Investigation of Visualization Needs for Vertical Repetitive Projects

by

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A thesis

Presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Civil Engineering

Waterloo, Ontario, Canada, 2018

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Repetitive construction projects, particularly high-rise buildings, are complex projects that suffer from cost overruns and delays. For these projects, efficient repetitive scheduling becomes necessary. Repetitive scheduling, however, remains less utilized in the industry due mainly to its visualization challenges. In an effort to improve schedule visualization, this thesis surveys available software packages for scheduling repetitive and non-repetitive projects and summarizes the visualization challenges for high-rise buildings.

To improve schedule visualization, a new visualization method, Activity Continuity on Time-Inclined Visual (ACTIV), has been developed in this thesis. ACTIV changes the typical slanted lines of the repetitive schedule into vertical lines that resemble the shape of the high-rise building. The main concept is to represent the time-axis at an angle, rather than the typical horizontal orientation. To incorporate many activities, the time-axis angle is calculated differently for each activity. Based on the results of using ACTIV on a case study project, its interesting capabilities include better scheduling of structural core activities presenting the time-axis on an activity-dependent angle and producing legible schedule reports. Recommendations for adapting the proposed method to other types of repetitive projects are made.

Acknowledgment

All praise and gratitude be to God, for it is only his grace that good deeds are accomplished.

I would like to express my deepest gratitude to all those who helped me in accomplishing my Master Thesis. I would like to express my wholehearted thanks to my supervisor Prof. Tarek Hegazy for his excellent guidance, patience and providing me a comfortable atmosphere for doing my Master Thesis. I would also like to thank the readers, Prof. Hassan Baaj and Prof. Chris Bachmann, for their time and their useful comments.

Finally, I must express my very profound gratitude to my beloved mother and inspiring father for providing me unbiased support and continuous encouragement throughout my years of study and through the process of reaching and writing this thesis. This accomplishment would not have been possible without them. Also, many thanks to my siblings who always stood by me in a difficult time and to all my dear friend for sharing their knowledge during the interviews in the field study.

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Chapter 1

Introduction

1.1 General

Repetitive construction projects incorporate a number of repetitive units (e.g., floors, road sections, multiple house) and can generally be categorized into non-linear and linear. Non-linear repetitive projects contain high-rise buildings (vertical) and projects with scattered units such as housing projects and multi-bridge rehabilitation projects. On the other hand, the characterization of the linear repetitive projects are resembled by horizontal geometric layout namely pipelines, railroad, and highways construction projects (El-Rayes & Moselhi, 2001) .

A construction project might contain both non-repetitive and repetitive activities simultaneously. High-rise buildings are an example of this case, where excavation and underground works are non-repetitive tasks, done only once, followed by repetitive typical floors. The nature of repetitive projects offers significant savings on cost and time. There are numerous benefits that can be achieved by maintaining crew-work continuity to achieve a good learning momentum (also known as learning-curve effect) that results in time and cost savings (Bakry, Moselhi, & Zayed, 2013). However, managing and planning a repetitive schedule with crew-work continuity can be challenging (Bakry et al., 2013). Using traditional scheduling techniques for non-repetitive projects, like the critical path method (CPM), to schedule repetitive projects has been commonly disapproved (Arditi, Asce, Tokdemir, & Suh, 2002; Hegazy, Asce, & Kamarah, 2008; Hegazy & Wassef, 2001; Reda, 1990; Russell & Wong, 1993). CPM does not compute or display productivity rates, tasks locations, and the resulting schedule does not legibly depict, visually, the large amount of data related to repetitive projects.

Repetitive schedules are very challenging to show the large amount of data related to repetitive units, crews, and productivity rates. The common bar charts are incapable of displaying actual location and progress rate (Duncan and Alvord, 2017). While it is possible to create copies of the tasks of one location and create a large bar chart of all the tasks in all locations, the bar chart becomes huge (e.g., a 30-section highway with 15 typical activities creates a 450-activity bar chart). As such, a bar chart is severely limited when it comes to visualizing a repetitive schedule as it cannot show which crew(s)/task(s) are fast or slow, and also makes it harder to spot the overall construction philosophy (Duncan and Alvord, 2017).

Despite large theoretical advancements in repetitive scheduling methods, the existence of their implementation has been limited in the US construction industry (Lucko et al., 2014). Duffy et al (2012) reported that this family of promising scheduling methods has not been actively used in practice. Yamı́n and Harmelink (2001) discussed the reasons for the wide use of bar charts in repetitive highway construction being its ease of use, good communication, and the general unawareness about repetitive scheduling methods. In a survey among 25 professionals and researchers, Boton et al (2013) reported that as compared to bar charts, linear planning was known by only 32% of respondents and used by only four percent.

With the recent advances in software and mobile apps related to project management, many different ways of visualizing data have emerged. There is a need, therefore, to investigate the currently available tools to determine the best features that can provide the best planning tools for the repetitive and non-repetitive project. Also, there is a need for a better way to visualize the schedule to make it more legible and easily understood by all project parties.

1.2 Research Objective and Scope

The primary objectives of this research are as follows:

1. Conduct a survey of recent commercial applications for project management and accordingly examine their advantage and limitations particularly on the schedule visualization side;

2. Conduct an extensive survey of recent repetitive scheduling software for project management and accordingly examine their advantages and limitation particularly on the visualization side; and
3. Document the most useful visualization features needed for repetitive and non-repetitive projects and recommend improvements to existing visualization methods to improve the liability of the schedule and manageability of repetitive projects, particularly high-rise building.

1.3 Research Methodology

The research methodology is shown in Figure 1.1 as follow:

1. Conduct extensive literature review of the technical methods used to schedule projects and provide a critique of their visualization features that confuse the repetitive scheduling process;
2. Conduct an extensive review of the literature mainly addressing areas of scheduling, accelerating and optimizing repetitive construction projects;
3. Study repetitive and non-repetitive scheduling methods and their visualization needs;
4. Utilize new commercial applications for project management;
5. Utilize new repetitive scheduling software for project management;
6. Recommend better visual application to facilitate better management of the project;
7. Suggest visual improvements for vertical repetitive projects;
8. Implement a case study for the vertical scheduling section.

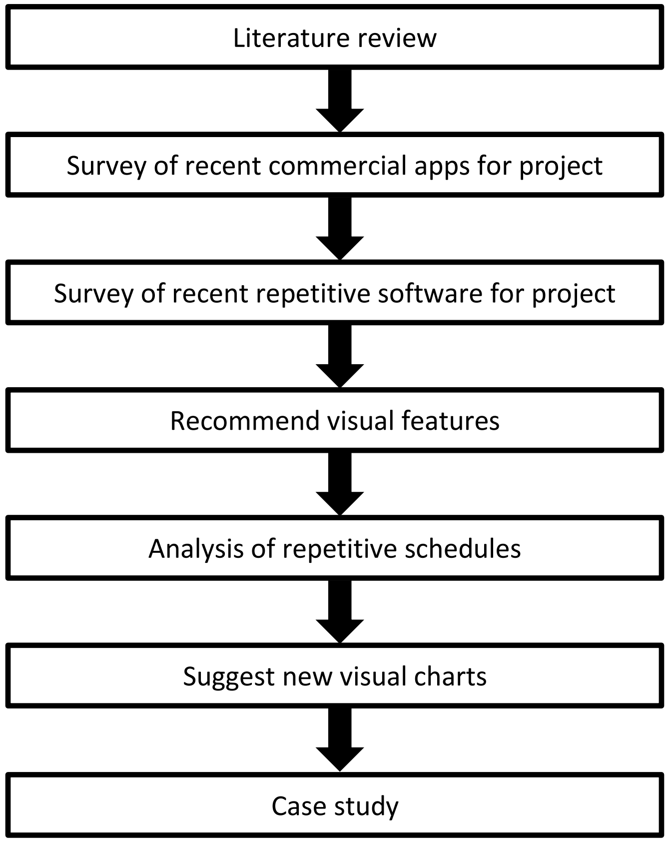


Figure 1.1 Research Methodology

1.4 Thesis Organization

This thesis is presented in six chapters. The second chapter presents a comprehensive literature review. It focuses on existing tools and techniques for optimized scheduling of repetitive projects, and challenges with visualization for scheduling. Finally, chapter two ends by highlighting the identified gaps in the literature. The third chapter explains in detail the comparison among recent applications for non-repetitive scheduling. Chapter four discusses the comparison of current apps for repetitive scheduling. Chapter five suggests visual improvements for vertical repetitive projects. Chapter six is the thesis conclusion and recommendations for extensions to existing research delay analysis, recommended practices and proposed standards.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents a comprehensive literature review of the scheduling domain for repetitive and non-repetitive construction projects. This chapter is divided into four main sections. The first section discusses the main type of repetitive construction project. The second section introduces the basic repetitive scheduling methods. The third section presents recent research on repetitive scheduling. Then, the last section presents the challenges with the schedule visualization in repetitive projects.

2.2 Types of Repetitive Projects

Repetitive projects contain a series of repetitive activities that require resources to move units around. These units are usually identical or similar depending on the design. There are two types of repetitive projects: linear repetitive project such as highways, and nonlinear repetitive projects such as multiple-location housing projects (scattered), and high-rise building project (vertical) (Hassanein & Moselhi, 2004), as shown in Figure 2.1.

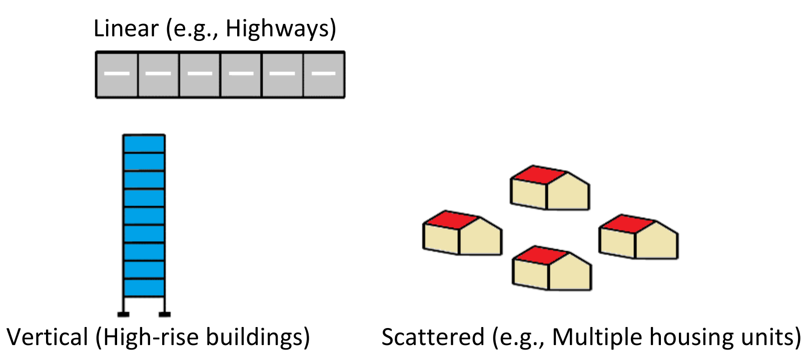


Figure 2.1 Types of Repetitive Scheduling

These types of projects are huge in size and contain construction and maintenance of infrastructure facilities. Vorester & Bafna (1992) classifies repetitive projects into: typical and non-typical repetitive projects. Typical repetitive projects contain tasks that have the same amount of work, and use resources that have the same productivity for each unit, which guide to a repetitive schedule formed. On the other hand, the non-typical repetitive projects contain tasks that have different amounts of work and use different resources with different productivity in each unit. In vertical and scattered projects, the worker of each unit depends on the previous unit (e.g., floor 3 starts after completing floor 2). On the other hand, in linear projects, any unit is not dependent on the previous one, which means workers can proceed from both sides of a road, for example (Hassanein & Moselhi, 2004). Also, while both vertical projects (high-rise buildings) and scattered projects (multiple houses) are nonlinear, scattered projects contain individual units in different locations and it is possible to work in different location at the same time, and move among the units in different ways.

2.3 Scheduling of Repetitive Projects

The most common scheduling technique used for traditional non-repetitive projects is the CPM. This technique, however, does not suit scheduling repetitive projects as it does not provide continuity of resource work (Ammar, 2012). The following subsections discuss the advantages and limitations of various techniques for scheduling repetitive projects.

2.3.1 Critical Path Method (CPM) for Repetitive Schedule

The Critical Path Method is known as a duration-driven method and was developed by James Kelly and Morgan Walker in 1950 (Stretton, 2007). The CPM is appropriate to construction projects that have multiple relationships between activities. After the network of tasks is made, this method is able to calculate critical activities, the critical path, and a total float of each activity, as shown in Figure 2.2.

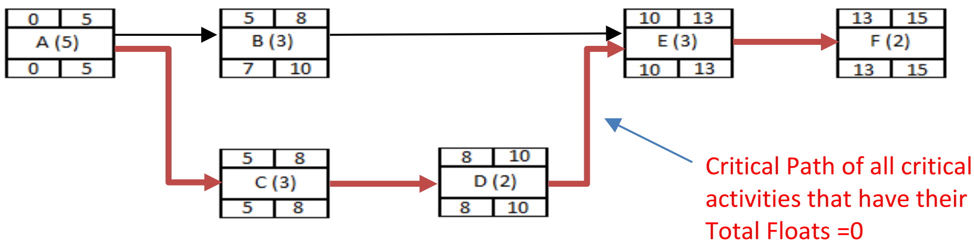


Figure 2.2 CPM Network with Logical Relationships

While the CPM technique has excellent facilities for scheduling non-repetitive projects, it is not a suitable tool for scheduling repetitive projects. Figure 2.3 displays an example of a project with 4 typical floors. Using CPM to visualize the project network, the schedule becomes challenging due to the large amount of information, even for the small building of four units (Senior & Halpin, 1998). CPM also does not present the activities' productivity (Ammar, 2012).

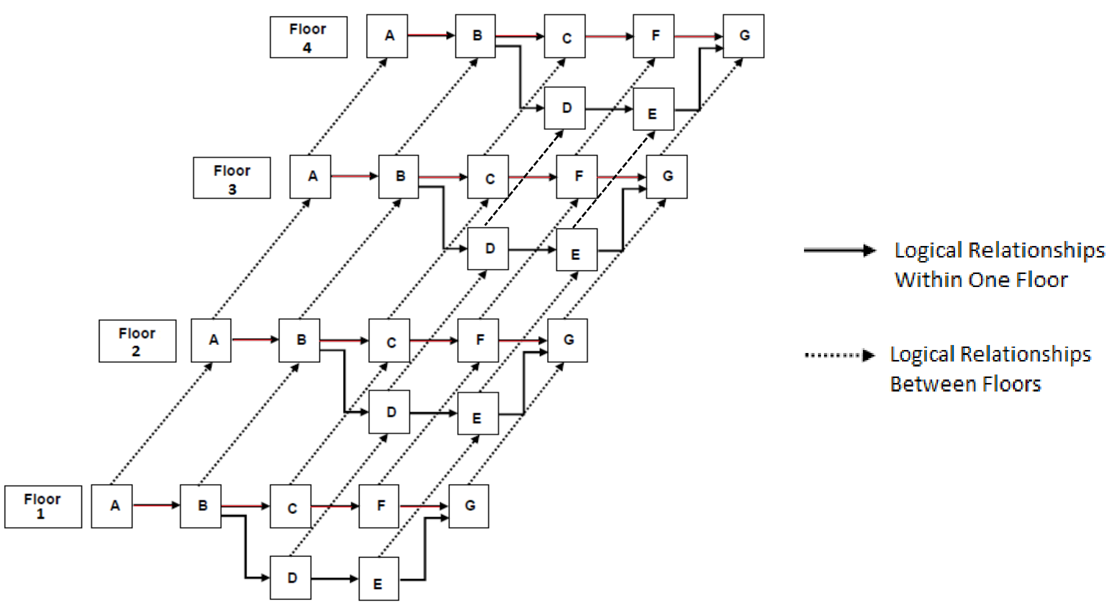


Figure 2.3 CPM Network for Multi-Storey Building

For instance, a repetitive project consisting of 100 units, and each unit containing 7 tasks would creates a 700-task network, which is complicated to visualize and schedule, compared to other repetitive scheduling techniques.

There are several limitations of using CPM for scheduling a repetitive project, and the most common of these restrictions are listed as follows (Arditi et al., 2002; Duffy, 2009; Hegazy, 2003; Ioannou & Yang, 2016b; Srisuwanrat, 2009; Tokdemir, Arditi, & Balcik, 2006):

- In order to meet deadline duration of repetitive projects, the CPM is a duration driven schedule technique, and it does not take into account the resources for calculating schedules;
- The network relationship that is used in the CPM become confused and unmanageable when applied to repetitive projects;
- CPM is not able to maximize efficiency in resource operation;
- CPM does not provide a legible graphical presentation when applied to large repetitive projects;
- CPM does not guarantee continuous resource operation along repetitive units.

2.3.2 Line of Balance (LOB)

Line of Balance (LOB) is a resource-driven technique used to schedule repetitive projects (Ammar, 2012). This technique was developed by Goodyear company in 1940 for managing and controlling repetitive projects (Yang & Ioannou, 2004). After that, it was applied by the USA navy in 1950 for repetitive programming projects in industrial manufacturing (Arditi, Tokdemir, & Suh, 2001). The LOB is a graphical scheduling technique that does not focus on network analysis. The primary benefit of using LOB is in the graphical schedule presentation (Tokdemir et al., 2006). The objective of using LOB technique for repetitive projects is summarized as follow:

1- Maintain the consistent rate of repetitive work;

2- Balance the resource size of equipment and crews based on the production rate;

3- Evaluate a flow line of the production rate of each unit in the repetitive project;

4- Ensure that crews move in a continuous manner among repetitive units.

An example of using LOB technique for a high-rise project is shown in Figure 2.4. The graphical presentation of LOB technique displays the number of the floor on the Y-axis and time on the X-axis. In addition, it shows the start and finish period of the tasks for each floor. The LOB schedule control can be realized by plotting the actual progress rate for each task on the same graphical presentation, which to provide a comprehensive summary of the project status at any point in time. The LOB schedule presents a sequential network of three following tasks, starting from task A and ending with task C. The LOB technique displays a number of crews for each task and their movement between each floor. In addition, the continuity of each crew is required to complete the project. For instance, task C contains three crews that are employed for its implementation; the first crew is allocated to the first floor and moves to the fourth floor, the second crew is assigned to the second floor and moves to the fifth floor, while the third crew is allocated to the third floor.

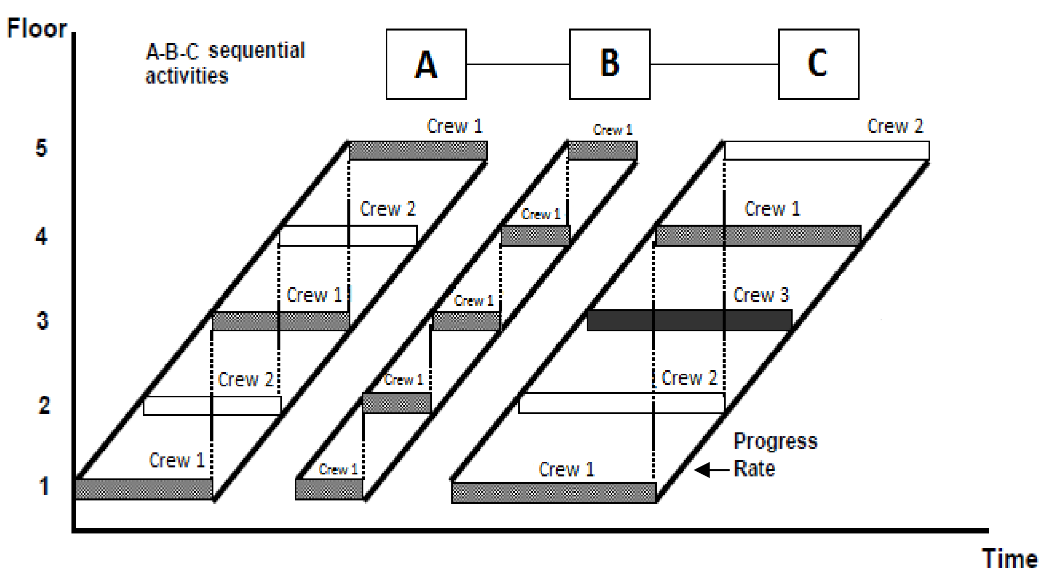


Figure 2.4 LOB Schedule for High-Rise Building Project

In order to suit the nature of repetitive projects, the essential principle of LOB technique has several limitations that need to be improved. These are as follows:

- The assumption of LOB is that the tasks are identical in all units, which is unrealistic since the amount of work in repetitive units is rarely the same (Lutz, 1990; Yang, 2002; Srisuwanrat, 2009);
- The presentation of LOB schedule becomes unclear when many parallel tasks are placed in a specific period (Kavanagh & Asce, 1986); and
- LOB technique is not widely used in construction projects due to it's visualization challenges (Lutz, 1990; Yang, 2002).

Despite these limitations, the LOB technique has the capability for planning and scheduling repetitive projects.

2.3.3 Linear Scheduling Model (LSM)

Linear scheduling model is another technique used to schedule repetitive projects. The LSM was developed partially from the LOB technique (Cho, Hong, & Hyun, 2011). However, the origin of this technique is still not clear (Mahdi, 2004). LSM is used for scheduling linear projects, such as highway, pipelining and bridges (Yamín & Harmelink, 2001).

An example of using LSM technique for highway projects is shown in Figure 2.6. The graphical presentation of LSM technique indicates location on the Y-axis and time on the X-axis. In addition, activities are represented in LSM by lines instead of bars. The graphical presentation of LSM technique displays the start (time and location) as well as the finish (time and location) of activity along the road sections. The graphical presentation of the LSM technique shows three types of activities such as lines, bars, and blocks. For instance, activity B is a separate activity (not repeated during the project) that occupies locations eight and nine for seven-time units. Once the time is determined through network analysis, it can be added to the linear schedule projects.

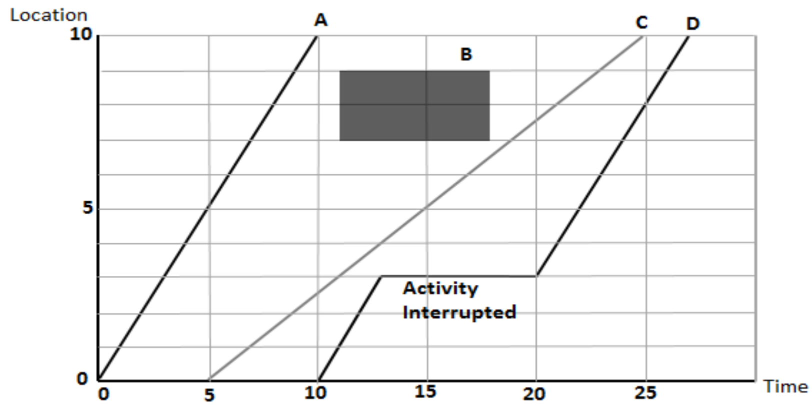


Figure 2.5 LSM Schedule for a Highway Project (Based on Harmelink, 1995)

The LSM schedule control can be realized by plotting the actual progress rate for each activity on the same graphical presentation, which to provide a comprehensive summary of the project status at any point in time. The graphical display of LSM technique represents the production rates of activities by the slope of each line (Harmelink, 1995).

In an interesting study focusing on schedule visualization, Spencer & Lewis (2005) discussed various types pf LSM activities and their visual representations: linear intermittent segment, linear continuous segment, linear intermittent partial-span, linear continuous partial-span, linear intermittent full -span, linear continuous full-span, full-span block, partial-span block, discrete bar, repetitive bar, and intermittent bar, as follows (Figure 2.7):

- **Linear Intermittent Segmented:** These activities occur throughout the project from the real start to finish. The project and work is segmented and stops and starts based on equipment locations, or spread.
- **Linear Continuous Segmented:** These activities are continuous throughout the project physical start and finish where construction is segmented, but does not start and stop, based on availability of equipment.

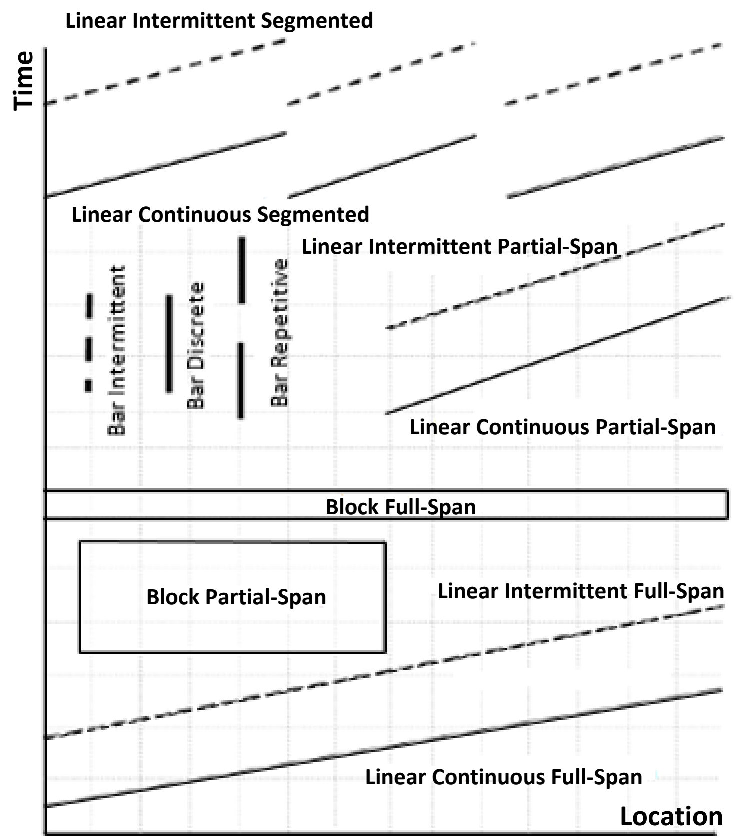


Figure 2.6 Activity types in Linear Scheduling Model (Based on Spencer & Lewis, 2005)

- **Linear Intermittent Partial-Span:** Activities that start at some point in the middle of the project at particular locations where the work is constant, but not for the entire term of the project.
- **Linear Continuous Partial-Span:** Activities that involve continuous constructions activity beginning somewhere in the middle of the project to the end.
- **Linear Intermittent Full-Span:** Construction activity that occurs constantly from the start of the physical project work until the end at various project locations.
- **Linear Continuous Full-Span:** These activities are continuous through the physical duration of the project, from start to finish, occurring at all locations.

- **Block Full-Span:** These construction activities occur intermittently as needed throughout the duration of the whole project.
- **Block Partial -Span:** These activities occur intermittently, but only at particular project sites where construction has reached a physical midpoint.
- **Bar Discrete:** Construction activities that take place only at a particular location of the project.
- **Bar Intermittent:** Activity type varies at a particular site and is irregularly interspersed throughout the project.
- **Bar Repetitive:** The activities are repeated in the construction process only at a particular site of the project.

Assigning visual attributes to different states of the activities is interesting and the study was among the early efforts to improve scheduling from the visual view point. It is noted that in Figure 2.7, the graphical presentation of LSM technique displays location on the X-axis and time on the Y-axis (which is mirrored and rotated from the schedule representation in Figure 2.6). The advantages of using LSM is its ease of use (Yamín & Harmelink, 2001). However, in order to suit the nature of repetitive projects, the essential principle of LSM technique has two key limitations: its graphical presentation does not directly show the duration of the Chrzanowski & Johnston (1986); and the schedules become visually complex and not readable when many activities are placed in a specific period (Yamín & Harmelink, 2001).

2.4 Research on Repetitive Scheduling

A comprehensive review of existing literature on repetitive scheduling was conducted, with a focus on the development over the last ten years. An overview of the publications is presented in Table 2.1.

Table 2.1 Research Summary on Repetitive Scheduling

Research	**Overview**
(Huang & Halpin, 2000)	In 2000, the POLO system was developed by Huang & Halpin to allow the user to view linear scheduling and interact with the LP model.
(Dhanasekar, 2000)	Dhanasekar identified the minimum requirements for repetitive scheduling through sensitivity analyses. This simulation model reduced the resources while maintaining the project length and activities scheduled.
(Askew, Al-jibouri, Mawdesley, & Patterson, 2002)	Askew, Al-jibouri, Mawdesley, & Patterson in 2002 claimed their computerized program was just as effective as an actual project planner in developing scheduling plans.
(Mattila & Park, 2003)	In 2003, Mattila & Park identified key activities using linear and repetitive scheduling to determine which was most effective.
(Moselhi & Hassanein, 2003)	A model to maximize linear scheduling projects was proposed in 2003 by Moselhi & Hassanein that allowed simultaneous work and activities while taking into account various factors that could interfere with scheduling, such as weather and physical obstructions.
(Kallantzis & Lambropoulos, 2004)	Using minimum and maximum limits of time and distance, Kallantzis & Lambropoulos, developed a scheduling method for linear projects that could calculate the critical path.
(Mahdi, 2004)	In 2004, Mahdi suggested repetitive scheduling could be enhanced through the use of linear scheduling.
(Yang & Chang, 2005)	In 2005, Yang & Chang, looked at resources, inluding funding, and how these impacted the scheduling of repetitive and linear projects. They proposed that the resulting issues caused by lack of funding or resouces could be solved using LP if we do not rely on chance-constrained programming but provide specific input instead.
(Tokdemir et al., 2006)	The Advanced Linear Scheduling System (ALISS) (Tokdemir et al., 2006) used information technology to fix issues with Line of Balance scheduling.
(Liu & Wang, 2007)	In 2007, Liu & Wang developed a model to deal with linear scheduling issues that took into account planning objectives and resources to improve the project outcomes.
(Ipsilandis, 2007)	Ipsilandis, in 2007, proposed a linear model that allowed for multiple scheduling possibilities for projects, taking into account cost and project timelines.
(Kallantzis,Soldatos,&Lambropoulos, 2007)	Kallantzis,Soldatos,&Lambropoulos, 2007, compared the critical path of repetitive projects and network scheduling projects to come up with a set of rules to change a linear project into a CPM network project.

(Georgy, 2008)	Using AutoLISP programming, (Georgy, 2008), suggested the use of a genetic algorithm-based scheduling system to manage resources in a linear schedule that would result in more stable resource usage.
(Staub-French, Russell, & Tran, 2008)	In 2008, Staub-French, Russell, & Tran, used a 4D CAD model using 3D CAD software and linear planning software interactions to relate the product and process models for projects.
(Lucko, 2008)	Lucko's 2008 proposal of a mathematical analysis for scheduling linear or repetitive construction projects was not dependent on graphical views and was claimed to be effective despite changes in project activity buffers or productivity.
(Russell, Staub-French, Tran, & Wong, 2009)	Russell, Staub-French, Tran, & Wong's 2009 research surrounded scheduling techniques for large-scale linear projects, mapping graphics and scheduling, to come up with new construction methods and project schedules.
(Liu & Wang, 2009)	(Liu & Wang, 2009), proposed a model using constraint programming that helped minimize costs and maximize profits, maintain project timelines, and optimizing the overall project plan.
(Sharma, McIntyre, Gao, & Nguyen, 2009)	(Sharma et al., 2009) developed a scheduling method to synchronize highway construction projects with the resulting traffic closures. They called this method the Traffic Closure Integrated Linear Schedule (TCILS).
(Lucko, 2009)	In 2009, Lucko used singularity functions to determine minimum project time required by considering all project activities and limitations as well as the time between individual activities.
(Lucko & Peña Orozco, 2009)	(Lucko & Peña Orozco, 2009) used singularity functions to determine constructions project delays for linear schedules.
(Chou, 2011)	In 2011, Chou looked at the costs and possible setbacks of construction projects based on the input of project managers to develop a budgeting tool to assess cost distribution earlier in projects.
(Lucko, 2011)	(Lucko, 2011) proposed that using singularity functions to analyze linear schedules could help with resource optimization.
(Duffy, Oberlender, & Seok Jeong, 2011)	Duffy, Oberlender, & Seok Jeong's 2011 study used an API to show project complications when and where they occurred allowing for a more efficient handling of those obstacles.
(Duffy, Woldesenbet, Jeong, & Oberlender, 2012)	Duffy, Woldesenbet, Jeong, & Oberlender's 2012 study used an automated alignment-based linear scheduling program to analyze how changes in the project plan affect the cost and completion time of the project.
(Liu & Wang, 2012)	(Liu & Wang, 2012), considered how to improve performance on a project by using both single and multi-skilled workers. The study

	used a CP model to manage complicated scheduling issues and introduced several rules to investigate that could assist with scheduling.
(Tang, Liu, & Sun, 2014a)	(Tang et al., 2014a) discussed using a linear scheduling method and CP to address scheduling control issues in railroad construction.
(Hegazy,Abdel-Monem, & Atef Saad, 2014)	Tracking and control of repetitive projects can be managed using specialized linear scheduling program as shown in (Hegazy,Abdel-Monem, & Atef Saad, 2014). Information is fed into the system as the project progresses making project control decisions easier.
(Acebes, Pajares, Galán, & López-Paredes, 2014)	(Acebes et al., 2014), proposed using an EVM with project risk analysis to keep projects on track and within the plan knowing the expected variations.
(Tang, Liu, & Sun, 2014b)	Lucko & Peña Orozco, 2009, proposed a two-stage CP method to optimize resources while considering project delays.
(Su & Lucko, 2016)	In 2016, Su & Lucko combined linear scheduling and LOB to review variations in projects both graphically and mathematically with an aim to optimize scheduling for project crews.
(Ibrahim Bakry, Moselhi, & Zayed, 2016)	(Ibrahim Bakry et al., 2016), proposed an algorithm that did not have to rely on historical data to optimize repetitive construction scheduling but used Fuzzy set theory to analyze project constraints and variations.
(Ioannou & Yang, 2016a)	(Ioannou & Yang, 2016a), used an RP2 computer program for RSM to create a standard schedule for all types of repetitive projects, showing line, block and bar graphs, and several correlations between project activities.
(Lucko, Araújo, & Cates, 2016)	In 2016, Lucko, Araújo, & Cates proposed an algorithm to convert linear schedules from aerospace industry slip charts.

2.5 Conclusion

Specialized scheduling and management tools are needed when dealing with repetitive projects due to their nature. This chapter discussed several techniques used for scheduling repetitive projects. Since the 1960's there have been many proposed solutions to the issues of scheduling repetitive projects, including the use of CPM, which has proven ineffective. CPM is difficult to develop for repetitive projects even with advancements in computer technology. Since the introduction of LOB techniques for construction projects, it has become easier to maintain work flow and construction crews through scheduling. LOB schedules are still not perfect because they were initially designed for the manufacturing industry which is significantly different than the construction industry. Other techniques such as LSM have been proposed in the literature. LOB and LSM schedules offer visuals that allow the user to ‘see’ how the project will progress, rather than simply showing just dates; they provide a lot of information in a simple format making them a better model for repetitive projects. However, the key challenge in LOB and LSM schedules is the complex visuals for any reasonable size projects. The literature also indicates that some combination of LOB and CPM techniques would be beneficial in repetitive scheduling. One gap in the literature is the lack of schedule visualization efforts for high-rise buildings which have become more and more prevalent in today’s society. The literature review also revealed various studies on schedule acceleration and optimization through the use of computers to schedule, with much less efforts on improving visualization.

Chapter 3

Comparing Recent Applications for Non-Repetitive Scheduling

3.1 Introduction

This chapter provides an overview and comparison of available software packages and applications (apps) for scheduling construction projects, which are typically non-repetitive. Although there is a large number of software systems available commercially, the survey of this chapter focuses on well-known systems that are taking the majority of market share. The objective is to explore and compare their features, particularly visualization of information. This chapter ends by reporting the most distinguished features of ten key systems.

3.2 Comparison Criteria

Three main criteria are used in this research to compare project management software: general features, project management features, and visualization capabilities. Details of these criteria are shown in Table 3.1.

Table 3.1 Evaluation Criteria for Project Management Software

General Features	Project Management	Visualization Capabilities
• Free Trial version • Hosting Price • Warranty	• Project Milestones • Task Management • Report Generation • Cash Flow • Scheduling • Mobile Version • Time Tracking • Project Integration • Import/Export • Integration with Apps • Shared Calendar • Online Browser Editing	• Dashboard • Template • Sample Data • Easy Visual • Actual vs Plan • Has New Visualization • Shows Crews • Shows Link to File • Link to Picture/Drawings

3.3 Overview of Existing Commercial Software

This section describes ten popular commercial software systems for non-repetitive scheduling in construction: Primavera, Microsoft Project, UDA Construction-Suite, Procore, Candy, Buildertrend, BIM 360, e-Builder, GenieBelt and Jonas Premier.

Working copies (free trial versions) of these software systems were used to perform the evaluation. However, for some of these systems (Procore, e-Builder, Candy), no evaluation version was available, thus, the evaluation was based on video demonstrations, in addition to other information available on the software website. Additionally, some of the free trial versions did not provide access to the full software features. The detailed evaluation of each software system is provided in the following subsections.

3.3.1 Primavera

Primavera is the most widely used software for scheduling and on its own has almost 55% of the market share, followed by Microsoft Project (35%), while all other systems share only a 10% of the market (Laurie & Asheesh, 2012). Priomavera is known for its powerful features and suitability for large-scale projects, and multiple projects. It has unparalleled features for scheduling, tracking, resource leveling, monitoring, and different levels of reports(Collins, 2014). One of the key benefits of this software is that it helps users to manage projects, from initiation to closing.

Data Input: Primavera software has a project charter template to prepare for a project between a customer and a client. In addition, it has workflow templates describing the stages/lifecycle of the project for approval before commencing to reduce misunderstanding. The software has the ability to display the project's strategic alignment with the company's portfolio. The software allows the user to enter activities into a work breakdown structure (WBS) template and view as a milestone, critical path, or earned value (EV) as shown in Figure 3.1. It also displays resource allocations in different legible views as shown in Figure 3.2.

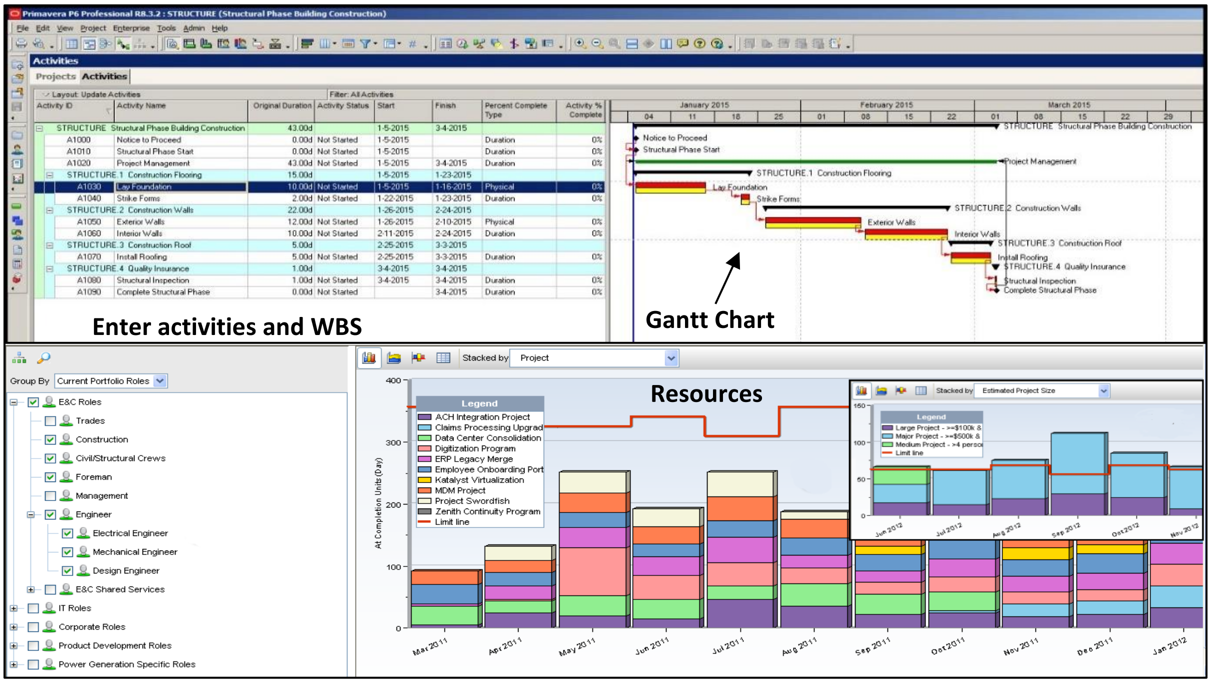


Figure 3.1 Activities and Resource Information in Primavera

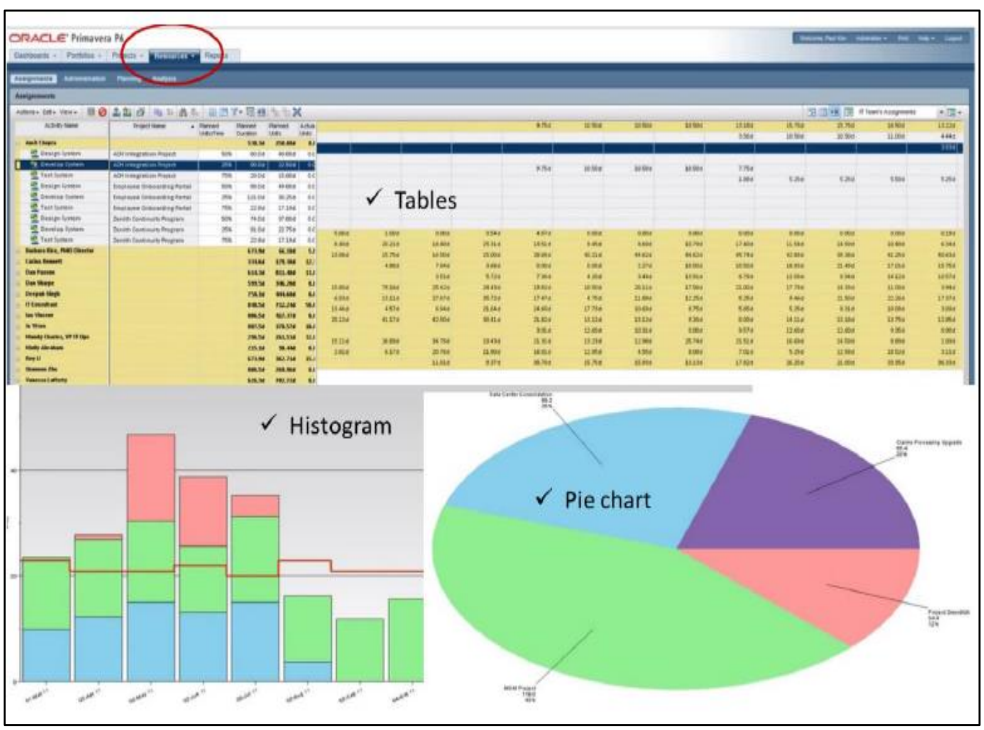


Figure 3.2 Different Views of Resource Assignment or Allocations from Primavera

Outputs: Primavera software has the ability to compare schedule versus baseline and analyze schedule quality with reference to similar past projects in the archive of the software. The software has the ability to document project information in a workspace, which is like a chat room/group that allows team members and/or stakeholders to see what is going on in the project in terms of issues or potential risk. Furthermore, it enables team members to record progress and see their to-do list. Progress can be emailed to stakeholders, and available on mobile phone. The software contains multiple reporting formats and a customizable dashboard to see project reports, as shown in Figure 3.3.

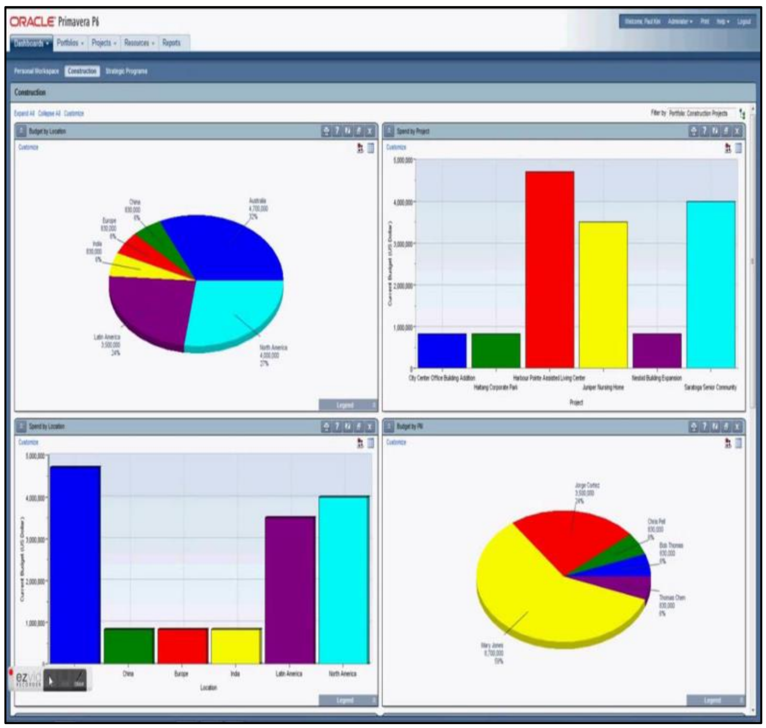


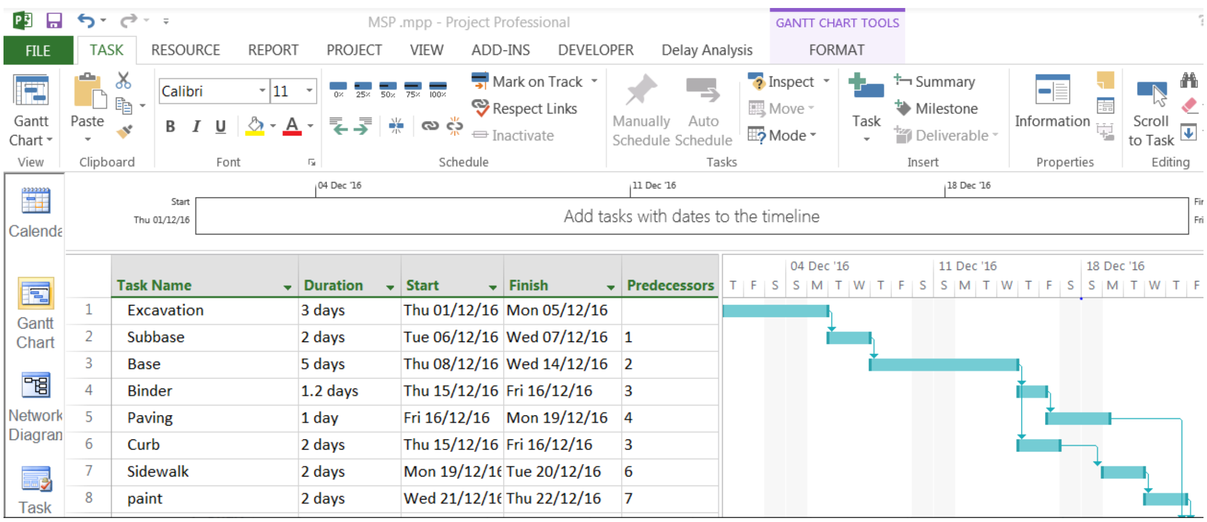
Figure 3.3 Multiple Reporting from Primavera

Discussion: Primavera software is powerful software that has legible views for inputs and outputs. The software includes essential functions needed for planning and project control such as resource leveling, risk analysis, EVM and cash flow. However, the software does not incorporate new or innovative visuals, only colored Gantt charts.

3.3.2 Microsoft Project

MS Project software is the second most common software on the market for project management. Its ease of use and consistency with all MS products are the keys to its wide use.

Data Input: The software has the ability to show, set, and clear baseline details. The baseline allows users to compare original and actual scheduled details so they can keep tracking and managing the progress of the project resources and schedules. In addition, the software lets the user enter activities into a WBS template and view as a milestone and critical path, as shown in Figure 3.4.



	Task Name	Duration	Start	Finish	Predecessors
1	Excavation	3 days	Thu 01/12/16	Mon 05/12/16	
2	Subbase	2 days	Tue 06/12/16	Wed 07/12/16	1
3	Base	5 days	Thu 08/12/16	Wed 14/12/16	2
4	Binder	1.2 days	Thu 15/12/16	Fri 16/12/16	3
5	Paving	1 day	Fri 16/12/16	Mon 19/12/16	4
6	Curb	2 days	Thu 15/12/16	Fri 16/12/16	3
7	Sidewalk	2 days	Mon 19/12/1	Tue 20/12/16	6
8	paint	2 days	Wed 21/12/1	Thu 22/12/16	7

Figure 3.4 Activities Entered into a Work Breakdown from Microsoft Project

Outputs: MS Project software creates different types of reports, including estimating report, resource report, project summary report, and in progress report (Figure 3.5). In addition, it makes project mangement easy by enabling project managers to analyze resources, budgets and timelines. Users of this software are able to create a dashboard for any project. An example of a project dashboard is shown in Figure 3.6.

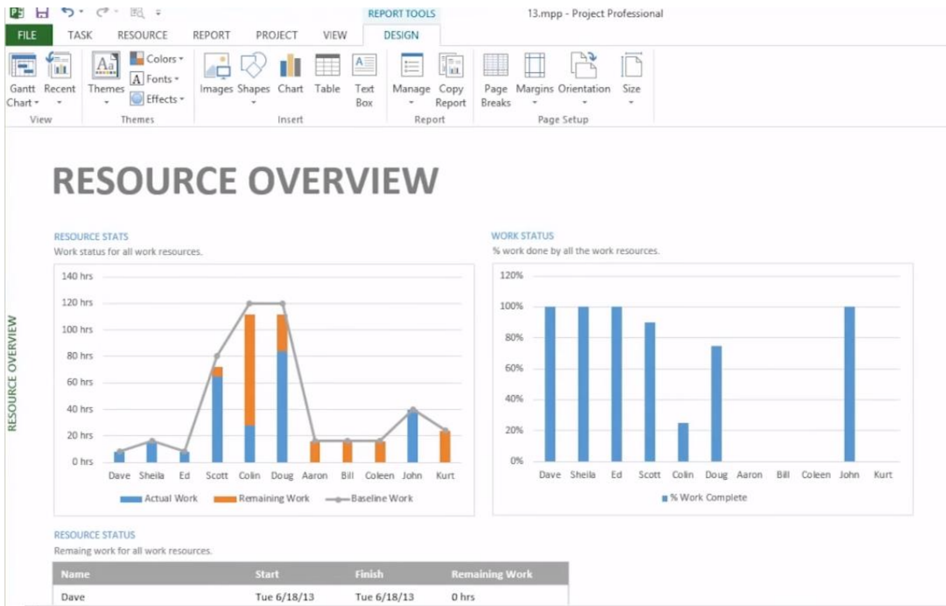


Figure 3.5 Resource Report from Microsoft Project

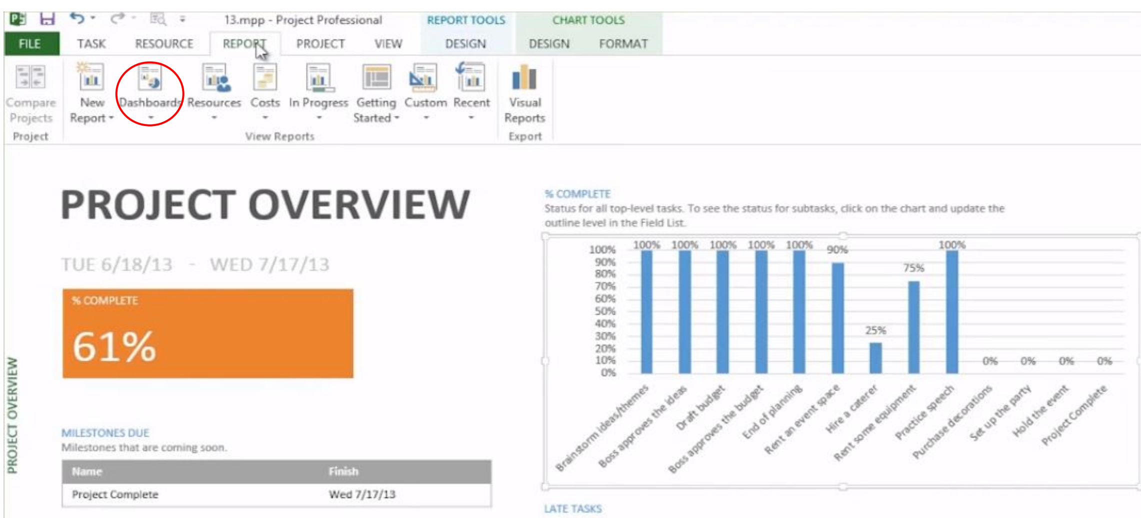


Figure 3.6 Dashboard from Microsoft Project

Discussion: Microsoft Project is a powerful software for a construction projects. The software contains important functions needed for planning and project control such as reporting and cost estimate, EVM and cash flow reports. However, it doesn't include important functions needed for planning and project control such as resources and resource leveling. Also, all its visuals are easy to understand, although no innovative visuals are used.

3.3.3 UDA Construction-Suite

Construction-Suite delivers a combination of Customer Relation Management (CRM) features with project management and estimating tools that push the industry standard further than traditional standards (UDA ConstructionSuite, 2018).

Data Input: This software has the ability to show, set, and clear baseline details. The baseline allows users to compare original and actual scheduled details, so they can keep tracking and managing the progress of the project resources and schedules. In addition, it has the ability to import data from MS Project and Primavera software. The software lets the user enter activities into a WBS template and view as a milestone and critical path, as shown in Figure 3.7.

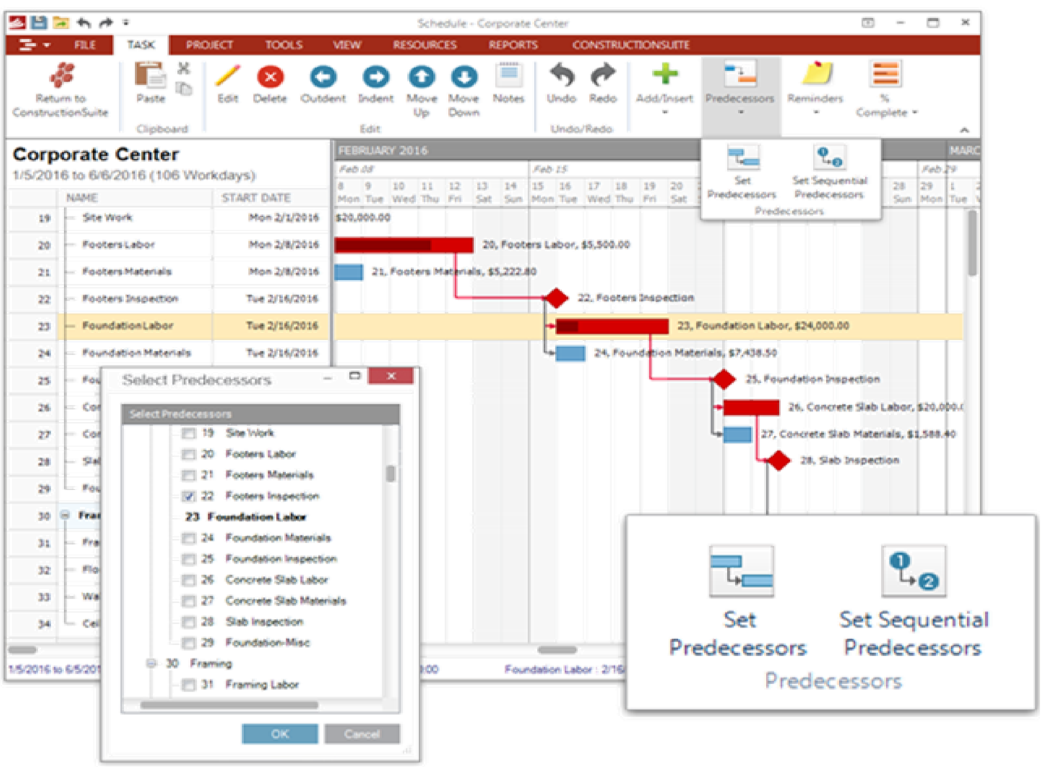


Figure 3.7 Enter Activities into a Work Breakdown from UDA Construction-Suite

Outputs: UDA construction-Suite software generates various reports, such as estimating report, scheduling report, project summary report, contact report, cash flow report, and weather report. It can also produce reports depending on user type (project manager, vendor, supplier, customer). Users of this software are able to create an estimate for any project (Figure 3.8), which is a feature not fully available in Primavera.

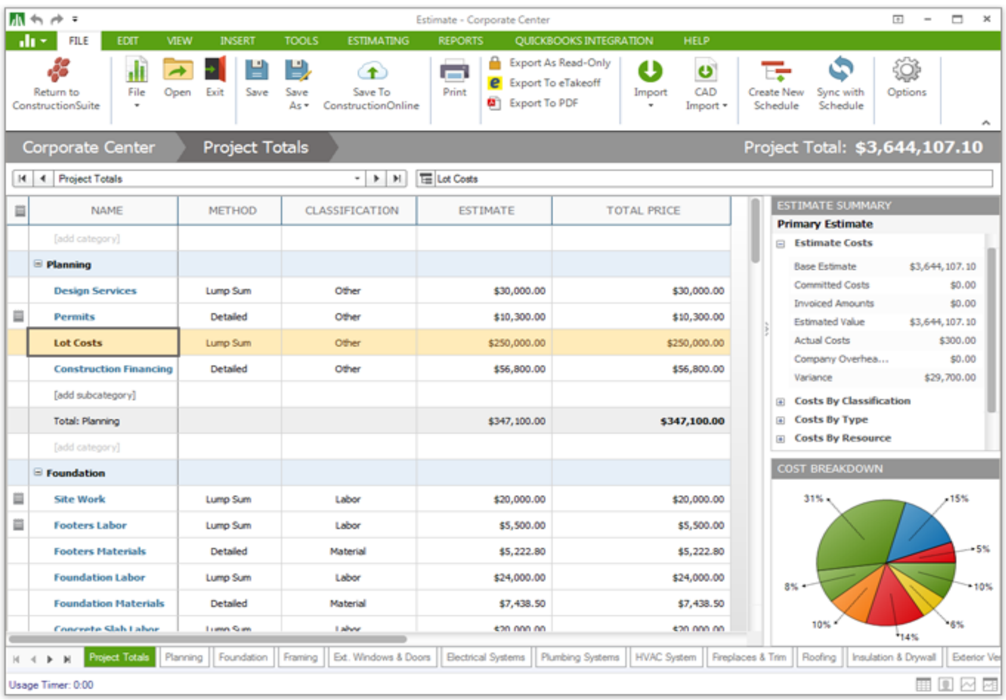


Figure 3.8 Cost Estimating Report from UDA Construction -Suite

Discussion: UDA construction-Suite is a useful software for construction projects. The software includes essential functions needed for planning and project control such as reporting and cost estimate. The software is compatible with several other softwares, such as Primavera, and MS Project. However, it doesn't include essential functions needed for planning and project control, including resource management and resource leveling, EVM and cash flow reports. However, all its visuals are clean and easy to understand, although no radical visuals are used.

3.3.4 PROCORE

Procore software is a cloud-based application for establishing connections among people, applications, and devices. The software provides communication through a platform to manage risk, build quality projects safely and within budget (Procore, 2016).

Data Input: Procore software has the ability to view different types of documents, such as drawings, schedules, contracts, and submittals. In one of its unique visuals, it allows users (contractor, architects, and engineers) to share project data obtained from the project site and to improve the progress of the project, as shown in Figure 3.9. Drawing management is the main feature of this software; it allows users to compare any new version of a drawing with the old one(s) and show all the changes with different color.

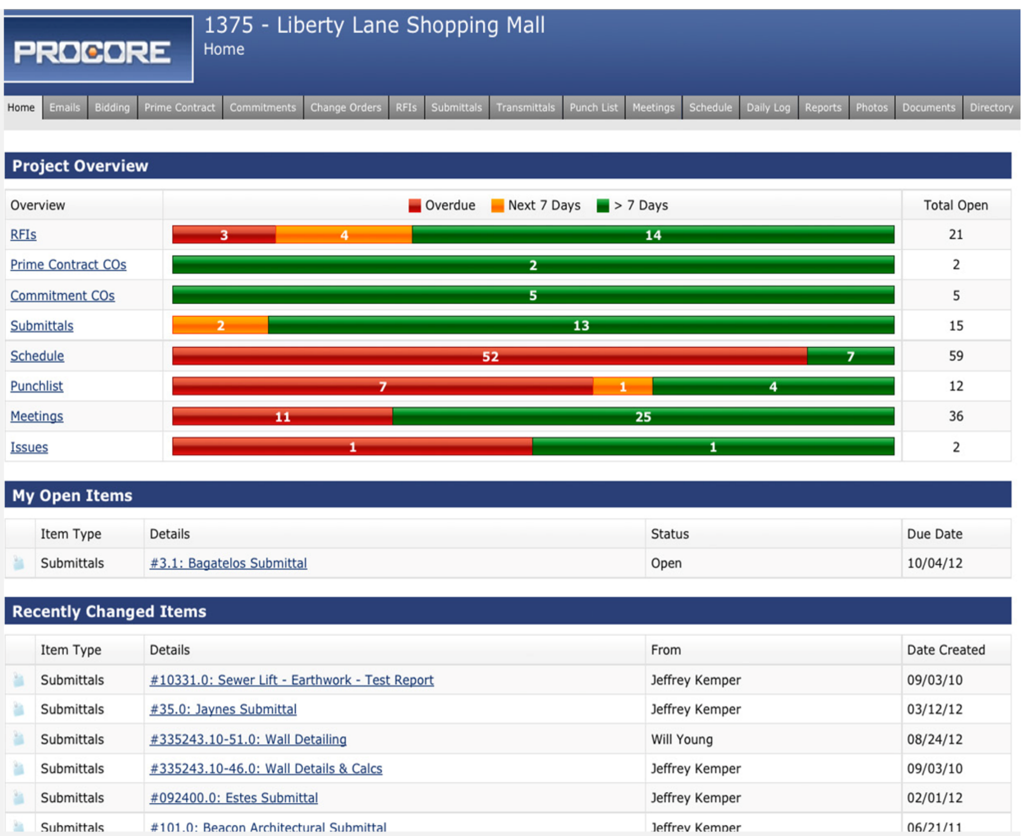


Figure 3.9 Project Overview from Procore

Outputs: Procore displays schedules in a calendar chart, as shown in Figure 3.10, which is less legible than a Gantt chart. Each activity can be edited and reviewed individually by activity name or by crew name. There are no extensive reporting functions available in the Procore software.

Figure 3.10 Project Schedule Shown on a Calendar Chart

Discussion: Procore is a useful software for a construction projects because it contains essential functions required for planning and project control such as submittals, drawings, contracts, and schedules. It doesn’t however, include essential services needed for planning and project control such as resource management, resource leveling, cost, EVM, and cash flow reports. Its interesting visuals are good for communicating progress data among the project parties but, its scheduling visuals lag behind other software packages available.

3.3.5 Candy

Candy is an application for planning, estimating, and project control. The software focuses on project control in the construction industry, a field that has gained enormous importance.

Data Input: Candy defines the project work breakdown structure and activities, then draws a detailed bar chart (Figure 3.11), as typically done in other software. It also offers control of resource rates and projected cash requirements. It links with the "build smart" cost management system, which is used for financial cost-management of all projects in costumer's enterprise.

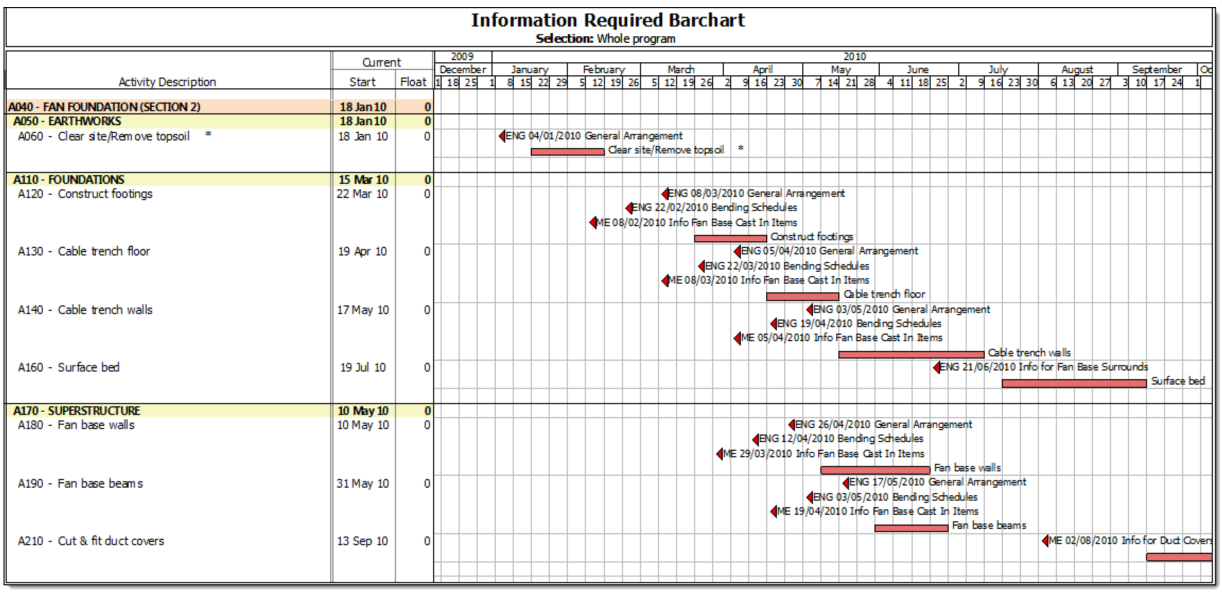


Figure 3.11 Work Breakdown Structure and Bar Chart

Outputs: Among the good visuals produced by Candy, the EV report is available to forecast and track cost against a baseline budget, as shown in Figure 3.12. Also, it has detailed EVM reports for Budgeted Cost for Work Scheduled (BCWS), Actual Cost of Work Performed (ACWP), and Budgeted Cost of Work Performed (BCWP).

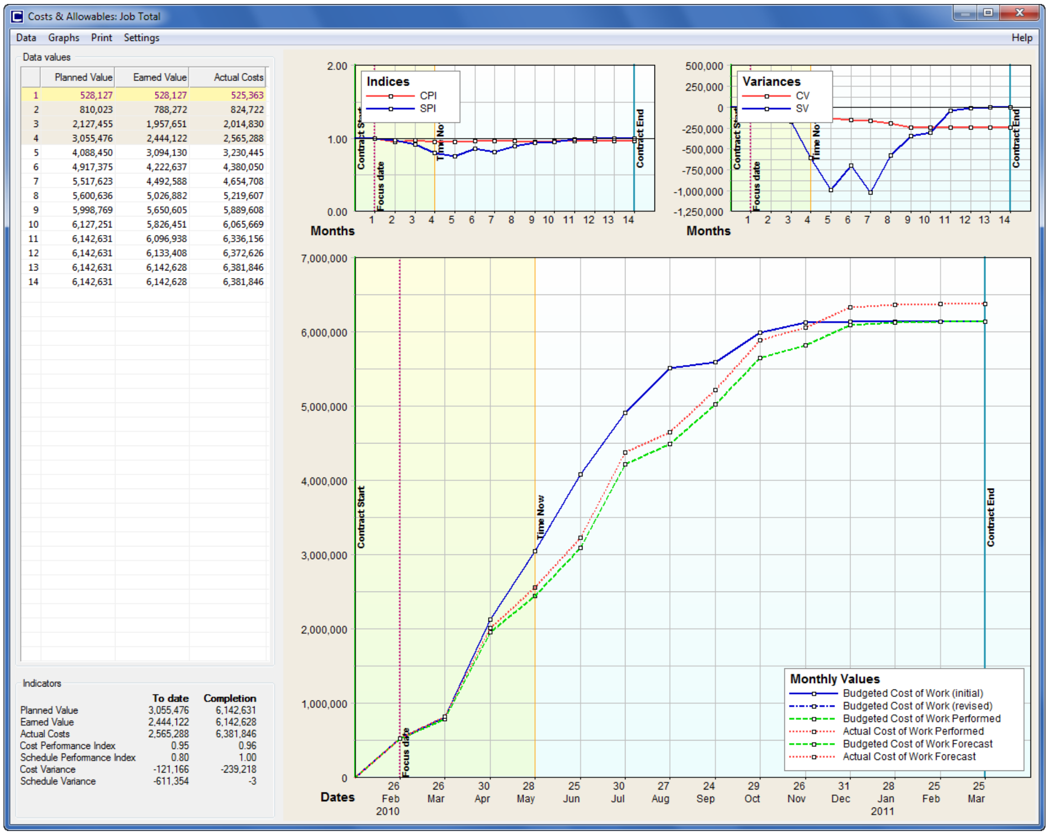


Figure 3.12 Earned-Value Management (EVM) Report from Candy

Discussion: Candy is useful for construction projects because the software includes significant functions required for planning and project control such as activity duration, resource rates, and project cost control. However, it doesn't add essential features needed for planning and project control such as resource leveling. No innovative visuals for the schedule are included in this software.

3.3.6 Buildertrend

Buildertrend is a cloud-based software for homebuilders and remodelers. It improves the communication between the builders and subcontractors in dealing with the tasks and building process while allowing clients to observe the progress of their home (Santos, 2017).

Data Input: Buildertrend software has features that are very helpful for custom homebuilders such as change orders and managing selections. The software lets the user enter activities into a WBS template and view milestones and the critical path on a legible bar chart view, as shown in Figure 3.13.

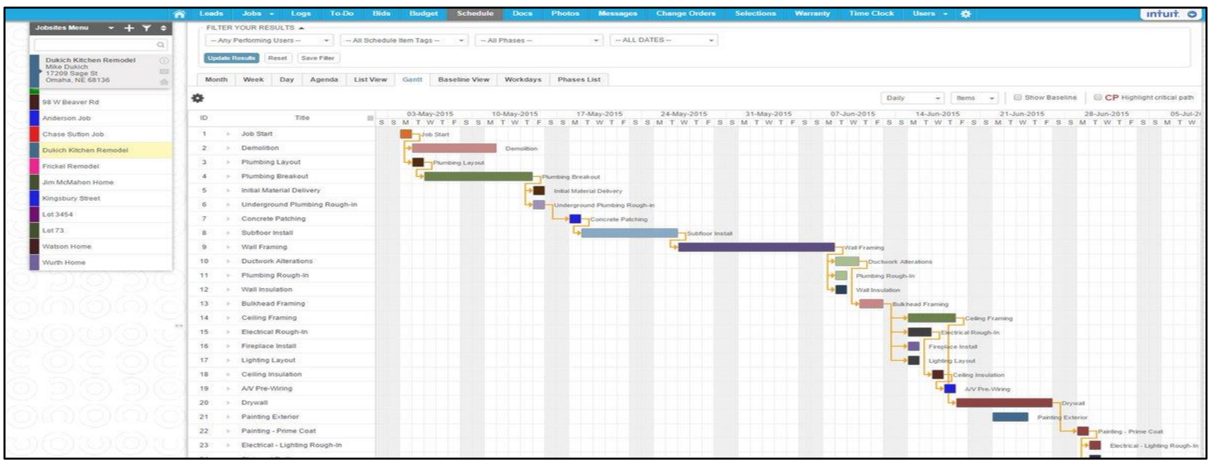


Figure 3.13 Activity Entered into a Work Breakdown from Buildertrend

Outputs: Buildertrend software doesn't include reporting functions for planning and project control, cost estimation, resource leveling, or cash flow reports.

Discussion: Buildertrend is a useful software for a small construction projects. The software covers functions required for project control such as a daily log for the employee using GPS, editing and uploading photos, and real-time updating, with notification to all parties involved. However, it doesn't include estimation, resource leveling or cash flow reports.

3.3.7 BIM 360

BIM 360™ is a field management software for 3D and 2D environments that combines mobile technologies at the construction site with reporting and cloud-based collaboration. BIM 360 has helpful features for custom homebuilders to create a 3D model of the house.

Data Input: BIM 360 allows the user to enter activities into a work breakdown structure in a simple way and display a Gantt chart linked to the location in the 3D model, as shown in Figure 3.14. The software has the ability to plan and schedule each section of the building individually, as shown in Figure 3.15.

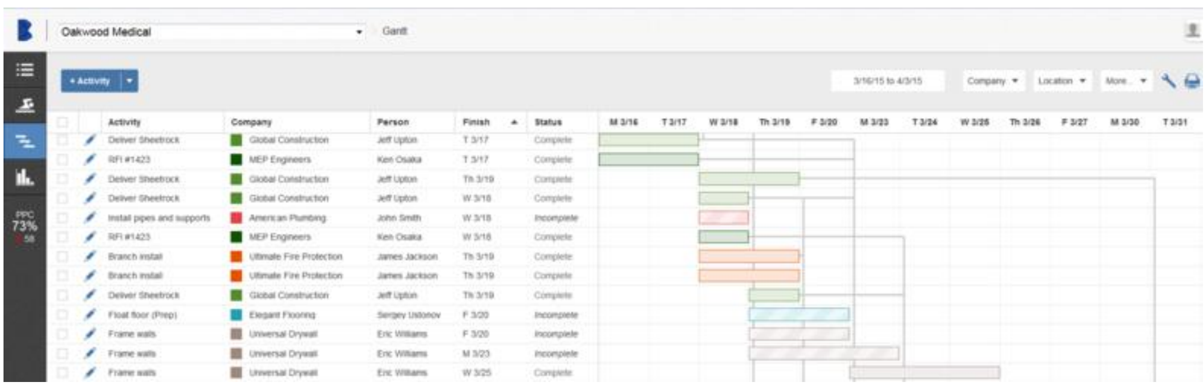


Figure 3.14 Activities, Work Breakdown Structure, and Bar Chart

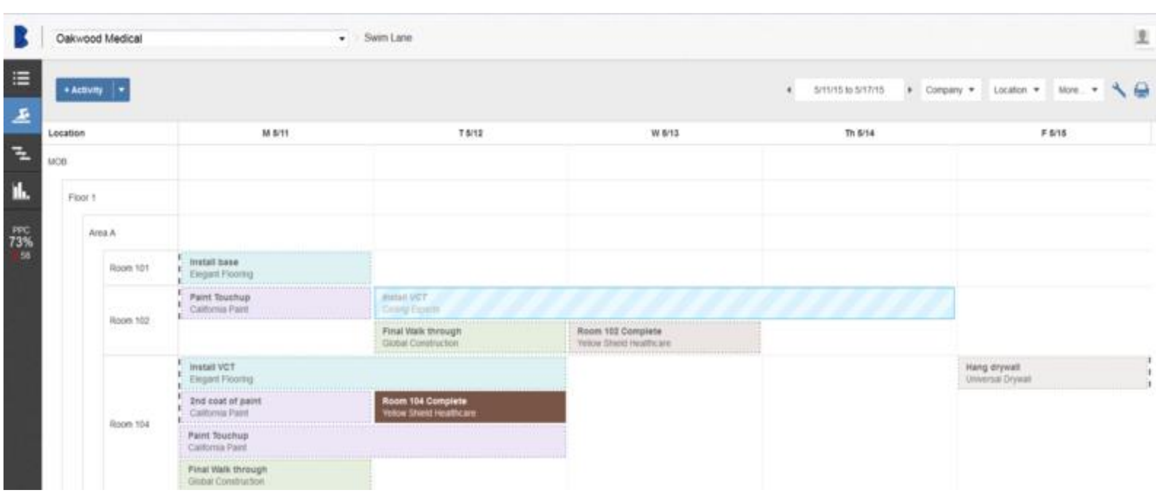


Figure 3.15 Planning and Schedule Project from BIM360

Outputs: BIM 360 software includes different types of reports, such as a safety issue tracker, safety checklist conformance, and most common fault causes, as shown in Figure 3.16.

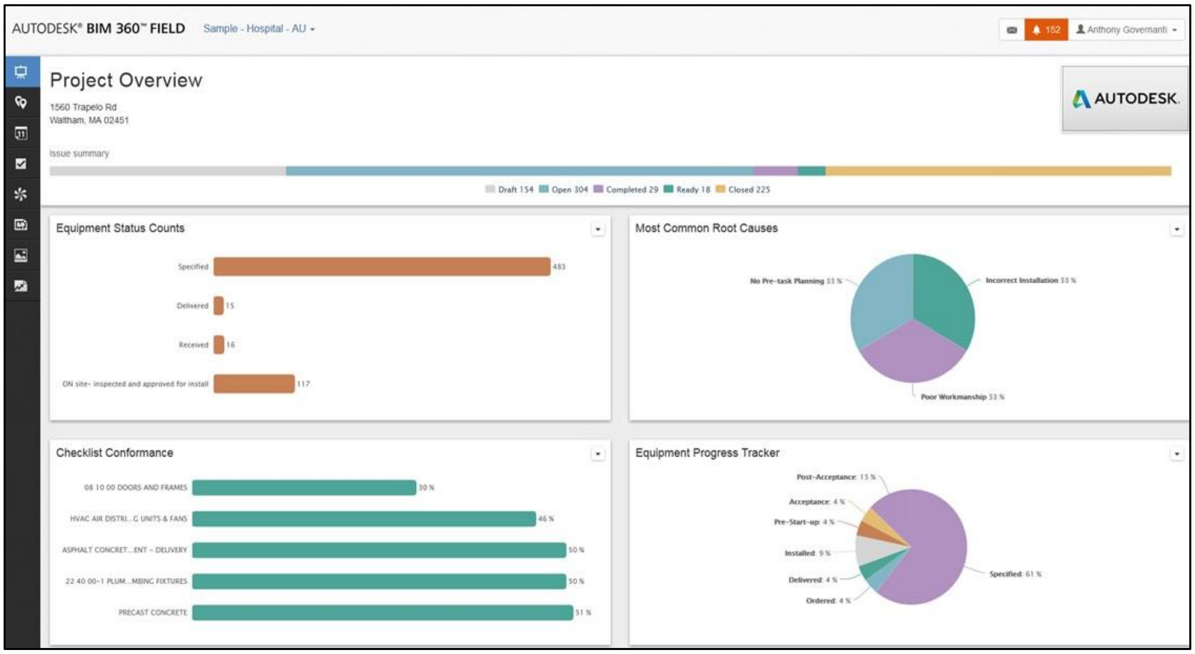


Figure 3.16 Multiple Reporting in BIM360

Discussion: BIM 360 is a suitable software for custom house construction. The software covers essential functions required for planning a project, such as the ability to edit the 3D model of the construction project. The software displays different types of reports like issue tracking, and safety reports. However, it doesn't include essential functions such as cost estimation, resource leveling, project control and cash flow reports. No interesting visuals, other than 3D and space planning views (Figure 3.15), are included in this software.

3.3.8 e-Builder

e-Builder is a construction management software solution that manages capital programs in terms of cost, schedule, and documents. It is a complete solution designed to reduce surprises for owners of capital programs(e-Builder, 2018).

Data Input: e-Builder software displays the activity progress, resource management and Gantt charts, as shown in Figure 3.17. Among its interesting views, it displays the current process on a work flow diagram to show the current stage of the work in blue, as shown in Figure 3.18.

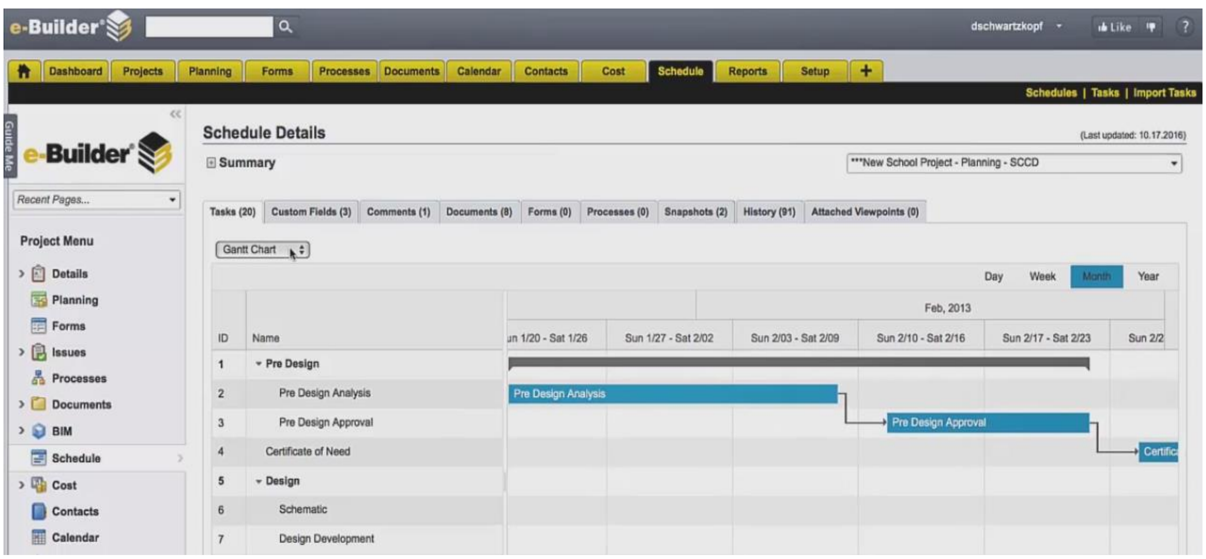


Figure 3.17 Enter Activity into a Work Breakdown from e-Builder

Outputs: e-Builder software supports reporting functions for planning and control of capital projects, such as cost estimation and cash flow reports, as shown in Figure 3.19.

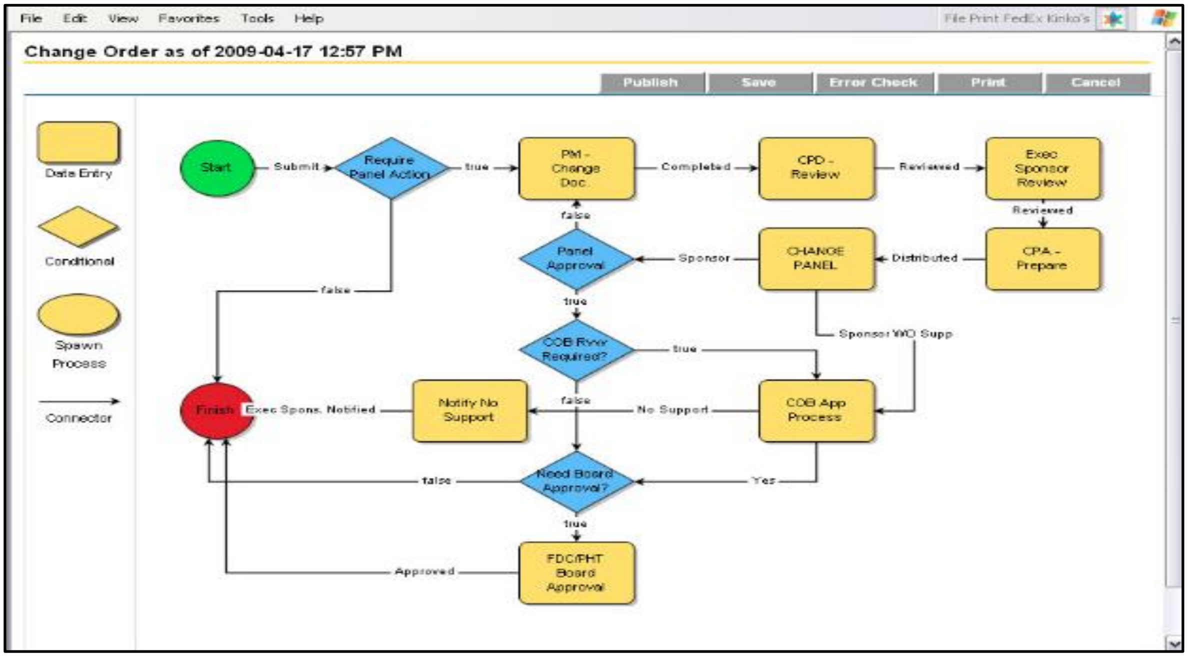


Figure 3.18 e-Builder Work Flow Diagram

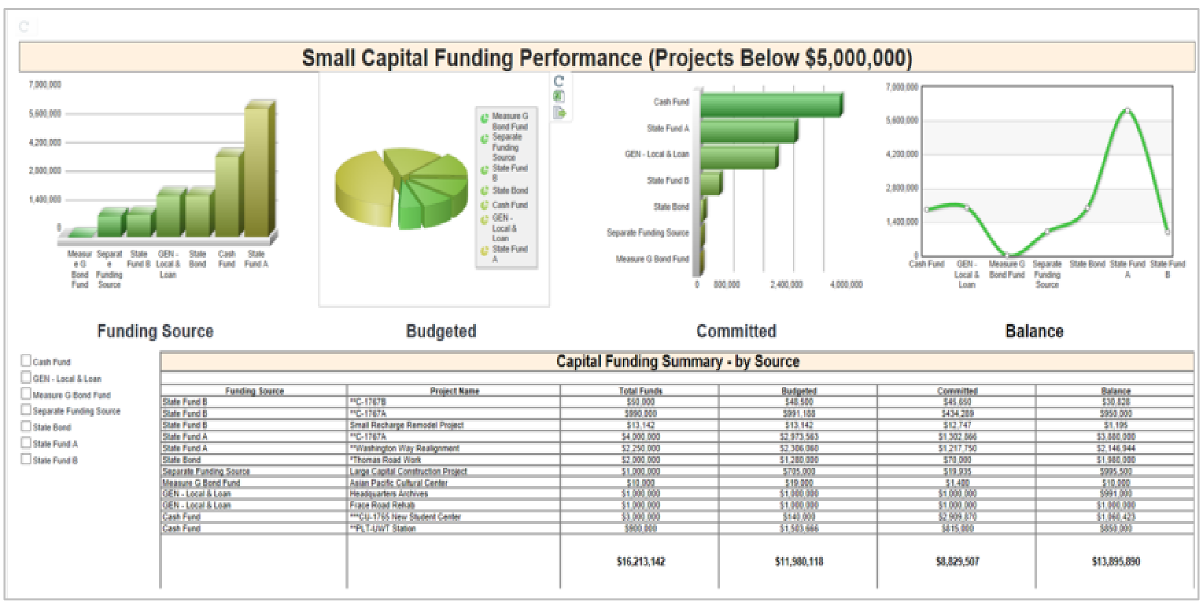


Figure 3.19 Cost Estimation Report from e-Builder

Discussion: e-Builder is a useful software for construction projects. The software has the ability to show the work flow with the current stage color-coded. However, it doesn't include time tracking or resource leveling.

3.3.9 GenieBelt

GenieBelt is a project management software for construction with active program management, project overviews, reporting, a full audit trail, document sharing, and automated drawing control (GenieBelt, 2018).

Data Input: The software includes a visual dashboard and powerful team formation, invitation, and notification. All activities are color-coded and linked to resource photos, as shown in Figure 3.20. It has a full audit trail of all tasks assigned to resources. Project teams can be created from the people in different companies, including architects, engineers, and contractors.

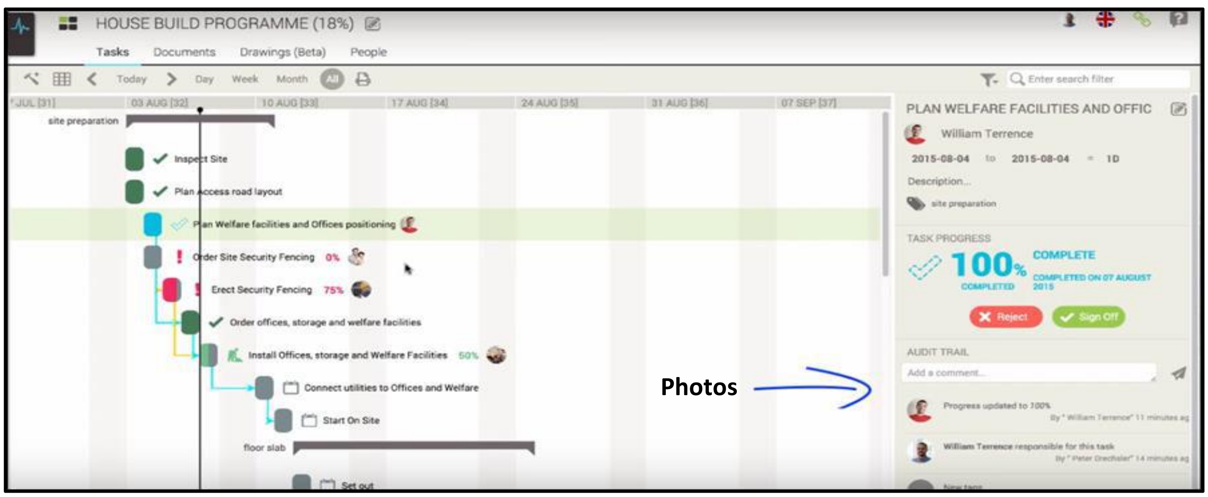


Figure 3.20 Color-Coded Activities with Resource Photos

Outputs: Document sharing and issue sharing functions are available in this software. Each group or company that is linked with the project can upload the required drawings and documents and every team member has the ability to see that information.

Discussion: Dashboards and team member invitations are the main features of this software. Although documents can be shared with this software, the reporting function is not extensive and scheduling features like estimation and resource leveling are lacking.

3.3.10 Jonas Premier

This is a cloud-based job costing and accounting solution designed for use by general contractors and subcontractors, homebuilders, design-builders, and land developers. The system covers estimating and job costing, project management, purchasing, accounting, billing, time and expense tracking, subcontractor management, inventory and equipment tracking, document approvals, reporting, and more (Jonas Premier, 2016).

Data Input: The software creates a legible bar chart, as shown in Figure 3.21. It handles multiple companies, and even intercompany relationships. It breaks down jobs by cost items, where users can copy the cost items from a master template or a similar job. At the detailed level, it links to related locations and departments, which is a unique feature to this software.

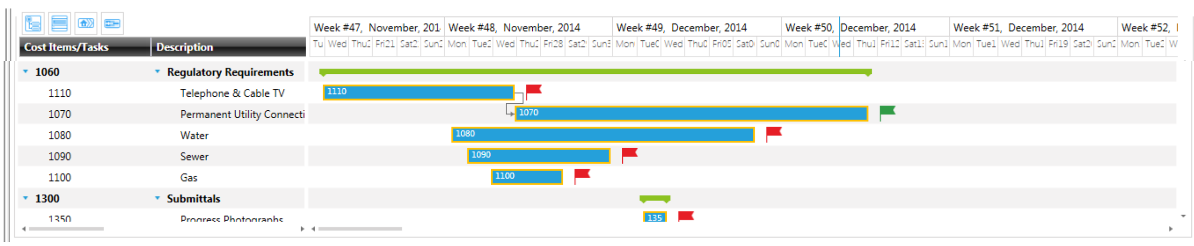


Figure 3.21 Activities and Bar Chart

Outputs: Project managers can compare original estimates to current estimates, estimate cost at completion, and prepare submittals and RFIs. Graphical reports of cost items can be generated in Excel. It can easily attach any third-party. Purchase orders can be added using this software. Users can choose the venders and the jobs allocated to them.

Discussion: Jonas Premier is a useful software for construction projects because of the document sharing capability. The main power of this software is in cost estimating, but it doesn’t include important scheduling features such as resource leveling or cash flow reports. However, its visuals are clear and easy to read.

3.4 Comparison of the Ten Non-Repetitive Software Systems

Table 3.2 summarizes a comparative feature evaluation of the ten non-repetitive scheduling software discussed. Each software was evaluated according to whether or not it covered each function. All software systems provide high quality graphical presentations, yet, schedule visualization does not extend beyond the traditional bar chart.

Table 3.2 Comparison Software Features Evaluation Criteria

	Primavera	Microsoft Project	UDA Construction-Suite	Procore	Candy	Buildertrend	BIM 360	e-Builder	GenieBelt	Jonas Preimier
General										
Free Trial Version	☑	☑	☑	☑	☑	---	☑	---	☑	☑
Hosting Price	☑	☑	☑	☑	---	☑	☑	☑	☑	☑
Warranty	☑	☑	☑	☑	---	☑	---	---	---	---
Project Management										
Project Milestone	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Tasks Management	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Report Generation	☑	☑	☑	---	☑	---	☑	☑	---	☑
Cash Flow	☑	☑	---	---	☑	---	---	☑	---	☑
Scheduling	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Mobile Version	☑	☑	☑	☑	---	☑	☑	☑	☑	---
Time Tracking	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Project Integration	☑	☑	☑	☑	---	☑	☑	---	☑	☑
Import&Export	☑	☑	☑	☑	☑	---	☑	---	---	---
Integration with Apps	---	---	---	---	---	---	---	---	☑	☑
Shared Calender	☑	☑	☑	☑	☑	☑	☑	☑	☑	---
Online Browser Editing	---	---	☑	☑	---	☑	☑	☑	☑	☑
Visualization										
Dashboard	☑	☑	☑	☑	---	☑	☑	☑	☑	☑
Template	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Sample Data	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Easy Visual	☑	☑	☑	☑	---	☑	☑	☑	☑	☑
Actual vs Plan	☑	☑	---	---	---	☑	☑	☑	☑	☑
Has New Visualization	☑	---	☑	☑	---	☑	☑	☑	☑	☑
Shows Crews	☑	☑	---	---	---	☑	☑	---	☑	---
Shows Link to File	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Link to Pictures/Drawings	☑	---	---	☑	---	☑	☑	---	☑	☑

3.5 Conclusion

This chapter presented a survey and comparison among recent non-repetitive projects management software. These softwares exhibited many exciting features and visuals. Yet, schedule visuals do not vary much from a color-coded bar chart to show the different activities and their timings. Such a representation still has serious limitations for repetitive projects. Recent advances to scheduling repetitive projects are discussed in next chapter.

Chapter 4

Comparison of Recent Applications for Repetitive Scheduling

4.1 Introduction

This chapter presents a comparison of several repetitive scheduling software, particularly in terms of their visualization capabilities. The unique features of each software are first discussed in this chapter, followed by a detailed comparison table of their features.

4.2 Comparison Criteria

The same three main criteria used in chapter 3 to compare among project management software are also used in this chapter to compare among repetitive-scheduling software: general features, project management features, and visualization capabilities. However, the sub-criteria that relate to repetitive scheduling are different, and are as shown in Table 4.1.

Table 4.1 Evaluation Criteria for Repetitive Scheduling Software

General Features	Project Management	Visualization Capabilities
• Free Trial version • Hosting Price • Warranty	• Resources/Crews • Resource Leveling • CPM Analysis • Pert/Risk Analysis • Optimization • Cash Flow • Actual Cost • Delays Analysis • Project Integration • MS Project Import/Export • Shared Calendar	• Ease of Planning • View individual Resource • Clear Schedule • Resource Continuity • Ease of Updating • Innovative Visualization • Shows Crews • Link to Photos/Drawings

4.3 Overview of Top Repetitive-Scheduling Software

This section describes seven popular commercial software systems for repetitive scheduling: Spider Project Professional (Russia), ChainLink (England), TimeChainage (England), TILOS (Germany), ASTA Powerproject (England), VICO (United States), and LinearPlus (England).

Working copies (free trial versions) of these software systems were used to perform the evaluation. However, for some of these systems (Vico, LinearPlus), no evaluation version was available, thus, the evaluation was based on video demonstrations, in addition to other information available on the software website. Additionally, some of the free trial versions did not provide access to the full software features. The detailed evaluation of each software system is provided in the next subsections.

4.3.1 Spider Project Version 10

Spider Project is a project management software suite developed in Russia by Spider Management Technologies in 1993 (Spider Project Team, 2016). This software allows contractors to manage linear projects such as highway and pipeline projects. Spider Project has visuals for the activity network, Gantt chart, and linear chart.

Data Input: Spider Project inputs include activities, network, organization breakdown structure (OBS), and WBS. The main project view in Spider Project is the activity Gantt chart (Figure 4.1) where users can enter the initial data. Activites in Spider Project are defined by time and cost. In addition, users can define the resources, their availability limits, and their cost data, as shown in Figure 4.2.

Activities and Critical Path

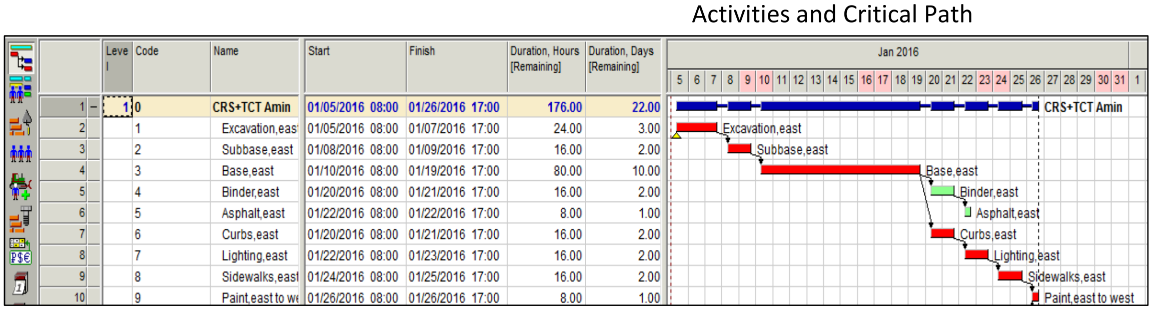
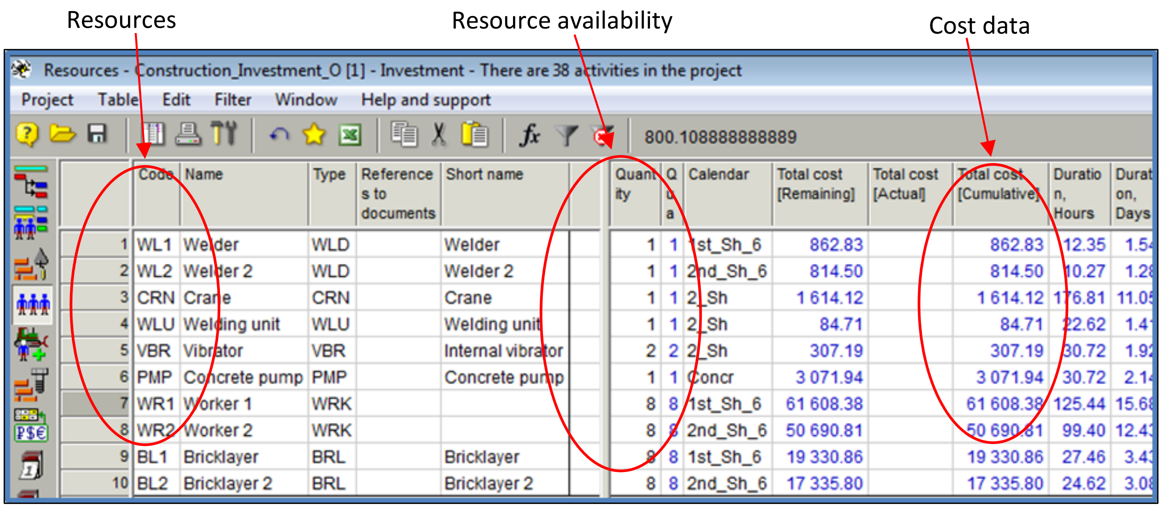


Figure 4.1 Spider Project Shows Network Linked Critical Path Float



	Code	Name	Type	References to documents	Short name		Quantity	Qua	Calendar	Total cost [Remaining]	Total cost [Actual]	Total cost [Cumulative]	Duration, Hours	Duration, Days
1	WL1	Welder	WLD		Welder		1	1	1st_Sh_6	862.83		862.83	12.35	1.54
2	WL2	Welder 2	WLD		Welder 2		1	1	2nd_Sh_6	814.50		814.50	10.27	1.28
3	CRN	Crane	CRN		Crane		1	1	2_Sh	1 614.12		1 614.12	176.81	11.05
4	WLU	Welding unit	WLU		Welding unit		1	1	2_Sh	84.71		84.71	22.62	1.41
5	VBR	Vibrator	VBR		Internal vibrator		2	2	2_Sh	307.19		307.19	30.72	1.92
6	PMP	Concrete pump	PMP		Concrete pump		1	1	Concr	3 071.94		3 071.94	30.72	2.14
7	WR1	Worker 1	WRK				8	8	1st_Sh_6	61 608.38		61 608.38	125.44	15.68
8	WR2	Worker 2	WRK				8	8	2nd_Sh_6	50 690.81		50 690.81	99.40	12.43
9	BL1	Bricklayer	BRL		Bricklayer		8	8	1st_Sh_6	19 330.86		19 330.86	27.46	3.43
10	BL2	Bricklayer 2	BRL		Bricklayer 2		8	8	2nd_Sh_6	17 335.80		17 335.80	24.62	3.08

Figure 4.2 Defining Project Resources

Outputs: The main output of the software is its linear schedule, which displays time on the vertical axis and distance on the horizontal axis, as shown in Figure 4.3. Interestingly, the software shows all crew details underneath the linear schedule (in flowline representation), which is an enhanced way to visualize the many schedule data. In addition, it has multiple views related to resource accumulation, progress information, and cash flow (Figure 4.4).

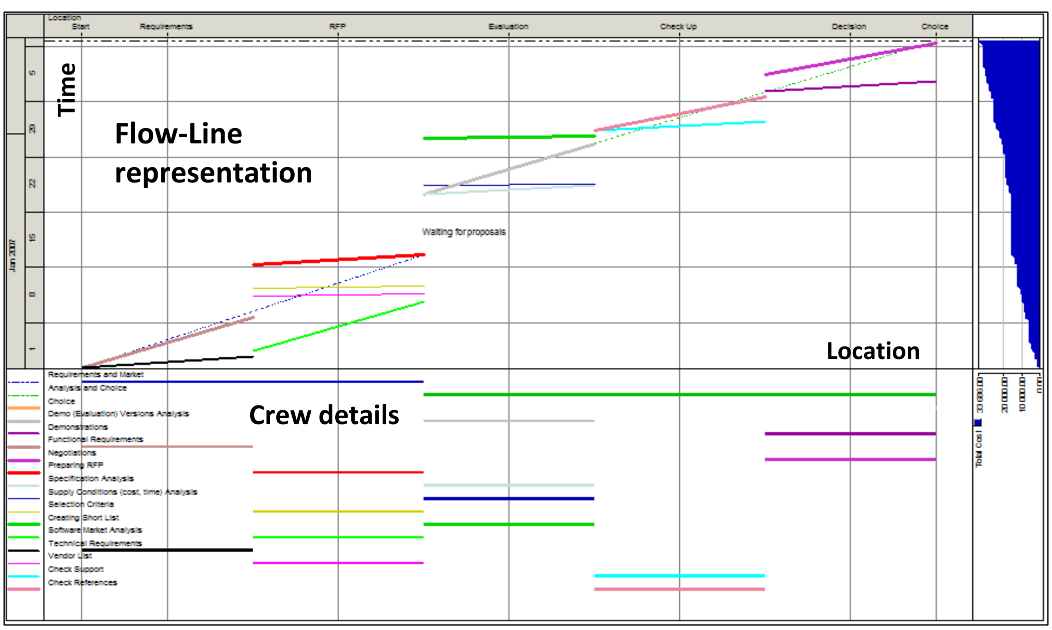


Figure 4.3 Linear Schedule and Crew Details

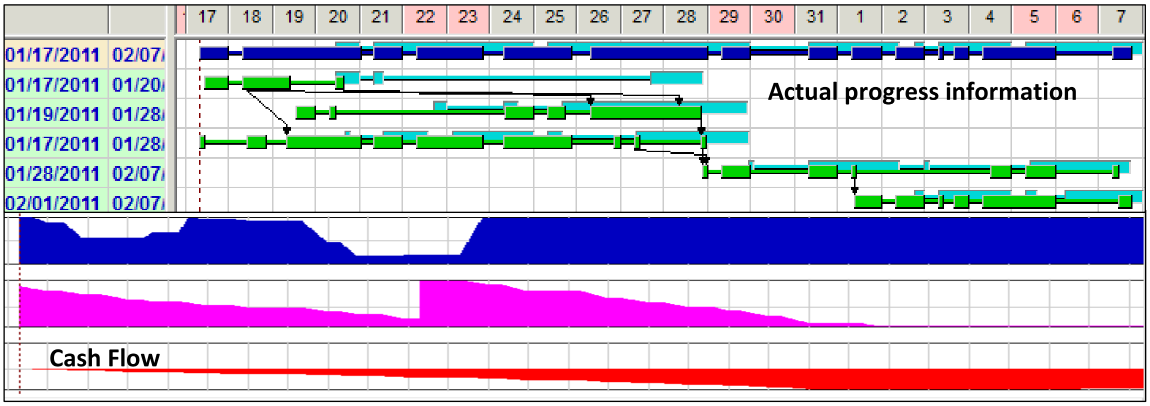


Figure 4.4 Progress Information, Resource Profile, and Cash Flow

One of the powerful features of Spider Project is its risk analysis, which uses Monte-Carlo simulation, which can be used to analyze trends of any project parameter, like project duration or cost, as shown in Figure 4.5.

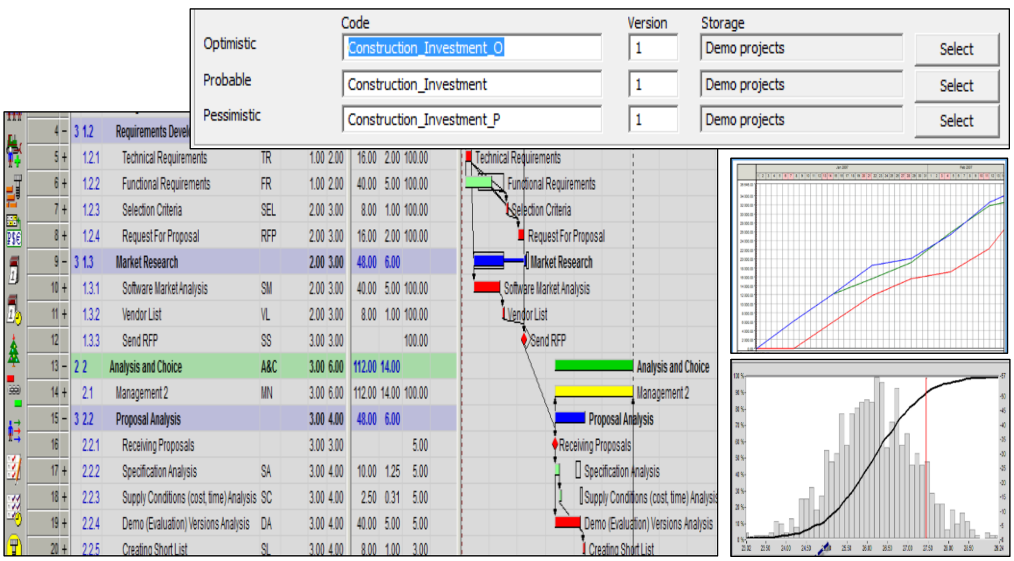


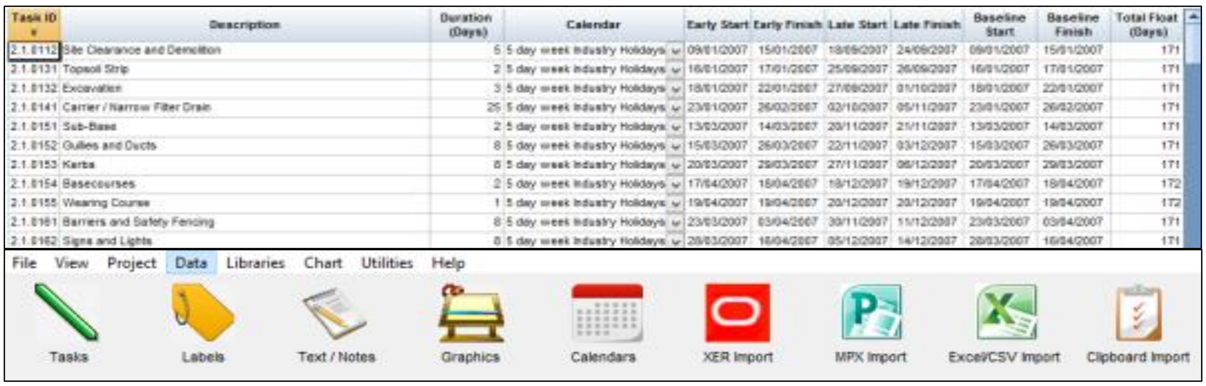
Figure 4.5 Risk Analysis

Discussion: Spider Project software is very suitable for linear projects but not vertical or scattered. The software includes essential functions needed for planning and project control such as resource leveling, cash flow, risk analysis, EVM, etc. All visuals are clear and easy to understand in this software.

4.3.2 ChainLink Version 5

ChainLink was developed by Steven Wood Software in the United Kingdom in 1984 (ChainLink 5.0, 2016). ChainLink uses time-location linear scheduling representation. The software is used for linear projects with repetitive natures, such as highways or tunnels.

Data Input: ChainLink allows users to enter the activities manually (as shown in Figure 4.6), or import the activities from a scheduling program such as MS Project or Primavera.



Task ID	Description	Duration (Days)	Calendar	Early Start	Early Finish	Late Start	Late Finish	Baseline Start	Baseline Finish	Total Float (Days)
2.1.0112	Site Clearance and Demolition	5	5 day week Industry Holidays	09/01/2007	15/01/2007	18/09/2007	24/09/2007	09/01/2007	15/01/2007	171
2.1.0131	Topsoil Strip	2	5 day week Industry Holidays	16/01/2007	17/01/2007	25/09/2007	26/09/2007	16/01/2007	17/01/2007	171
2.1.0132	Excavation	3	5 day week Industry Holidays	18/01/2007	22/01/2007	27/09/2007	01/10/2007	18/01/2007	22/01/2007	171
2.1.0141	Carrier / Narrow Filter Drain	25	5 day week Industry Holidays	23/01/2007	26/02/2007	02/10/2007	05/11/2007	23/01/2007	26/02/2007	171
2.1.0151	Sub-Base	2	5 day week Industry Holidays	13/03/2007	14/03/2007	20/11/2007	21/11/2007	13/03/2007	14/03/2007	171
2.1.0152	Gullies and Ducts	8	5 day week Industry Holidays	15/03/2007	26/03/2007	22/11/2007	03/12/2007	15/03/2007	26/03/2007	171
2.1.0153	Kerbs	8	5 day week Industry Holidays	20/03/2007	29/03/2007	27/11/2007	06/12/2007	20/03/2007	29/03/2007	171
2.1.0154	Basecourses	2	5 day week Industry Holidays	17/04/2007	18/04/2007	18/12/2007	19/12/2007	17/04/2007	18/04/2007	172
2.1.0155	Wearing Course	1	5 day week Industry Holidays	19/04/2007	19/04/2007	20/12/2007	20/12/2007	19/04/2007	19/04/2007	172
2.1.0161	Barriers and Safety Fencing	8	5 day week Industry Holidays	23/03/2007	03/04/2007	30/11/2007	11/12/2007	23/03/2007	03/04/2007	171
2.1.0162	Signs and Lights	8	5 day week Industry Holidays	28/03/2007	18/04/2007	05/12/2007	14/12/2007	28/03/2007	18/04/2007	171

Figure 4.6 Defining Activities in ChainLink

Outputs: ChainLink software displays a linear schedule (in flowline representation) with time on the vertical axis and distance on the horizontal axis. The software has the ability to present various activity types such as block activities. In addition, it allows for different representation options of activities by changing color, type of line and directions, and the shape for each activity. Image files, such as the road profile or other pertinent information related to the linear schedule, can be added to the diagram. This provides good visualization of the project, as shown in Figure 4.7. The schedule, however, can be cumbersome and difficult to understand when many activities are involved.

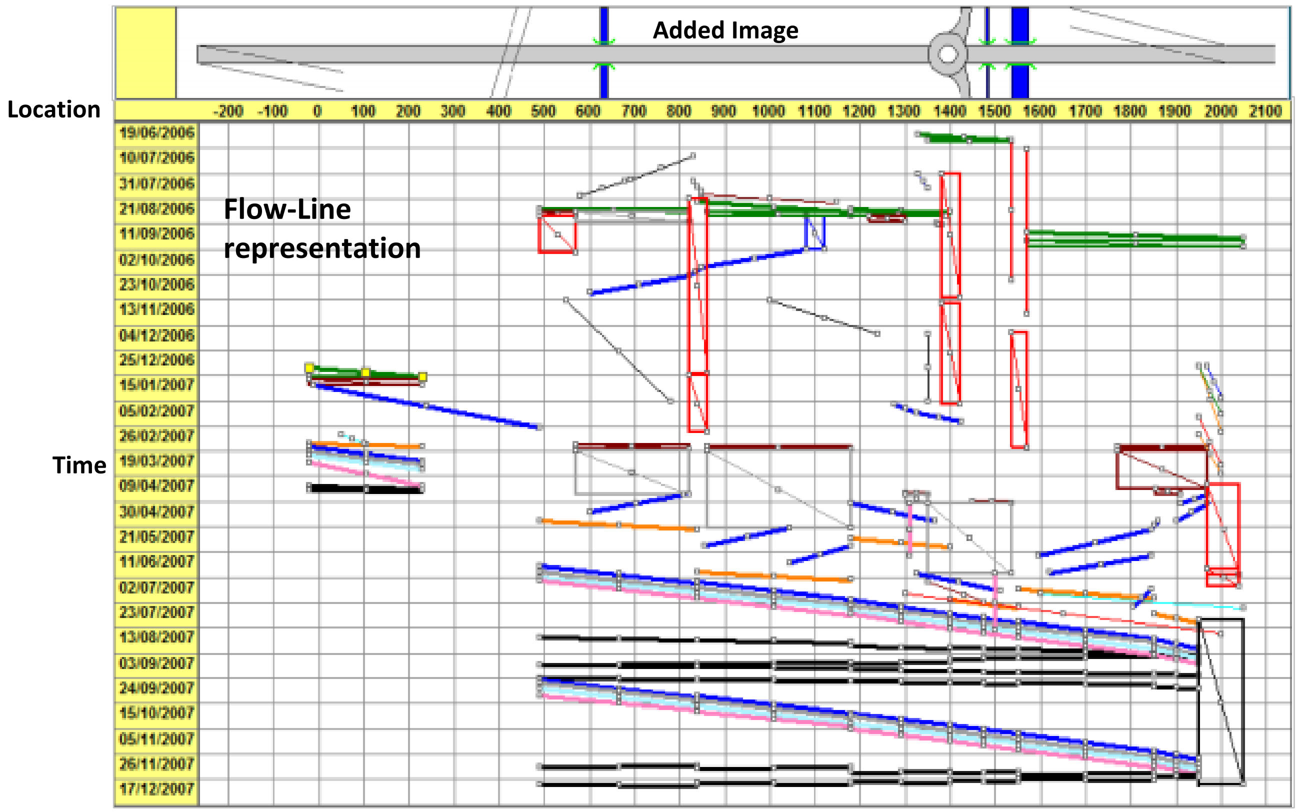


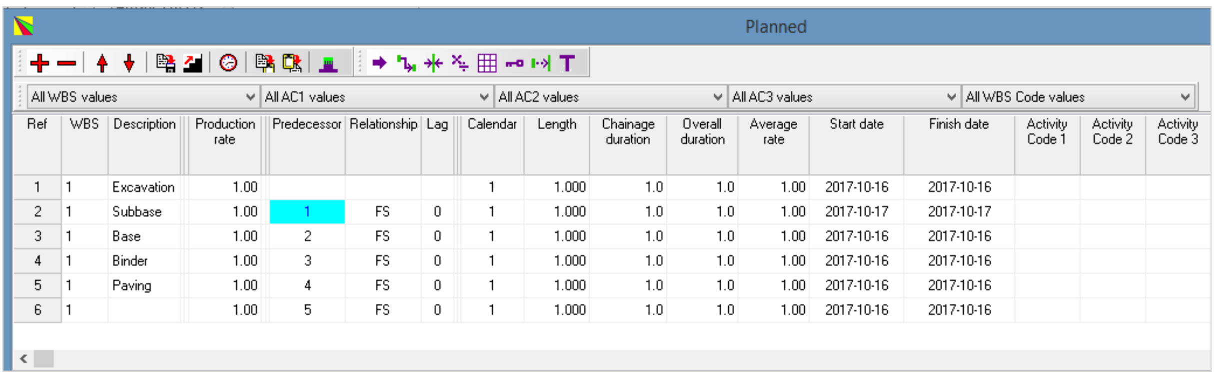
Figure 4.7 ChainLink Chart for a Road Project (Linear Scheduling)

Discussion: ChainLink is a useful software for linear projects, not vertical or scattered. It includes several features useful to visualizing a schedule, such as various activity types and additional graphics. However, the software is not able to estimate the activities information including resources, crews, costs, and methods. Other important features such as cash flow, EVM, and resource leveling are not available in this software. Also, there are no reporting functions available in the standard version of the software. It is claimed that in the professional version of the software, one can obtain histograms, financial graphs, and resources.

4.3.3 TimeChainage Version 8.2

TimeChainage software was developed by Peter Milton Planning in the United Kingdom (TimeChainage, 2017) for both linear repetitive projects such as roads, tunnels, and pipelines, as well as scattered projects like multiple houses, but not vertical projects.

Data Input: TimeChainage software allows users to input activity data and actual data to track project duration, in a spreadsheet, as shown in Figure 4.8. In addition, it enables users to input details including a WBS form, production rates, chainage length, and activity relationships.



Ref	WBS	Description	Production rate	Predecessor	Relationship	Lag	Calendar	Length	Chainage duration	Overall duration	Average rate	Start date	Finish date	Activity Code 1	Activity Code 2	Activity Code 3
1	1	Excavation	1.00				1	1.000	1.0	1.0	1.00	2017-10-16	2017-10-16			
2	1	Subbase	1.00	1	FS	0	1	1.000	1.0	1.0	1.00	2017-10-17	2017-10-17			
3	1	Base	1.00	2	FS	0	1	1.000	1.0	1.0	1.00	2017-10-16	2017-10-16			
4	1	Binder	1.00	3	FS	0	1	1.000	1.0	1.0	1.00	2017-10-16	2017-10-16			
5	1	Paving	1.00	4	FS	0	1	1.000	1.0	1.0	1.00	2017-10-16	2017-10-16			
6	1		1.00	5	FS	0	1	1.000	1.0	1.0	1.00	2017-10-16	2017-10-16			

Figure 4.8 Time Chainage Input Activity Information

Outputs: TimeChainage produces a repetitive schedule (in flowline representation) with location (or unit number) on the horizontal axis and time on the vertical axis, as shown in Figures 4.9 and 4.10 for a linear project, and a scattered project, respectively. Other project details, such as text notes and graphical elements, can be added to the schedule. Users can input actual production of activity progress to track the project during construction. The software has variety of reports to compare planned versus actual progress, as shown in Figure 4.11. However, TimeChainage does not show a bar chart report for any repetitive unit.

Discussion: TimeChainage is a useful software for scheduling linear and scattered projects. It has extensive reports to compare actual versus planned schedules. Yet, it doesn't include functions needed for planning and project control such as resource management and resource leveling.

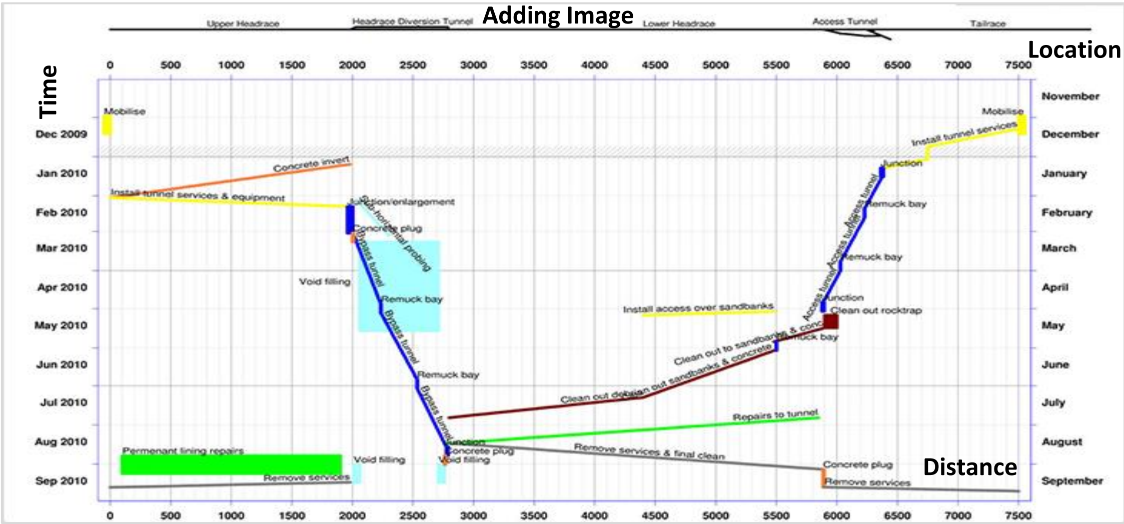


Figure 4.9 TimeChainage Schedule for a Road (Linear Schedule)

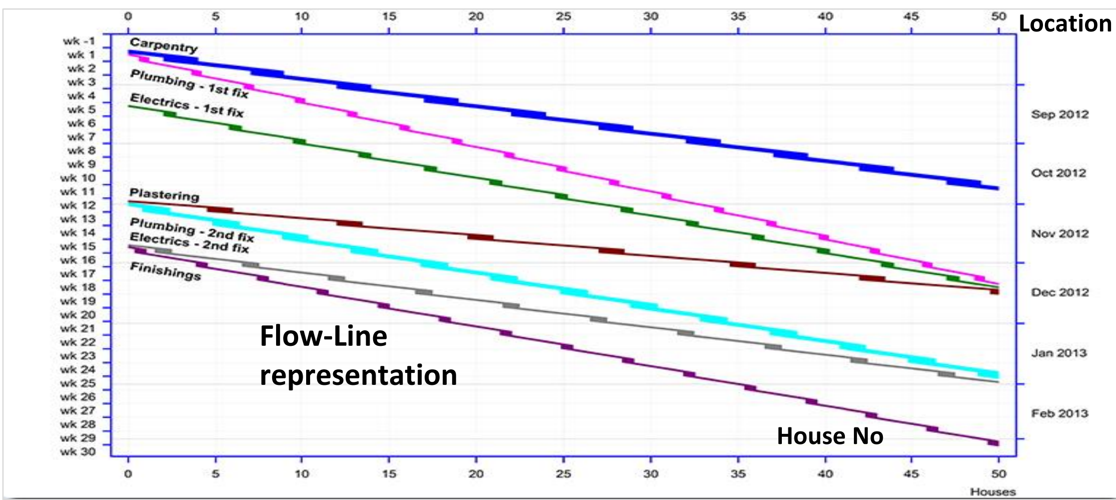


Figure 4.10 TimeChainage Chart for a Multi-House Scattered project

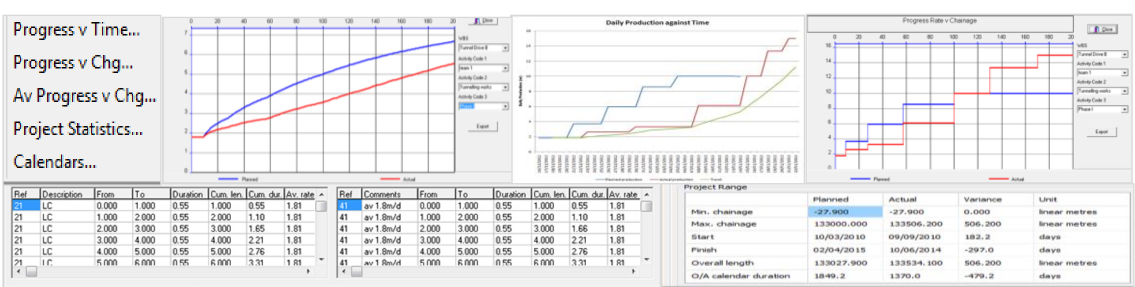


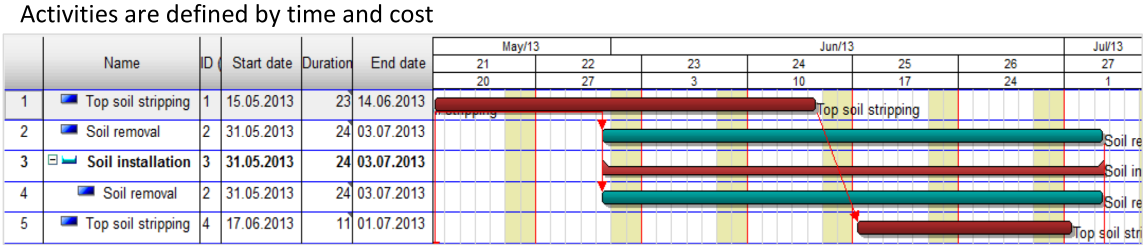
Figure 4.11 Various Reports on the Planned Versus Actual Schedule

4.3.4 TILOS Version 7

TILOS software is mainly for linear project management such as highways, railways, tunnels, and pipelines. The software was developed in Germany by Trimble (TILOS, 2016). TILOS software is able to present both Gantt charts and flowline schedules. In addition, it has strong monitoring features along the production line.

Data Input: Users can enter activity data by defining their time and cost, and the detailed CPM network and Gantt chart, as shown in Figure 4.12. In addition, it allows users to either enter the activities in tabular format or draw the activity on the schedule directly. The software allows users to define resources and their availability, as shown in Figure 4.13. It also allows users to import and export project information to several formats such as plain text data, MS Project, ASTA Power project, Microsoft Excel and Primavera.

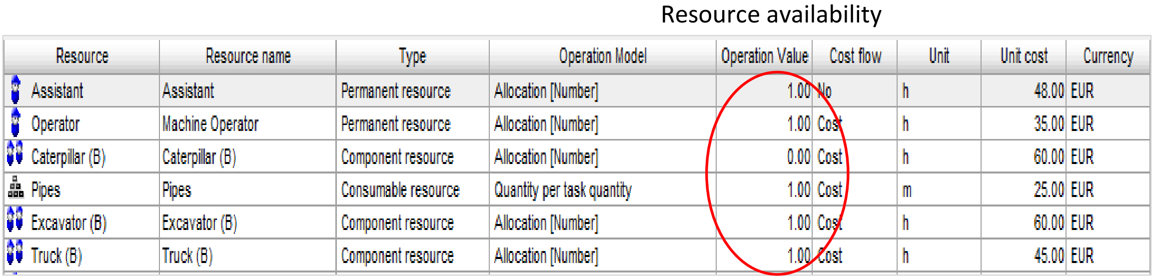
Activities are defined by time and cost



	Name	ID	Start date	Duration	End date
1	Top soil stripping	1	15.05.2013	23	14.06.2013
2	Soil removal	2	31.05.2013	24	03.07.2013
3	**Soil installation**	3	**31.05.2013**	**24**	**03.07.2013**
4	Soil removal	2	31.05.2013	24	03.07.2013
5	Top soil stripping	4	17.06.2013	11	01.07.2013

Figure 4.12 TILOS Data Entry

Resource availability



Resource	Resource name	Type	Operation Model	Operation Value	Cost flow	Unit	Unit cost	Currency
Assistant	Assistant	Permanent resource	Allocation [Number]	1.00	No	h	48.00	EUR
Operator	Machine Operator	Permanent resource	Allocation [Number]	1.00	Cost	h	35.00	EUR
Caterpillar (B)	Caterpillar (B)	Component resource	Allocation [Number]	0.00	Cost	h	60.00	EUR
Pipes	Pipes	Consumable resource	Quantity per task quantity	1.00	Cost	m	25.00	EUR
Excavator (B)	Excavator (B)	Component resource	Allocation [Number]	1.00	Cost	h	60.00	EUR
Truck (B)	Truck (B)	Component resource	Allocation [Number]	1.00	Cost	h	45.00	EUR

Figure 4.13 TILOS Resources and Costs

Outputs: TILOS software displays different views and reports. Its linear schedule (flowline representation) shows time on the vertical axis and location on the horizontal axis. It has the ability to add scaled images to the schedule, thus the location becomes indicative of the real location on the project, as shown in Figure 4.14. TILOS displays resources and costs in charts that show the rate of cost and resource usage in the project.

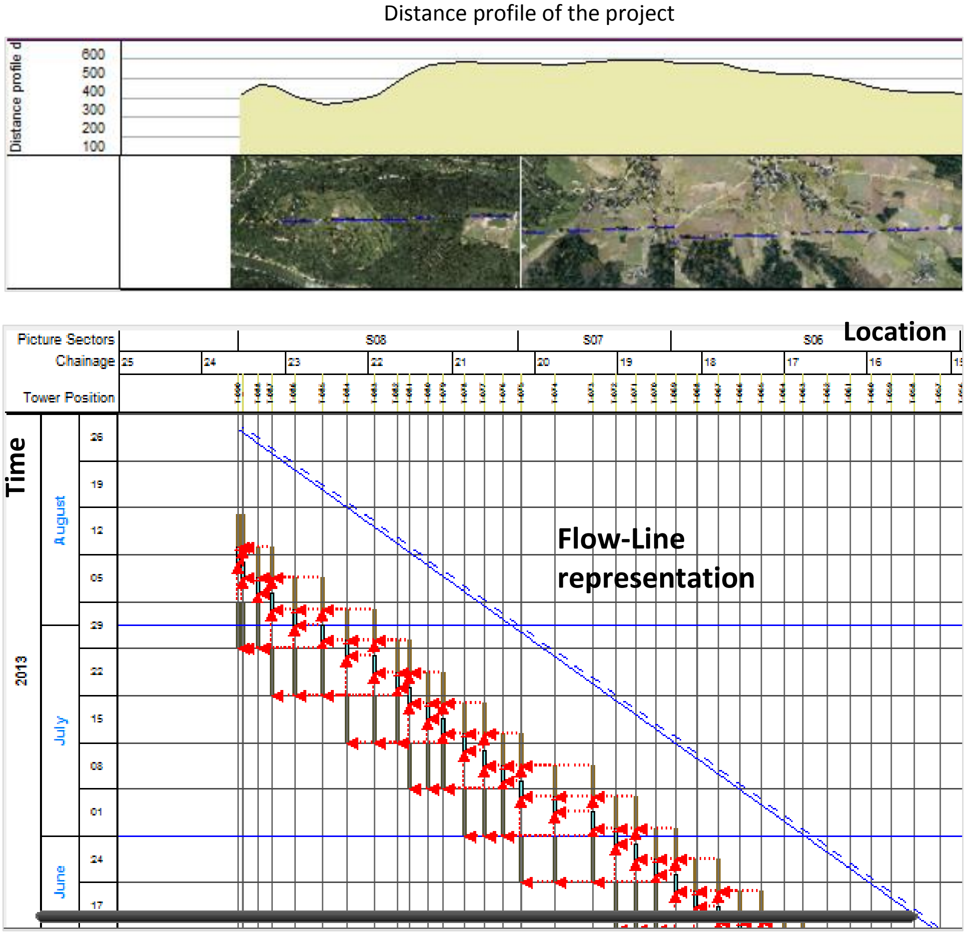


Figure 4.14 TILOS Linear Schedule for a Road Project

Discussion: TILOS is a powerful software for linear projects. The software is easy to use and has many interesting visuals. It has many features for visualizing linear projects and adding graphics. It displays many reports for planning and project control, including cash flow, and EV calculation. The schedule, however, can be cumbersome and difficult to understand when many activities are involved.

4.3.5 ASTA Powerproject Version 14

ASTA Powerproject software is mainly used for linear projects. The software was developed in the United Kingdom (Asta Powerproject, 2016). This software has the most extensive visuals among the surveyed software.

Data Input: ASTA software has a simple interface to allow users to enter activity data, as shown in Figure 4.15, in addition to defining resources and costs.

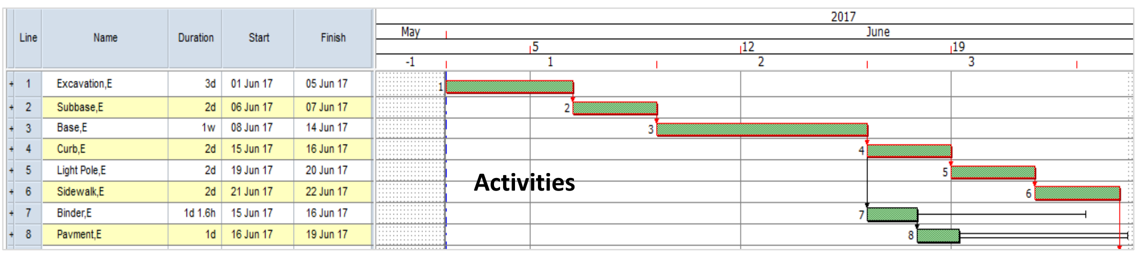


Figure 4.15 Defining Activities in ASTA Powerproject

Outputs: The software has an interesting visualization that shows the linear schedule as a set of stacked trapezium bars (top of Figure 4.16), as well as flowlines (bottom of Figure 4.16). The schedule has time on the horizontal axis and location on the vertical axis. It also has Gantt chart views to represents planned work versus actual progress. In addition, the software has cash flow and resource leveling, and EV reports, as shown in Figure 4.17.

Discussion: ASTA software has many features for scheduling linear projects. It has a clear and organized interface. The software includes essential functions needed for planning and project control such as resource leveling, cost estimates, project tracking, and EVM. The software has multiple schedule views to improve the understanding of the information. Its color-coded linear schedule visuals and dashboards are innovative.

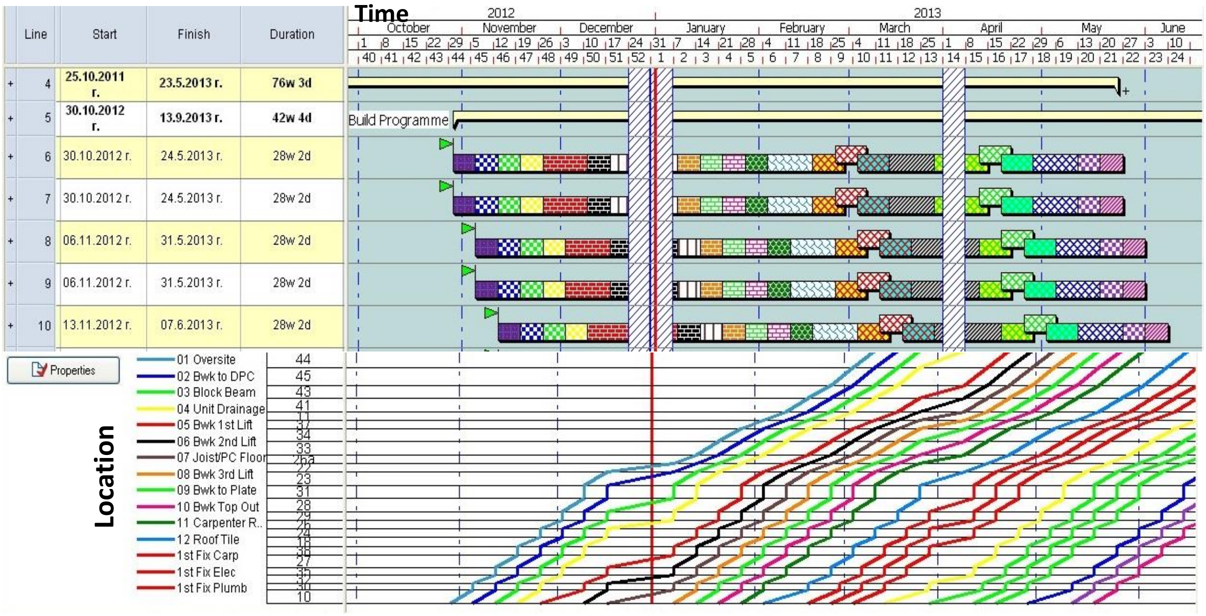


Figure 4.16 ASTA Powerproject Shows Flow Line Representation

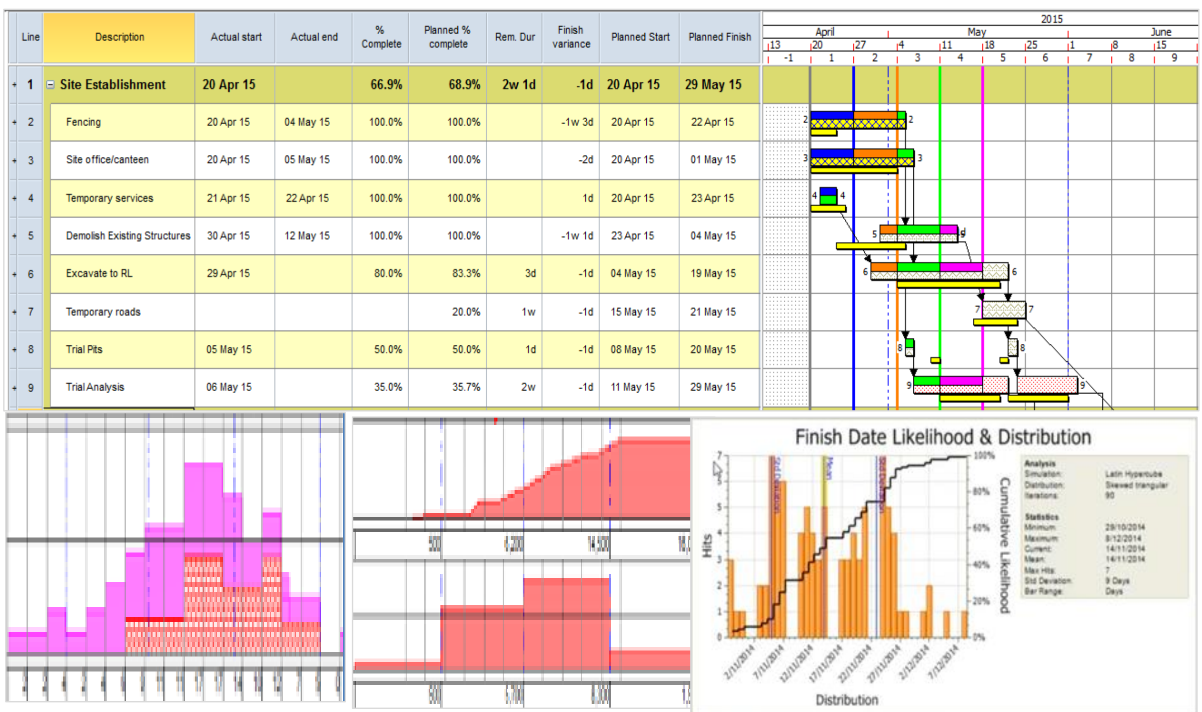


Figure 4.17 ASTA Powerproject Reports

4.3.6 VICO Version 5D

VICO is a project management software suite developed in in United States by VICO development in 2007 (VICO Software, 2018). the software allows contractors to manage repetitive construction projects such as high-rise building projects, but not horizontal projects. VICO has visuals for the activity network and Gantt chart, as well as 3D model.

Data Input: VICO inputs contain activities, networks, and WBS. The main project view in VICO is an activity Gantt chart (Figure 4.18) where users can enter the initial data. In addition, it allows users to import data from a scheduling program such as Revit, ArchiCAD, and Tekla.

Activities and Network Linked Critical Path

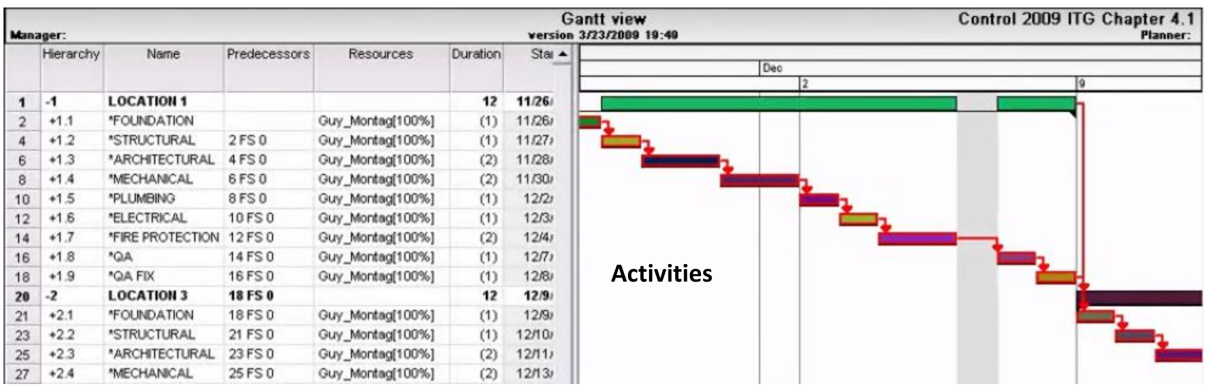


Figure 4.18 VICO Shows Network Linked Critical Path Float

Outputs: VICO shows a linear schedule (in flowline representation) with time on the horizontal axis and location on the vertical axis, as shown in Figure 4.19. In addition, it allows for representation options of activities by changing color and directions. Interestingly, the software allows the user to integrate the 3D model with the planning schedule simultaneously, which is a feature not available in other software. This provides better visualization of the project, as shown in Figure 4.20. The report functions are not available in the standard version of the software. It is claimed that in the professional copy of the software, one can obtain histograms, financial graphs, and resources.

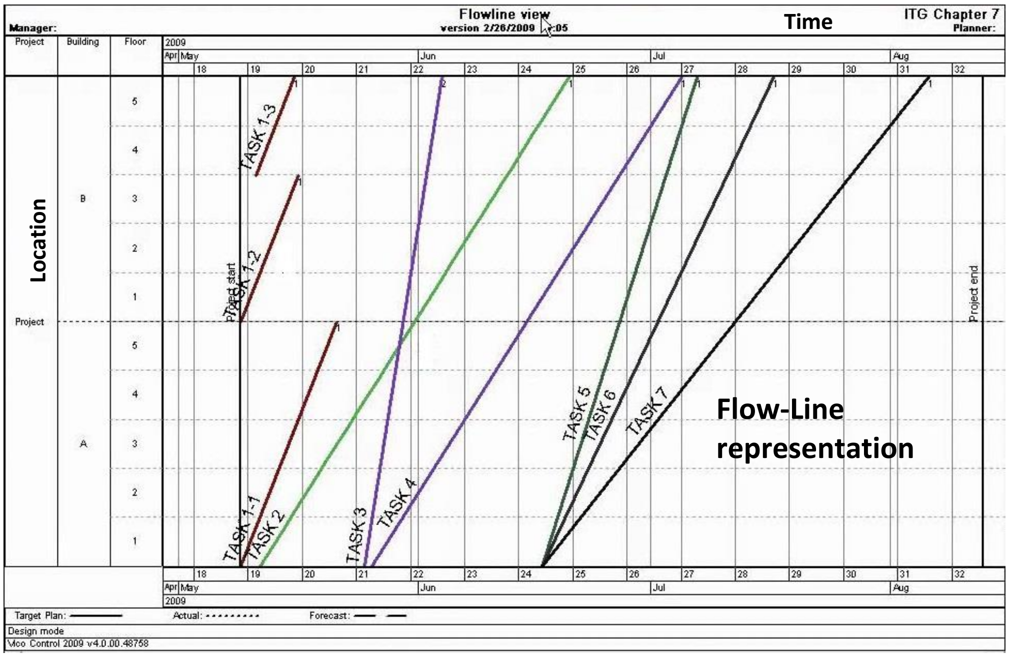


Figure 4.19 VICO Chart for a High-Rise Project

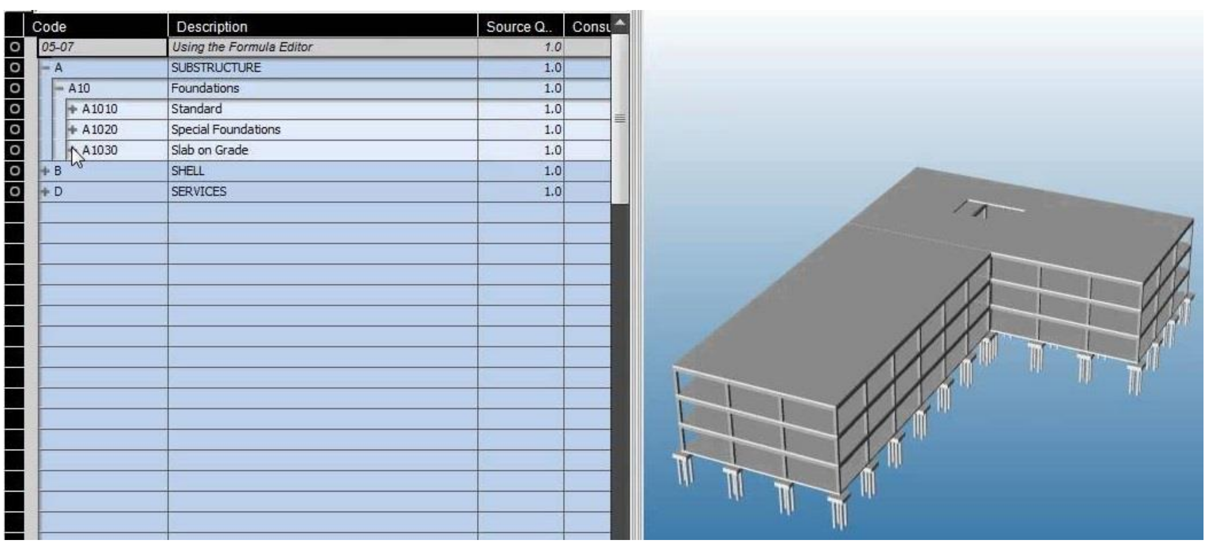


Figure 4.20 Integrated 3D Model with Planning Schedule in VICO

Discussion: VICO software is very suitable for vertical projects but not horizontal or scattered. The software includes an essential feature to visualize a schedule, such as a 3D model. However, the standard version of the software does not include essential functions needed for planning and project control such as resource availability, cash flow, and EV calculation. Unfortunately, the trial version of this software is no longer available for student use, so a detailed critique cannot be provided at this time.

4.3.7 LinearPlus Version 2.1

LinearPlus was created by PCF Ltd., in the United Kingdom (LinearPlus, 2016). LinearPlus is a timelocation linear scheduling software used for linear projects such as pipelines, tunnels, and railways. The software has the ability to display the visual material to be combined in the linear drawing.

Data Input: LinearPlus allows the user to enter the activities manually in a spreadsheet, or to the graphical chart, as shown in Figure 4.21. The graphical chart displays activity as a Gantt chart in the schedule, which is a feature not available in other software. The software allows the user to import data from a scheduling program such as Primavera. Also, it allows the user to import vector files, such as HP-GL and dxf file.

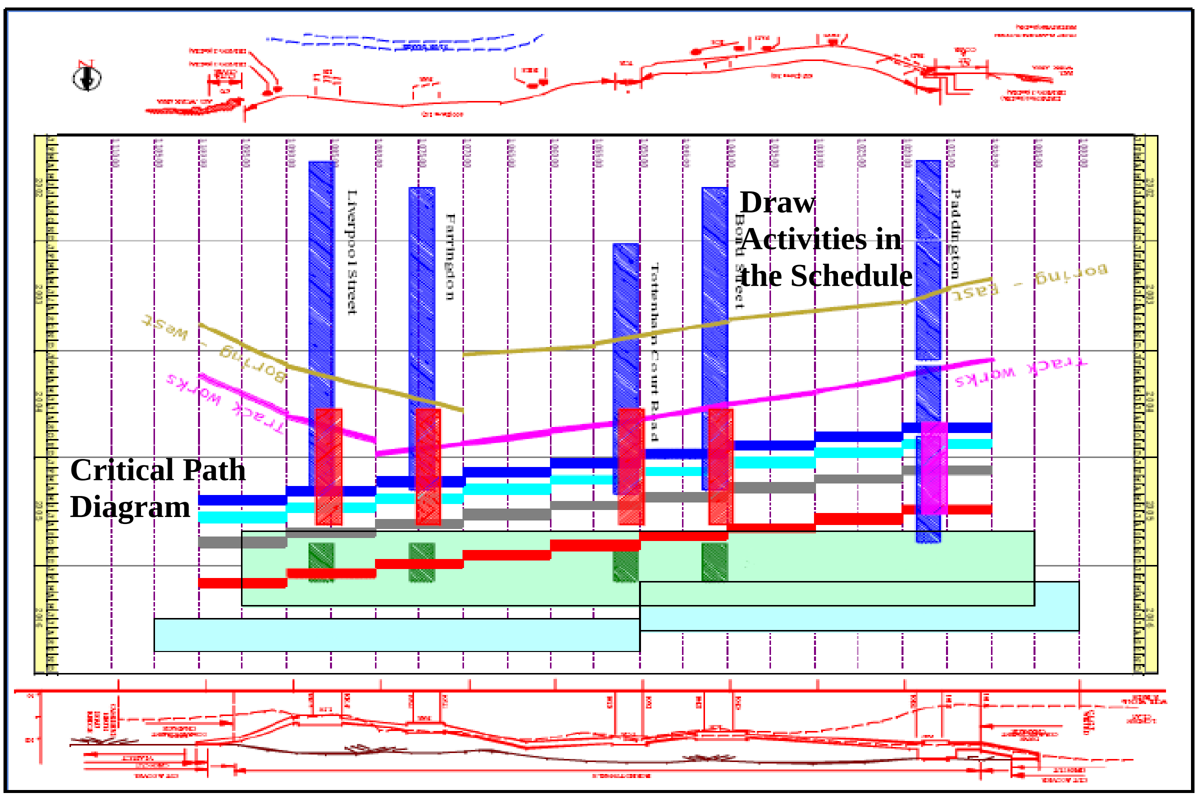


Figure 4.21 LinearPlus Showing Network Linked Critical Path in the Schedule

Outputs: LinearPlus software shows a linear schedule (in flowline representation) with time on the horizontal axis and location on the vertical axis, as shown in Figure 4.22. LinearPlus software has the ability to present various activity types such as block activities. Also, it allows for different representation options of activities by changing type of line, color, directions, and the shape for each activity. Image files can be added to the diagram, such as the road profile or other pertinent information related to the linear schedule, which provides good visualization of the project, as shown in Figure 4.22. Interestingly, the software displays resource and cost details under the linear schedule, which is an enhanced way to visualize the schedule data.

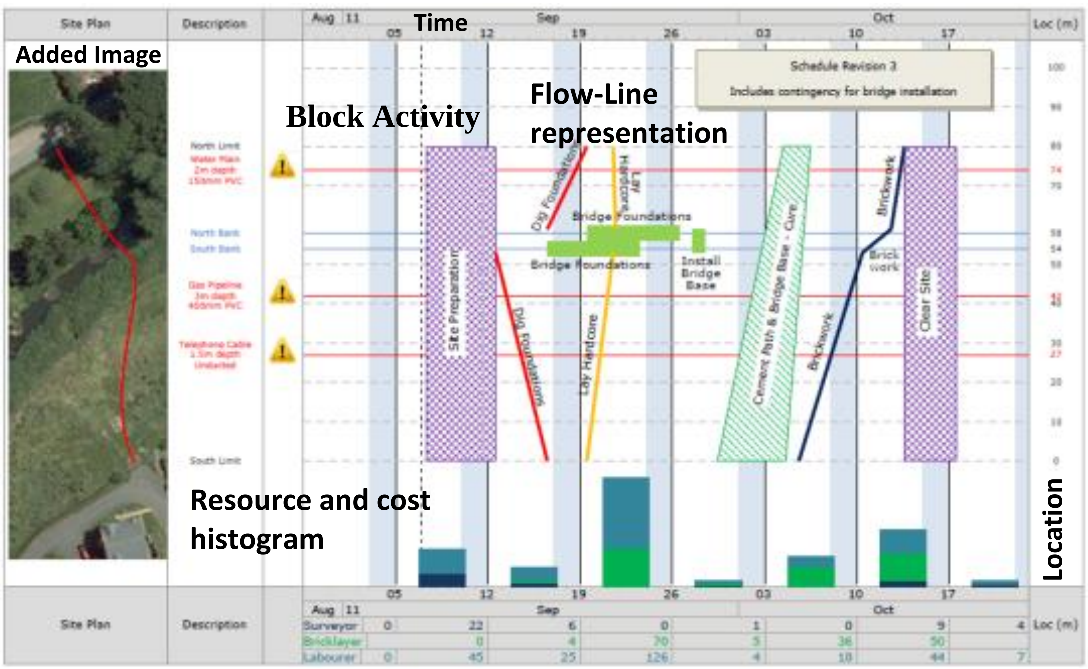


Figure 4.22 LinearPlus Chart for a Road Project (Linear Scheduling)

Discussion: LinearPlus is a useful software for linear projects. It includes several features useful to visualizing a schedule, such as various activity types and additional graphics. Its Gantt chart schedule visuals are innovative. The software includes important functions needed for planning and project control such as resource and cost histogram. However, the software is not able to estimate the activity information, including cash flow, EVM, and resource leveling.

4.4 Comparison of Seven Repetitive Scheduling Software

Table 4.2 summarizes a comparative feature evaluation of the seven repetitive scheduling software discussed earlier. Each software was evaluated according to whether or not they cover each function. All software systems provide high quality graphical presentations, yet, schedule visualization does not extend beyond the traditional bar chart.

Table 4.2 Comparison Software Features Evaluation Criteria

	Spider Project	Chainlink	TimeChainage	Tilos	Asta Powerproject	Vico	LinearPlus
General Features							
Free Trial Version	☑	☑	☑	☑	☑	—	—
Hosting Price	☑	☑	☑	☑	☑	☑	☑
Warranty	☑	☑	☑	☑	☑	☑	—
Project Management							
Resources /Crews	☑	☑	☑	☑	☑	☑	—
Resource Leveling	☑	—	—	—	☑	☑	☑
CPM Analysis	☑	—	—	☑	☑	☑	☑
Pert/Risk Analysis	☑	—	—	☑	☑	☑	—
Optimization	☑	—	—	☑	☑	☑	—
Cash Flow	☑	—	—	☑	☑	☑	—
Actual Cost	☑	—	☑	☑	☑	☑	☑
Delay Analysis	☑	—	—	—	☑	—	—
Project Integration	☑	☑	☑	☑	☑	☑	☑
Issue Tracking	☑	—	—	☑	☑	☑	—
MS Project Import/Export	☑	☑	—	☑	—	—	—
Shared Calender	☑	☑	☑	☑	☑	☑	—
Visulization Capabilities							
Ease of Planing	☑	—	☑	☑	☑	—	—
View Individual Resource	☑	—	—	☑	☑	—	☑
Clear Schedule	☑	—	☑	☑	☑	☑	☑
Resource Continuity	☑	—	—	☑	☑	☑	—
Easy Updating	☑	—	☑	☑	☑	—	☑
Innovative Visulization	—	☑	—	☑	☑	☑	☑
Show Crews	☑	—	—	☑	☑	—	—
Link to Photos/Drawings	—	☑	—	☑	—	☑	☑

4.5 Conclusion

This chapter presented a survey and comparison between recent repetitive projects management software. These software displayed many exciting features and visuals. The schedule visuals in most software do not vary much from a color-coded activity to display the various activities and their timings. Such a representation still has limitations for repetitive projects, particularly vertical high-rise buildings.

Chapter 5

Improved Schedule Visuals for Vertical Repetitive Projects

5.1 Introduction

This chapter introduces improved schedule representation of high-rise building projects. This can help construction managers better understand and communicate the schedule information. A new visual representation has been developed to clearly show the repetitive schedule of vertical projects in a way that resembles the shape of the building. A case study of a high-rise building is then used to demonstrate the new visual approach.

5.2 Visual Challenges in High-Rise Buildings

A key challenge of vertical schedules is that all lines are inclined, and this does not give a good visual representation of a vertical structure, as shown in Figure 5.1. The figure shows another serious problem in scheduling high-rise buildings. The schedule relates to three structural-core activities (columns, beams, and slabs) along a five-storey building. Although the three activities are shown to run in parallel, the figure shows a serious problem in the schedule. In this schedule, the columns of the second repetitive floor are scheduled to start at time Sc2 before the slab of the first floor is completed at time Fs1. This disrupts practical logical relationships that columns at the upper floors require the slabs at the lower floor be completed. To avoid this schedule problem in the traditional visual, the activities that form the core vertical structure (concrete or steel) of the high-rise building has to be finished at any level before the other level starts. Hegazy et al (2008) for instance, display five stories of high-rise building including a group of structural core activities; the structural core activity in a second level Ssc2 starts after the completion of the first floor Fsc1, as shown in Figure 5.2. While this corrects the schedule for the core activities, the fact that all lines are inclined does not visually match the nature of the building, which brings a visual discomfort in reading or communicating the schedule information.

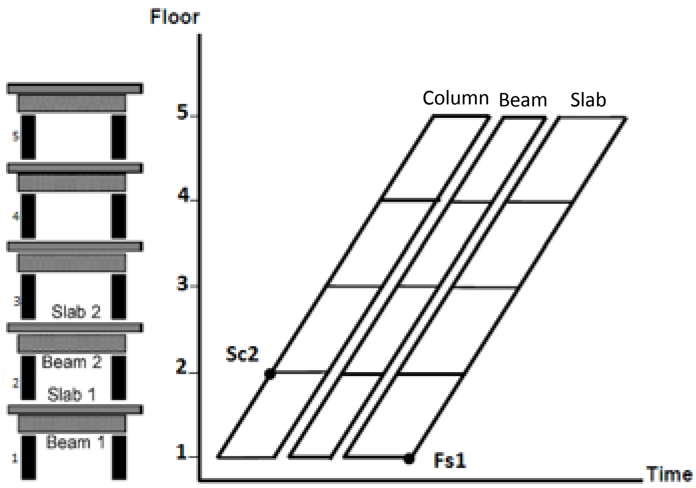


Figure 5.1 3D Vertical Structure Problem

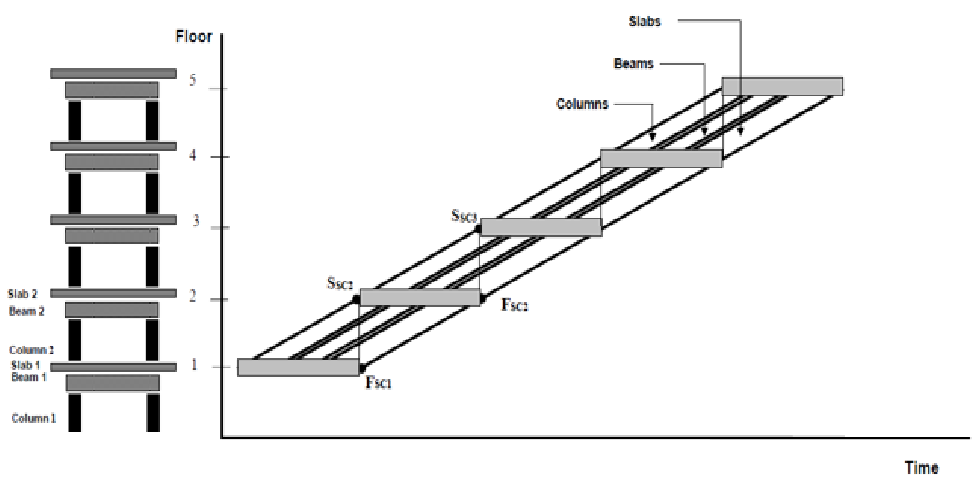


Figure 5.2 Corrected Schedule for Structural Core Activities

5.3 A New Visual Representation of the Schedule

A new schedule visualization for vertical repetitive activities is proposed in this chapter. Compared to the traditional visual in Figure 5.2, the new visual method, called Activity Continuity on Time-Inclined Visual (ACTIV), does not use time as a horizontal axis, rather, time is drawn at an angle so that all the schedule becomes close to vertical, as shown in Fig. 5.3. Details of the development and implementation of this new visual are discussed after the description of the case study in the next subsections.

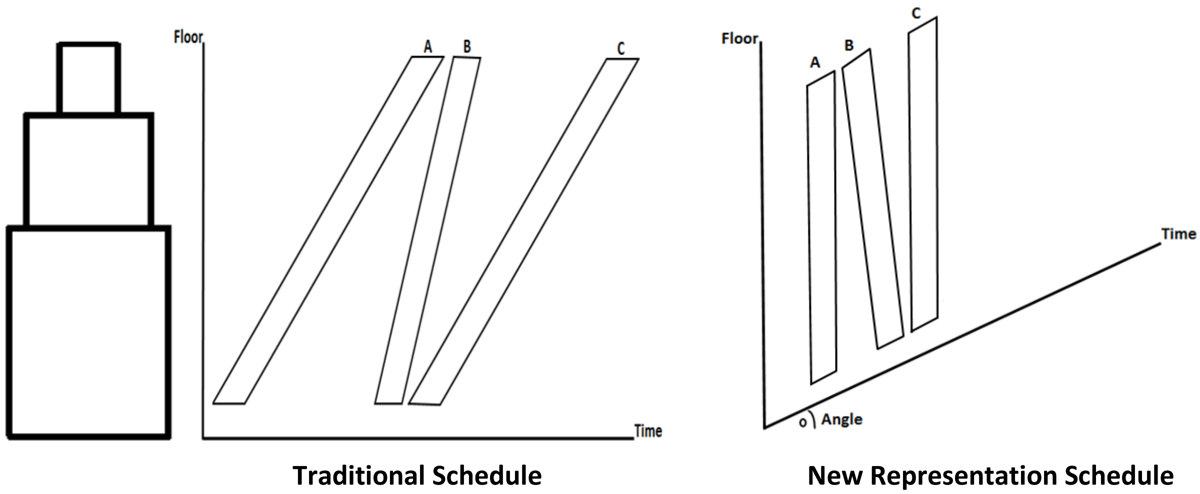


Figure 5.3 Basic Idea Behind the Proposed Schedule Visualization

5.3.1 Case Study

To illustrate the proposed visualization method, the following case study (adapted from Hegazi and Kamarah 2008) is implemented. The case study relates to a five-storey high-rise building. Table 5.1 shows the activities of each floor, along with their durations and number of crews. The building is served by one elevator that needs an elevator room on each floor. The building facade is comprised of pre-cast walls and windows. The building 3D model is shown in Figure 5.4.

Table 5.1 Activities, Durations and relationships within each floor

No	Activity	**Code**	Depends on	Duration	Crews
1	Column	**C**	-	3	1
2	Beam	**B**	1	3	1
3	Slab	**S**	2	3	1
4	Pre - cast wall	**P**	3	5	1
5	Elevator room	**E**	4	5	1
6	Windows	**W**	5	6	2
7	Tiling\Flooring	**TF**	6	5	3
8	Doors	**D**	7	4	3

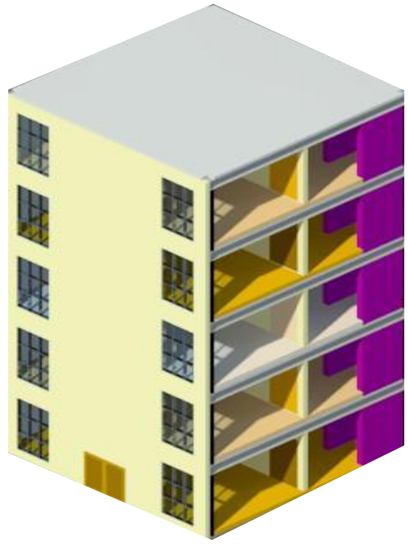


Figure 5.4 3D model of the Case Study

5.3.2 ACTIV Schedule for Activity Group with Single Crew

Using the proposed ACTIV method for schedule visualization, the case study has been implemented, starting with the structural core activities (first three activities in Table 5.1): columns (C); beams (B) and slabs (S).

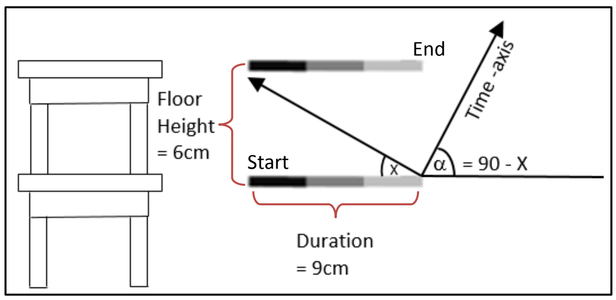
ACTIV schedule is created in two steps: 1) dividing the list of activites into groups based on time and number of crew; 2) establishing the angle of the time axis, based on the duration of each activity. In the first step, the list of activities shown in Table 5.1 were divided into five groups (work packages), as follows:

1. Structural-core activities;
2. Pre-cast wall (P) and elevator room activities (E)
3. Windows (W)
4. Tiling/flooring activity (TF),
5. Doors (D).

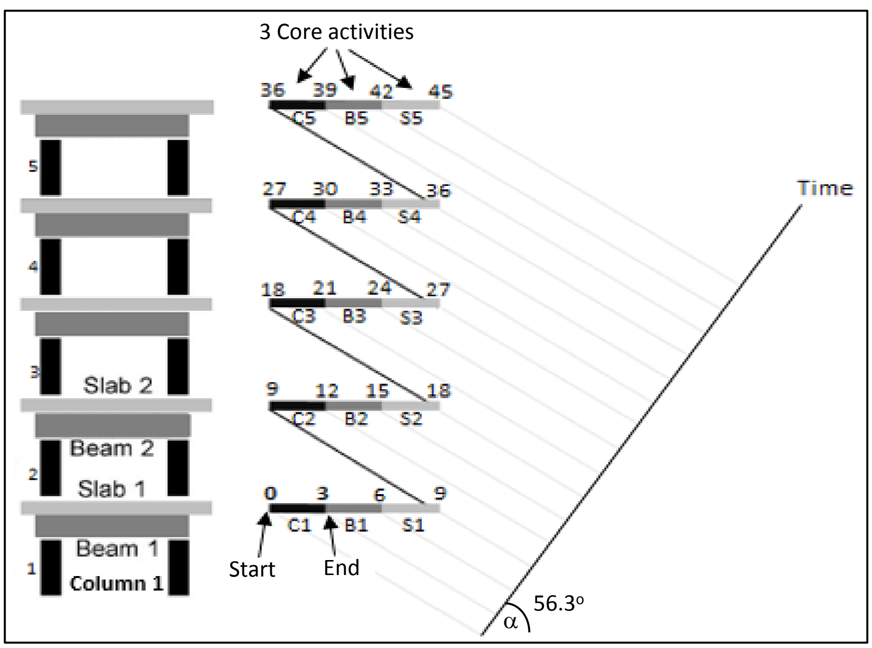
Starting with structural core activities, these activities set the rhythm for the other activities. ACTIV recognizes the physical necessity of completing all structural activities on each floor before starting any other activities on this floor or upper floors. For core activities, ACTIV sets the rotation angle (α) for the time axis (from horizontal), as shown in Figure 5.5a, as follows:

$$\alpha = 90^o - X$$
$$= 90^o - \tan^{-1}\left(\frac{Floor\ Height\ in\ cm}{Duration\ in\ cm}\right)$$
$$= 90^o - \tan^{-1}(6/9) \quad = \ 56.3^o \qquad (1)$$

Using this angle, the schedule of the strutrual-core activities is drawn as shown in Figure 5.5b.



(a) Time-axis Rotation Angle (α) for One Crew



(b) Schedule of the Core Activities

Figure 5.5 Proposed "Activity Continuity on Time-Inclined Visual (ACTIV)" Schedule Representation

As shown in Figure 5.5, ACTIV schedule shows time of activities for each floor. For example, column (C1) starts from day 0 to day 3 for the first floor, beam (B1) starts from day 3 to day 6 for the first floor, and slab (S1) starts from day 6 to day 9 for the first floor along the project. The second floor starts after the last activity finishes on the lower floor. Core activities are defined with different colors. For instance, column activity is defined with black color, beam activity is defined with dark gray color, and slab activity is defined with of light gray color. Activities are defined with number of crew, and in this case all structural core activities are defined with one crew. ACTIV schedule shows the location on the vertical axis. For a cleaner visualization, the 3D model of the building (designed using Revit software) can be shown on the side, as shown in Figure 5.6, with all the inclined lines hidden.

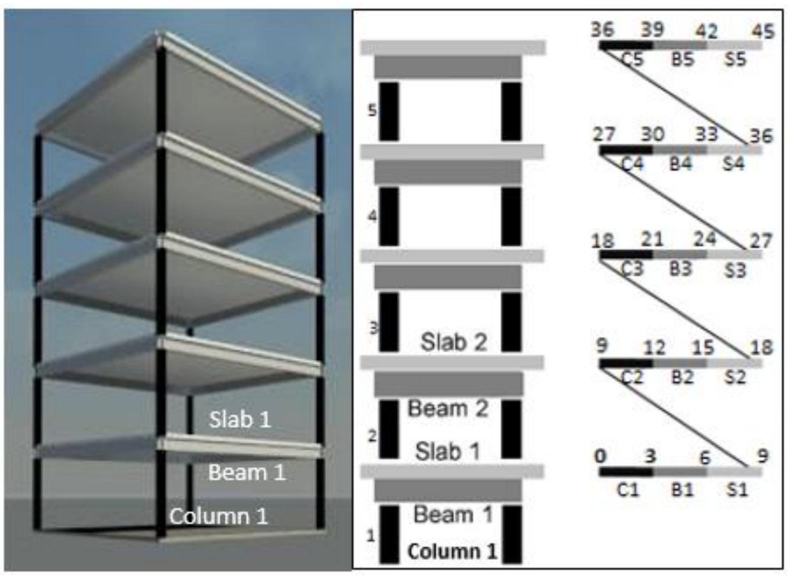


Figure 5.6 3D Model Displays the Process of ACTIV Schedule Model for Core Activities

5.3.3 ACTIV Schedule for Next Group (Single Crew)

After drawing the schedule of the core activities, the next group of activities can be drawn. However, since each group has different durations, the angle (α) that was used to draw the core activities may not be suitable for the next group. This is illustrated in Figure 5.7.

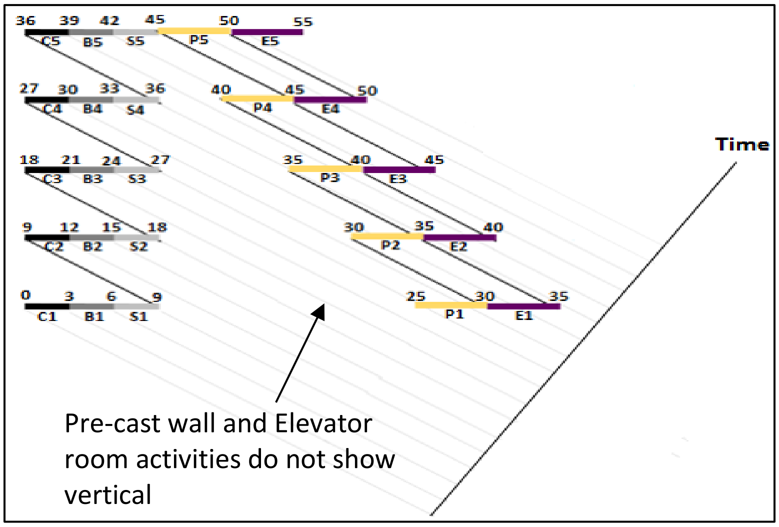


Figure 5.7 2nd Group Does Not Show Vertical when Using the (α) of the First Group

To avoid schedule visualization inconsistency, ACTIV represents the second group of the pre-cast-wall and elevator-room activities with a new angle of 40°, calculated using Equation (1), given the duration of 5 days (5 cm), as shown in Figure 5.8.

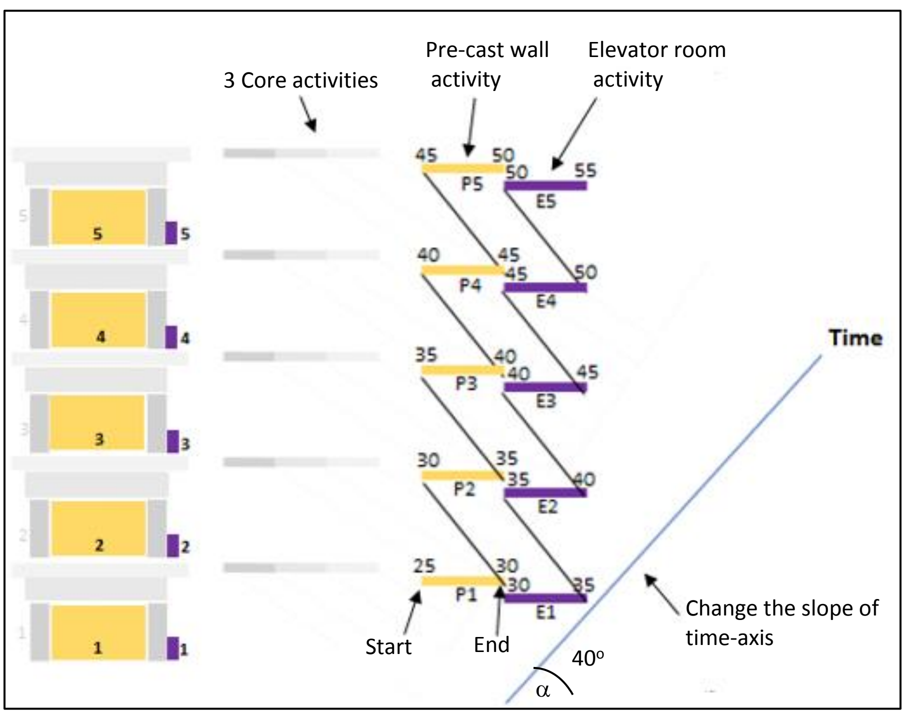


Figure 5.8 ACTIV Schedule Model for Second Group of Activities

Figure 5.8, displays the start date of pre-cast wall and elevator room activities on a particular floor that become dependent on different floors. This establishes a vertical dependency between floors, which means the upper floor starts after the lower floor for each activity. ACTIV schedule model shows duration of activities for each floor. For example, pre-cast wall (P1) activity starts from day 25 to day 30 for the first floor, and elevator room (E1) activity begins after fininshing the pre-cast activity for the first floor from day 30 to day 35 for the first floor along the project. The second group of activities is defined with a different color. For example, pre-cast wall activity is defined with beige color, elevator room activity is defined with purple color. Activities are defined with number of crew, and in this case all second group activities are defined with one crew. ACTIV schedule model displays the location (vertical model) on the vertical axis and time on the horizontal axis.

5.3.4 ACTIV Schedule Next Group (Multiple Crews)

In order to complete the schedule and add the remaining groups, an important consideration has to be taken when dealing with activity groups that use multiple crews. For example, the third group of activities relates to windows installations. When calculating the new angle (α) using Equation 1, (45^o), it results in a visual that is not vertical, as shown in Figure 5.9.

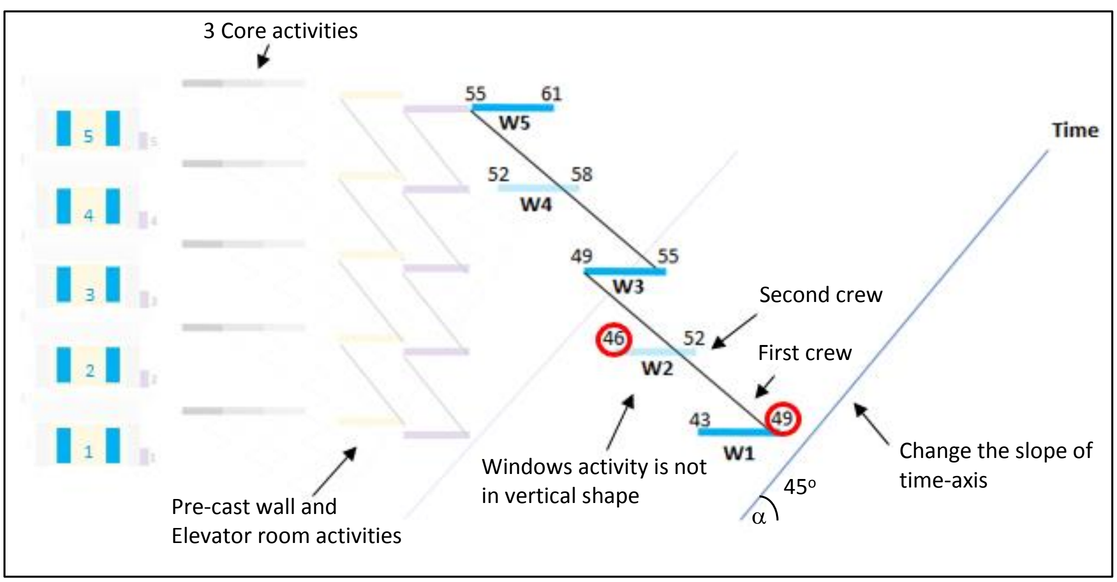


Figure 5.9 ACTIV Schedule Model with Group 3 That Has Two Crews

As shown in Figure 5.9, because the windows activity contains two crews, each crew skips one floor. For example, crew 1 starts at floor 1, then moves to floor 3 (because crew 2 works in floor 2). Therefore, the calculation of the angle (α) can be generalized to consider any number of activity crews, as in Equation 2, as follows:

$$\alpha = 90^{o} - X$$
$$= 90^{o} - \tan^{-1}\left(\frac{No.of\ Crews\ x\ Floor\ Height\ in\ cm}{Duration\ in\ cm}\right) \quad (2)$$

Accordingly, the revised angle becomes 26.57° and the schedule is as shown in Fig. 5.10.

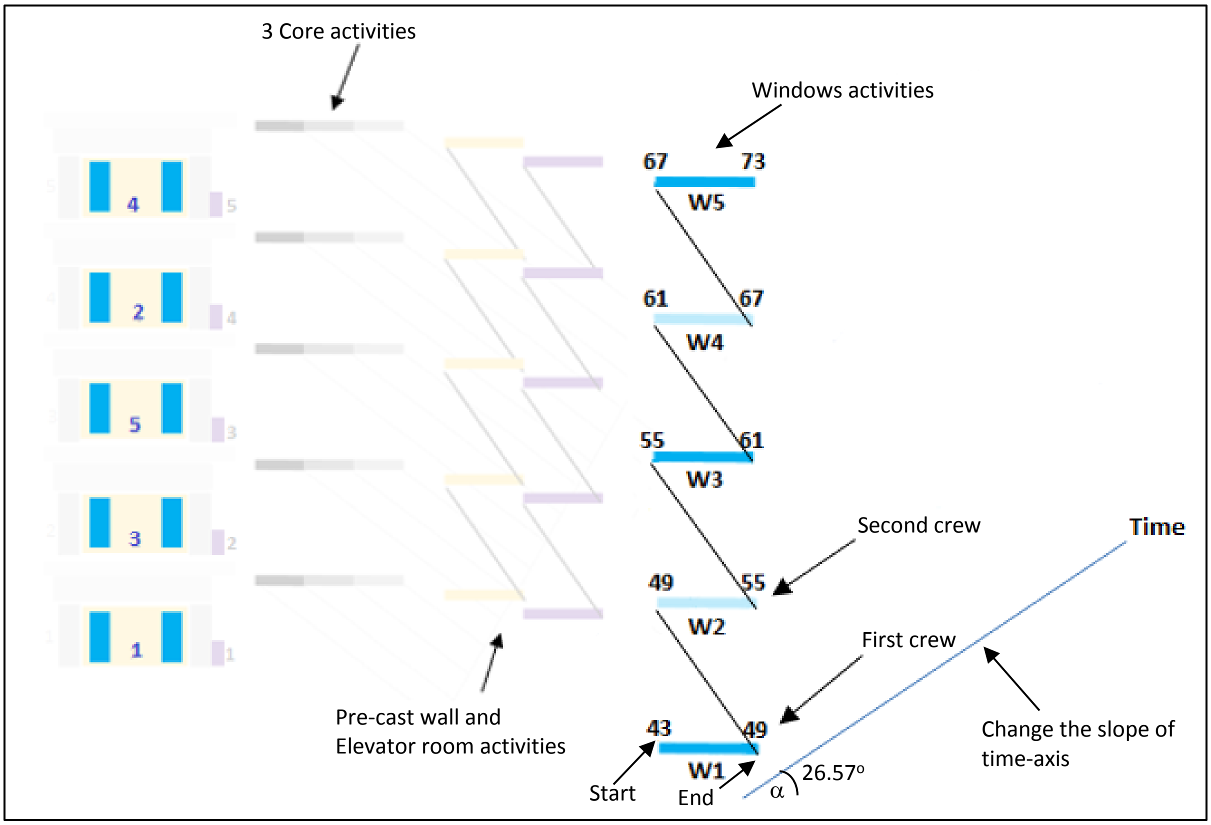


Figure 5.10 ACTIV Schedule with Revised Time-axis Angle

In another approach to view multiple crews without the need for using Equation 2, it is possible to separate the work of each crew to show continuity, as shown in Figure 5.11.

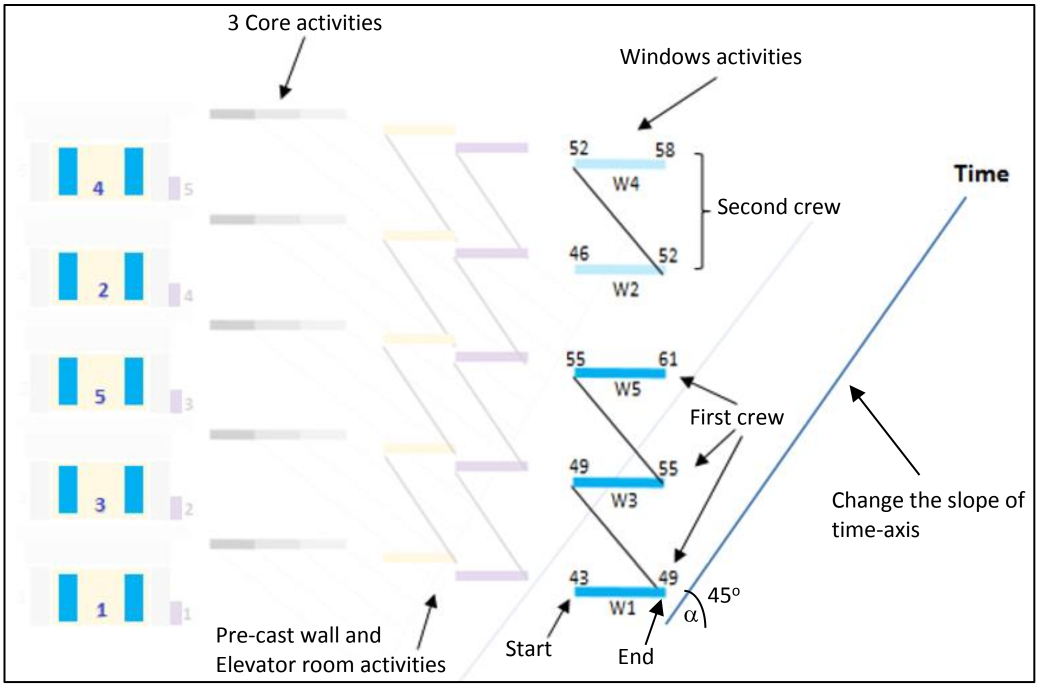


Figure 5.11 ACTIV Schedule Model with Separate Crews

In Figure 5.11, ACTIV schedule model shows duration of windows activity for each floor. For example, windows activity starts from the first floor (W1) from day 43 to day 49, then start the third floor (W3) from day 49 to day 55, then start the fifth floor(W5) from day 55 to day 61, while the second crew start the second floor (W2) from day 46 to day 52, then start the fourth floor (W4) from day 52 to day 58. Windows activity is defined with two different colors due to the number of crews. For instance, the first crew of window activity is set with dark blue color, and the second number of teams are assigned the bright blue color.

After designing the schedule for window activity, the remaining two groups for tiling/flooring and doors have been added. To avoid schedule inconsistency for tiling/flooring activity, ACTIV method changes the order of designing its schedule as shown in Figure 5.12. Tiling/flooring activity is defined with three different colors due to the number of crews. For instance, the first crew of tiling/flooring activity is set with orange color, the second number of teams are assigned a bright orange color, and the third number of the crews is set with bright orange color and line of orange color on the center.

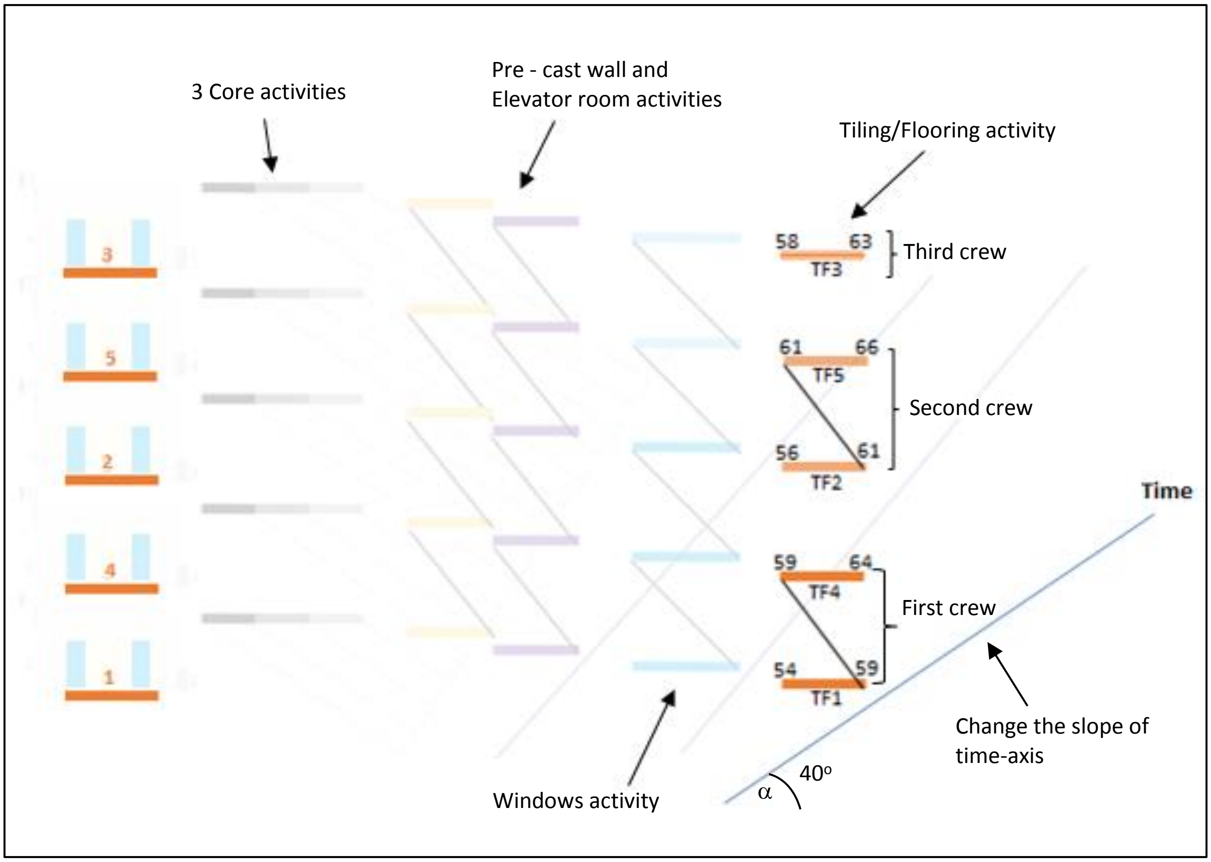


Figure 5.12 ACTIV Schedule with Tiling/Flooring Activity

As shown in Figure 5.12, the ACTIV schedule model shows duration of tiling/flooring activity for each floor. For instance, tiling/flooring activity starts from the first floor (TF1) from day 54 to day 59, then starts the forth floor (TF4) from day 59 to day 64, the second crew starts the second floor(TF2) from day 56 to day 61, then starts the fifth floor (TF5) from day 61 to day 66, the third crew starts the third floor (TF3) from day 58 to day 63. To avoid schedule inconsistency for doors activity, ACTIV method changes the order of designing its schedule as shown in Figure 5.13.

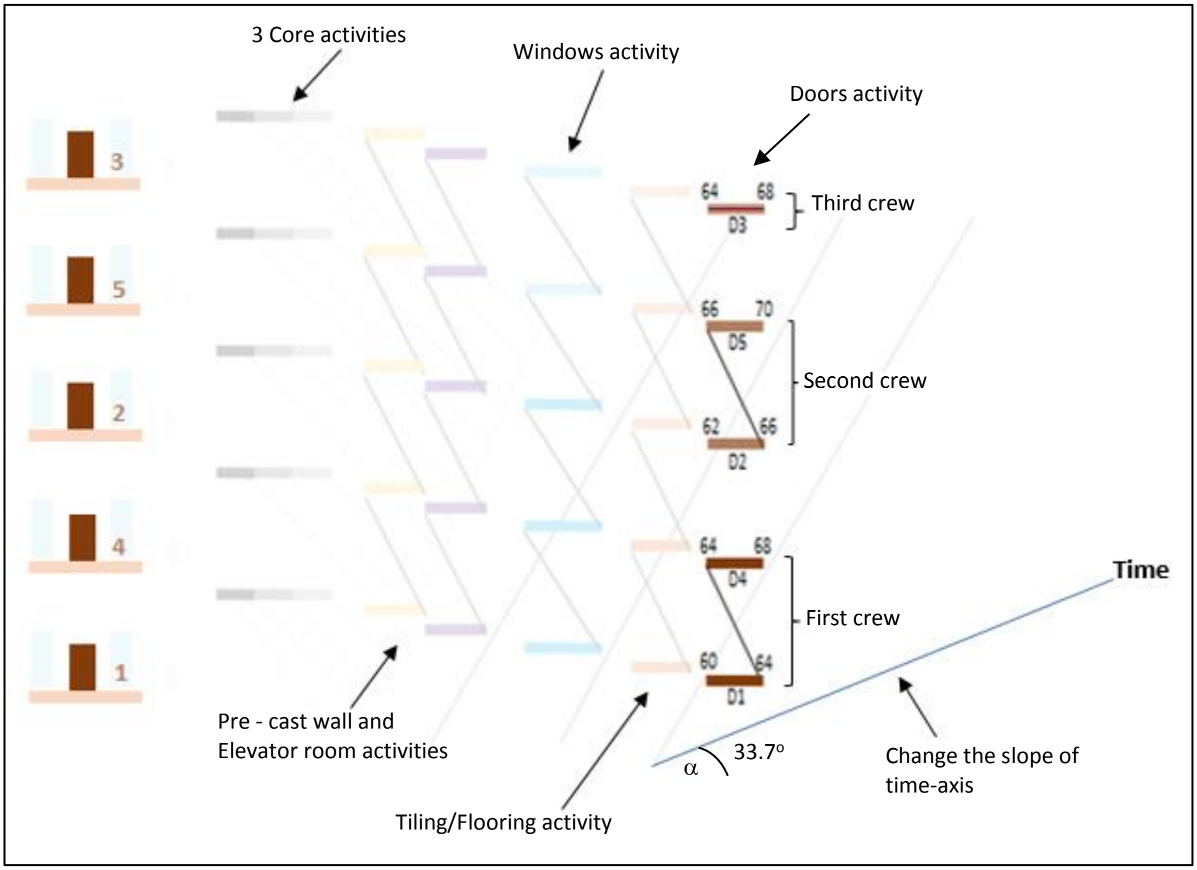


Figure 5.13 ACTIV Schedule with the Doors Activity

As shown in Figure 5.13, as with previous activity, ACTIV represents the fifth group of the doors activity with a new angle of 33.7°, calculated using Equation (1), given the duration of 4 days (4cm). Doors activity is defined with three different colors due to the number of crews. For instance, the first crew of suite doors activity is set with brown color, the second number of crews is assigned the bright brown color, and the third number of the crews is set with the bright brown color and line of brown color on the center. ACTIV schedule model shows duration of suite doors activity for each floor. For example, suite doors activity starts from the first floor (D1) from day 60 to day 64, then starts the forth floor (D4) from day 64 to day 68, the second crew starts the second floor(D2) from day 62 to day 66, then starts the fifth floor (D5) from day 66 to day 70, the third crew starts the third floor (D3) from day 64 to day 68.

After finishing ACTIV schedule model for each group of activity, a clear schedule of all activities is integrated with a 3D model design to display the final sheet for designing a high-rise building in a vertical manner, as shown in Figure 5.14.

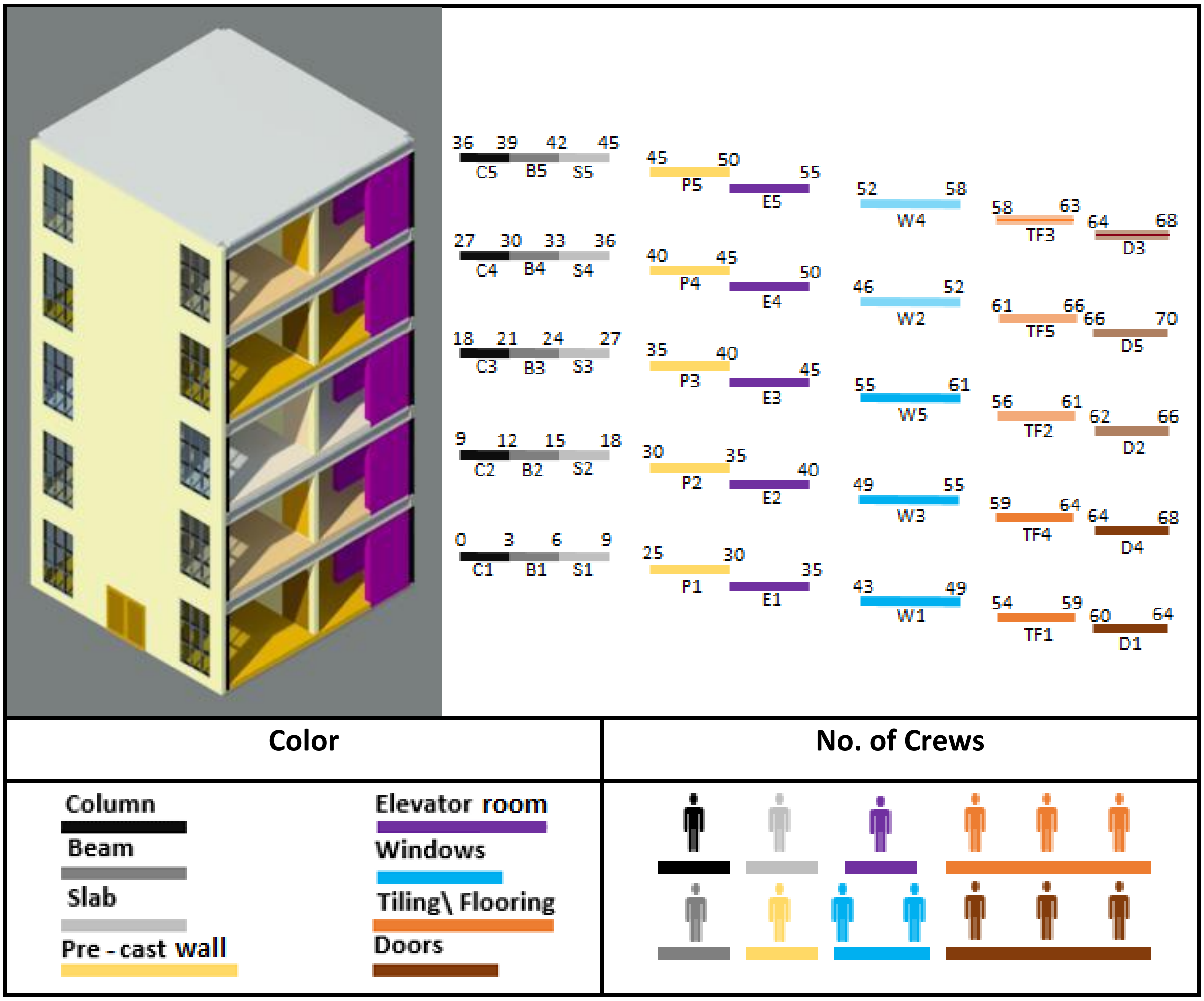
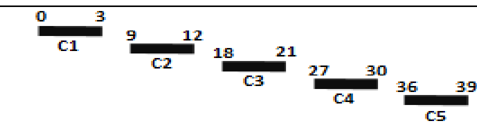
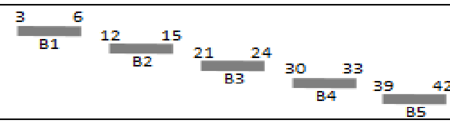
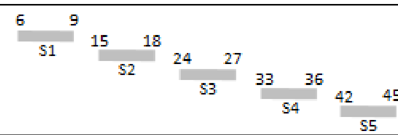
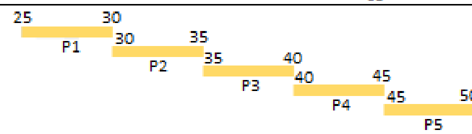
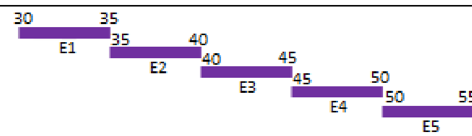
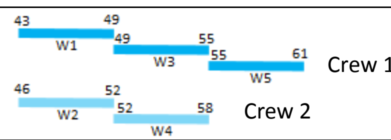
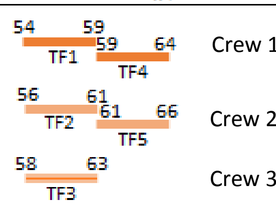
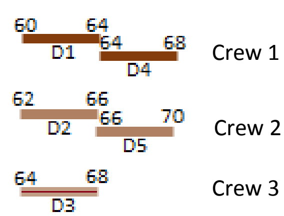


Figure 5.14 Final ACTIV Schedule

5.3.5 ACTIV Reports

Based on the ACTIV representation, two visual reprots have been established in order to legibly represent the schedule data from different view points: activity-by-activity and floor-by-floor. For the eight activities of the present case study, Table 5.2 shows the detailed activity-by-activity report.

Table 5.2 Activity-by-Activity Report

Activity	Crews	Duration	Bar Chart
Columns	1	3	
Beam	1	3	
Slab	1	3	
Pre-cast wall	1	5	
Elevator room	1	5	
Windows	2	6	
Tiling/Flooring	3	5	
Doors	3	4	

As shown in Table 5.2, the bars display each activity individually. For example, the "Columns" activity starts from day 0 on the first floor, and ends on day 39 for the fifth floor. All activities and their crews are also color-coded for clarity.

Figure 5.15 also shows the second ACTIV report which gives floor-by-floor information. The report represents all activities in a vertical manner. Activities are defined with different colors, and determined with a number of crews.

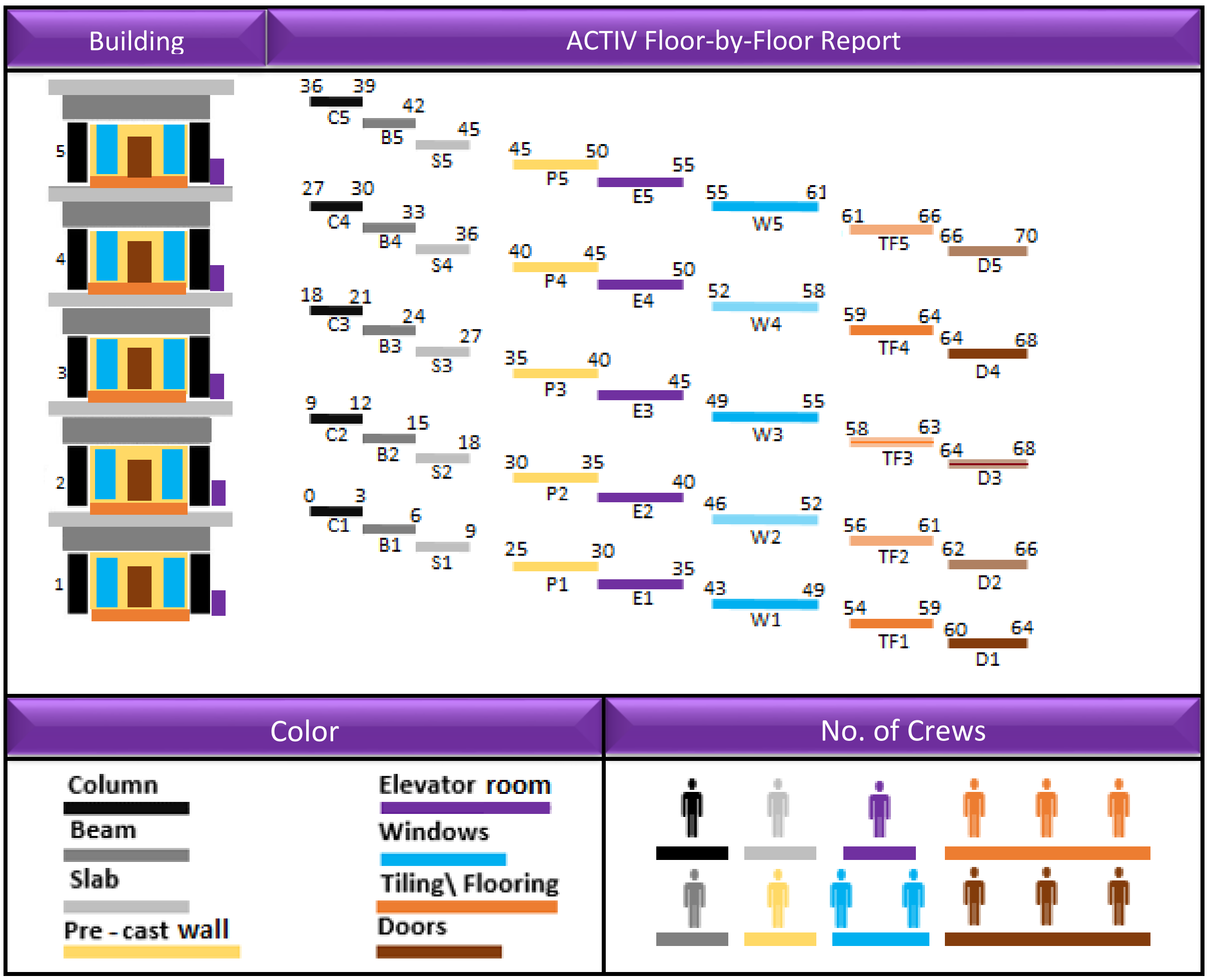


Figure 5.15 Floor-by-Floor Report

5.4 Validation

In order to validate the ACTIV schedule model, several meetings have been done with an expert panel that includes academics (professors and experienced graduate who are familiar with repetitive scheduling), in addition to one expert facility manager who participated in managing various high-rise building construction. The meetings were conducted periodically to get feedback on the concept and how to handle multiple activities that use different numbers of crews. These meetings resulted in an overall positive feedback on the proposed method, which is a simple type of validation and confirmation of its feasibility. More extensive validation is planned as part of future work to test the model on real-life projects.

5.5 Conclusion

The case study of a five-storey building is adopted in this chapter. A new method, ACTIV, has been developed to improve the schedule visualization of vertical buildings. ACTIV changes the typical slanted lines of the repetitive schedule into vertical lines that resemble the shape of the high-rise building. The main concept is to represent the time-axis on an angle, rather than the typical horizontal orientation. To incorporate many activities, the time-axis angle is calculated differently for each activity. For better legibility, ACTIV also uses 3D BIM model to represent the building and link the schedule of each floor. Two reports are also generated to represent the schedule data from two perspectives: activity-by-activity and floor-by-floor.

Chapter 6
Conclusion

6.1 Summary and Conclusion

This thesis surveyed available software packages for scheduling repetitive and non-repetitive construction projects. The surveyed software systems were compared in terms of three main criteria: general features, project management features, and visualization capabilities. Accordingly, a summary of the schedule visualization gaps, particularly for high-rise buildings, was discussed. It was found that structural core activities require special care in their schedule visualization. Also, the slanted lines of the schedule do not match the vertical nature of the buildings. To overcome these gaps and improve schedule visualization, a new visualization method, ACTIV, was developed in this thesis. ACTIV changes the repetitive schedule slanted lines into more vertical lines so the time-axis is on an angle. ACTIV is able to incorporate more activities into scheduling by calculating the time-axis differently for each activity. For better legibility, ACTIV also uses 3D BIM model to represent the building and link the schedule of each floor. Two reports are also generated to represent the schedule data from two perspectives: activity-by-activity and floor-by-floor.

Based on the results of using ACTIV on a case study project, its interesting capabilities can be summarized as follows:

1- It models the structural core activities as one assembly with a unified production rate to avoid schedule errors;

2- It introduces a simple equation to calculate the time-axis angle of each activity, based on the activity duration and its number of crews; and

3- It produces two visual reports to help communicate the repetitive schedule to the work crews in a legible manner.

6.2 Research Limitations

Despite its benefits, the proposed ACTIV model has several limitations that need to be addressed, as follows:

1- The BIM model of the project is only manually linked to the ACTIV schedule;

2- The ACTIV visualization currently focuses on determining a legible schedule at the project planning phase, and does not to show a comparison between planned schedule and actual progress;

3- The ACTIV model is limited to vertical repetitive projects (high-rise building), not horizontal (highways), or scattered (Multiple housing unit) projects;and

4- The ACTIV model assumes identical activity units.

6.3 Future Research

The proposed model proved its suitability as a new visualization method for the schedule of high-rise projects. Still, a number of improvements could be investigated in future research, including:

1- Adapting the model to other repetitive projects such as highways and scattered project;

2- Applying the model to a real construction repetitive project to quantify its effectiveness from the scheduling and communication sides;

3- Adding cost information to each activity; and

4- Implementing the proposed approach as an add-on to existing scheduling programs to improve their effectiveness.

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