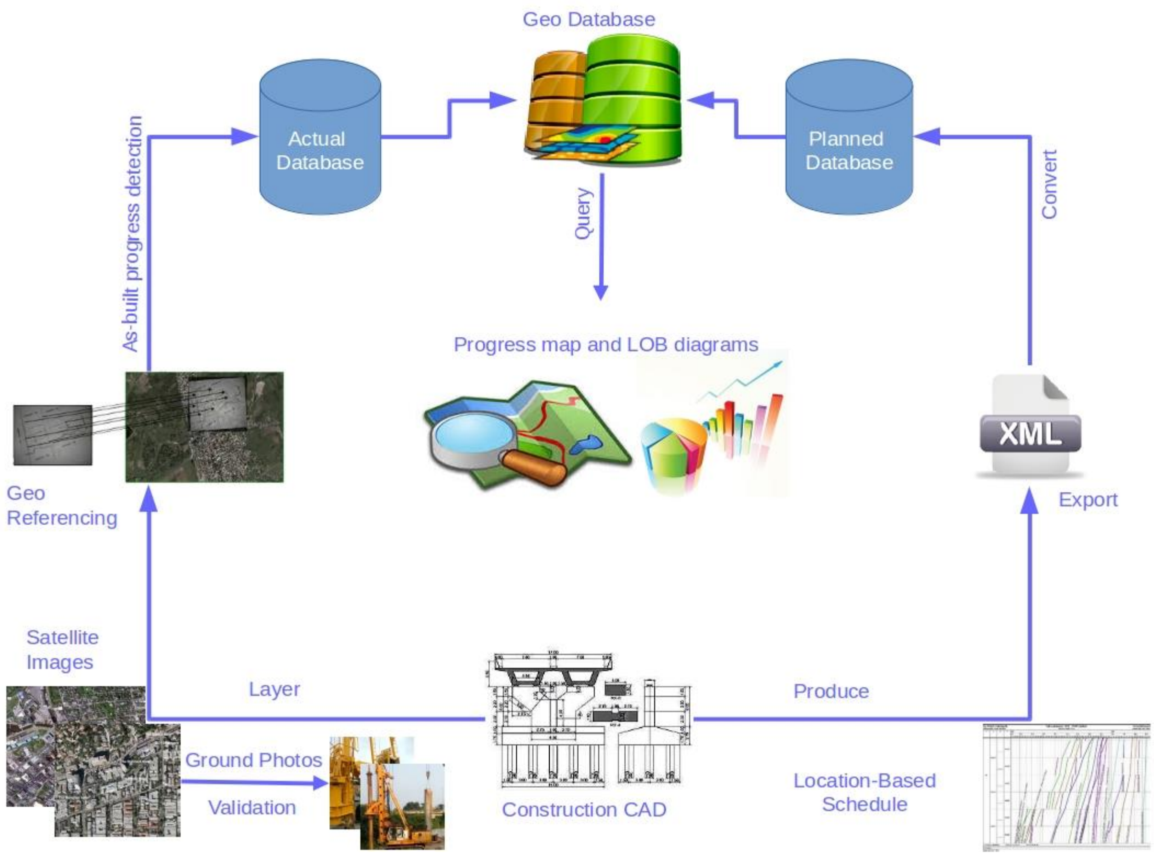


Figure **3.2**: The Main Components of the Automated Monitoring System

Development of Automated Progress Monitoring

Actual and Planned Progress

The first step is to extract the construction schedule in order to input in the proposed prototype model. The schedule can be extracted from Vico Control software. The schedule information for a linear and repetitive project includes list of repetitive work tasks, their planned start and finish dates of each unit or location in the project. As an example, the schedule information of a project with 3 units and four tasks can be seen in Table 1.

Table 1: Planned Start and Finish Dates of Task 1-3 in Units A-C

Unit	**Task 1**	**Task 2**	**Task 3**	**Task 4**
A	t_{A_1}	t_{A_2}	t_{A_3}	t_{A_4}
B	t_{B_1}	t_{B_2}	t_{B_3}	t_{B_4}
C	t_{C_1}	t_{C_2}	t_{C_3}	t_{C_4}

In addition to construction schedule, actual progress of each location/unit must be identified from satellite image using remote sensing techniques. The planned progress of each location or unit can also be calculated from the extracted schedule based on the date of data acquisition. Using integration of planned and actual progress for each location, a system can be developed to automatically measure progress of each location and report the progress through location-based diagrams and visualization techniques.

Automated Progress Detection

The main function of the proposed prototype model is to automatically identify different construction stages from multi-temporal satellite images. The extraction framework may be divided into four steps. As an initial stage, all multi temporal and multi-source data are co-registered into one single coordinate system. Secondly, construction CAD design must be aligned and matched with the approximate location of construction sites on satellite image. In the third stage, the system detects current construction stage by applying different image processing and feature extraction algorithms. Finally, spatiotemporal database is updated according to the current or revised progress status of each location.

Image co registration and CAD design alignment

In this process, satellite images are the main source for data collection. Multi-platform and multi-temporal images are affected to deformation because of their orbital direction, viewing direction, sun elevation and etc. Therefore, same geographical objects which are found on different temporal images are represented in different geographical location with distinct visual appearance. To overcome mismatching problems of these images, each image must be co-registered into one system. In this study, technique of image to image object-based geo registration is applied. These conjugate geographical objects from different images are identified and spatial coordinate translation between images is calculated. Finally these translation parameters are used to rectify the spatially deformed images.

CAD drawing represents the construction design of a project, including relative coordinates, shape, size and orientation of construction structures in each location. Coordinate system used in CAD drawing is defined in an arbitrary system and therefore it is not according to geographical reference system. To identify the construction site on top of geographically corrected satellite images, the construction design must be properly referenced with geographical coordinates. Therefore, in alignment process, the coordinates match with similar structures from both images and then CAD drawing finds the translation between two data sources. Prior to this, CAD drawing must be scaled and oriented to true north. In such a way, it is easy to match similar features except the existing coordinate shift. Topological relation between construction sites is used for structure matching. After matching the image and CAD drawing, it is possible to properly overlay the two different data layers and hence the approximate construction site location can be found on top of the satellite images.

Progress stage detection

After identification of the construction site, next step is to detect current construction progress per each location. There are several possible methods for feature recognition from satellite images (Amsaveni, 2013). These extraction methods depend on the characteristics of the interested object or phenomena. In this study, three different image processing methods are used: Object Base Image Analysis (OBIA), Template based image recognition and vegetation index images. Images are interpreted with their visual characteristics such as shape, size, color, pattern, orientation and contextual information. Construction object is also identified based on above visual characteristics (Blaschke, 2014).

OBIA is a process which separates the image into several segments and analyses these segments according to their shape, size, color and orientation (Zhou, 2005). Using this method, it is possible to identify the object using the predefined geometric parameters.

Template based image recognition aims to find the best correlated image location according to the predefined template. This method is suitable for complex structures which are difficult to be expressed in simple geometrical elements. This method is used to identify the similar visual structure from images. Clipping image with such a construction stage can be considered as a sample template which moves through whole image and finds the correlations between template and each location in image. Finally highest correlated location is considered as the best matching point. In this way, each construction location can be detected as well as the construction progress of the selected template

Image Indexing –Normalized Difference Vegetation Index (NDVI) is an image analysis method based on spectral quality of different image bands. NDVI is most suitable for green area mapping. This spectral quality of NDVI image can be used for progress identification. Once the construction project commence, surrounding vegetation is destroyed and bare soil appears. As result of these changes, the NDVI value of each location also varies. Theses NDVI changes indicate certain progress stage for each location. Using above single analysis method, different construction structures and their progress stages can be automatically detected.

Spatiotemporal Database Updating

Spatiotemporal database is a database which represents the actual construction progress for each location with their geographical coordination and time (date) of image acquisition. Once construction progress is detected, the geographical location is extracted and matched with CAD drawing to find the most suitable construction location. Finally, the progress status of construction location is updated. In this process, detected progress stage is cross checked with the previous sequence of construction tasks of a particular location. If it matches with the previous construction sequence then it is considered as a successful identification.

Validation

The proposed and developed approach in this study was to complement the progress data collection at the site by providing the multi-temporal synoptic top-view image and matching the derived information with the progress data recorded by the project contractors. The question is: how reliable is the extracted information able to reflect the real situation? Here, the validation process aims at evaluating the accuracy of feature extraction for each construction stage by comparing the acquired results with the actual progress data. The ground- based construction progress reports can be considered as the ground truth data. The detected repetitive activities per each location are cross checked with their actual status recorded from the monthly progress reports, which are generated through the frequent site visits. The evaluated accuracy is represented in a form of confusion matrix that reports the correctly detected samples (True Positive), the incorrectly detected samples (False Positive), the correct but ignored samples (False Negative) and the correctly ignored samples (True Negative).

Development of Web Interface

The development of web-interface consists of the following aspects:

A. Architecture

The purpose of creating this web-interface is to automatically measure actual progress of a repetitive construction project with respect to accessibility, usability and readability.

Using this interface, end-user would be able to generate progress reports in very straightforward steps. The user needs to access to a normal computer in order to upload planned schedule and available site photos for each location. The progress data is also reported in line of balance diagrams and a top view progress map as well as available construction site photos.

- Architecture

System architecture involves all components which generated the final output as the web interface. Prime components of the system include 1) Operating system: a platform to host all other middleware tools such as application server, database management server and web interface. 2) Application server: works as a store layer for hosting satellite images with different dates. 3) Database management server: to save spatial data in the form of tables 4) Web interface: consists of open source libraries to represent geographic data and generate diagrams and a map to visualise planned and actual construction progress.

- Logic/Data Flow

Data flow involves all required phases to get the final output. These phases include data collection, data integration, retrieving data and data representation.

- Collection of planned and actual data:

This phase represents the accumulation of remote sensing and GIS in terms of data formatting. Actual progress data is directly acquired in the form of shape file, while planned data is exported in the form of XML file from Vico software. Both datasets “planned and actual” are used to process and output the progress reports. However, these datasets are integrated or unified in order to be processed.

- Data integration

This phase aims to unify data structure for both datasets by writing scripts to convert planned and actual data in the form of tables into Postgres database. Postgres Relational Database Management System (RDBMS) is a well-known engine which supports spatial data type and gives high performance with large-scale data. By the end of this phase, database created with tables contain location info; the planned and actual start and finish dates of construction tasks.

- Querying data

Using stack of open-source technologies such as PHP, Python, OpenLayers, GeoServer, enable retrieving and sending such data to the proper library (e.g. High charts) to visualize retrieved data in progress reports.

- Progress reports

As a final output from the system and using previously queried data, both planned and actual progress can be visualized in different graphical techniques on the web interface. The proposed system uses line of balance diagrams and a progress map to represent the progress data in simple graphical formats. The following diagrams are used to visualize the progress data for each location:

1) Progress chart can determine the number of units locations for which each of the repetitive task has been completed on a specific time. The main purpose of progress

diagram is to develop a comparison of current progress with planned objectives.The bars which are below the balance line are the elements of the Endeavour which can be picked up by top management as requiring remedial action. The balance line can be obtained from the scheduling software by calculating the planned status of each location for a particular time (date). Figure 3.3 shows an example of the progress chart for four repetitive tasks.

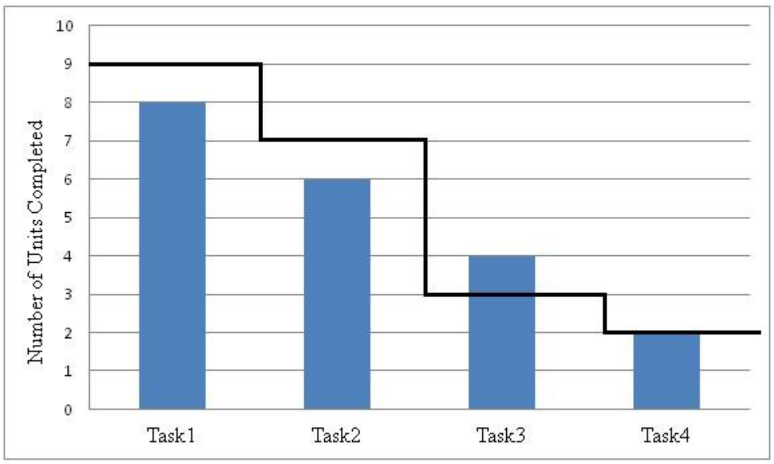


Figure 3.3: A Typical Progress Chart for Task 1-4

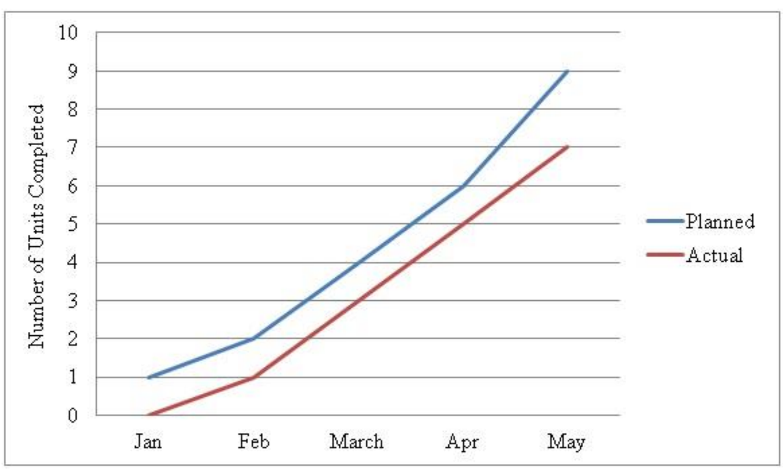


Figure 3.4: A Typical Objective Diagram

2) The objective diagram as shown in Figure 3.4 also is provided to record the cumulative events of unit completion. The actual trend of progress can also be determined with another line.

3) Location-based progress map as shown in Figure 3.5 is the top-view satellite image which contains the necessary information for each location. This information includes location ID, planned, actual progress, and station or segment number in the project and zone information for each project location. Each progress stage is also represented by a specific colour on the top-view image. The progress map also allows the user to observe available site photos taken in a particular time (month) per each location.

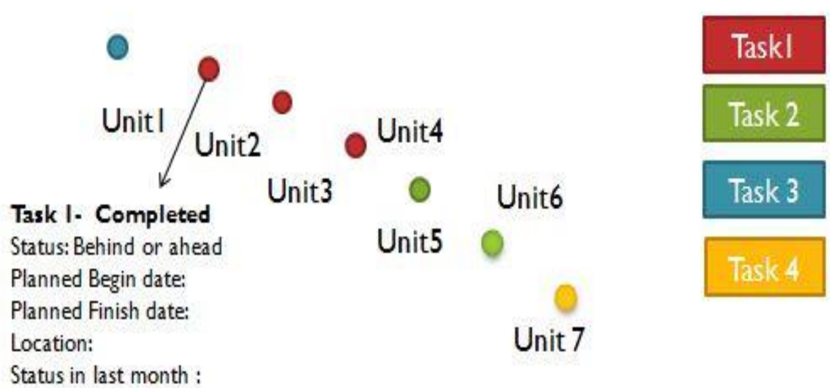


Figure 3.5: Proposed Progress map

Chapter 4

Results and Discussion

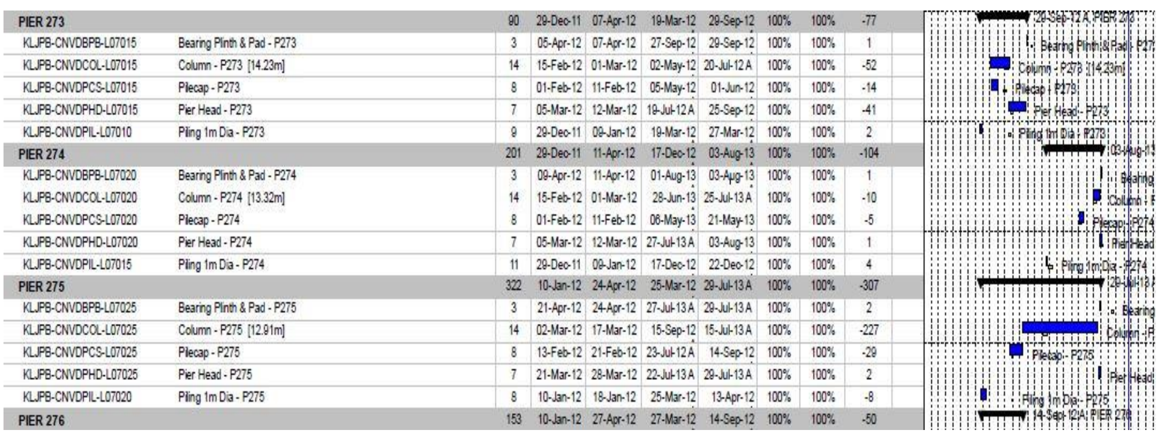
4.1 Introduction

The chapter demonstrates and evaluates the LBM methodology for progress monitoring of Kelana Jaya LRT extension project with the aid of Vico control software. The benefits of location-based approach will be extensively evaluated and analyzed in comparison to activity-based progress monitoring and reporting. As it was explained in research methodology, the CPM schedule of case study is first represented and visualized into flowline diagram. The schedule is then converted to an optimized location-based schedule which can be managed and controlled in LBM methodology. The research performs the Monte Carlo risk analysis using Vico control software in order to estimate the impact of variations of schedule and hence provide probability of outcomes based on previous actual progress data from the linear project. The study uses LBM methodology to monitor and evaluate the progress of repetitive tasks, the flow of resources and project deviations for 9 piers from the selected segment of Kelana Jaya LRT extension project. The actual progress data is reported into location-based monitoring tools including flowline and control charts. The study also introduces an empirical research on deviation using actual progress data to evaluate the progress of each repetitive task. In addition, the total effects of deviations are measured and forecasted in the flowline diagram to suggest necessary control actions. In the second section, this chapter also presents the results for use of several image processing techniques for automatic detection of construction stages.

Afterwards, the chapter will look into the framework to develop a web-based progress monitoring and reporting of Kelana Jaya LRT extension project.

4.2 CPM Schedule in Gantt chart and Flowline

The project planners for Kelana Jaya project use critical path method (CPM) to plan, monitor and control the project. The CPM schedule and progress status of activities can be found in the traditional Gantt chart which is documented in monthly progress reports. The chart shows the planned and actual start/finish and duration of each task in different piers and stations. The Gantt chart is also used to indicate the status of each activity in the current date using a vertical line. The chart includes the completion rates of each activity in percentage, the variance of schedule and current progress as well as total float. Figure 4.1 shows the Gantt chart of CPM schedule of a segment in Kelana Jaya project.



PIER 273		90	29-Dec-11	07-Apr-12	19-Mar-12	29-Sep-12	100%	100%	-77
KLJPB-CNVDBPB-L07015	Bearing Plinth & Pad - P273	3	05-Apr-12	07-Apr-12	27-Sep-12	29-Sep-12	100%	100%	1
KLJPB-CNVDCOL-L07015	Column - P273 [14.23m]	14	15-Feb-12	01-Mar-12	02-May-12	20-Jul-12 A	100%	100%	-52
KLJPB-CNVDPCS-L07015	Pilecap - P273	8	01-Feb-12	11-Feb-12	05-May-12	01-Jun-12	100%	100%	-14
KLJPB-CNVDPHD-L07015	Pier Head - P273	7	05-Mar-12	12-Mar-12	19-Jul-12 A	25-Sep-12	100%	100%	-41
KLJPB-CNVDPIL-L07010	Piling 1m Dia - P273	9	29-Dec-11	09-Jan-12	19-Mar-12	27-Mar-12	100%	100%	2
PIER 274		201	29-Dec-11	11-Apr-12	17-Dec-12	03-Aug-13	100%	100%	-104
KLJPB-CNVDBPB-L07020	Bearing Plinth & Pad - P274	3	09-Apr-12	11-Apr-12	01-Aug-13	03-Aug-13	100%	100%	1
KLJPB-CNVDCOL-L07020	Column - P274 [13.32m]	14	15-Feb-12	01-Mar-12	28-Jun-13	25-Jul-13 A	100%	100%	-10
KLJPB-CNVDPCS-L07020	Pilecap - P274	8	01-Feb-12	11-Feb-12	06-May-13	21-May-13	100%	100%	-5
KLJPB-CNVDPHD-L07020	Pier Head - P274	7	05-Mar-12	12-Mar-12	27-Jul-13 A	03-Aug-13	100%	100%	1
KLJPB-CNVDPIL-L07015	Piling 1m Dia - P274	11	29-Dec-11	09-Jan-12	17-Dec-12	22-Dec-12	100%	100%	4
PIER 275		322	10-Jan-12	24-Apr-12	25-Mar-12	29-Jul-13 A	100%	100%	-307
KLJPB-CNVDBPB-L07025	Bearing Plinth & Pad - P275	3	21-Apr-12	24-Apr-12	27-Jul-13 A	29-Jul-13 A	100%	100%	2
KLJPB-CNVDCOL-L07025	Column - P275 [12.91m]	14	02-Mar-12	17-Mar-12	15-Sep-12	15-Jul-13 A	100%	100%	-227
KLJPB-CNVDPCS-L07025	Pilecap - P275	8	13-Feb-12	21-Feb-12	23-Jul-12 A	14-Sep-12	100%	100%	-29
KLJPB-CNVDPHD-L07025	Pier Head - P275	7	21-Mar-12	28-Mar-12	22-Jul-13 A	29-Jul-13 A	100%	100%	2
KLJPB-CNVDPIL-L07020	Piling 1m Dia - P275	8	10-Jan-12	18-Jan-12	25-Mar-12	13-Apr-12	100%	100%	-8
PIER 276		153	10-Jan-12	27-Apr-12	27-Mar-12	14-Sep-12	100%	100%	-50

Figure 4.1: Gantt chart based on the CPM Schedule of Segment 7

To evaluate the benefits of this tool, it is worth noting that using this method it is simple to know whether a repetitive task has commenced or finished, however it is difficult to measure actual completion rates accurately for those tasks which have started but are still in progress. Nevertheless, using this visualization method, it is quite quick to identify tasks which are behind or ahead of schedule. Despite the benefits of Gantt chart, the following can be considered as the disadvantages of Gantt chart in monitoring the progress of elevated guideway construction:

- Due to large number of piers, the Gantt chart has numerous rows representing more than 4000 repetitive activities in Kelana Jaya line project. Therefore, the progress reports are usually too long and space consuming.
- More importantly, it does not clearly show the effect of deviations on overall progress. For instance, when the progress of one pier is delayed, it is not easy to visualize the impact of this variation on other piers in next station.
- In addition, deviations cannot be differentiated between startup delays, interruptions and slowdowns for each repetitive task
- The impact of deviations on other project segments also cannot be clearly visualized. Therefore, the process of forecasting for a project with 13 segments can be a time consuming and troublesome process.
- The progress in one month can only be compared with another month only when using few status lines. For example, it is not possible to compare the planned and actual progress of column or pier head works in July and August without comparing two monthly progress reports.
- In addition, this way of schedule reporting does not provide information about the flow of resources working on each task while this information is critical for such a large projects when planners decide

- On top of all, it is not possible to determine the production rates of different tasks. In another word, it is not clear to identify in the schedule which tasks have higher production rates. In Kelana Jaya line, the planners and decision makers do not have a clear visualization of productivity rates based on the Gantt chart while resource allocation is very dependent on knowing the productivity rates of actual progress for every task in the project

In contrast, the flowline visualization of schedule benefits project planners with providing more useful information about planned and actual production in different months, the flow of resources, productivity rates and etc.

4.3 Flowline Visualization of CPM Schedule

Given the weaknesses of Gantt chart in reporting the progress, the CPM baseline schedule was visualized into flowline diagram for representation of more useful information on a single char as shown in Figure 4.2. Locations in this linear project are broken down into stations and piers based on locations hierarchy of each pier. In location-based planning, the highest level of this hierarchy usually belongs to locations where it is possible to build the structure independently of other levels. An example is the span of elevated guideway which is built independently from other stations. In this time-location diagram, the slope of each task represents the productivity rate of each task which identifies which tasks go slower than others. The planned start and finish dates of activities can now be clearly determined in a glance. In addition, it is now easier to understand the logical relationship between the activities and the flow of corresponding resources in different locations. In comparison to this type of representation, Gantt chart does not provide visualization-based information on productivity rates of tasks and the flow of resource and hence it is difficult to understand relationships between locations in the project. In overall, flowline representation is a better tool to model production in repetitive construction.

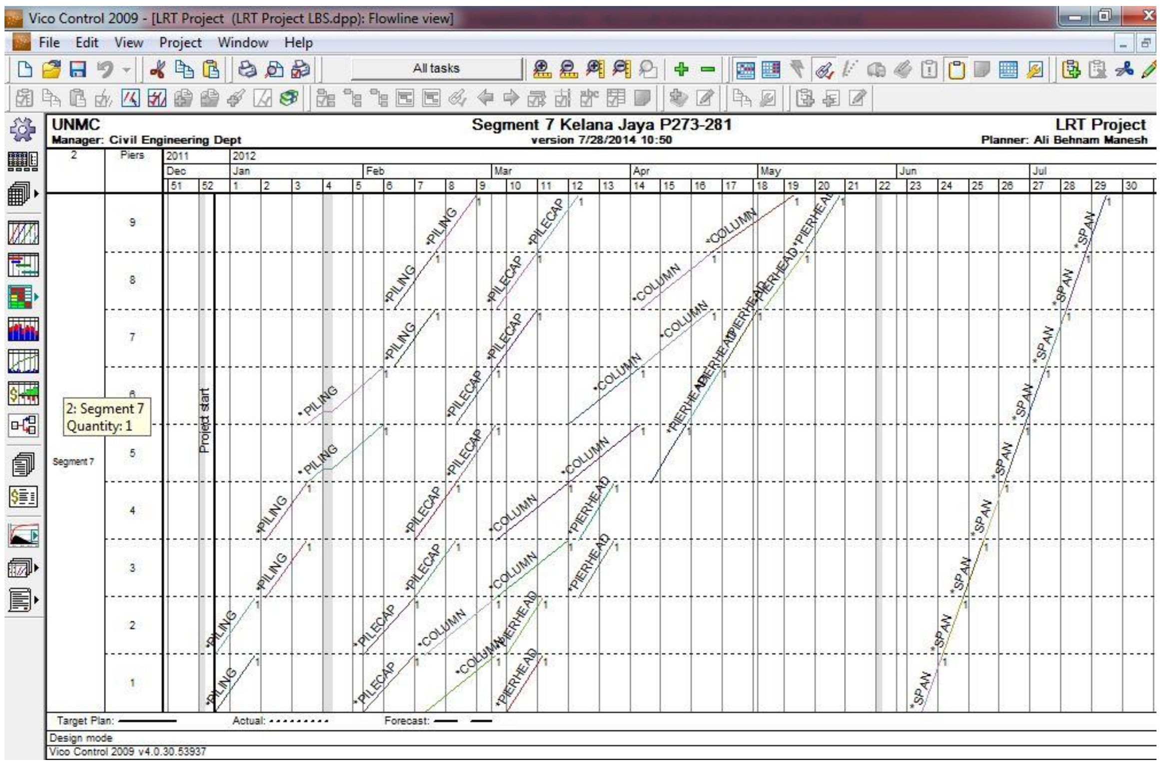


Figure 4.2: Flowline View of CPM schedule

4.4 Conversion of CPM to Location-Based Schedule

4.4.1 CPM Errors in Flowline

Despite the better visualization of planned progress, CPM schedule shown in the flowline in Figure 4.2 reveals some waiting time and errors which result in discontinuity of tasks between locations. There are few inconsistencies in the CPM schedule can be exposed using the flowline visualization of schedule. For example “pier head” task goes twice as fast as column and two crews have been allocated in the CPM schedule. Therefore, there is overlap and waiting for these crew which causes workflow disruption and poor utilization of crews working from location to another location. This work should be recombined into a single crew. It is evident that using flowline it is easier to observe waste and some discontinuities between locations. One reason for discontinuity and waiting time of task can be considered as the varying production rates and duration of tasks with the same quantity. For instance, the duration of column work with same quantity, changes over different locations, and therefore this causes some inconsistencies in the CPM schedule.

In contrast, in location-based scheduling, planning is easier by considering multiple locations as a single planning component and specific tasks which can be duplicated for each location. Therefore, the CPM model which consists of 4000 activities can be replaced by 100 tasks across 200 locations. As it was discussed in the literature, these benefits encourage planners to use location-based scheduling for better visualization and optimization of schedule and resources.

4.4.2 Schedule Optimization

As it was discussed before in literature, LBS methodology forces continuous flow of resources and suggests aligning the schedule through optimization for duration and continuity. In this process, empty spaces between tasks and locations are eliminated by pull based system. Pull based system changes the production rates so that slope of preceding and succeeding tasks becomes similar. As result of this constraint, sometimes the start of a task may be delayed so the workflow would be continuous through various locations. In addition, the varying production rates and inconsistent lags between activities in different location can be eliminated by combining the same type activities into one task. As shown in Figure 4.3, the improvement was applied to “pier head” by allocating one crew for this task instead of two. In Vico control, all the activities were combined into one task for each type. Then the tasks were split into two crews for piling, pilecap and column as their productivity rate is half of the pier head and span tasks. In addition, all the tasks were planned to be as soon as possible and paced to maintain the concept of continuity. And finally the CPM logic was reinserted to get the timing as per the original schedule. This results in a schedule which almost matches the CPM schedule but which can be now managed and controlled as a LBM (LBM) schedule.

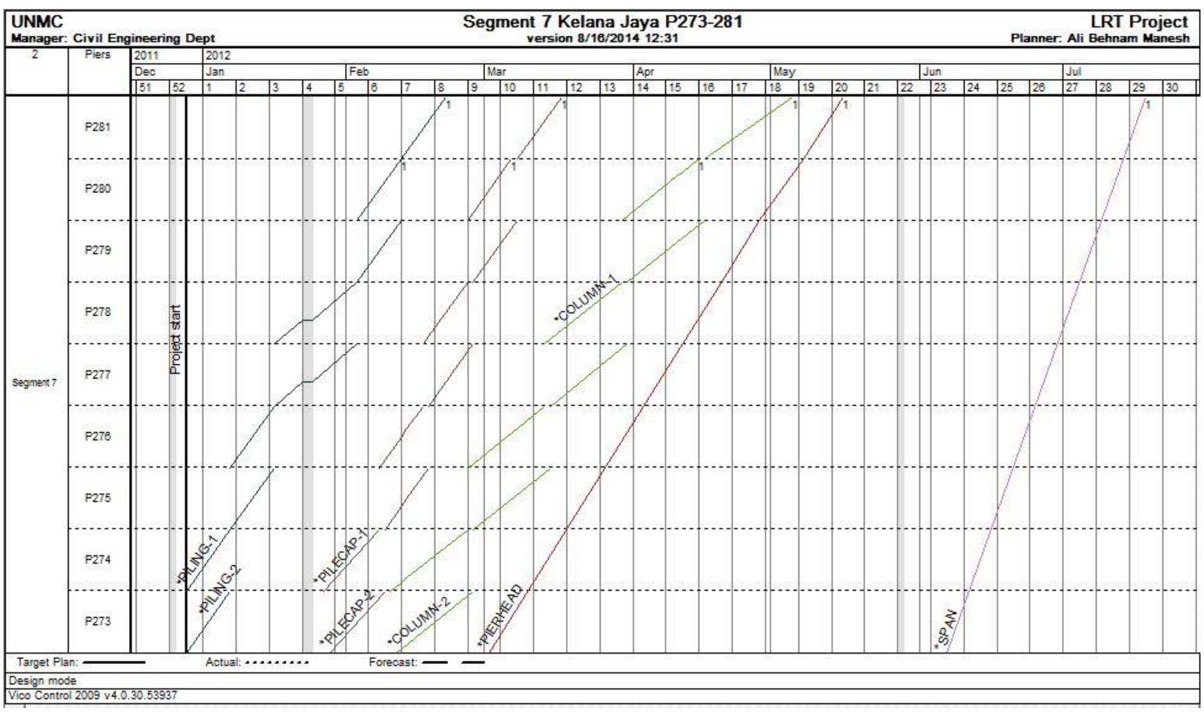


Figure 4.3: Improved Schedule after Optimization

In the actual location-based planning process, aligning schedule is achieved by altering the productivity rates in order to align the slopes of proceeding and succeeding tasks. In that case, the slope of tasks will be as close to parallel as possible and hence the schedule reduces the interruption time between tasks through a continuous work flow.

The productivity rates can be changed by altering the crew size and amount of resources to achieve an aligned and continuous schedule. However in this study, the existing production rates of different tasks are not aligned to maintain the resources availability and other planning parameters. Nevertheless, the main advantage of this approach is evaluated when each task is given one specific crew which can flow continuously between locations with the least waste time.

4.4.3 Location-Based Layered Logics

In large multiple unit projects such as Kelana Jay, the common control action chosen by planners is to change the sequence of locations due to unexpected reasons such as relocation of services, accidents, weather conditions and etc. In these cases, a planner faces a big challenge to change the logic between locations and hence loses the flow of resources.

The combination of CPM logics and location-based logic makes the process of scheduling more efficient and time saving as planner would not need to spend considerable time for copying links and updating changes of logics. Therefore, more time can be allocated for optimization of production rates and resources consumption.

Location-based layered logic is used in location-based schedule to minimize the number of links between activities and locations. The power of layered logic completely depends on the location-based schedule of project and how quantities are allocated for both tasks and locations. Layer 1 logic is the most powerful form of layered logic as it follows the same logic to all locations where preceding and succeeding tasks take place together. Since this project includes over 500 locations, the use of layer 1 logic decreases the number of relationships between activities. The typical example of this layer is the

Finish-Start relationship between piling and pilecap task in the same pier with consideration of required lags. Layer 2 in this location-based model relates the link between different hierarchies of locations. For example, launching segments can only start along the station only after pier head task per each and every location is complete. This requires another link which connects the task in one hierarchy of location to another. Layer logic 2 for launching segments may increase the duration. However, the continuity for use of launching gantry would be maintained which saves considerable time and cost as it minimizes the need for moving launching gantries to different locations. Layer 3 logic forces continuity between location-based tasks and allow the change of locations sequences of tasks. This layer is necessary for repetitive construction projects such as LRT as contractors may require completing work locations in different sequence.

4.5 Actual Progress Monitoring and Reporting

Based on further investigations on updating CPM schedule, it is common that revised planned dates are adjusted according to the actual data for many locations. This fact is evident when looking at the updated approved baseline program for September, October 2012 and March 2013 progress reports (Group, 2012). There are only a few occasions when updates are based on control actions planning. This is consistent with the previous studies which point out that there is a significant problem with the activity-based monitoring and control system for linear projects like LRT extension project. As Kenley and Sepannen (2010) discuss, it is common that the activity-based approach only depends on the process of updating the schedule based on time performance data and assessing the schedule for consequences using the constraints of the logic network. This provides consequence information only and it is provided long after the events which caused the problem have passed. The timing of the information is usually too late due to infrequent updates as the progress reports are produced on monthly basis. When one takes a behavioral view of the construction management processes in Kelana Jaya line, it is clear that decision makers do not want to admit that there are problems. The late provision of progress data and the failure to forecast future problems enables them to push the problems into the future by deciding to solve them later rather than taking actions now. Prior to effective control action, frequent monitoring is required to detect the possible deviations and their effects.

4.5.1 Monitoring Current Status

The first step for monitoring the progress is to collect the progress data in an effective way. Collection of location-based status data can be done using two different methods: 1) Centralized information collecting 2) Distributed information collecting

1) In centralized information collecting, a person in charge would visit each construction station to record the status of each pier in each segment of Kelana Jaya line. Although, this method does not give sufficient information about the exact start dates and detailed problems, it gives us a useful snapshot of progress in each individual location in each status date. In this approach, Prasarana as the client company would be responsible to take the track of the quantity variations, status of each pier as well as resource requirements in the segment.
2) In distributed methods, each contractor working in Kelana Jaya project should self-report about the status of their work location including accurate start and finish dates for each pier. In this approach, the crew responsible for piling,

pilecap, pier and launching works can inform the head office about outstanding issues and suggested control actions per location.

The best way recommended for such large project is the implementation of both strategies by double checking the information provided by both subcontractors through weekly meetings. As the first step of controlling process, it is essential to effectively update the status of each pier and repetitive task into flowline diagram and control chart.

4.5.2 Progress Stage and Detection of Deviations

Flowline

The best tools for visualization and reporting of actual progress are flowline diagram and control charts. Based on the monthly progress reports prepared by the project contractors, actual progress was obtained, visualized in the flowline. This is a powerful method which requires accurate information about the actual start and finish dates of each task as well as any interruptions in every location. This way of representation helps decision makers to implement better control actions after the deviations and their impact have been identified and visualized. Figure 4.4 the actual progress of the elevated guideway compared to the schedule for end of September 2012.

One of the benefits of this diagram is that not only it is easily to observe the change of location sequence but also the diagrams differentiates the startup delays from production rate deviations, interruptions. In addition, the diagram can be monitored historically since previous dates are also viewed unlike in Gantt chart that only shows the actual progress on a certain date or month and excludes the progress of previous months.

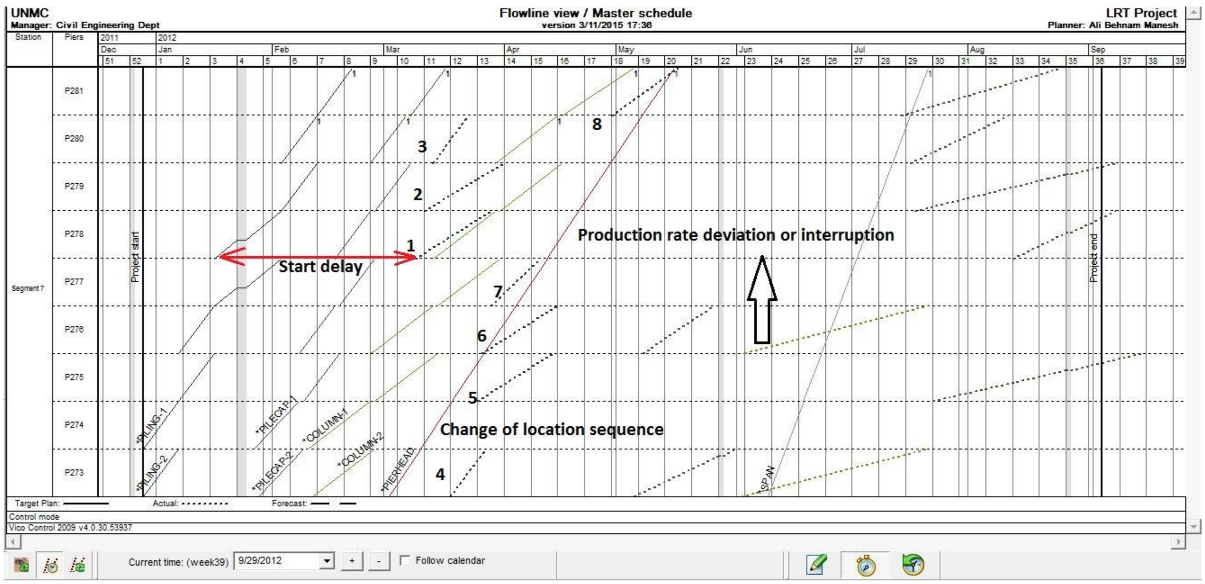


Figure 4.4: Actual Progress and Deviation Types in End of September 2012

The actual progress identified from the flowline can help the project decision makers to take the corrective actions to prevent further delays. With respect to construction of elevated guideway, different types of deviations and their typical causes are addressed as the following (Group, 2012):

1) Startup delays or too late start date of a task:

These types of delays are usually caused by late procurement, delivery of materials or not available resources on the site. Based on further investigations, starts up delays for this segment are caused for the following reasons:

- Site clearing works: trees cutting, removal of existing road kerb
- Road works: temporary road widening
- Delay in relocation of underground services for telecommunications cables and water pipes along the guideway
- 4 month delay for approval and implementation of traffic diversion

- Delay in the fabrication of launching gantries as well as the production and delivery of concrete segments box griders
- Design issues such as pending confirmation of additional retaining wall

As it can be seen in the figure, the delays in the relocation of services somehow forced the contractor to add one more crew working on piling tasks. Considering the acceptable productivity rates of piling work, resources were efficiently utilized which in fact mitigated the impact of previous startup delays in the most of work location. However, no work has been done at P274 due to the relocation of services and other potential reasons.

2) Deviation of production rate or actual/planned duration:

There are several reasons for this type of deviation to occur. First reason is that, there may be too few resources available on site to finish a task. For instance, a smaller crew than the planned size might have been allocated for a task to allow continuity for the succeeding task. Alternatively, the interference of other trades along the work location may cause some delay. However in this case for segment no. 7, four crews are working on pilecap while two teams were planned to be working. Later on, since the same crew and resources for pilecap can work on installing the formworks and rebar, column work carries on with the least startup delay. This explains the concern of contractor about further delays in pilecap works and hence the tendency for increasing the number of teams in order to begin pilecap works in 4 different columns at the same time. Despite the increased number of resources, productivity rate for pilecap task varied significantly. Therefore, it is necessary for top management to investigate about the possible reasons for the decreased productivity rate. Risks associated with a task should be measured prior to the start of production in a pier. These data should be communicated to stakeholders and preventive actions taken. Neglecting this can actually affect the productivity, and hence cause work interruptions, extra costs.

3) Change of location sequence or work sequence

Out of sequence deviations in linear and repetitive construction projects like LRT is a common event as planner has wide choice to complete the locations in different sequence depending on availability of resources, ready tasks and etc. However, change of sequence may result from poor communication between the subcontractors and crews. Sometimes, subcontractor also decides to start with an easier work location to finish more works later.

The main source of sequence changes may be the change in flow of resources from one segment to another. For example, since the contractor may not have sufficient information about the planned and actual number of excavators or boring machines, subcontractors starts with easier or more accessible piers. This is an evident fact between P278-279-280 and P275-276-277. Although this may not directly affect the original plan there is still a possibility of occurring delay when the contactor wrongly takes decision to start a task in a location earlier than necessary. In addition, as result of pending relocations of utilities in segment 7, the subcontractor proposes to change the launching sequence with 1 launching gantry (LG) from P273 to 2 LG from P321-375 and P321-P273.

4) Work interruptions

Construction of the elevated guide way can be interrupted due to some reasons. For example, the subcontractor may require moving the crews to another construction site because of urgent work to be done. Other causes sometimes relate to bad weather condition or slow productivity of preceding task. Since the Gantt chart of progress reports do not separate productivity rate deviation and work interruptions, it is not possible to identify whether long duration of pilecap works at P275, 279,281 is because of work interruption. Therefore, it is necessary for the contractors to document all the interruptions for each pier.

Control chart

Another important tool is production control chart where all the activities planned and actual start and finish dates are shown in the form of a matrix of tasks and location. Figure 4.5 shows the control chart for 9 piers in the selected segment.

Progress status for each task in this chart is highlighted and group with different color codes depending on the following status: a) the piling task for the pier has been completed as shown in the green color box b) the work is in progress and schedule c) yellow color indicates that the column work is in progress but the task is behind the schedule d) the red color shows that pier head and span for all the piers should have started and hence it is behind schedule e) Work interruption also can be reported based on two categories: On time and paused or late and paused.

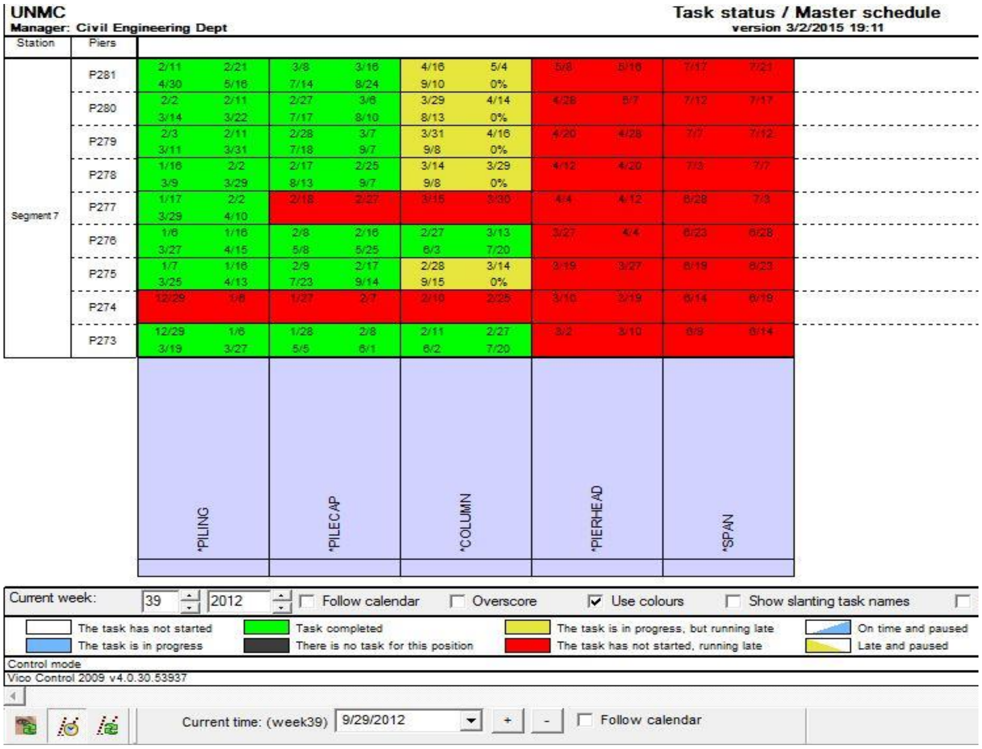


Figure 4.5: Control Chart in End of September 2012

Based on the control chart shown in Figure above, it is possible to immediately identify the piers where a task has not been completed and hence resulted in the next crew being unable to finish the other task in the same pier. During the site meetings, all the piers which have problems should be discussed and also a list of reasons for each pier should be produced by the contractor. However control charts unlike the way its name implies, should not be used to plan control actions as it is necessary to be informed about the location and resources availability as well as productivity rate. This approach can enhance the process of learning for the project if the control charts are printed in the consistent format with the same order of piers and pier tasks. This type of reporting significantly solves the problem of current practice of printing out a new set of Gantt chart every month.

4.5.3 Empirical Research on Deviation

The main reason for the accurate documentation of deviation is to enhance the process of learning from the previous mistakes in order to apply this experience in other segments of Kelana Jaya project which are very similar to each other. These experience should be considered in planning other locations of the same project or when doing pre-planning and risk analysis for future project. After classification of deviations types, this section presents an empirical study using actual data from the segment No. 10 in Kelana Jaya line. Figure 4.6 shows the flowline diagram including both planned and actual progress data from the beginning to the end of project.

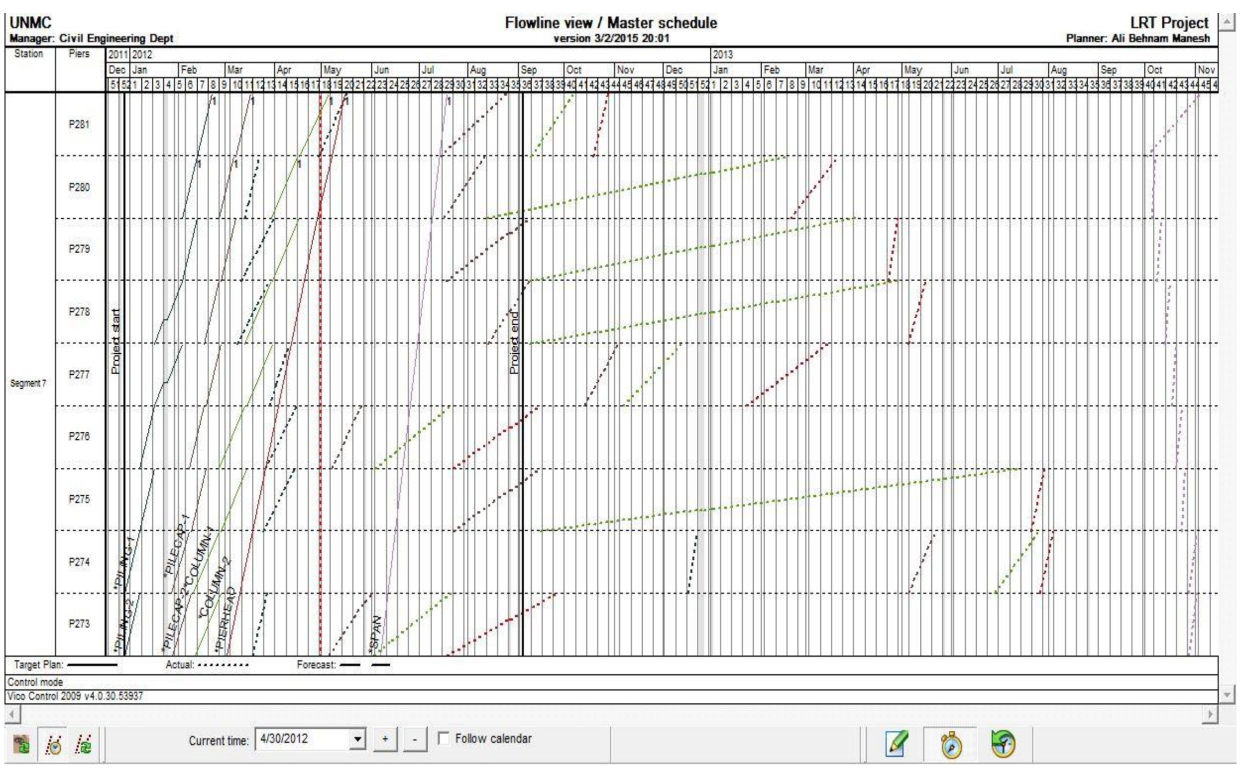


Figure 4.6: Actual Progress of Completed Guide Way, End of October 2013

Startup delays for each task and location can be measured by calculating the difference between actual start dates of succeeding activities and finish dates of preceding activities excluding time lags. Figure 4.7 demonstrates the startup delays for piling, pile cap, column and pier head works. The reason that launching span was excluded was the dependencies of this task on availability of launching machines as well as completion of the pier head in every pier of the segment. The findings show serious deviation in piling and pilecap task. The major startup delay in the second pier can be considered as the main cause for serious deviation in piling task. Other locations seem to have almost the same startup delays for piling. In contrast, the standard deviation of startup delay for pilecap between different locations shows that resources were split between several locations and hence not efficiently managed. On the other hand, column and pier head had minor startup deviations. Final delays are also calculated by measuring the difference between actual finish dates of succeeding and preceding tasks excluding time lags. Figure 4.8 demonstrates that piling, pilecap and column caused almost the same amount of delays. On the other hand, pier head had the least final delays despite productivity rate deviations was over 3 times more than the original plan.

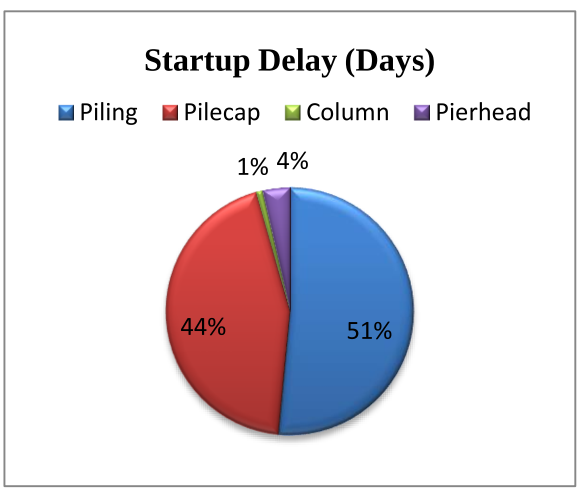


Figure 4.7: Startup Delays for Each Task

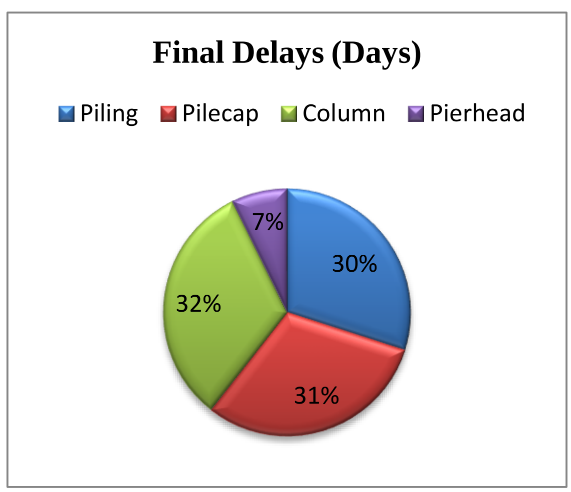


Figure 4.8: Final Delays for Each Task

Figure 4.9 also shows the average of productivity rate deviations for five tasks due to potential slowdowns or work interruptions. According to the figure, column was indicated as the task with highest deviations in durations. On average, column works were delayed 6 times more than the planned duration while surprisingly two extra crews were allocated to work on column tasks from end of August. Although, the increase of crews working on column prevented the startup delays, there were serious slowdowns in this task. In contrast, the actual duration of piling with high startup delays was close to the plan. Further investigations show that productivity rate deviations for column works varies significantly between different locations.

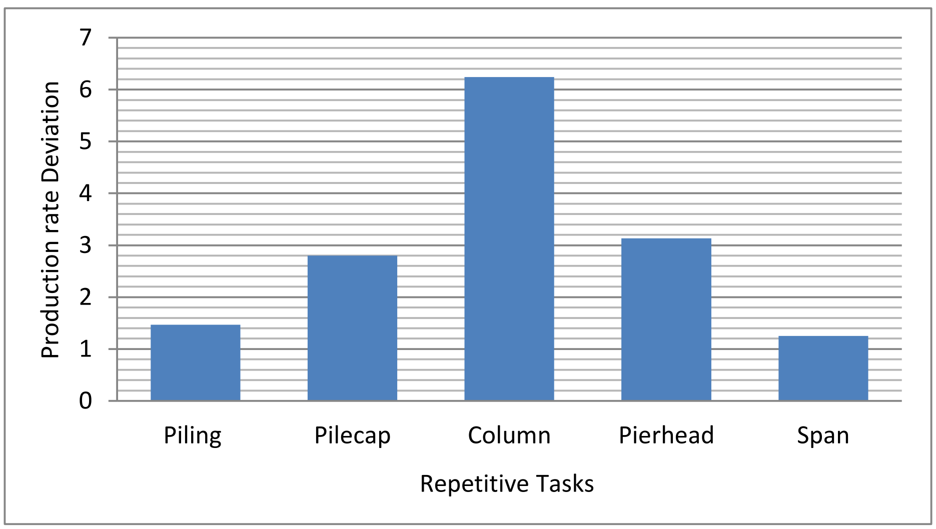


Figure 4.9: Production Rate Deviation for Each Task

4.6 Monte Carlo's Risk Simulations and Buffers

The basic assumption in the risk management methodology is that every planned break in the work continuity either costs money or adds more to the schedule. Therefore, each break in work should be evaluated to assess the costs or risk involved. In this study, the location-based schedule utilizes Monte Carlo simulation based on pessimistic, expected and optimistic estimation of duration for each task. Using this estimation, it is possible to estimate the impact of variations of schedule and hence provide different probability of outcomes.

The risk allocation and simulation covers the following items:

1. Start of Schedule: The delay that occurs before the task starts which is
2. Schedule task duration (as percentage): The estimation of task duration to measure it is going faster or slower than the planned
3. Beginning risk: The potential delay before the crew begins the task in a location. Therefore, this examines how likely it is for the crew to arrive on site on time.
4. Come-back delay: The potential delay before the crew returns the task after an interruption.

The risk levels were estimated based on the history of actual duration, startup delay, come-back and beginning risk. For each factor, the average of previous actual data was calculated and inserted into the software. The software uses an analysis of schedule iteration to anticipate the impact using the probability input. The iteration process is usually repeated up to 1000 times to make a form of probability distribution based on different scenarios. Based on the risk levels inserted, an estimate is made for start time and duration for every schedule task and simulation round. Furthermore, the temporal distribution in Figure 4.10 shows the likelihood of the project to be completed on time. The distribution forecasts the expected (31th of December 2013), earliest (14^{th} of June 2013) and latest completion date (20^{th} of August 2014) based on the risk levels.

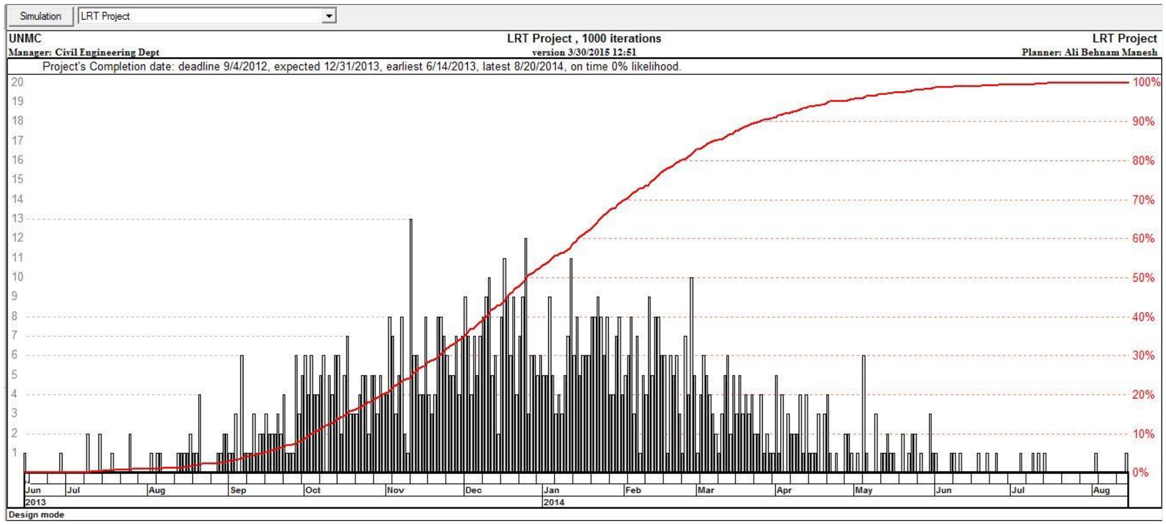


Figure 4.10: Monte Carlo's Simulation, Temporal Distribution

Planned buffers play essential role in minimizing the effects of variations in actual progress. A buffer is time or space allowance between two tasks which is planned by project planners to take into account the possible variations of production. This parameter can be observed through horizontal and vertical empty spaces. A time buffer represents an absorbable period of time allowed between two tasks in the same pier. This parameter absorbs any possible deviations such as startup delay and hence helps control managers to take necessary control actions. In contrast, space buffer is the available number of empty locations between two tasks. The vertical distance between tasks is considered as a space buffer in the flowline diagram.

In general, aligning the production rates and allocation of buffers are used to decrease level of risks in the project. Therefore, buffer is a necessary part of location-based planning to prevent any deviations which can cause work interruptions, start up delays and hence increased costs. Planning buffer size largely depends on resource availability of contractors and the size of locations. In this project, locations of construction sites are relatively big and tasks within same locations have Finish-Start relationship. Therefore, resources and gangs are able to physically work simultaneously in the same construction site along several numbers of piers.

4.7 Location-Based Forecasting

4.7.1 Total Effects of Deviations

Figure 4.11 shows the flowline diagram of the segment with actual progress as well as the forecast data. As it can be clearly seen, startup delay is a major type of deviation which caused serial delays for the succeeding tasks in every location.

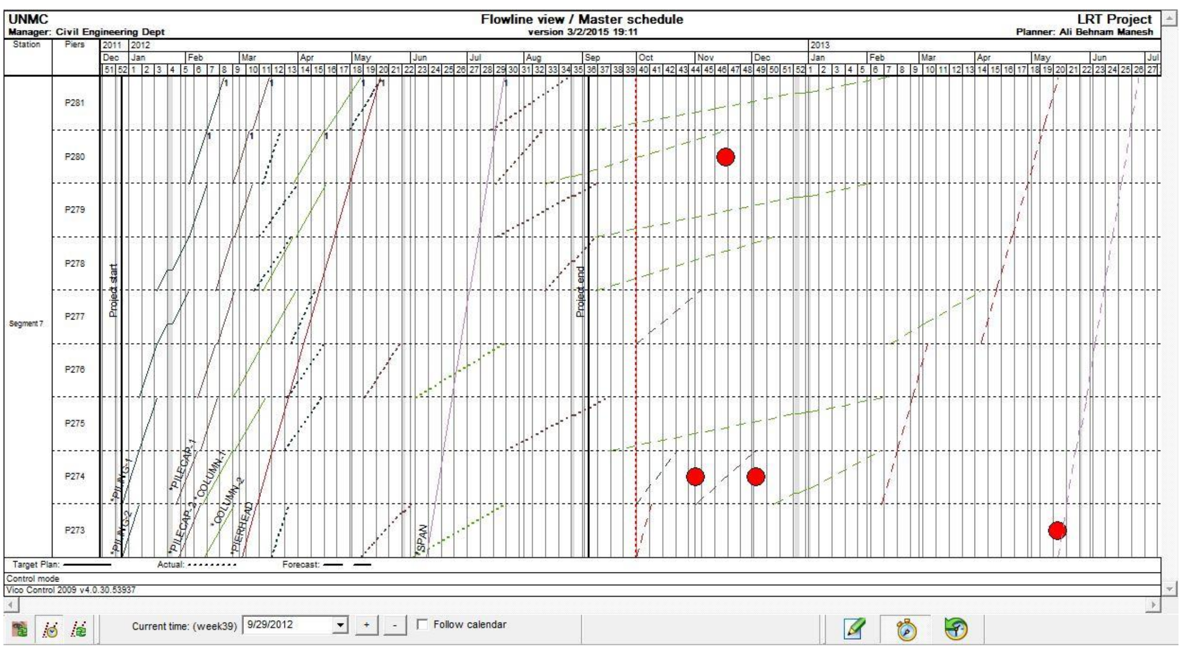


Figure 4.11: Total Effect of Deviations and Forecasting, End of September 2012

Startup delays

For example, as result of delayed site clearing, mobilization, traffic diversion and mainly the relocation of services, piling works started late by 6 to 10 weeks delay in all locations except P274. The contractor added one extra crew to finish works in multiple locations at the same time. However, instead of completing location P274 and then moving to the next locations, the subcontractor decided to expedite piling works by adding another crew to start three locations at the same time. This could be a common behavior which is resulted by a rough level of detail in the schedule. Instead of completing all the subtasks for piling works such as relocation of services and etc., the subcontractor may only finish part of the required work in many locations.

Production rate deviation

This type of deviation should be reduced by considering more accurate detailed tasks with the realistic estimation of subcontractor productivity rate. This deviation results in locations being incomplete and hence affects the progress of next crew and succeeding tasks. In this case, based on the schedule forecast, no work being done at P274 as well as major delays in piling and pilecap tasks in other location will prevent column and pier head task to progress according to original plan.

The deviation of productivity rate is also evident in column works of P278-281 where productivity rate is forced to be less than planned to allow continuity for pier head tasks after completion of column work in P274 and P277. On top of that, subcontractor uses 4 crews to complete the column works lower productivity rate as well as potential interruptions based on the forecast data. Instead, more efforts could be considered for starting work in P274 to prevent waiting times and interruption for other trades.

Change of location sequence

Another common deviation in this project was working out of sequence from one location to another location different from the planned sequencing. Although subcontractor is allowed to change the sequence of locations, problems arise when the changes are not synchronized with prioritization of the sequences. In another word, subcontractor should change the sequence only if this change does not eliminate the continuity of the resources flow. For example, in P277 column works was neglected and more resources than necessary were allocated for other piers. The same situation is applicable for pilecap works in P275, P276 onwards. Although it is not possible to keep in mind all the potential shortage or considerations of subcontractor, working out of sequence should be prevented by prioritizing the make-ready process. If the sequence is not carefully monitored and controlled, the progress becomes even more complex to control. In addition, working out of sequence causes cascading deviation since multiple trades may work in the same time with major slowdowns and discontinuities of work as seen in column and pilecap works. Therefore, the change of location sequence should be closely monitored and reported between contractors and subcontractors.

Each type of deviation has its own particular effect and consequences on the project. The forecast stage in location-based scheduling helps us identify the total impact of deviations and visually observe them in the flowline diagram. The effect of startup delay is dependent on time buffers between preceding and succeeding tasks and locations. If there is no buffer left, there will be delay in the start of succeeding task. On the other hand, sufficient amount buffer can absorb deviation when the delay is smaller than the buffer size. Startup delays can be minimized and mitigated by efficient procurement and delivery planning and good control of starting perquisites.

4.7.2 Possible Control Actions

The discussion about planning for control actions can never be accurate without having all the information about resource and location availability in addition to the willingness of subcontractors work longer days and etc. As discussed before, according to the flowline diagram, pilecap and column works are commenced in 4 places at the same time by either adding resources or overlapping the productions n multiple locations. This shows the traditional way of catching up the previous delays after the subcontractor has realized the major startup delays for piling and pilecap. This control action certainly causes problems in production control because it becomes more difficult to track and control the production rates and also to plan further control actions. This control action may have the undesired consequence of reduced productivity and interruptions while workers and resources end up walking around to look for work in other locations. However, if the production is well controlled, this could be an acceptable control action considering the cases where all the resources cannot be added to one certain location.

4.8 Development of an Automated Progress Monitoring System

The following section demonstrates and analyzes the results with respect to image processing techniques used in progress detection of elevated guideway construction. In addition, the framework for development of web-based monitoring system will be illustrated. The core processing includes interpreting different construction stages from multi-sensor and multi temporal satellite images and sub sequential extraction of the relevant information automatically prior to populating and updating the spatiotemporal

GIS database. The integration of this database with the planned schedule can provide a web-based monitoring interface for the measurement and visualization of progress using LBM and other graphical techniques.

4.8.1 Image Co-Registration and CAD Alignment

Pleiades and TerraSAR-X images were selected as typical high-resolution optical and radar images. Pleiades is a passive sensor which provides panchromatic and multispectral images with 0.5 and 2m spatial resolution respectively. The cloud penetration power of radar remote sensing is a good solution for limited coverage of optical images in tropical whether condition. The optical images were captured on 05 June 2013, 18 December 2013 and 31 January 2014 and radar images were acquired on 17 June 2013 and 05 October 2013. Figure 4.12 represents the construction drawing which contains information such pier unique ID, their northing and easting coordinates, pier dimensions, orientation, elevation and road center line. After co-registration of CAD drawing into a single reference system, all the satellite images can be overlaid on a single coordinate system.

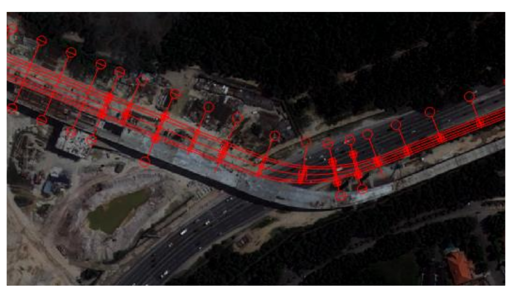


Figure 1: CAD Alignment

4.8.2 Progress Detection

Figure 4.13 illustrates the initial image interpretation process. In the beginning it was expected to identify four construction stages including bored pile platform and activities, pilecap construction, pier works and pier head construction, segment box grider (SBG) launching and post-tensioning activities. However the study investigated the detection of more than 10 construction stags as site clearance, bore piling works, pilecap structures: earth excavation, formwork installation ,concreting, backfilling, pier construction (ongoing), pier construction (completed), pier head construction, SBG launching (ongoing),SBG launching (completed). Figure 4.13 compares those identified construction stages from satellite images with their corresponding ground based appearances.

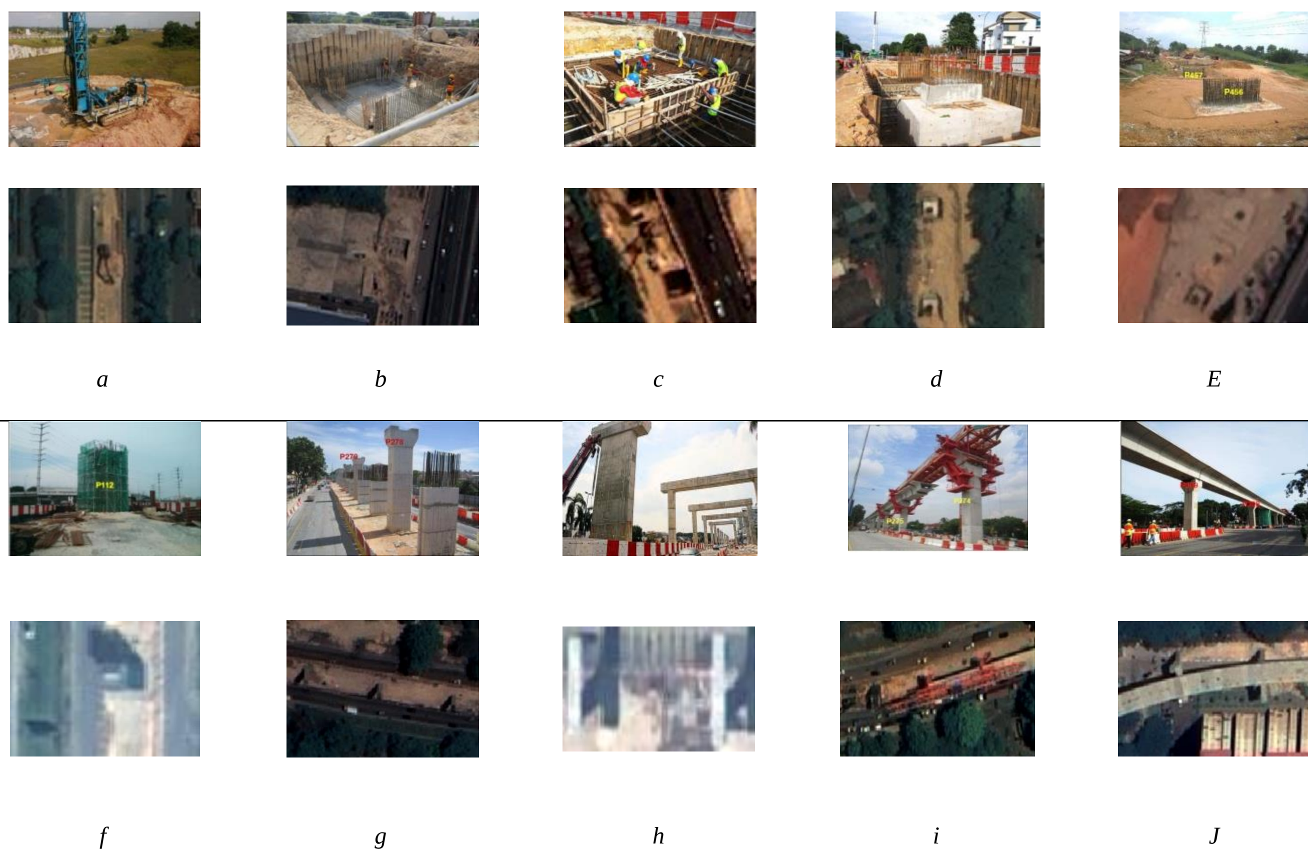


Figure 4.13: The ground base appearance of each construction stage with their optical image visual appearance a) Bore drilling works; b) Pile cap structures: earth excavation; c) Pile cap structures: formwork installation; d) Pile cap structures: concreting; e)) Pile cap structures: backfilling; f) Pier construction (ongoing); g) Pier construction (complete); h) Pier head construction; i) SBG launching (ongoing); j) SBG launching (completed)

However in this study, four repetitive construction tasks are monitored based on the construction schedule.

Site clearing and piling detection

After feasibility study, next challenge is the automated extraction of this visually interpreted information from satellite images. Figure 4.14 (two images on the left) illustrates 2 images of the same construction site in different date respectively June 2013 and 31 January 2014. In the top image, there was no evidence of construction however; in below image some preliminary construction (e.g. piling work) and site clearing works began. In addition, the green area of image also comparatively decreased. Figure 4.14 (the images on the right) show the NDVI images of both dates which gives higher value (brighter color) for greenery area and less value (darker color) for bare soil.

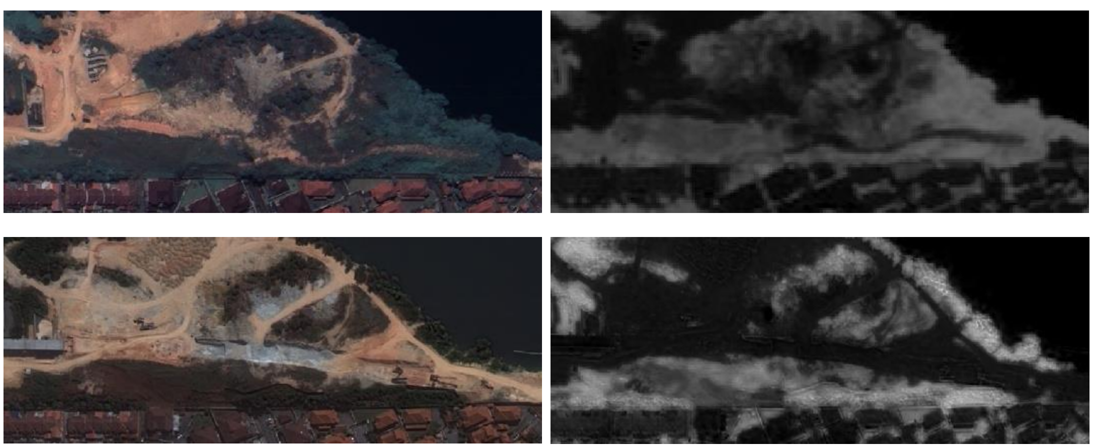


Figure 2: Site Clearing and Piling Detection, After (Top), Before (Below), Optical Images On the Left and NDVI Images on the Right

Pile cap detection

Figure 4.15 is the different preview image of pilecap construction. The best method for detection of pile cap construction is object-based image analysis method due to its regular shape. The square shape is the primary sign for this construction stage. Using image segmentation algorithms; the image is partitioned into object with similar color. Later, the image objects are analyzed in terms of their color, shape, orientation, size and area. The construction CAD drawing depicts that dimension of pile cap is around 8 meters. When the dimension data is converted to machine learning algorithm, shape is converted to elongation parameter. Elongation expresses the length to width ratio. The elongation value of square shape must be equal to 1. Similarly, area value of these objects must be around 64 square meters. By using both the area and elongation parameters, it is easily possible to extract the pile cap construction areas.

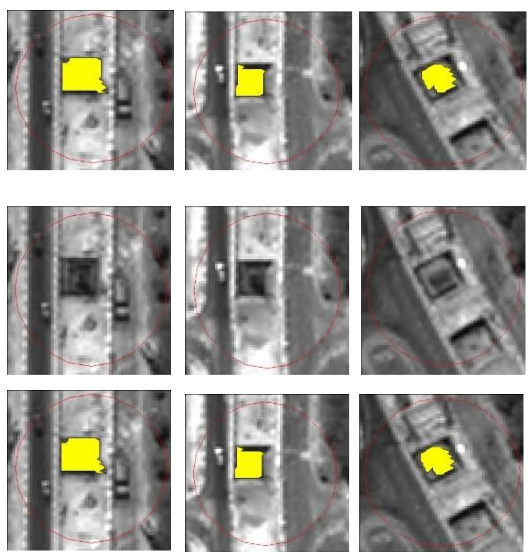


Figure 3: OBIA method for Pile Cap Detection

Segment launching detection

Similar to pilecap detection, SBG launching activities can also be detected using object based imaged analysis methods. Figure 4.16 shows the steps of span extraction. After images segmentation, shape, size and pattern of image objects must be analyzed. Spans are always linear features and have constant width as well as unique texture. These two parameters separate the SBG launch area from other similar objects. For the linear features, elongation has a higher value. Completed segment is considered when launching has been completed between the distance of two particular piers. Therefore, the method selected image objects where elongation is greater than ratio of the distance between two piers and span width. On the other hand, texture parameter is also used to remove the potential false alarms for the objects with similar dimensions.

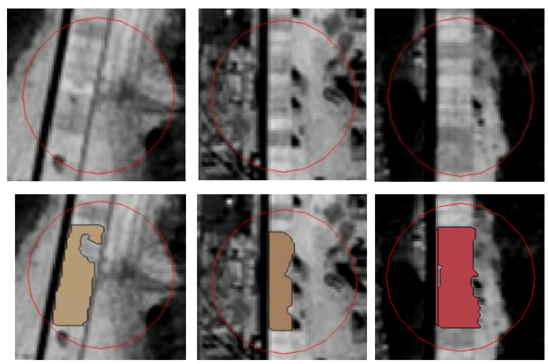


Figure 4: OBIA Method for SBG Launching Detection

Oblique images provide side view of high rise building. However, nadir images only give the footprint of object. The shadow information is the best solution for elevated features interpretation using single satellite image. The shadow direction, length and shape vary with solar position and sensor position. Therefore, template based image matching is good solution for such situation. This method was used for the extraction of both completed and under constructed pier works (Figure 4.13, f & g).

Figure 4.17 shows the corresponding sub image of each construction stage. These extracted sub images are considered as template images. The figure shows the selected construction site (LRT segment) in where circled areas are the proposed locations for the construction of piers. Each template is moved through all over the image and calculates normalized cross correlation (NCC) value for each point.

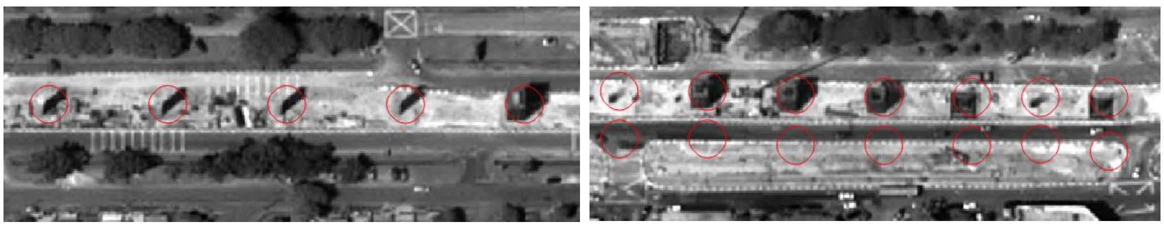


Figure 4.17: Template Base Image Matching Method for Column Works

Figure 4.18 presents the corresponding NCC image for each template. The brighter color areas represent the higher correlated area and hence these locations are considered as the detected completed piers. The detected points which are located outside the area of red color circle are considered as false alarms. Figure 4.19 shows the successfully detected pier after using template matching method. Four different construction tasks were automatically extracted from multi temporal optical images using image processing techniques. Finally, acquired information from remote sensing images is stored in a spatiotemporal database.

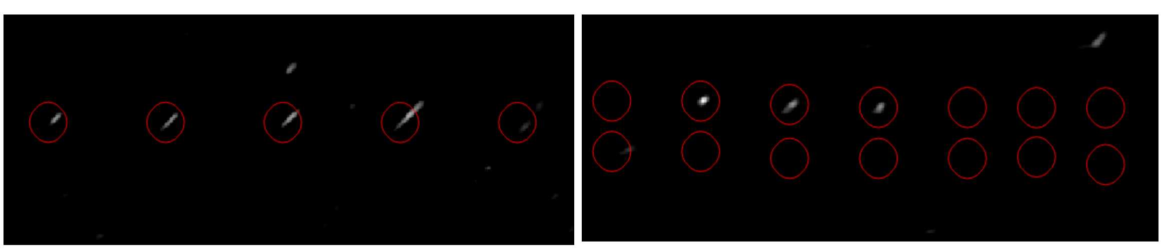


Figure 4.18: Corresponding NCC Image for Each Template

The database contains all the required information about each construction location including their geographical coordinates, corresponding image acquisition date and construction progress status.

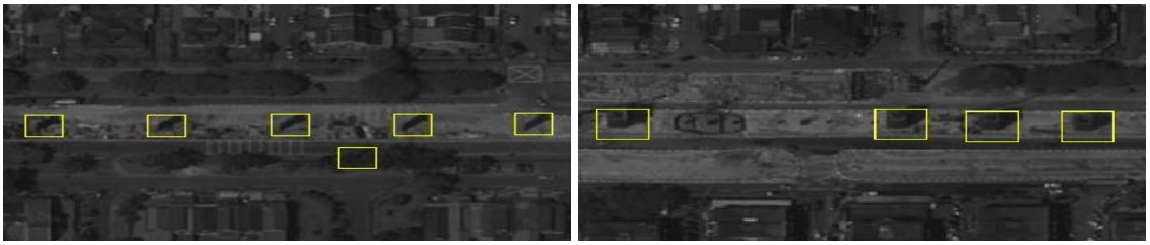


Figure 4.19: Successfully Detected Construction Site Using Template Matching

4.8.3 Validation Results

Table 2 reports the accuracy assessment computed for each stage. Overall accuracy is the ratio of correctly detected or ignored samples (e.g. 95+19) to the total number of concerned samples (e.g. 95+19+17+11). The precision represents the ratio of correctly detected samples to total detected samples (e.g. 95/ (95+11)) whereas the sensitivity is the ratio of correctly detected samples to the total truly correct samples (e.g. 95/ (95+17)). It is understandable that we could achieve higher accuracy with stage 1 and stage 4 when the construction activities look clearly different from the surrounding. During stage 2 and stage 3 of the pier construction, the appearance may be interfered by other city activities or buildings nearby, especially along the urban canyon, and hence the accuracy could be a bit lower. Overall, the proposed method achieved acceptable accuracy.

Table 2: Accuracy Assessment Report

Class		**Ground Truth Images**											
		Stage_1			Stage_2			Stage_3			Stage_4		
Object Recognition		True	False	Precision	True	False	Precision	True	False	Precision	True	False	Precision
	True	**95**	11	89.6	**19**	5	79.2	**77**	15	83.7	**176**	8	95.7
	False	17	**19**		7	**13**		18	**33**		4	**19**	
Sensitivity		84.8			73.1			81.1			97.8		
Accuracy				80.3			72.7			76.9			94.2

4.8.4 Web-Based Monitoring Interface

A web-based monitoring interface was designed to generate progress reports. The progress reports include: a top view satellite image as a progress map with the ground truth images of a specific location as well as objective and progress diagrams. The user is able to upload the baseline schedule from project management software program (e.g. Vico Control) to store planned progress data for each unit or location. In addition, available site photos for each location can be inserted through upload data section on the web interface. In this prototype model, actual database was updated based on 3 available satellite images from June, December 2013 and January 2014. Planned data was acquired based on baseline schedule for more than 30 piers under construction within a station in the case study project. The construction schedule and monitoring scope was limited to 4 main construction tasks: piling, pilecap, column (pier) and span launching. The system integrates two spatial databases to generate a unified data structure to be used in retrieving required inputs to generate the progress map and diagrams.

Line of balance diagrams

Figure 4.20 shows progress and objective diagram for a certain station and date in the project. Progress chart on the left represents planned and actual progress of each construction task for a certain station in January 2014.

For example, the actual progress of column (pier) works achieved is slower than he planned progress since actual number of pier completed for which pier works have been completed, is less than the planned number.

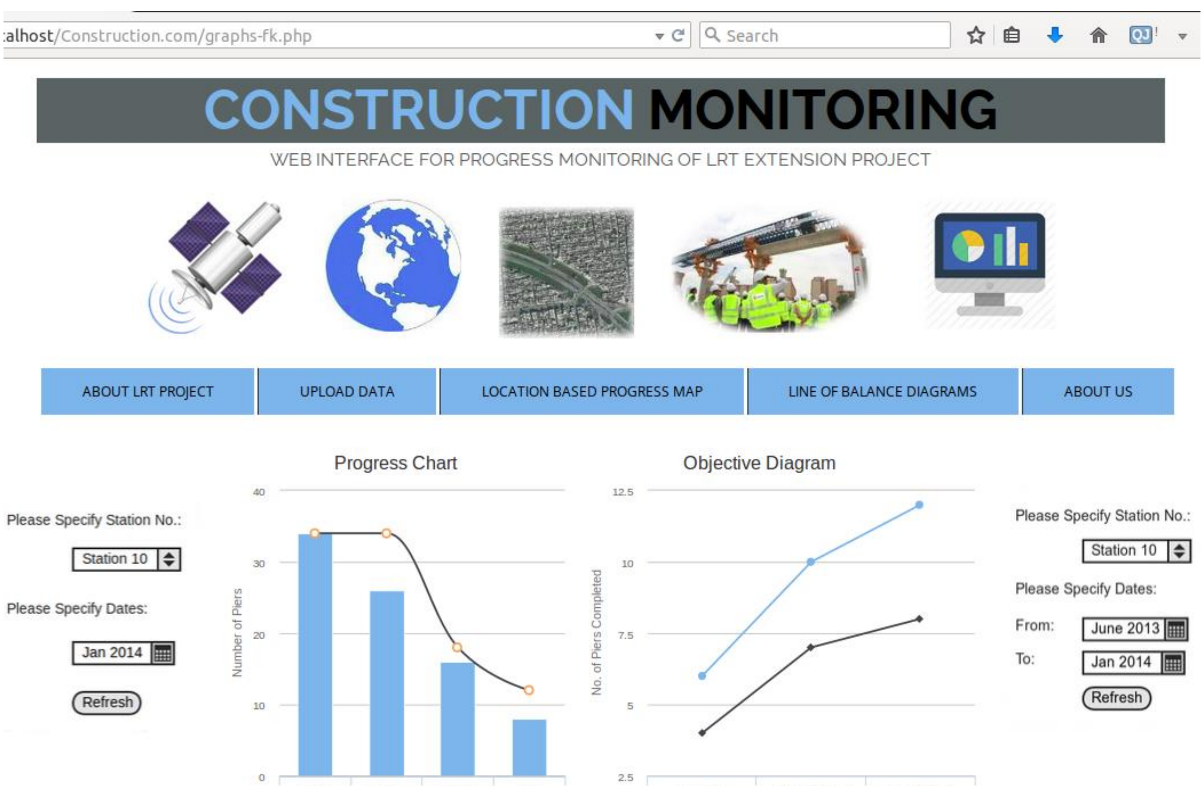


Figure 4.20: Line of Balance Diagrams on the Web-Based Interface

This diagram clearly indicates the remaining work for each station based on the progress of different tasks. Similarly, objective diagram compares the planned and actual number of completed span within a station per month. For example, planned progress calls for 6 completed units in June while 4 spans were completed in actual progress. These progress data can be also compared with different months depending on availability of satellite images. Using these two diagrams, project upper management can determine the tasks which are behind schedule and require better control actions. Furthermore, comparing the progress data for two consecutive months, it is possible to identify the amount work completed within a month period. The representation of actual and planned numbers of completed units over a period for each specific task can also be useful data for necessary control actions.

Progress map

One of the distinctive features of linear projects is that, while they are extremely repetitive, it remains important to visually observe where in the project work is being undertaken and what the progress level in each location is. For this reason, actual progress can also be visualized on top view satellite image for whole length of the project as shown in Figure 4.21. Therefore, geographic information system (GIS) plays an important role in visualization and gathering multi-source datasets**.**

Using color-coded icons and a pop-up window on the image, user can determine location ID for each pier, station number, zone information, planned and actual progress status.

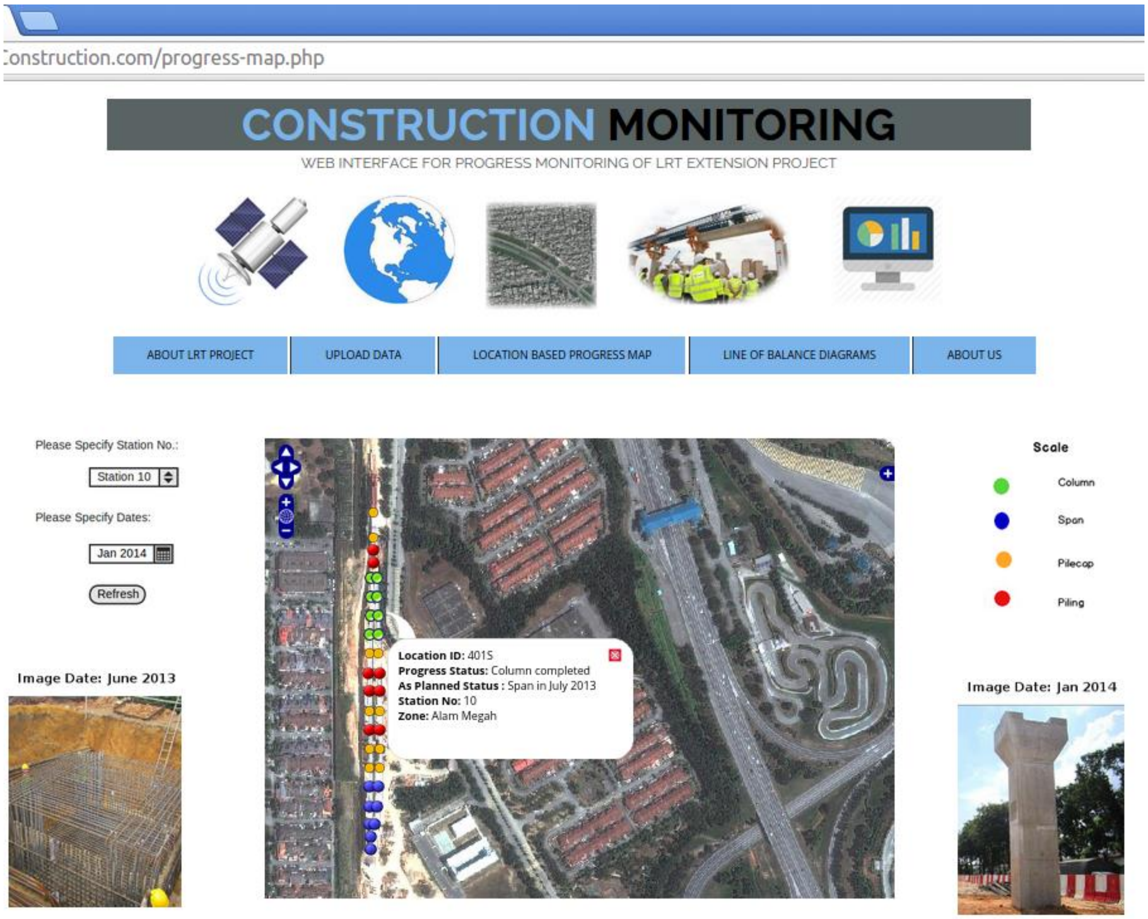


Figure 4.21: Progress map on the web-based interface

Furthermore, site photos taken for the selected pier for the corresponding and previous month can be observed to validate or compare the progress data. As a result, the proposed system can be a useful monitoring tool for project decision makers to visualize any deviations in order to take necessary control actions. Both LOB diagrams and progress map provide a brief summary of overall progress for each station in the project. Each site photo can also be classified according to its corresponding location and date. In general, the web-based interface is suitable for communication between client and contractors to react to problems in timely manner.

Chapter 5

Conclusions and Recommendations

5.1 Overview

Activity-based management methods like CPM are ineffective for modeling and monitoring the real nature of linear infrastructure projects like Kelana Jaya LRT extension line. The main weakness of these methods is to neglect the tracking of workflow and resources through locations based on a clear visualization of progress. Large amount of progress data designed in CPM networks makes the scheduling network too long and difficult to monitor and update. Moreover, activity-based methods are not good tools to visually detect the productivity rates of locations and deviations in the project. In contrast, location-based scheduling provide powerful techniques for monitoring and controlling the flow of resources and workflow using better visualization and reporting tools.

Manual data collection of progress in large linear projects is a time and cost consuming task. In these types of projects, the actual progress of each unit must be manually measured and documented in monthly or weekly progress reports. This manual data collection is usually subject to inaccuracies and delays in the detection of any deviations. Furthermore, the progress data for large projects with numerous units and work locations usually contain a considerable amount of textual information which is difficult to read and analyze. Although the construction industry benefited from many automated progress monitoring technologies in the past few years, there are a few limitations of their applications for large scale construction projects. In contrast, the top view satellite images can be a good tool for providing information about geographical location of the work units and the visualization of planned and actual progress.

5.2 Research Objectives and Achievements

5.2.1 Aim and Objectives

This research is undertaken to explore and evaluate the application of location-based management and automated progress monitoring for linear infrastructure projects. The specific aims and objectives of this research include:

A. Implementation of location-based management (LBM) components for monitoring linear infrastructure projects.

B. Evaluate and discuss the application of LBM for efficient monitoring and controlling of such projects.

C. Investigation on application of geographic information system (GIS) and satellite remote sensing techniques for progress monitoring of linear infrastructure projects.

D. Development of a web-based system for automated progress measurement, data collection and online progress reporting through satellite remote sensing techniques and GIS.

5.2.2 Achievements

All objectives were achieved in literature review and research findings from chapter 4. Literature review outlined the main benefits and weaknesses of CPM and PERT for monitoring linear projects. In addition, the principles and techniques of location-based management and current technologies for automated progress detection were extensively reviewed.

The achievements can be described as the following:

- The study implemented the location-based methodology and techniques as the monitoring tools for the progress of a small section of an elevated railway project using Vico control software. The flowline diagram was used to visualize the CPM schedule to in order to identify the CPM errors and improve the visualization. The same schedule was then remodeled and optimized based on the flowline methodology. This resulted in a schedule which can be monitored and managed as a location-based schedule. A risk analysis was performed using Vico control software to predict the completion date of the project based on the previous actual progress information.
- The thesis first evaluated the activity-based progress reporting tools which are commonly practiced. The flowline diagram was used to visualize the CPM schedule to in order to identify the CPM errors and improve the visualization. The flowline diagram and controlled charts were used to evaluate the schedule, progress and deviations. Furthermore, the study conducted on an empirical research on deviations for each tasks. The total impact of deviations was also forecasted in the flowline. The main benefits of location-based methodology and techniques for progress monitoring and report were extensively discussed.
- The literature review and methodology section extensively investigated the satellite remote sensing techniques and GIS online reporting. The methodology describes several feature recognition methods to detect different construction

tasks or stages. Area-based template matching was considered to be suitable for the identification of pier construction. In addition, object-based image analysis method was used for the detection of pile cap and span construction.

- This dissertation also introduced a framework of an automated system for progress measurement of large scale linear projects using satellite remote sensing technology. A prototype model was implemented in a small section of an elevated railway project using multi-temporal satellite images to evaluate the feasibility of the proposed framework. The framework is enhanced with the use of location-based progress reporting which provide better visualization techniques. Area-based template matching proved to be suitable for the identification of pier construction (Stage 3). In addition, object-based image analysis method was used for the detection of pile cap (Stage 2) and launching works (Stage 4). Piling and site clearing works (Stage 1) were monitored based on the image indexing method. The progress data extracted was inserted into a spatiotemporal database consisting of progress data for each work location and different dates.
- The progress data extracted was inserted into a spatiotemporal database consisting of progress data for each work location and different date. The spatiotemporal database was integrated with planned and actual progress data to detect deviations from the construction schedule. A web-based interface was developed to display progress reports which included a top view progress map and line of balance diagrams. The validation process aims at evaluating the accuracy of feature extraction for each construction stage by comparing the acquired results with the

actual progress data. The accuracy assessment report presented in the discussion reveals the high accuracy of the proposed system.

5.3 Conclusions

The specific aims and objectives of the research described above have been achieved. Specific conclusions from this research can be summarized into the following:

1. The activity-based methods are ineffective for progress monitoring and reporting of Kelana Jaya Line LRT extension projects as a linear project. CPM emphasizes the optimization of the duration of each repetitive task rather than maintaining the continuous flow of resources working on a task through several locations.
2. Prasarana Malaysia Berhad utilizes activity-based methods such as CPM and Gantt chart to report and communicate the schedule and progress of Kelana Jaya project. These conventional progress monitoring and reporting tools used in the project are not helpful to visualize and communicate the planned and actual progress of repetitive tasks, flow of resources and deviations in the project. Furthermore, activity-based methods do not differentiate between deviations types and also do not show how deviations affect the production overall on other project tasks and locations.
3. It is necessary to monitor and control linear projects based on continuous flow of resources rather an early starts. Location-based management enables the implementation of lean construction and concepts such as just in time and waste elimination for discrete linear projects like LRT.
4. Location based management and micro-management techniques allow planner to visually see the flow of resources as well as the effects of deviations on other

tasks and project locations. Progress information is visualized in flowline diagrams and control charts, to show the movement of resources, project deviations and their effects on other project units.

5. LBM encourages planners to resist the temptation to start ahead of schedule or out of sequence. On the other hand, if precedents activities and locations are not complete, it is needed to complete the locations rather working around them and start new locations.
6. Project planners in Prasarana should use large buffers between trades as a risk management (Optimum duration plus buffer equals traditional duration).
7. Production control is more important than planning. Controlling demands lean schedules, continuous progress monitoring and timely reactions to deviations to decrease their effects.
8. Geographic Information System (GIS) is very effective tool to store and manage the large amount of progress data to improve the visualization and communication of progress in large linear projects like Kelana Jaya line or similar projects.
9. It is important to know where in the linear project, work is being undertaken. For this reason it is beneficial to visualize the construction schedule and progress in 2D or 3D. Automated progress monitoring can also be helpful for top management to obtain accurate and quick information on the progress of whole project. The developed monitoring system in this thesis enhances the visualization of planned and actual progress of main construction stages in an automated process.

10. The proposed system can be a good tool to inform project top management about the overall progress in project on monthly basis. In particular, online progress reporting such as line of balance diagrams and a map-view image enables the project participants to evaluate the schedule, actual progress and also the geographical conditions of the project.
11. The web interface can significantly enhance the process of communication between project participants using a web-based system which can be easily accessible to all project decision makers.

5.2 Recommendations for Future Researchers and Further Enhancements

Several aspects of the proposed framework can be improved through future research. These enhancements are recommended for future researchers who are interested in implementation of LBMS and development of an automated progress monitoring.

i. It is useful to look into a larger distance of linear projects to evaluate the total effects of deviations from one segment/station to another.

ii. Location-based approach could also be implemented for non-linear segment of the research case study such as stations.

iii. The web-based monitoring system presented in this study can be enhanced by including location-based cost and quality information as well as outstanding issues and proposed control actions.

iv. The automated progress monitoring feature can be integrated with the system by using GPS devices from the construction site. With respect to the previous point, the information for resource movements can be also updated and communicated to the head office by site engineers using a GPS device.

v. The system can benefit from an optimization algorithm in order to maintain and also maximize resources work continuity to minimize the project duration and idle time between tasks.

vi. The research outcome suggests the investigation of the capabilities of Synthesis Aperture Radar (SAR) satellite images to enhance the detection process. SAR images provide high spatial resolution, weather and daylight independent images of earth surface which overcomes the cloud cover limitations of optical images. Moreover, the SAR images are more sensitive to the urban structures and the information fusion of both sensor images. Using both SAR and Optical images can increase the total number of available satellite images and hence the accuracy and reliability of monitoring results.

vii. Furthermore, the use of Unmanned Aero Vehicle (UAV) may provide more frequent and higher resolution images which lead to better progress monitoring. In the case of more frequent progress data acquisition on the weekly basis, the system could generate location-based control charts. Using control charts it is possible to determine the approximate start and finish dates of each task per location.

viii. The study can be considered as a small part of a wider implementation for integration of a web-based GIS platform with all the information in a large linear project for the design stage to asset management.

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