THE EFFECTIVENESS OF THE HYBRID GRAPHICAL REPRESENTATION METHOD IN VISUALLY COMBINING AND COMMUNICATING LOGICAL AND SPATIAL RELATIONSHIPS BETWEEN SCHEDULED ACTIVITIES

A Dissertation

by

MEENA NAGEEB

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2012

Major Subject: Civil Engineering

The Effectiveness of the Hybrid Graphical Representation Method
in Visually Combining and Communicating
Logical and Spatial Relationships Between Scheduled Activities

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Approved by:

Co-Chairs of Committee,	Stuart Anderson
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ABSTRACT

The Effectiveness of the Hybrid Graphical Representation Method
in Visually Combining and Communicating
Logical and Spatial Relationships between Scheduled Activities. (May 2012)

Meena Nageeb, B.S., the American University in Cairo;
M.S., Colorado State University

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Dr. Julian Kang

This research endeavor investigated the possibility to combine the visual advantages of both graphical schedule visualization methods, the Linked Gantt Charts (LGC) and Flowline graphs (FLG), derived from the activity-based and location-based scheduling systems, to help resolve some of their shortcomings by capitalizing on their combined strengths. In order to accomplish the goal of the research, a graphical representation system that combines these two scheduling visualization methods, LGC and FLG, is developed. Afterwards, the research attempted to empirically validate the ability of the proposed tool to visually communicate and combine logical and spatial relationships between scheduled activities. This is compared to comprehending the same information by looking at a stand-alone LGC or FLG. The accuracy and time, of deciphering various details of a sample project schedule, are used as parameters to evaluate the proposed scheduling visualization tool, and compare it to the existing LGC and FLG systems.

The Hybrid Graphical Representation (HGR) is the tool developed by this research to combine Linked Gantt Chart bars from the activity-based scheduling approach, and flow-lines from the location-based scheduling approach. The HGR concept is founded on the basic idea that both LGC and FLG share a common X-axis, *Time*. The only difference is in a LGC the *Activities* are listed on the Y-axis, while the FLG shows *Locations* on the Y-axis. This research proposed adding a third dimension to

the FLG, listing the project *Activities* on a Z-axis. Viewing the HGR 3D graph from the top, the user will observe the Gantt bars with *Time* on the X-axis and the *Activities* listed on the Z-axis. Observing the schedule from the front view, the user will see the flow-lines developed from the location-based scheduling approach with *Locations* on the Y-axis and *Time* on the X-axis. After conducting a series of online surveys measuring the time and accuracy of using a prototype HGR schedule, it was found that the users were able to reap the benefits of both scheduling approaches (LGC and FLG), and visually link and communicate information concerning the activities' logical relationships and spatial relationships. However, it took the participants a relatively longer time to achieve that higher accuracy utilizing the HGR tool.

DEDICATION

Dedicated to…

My Parents, for their support, and

My wife Maggy, for her love and prayers

ACKNOWLEDGEMENTS

"Thus far the Lord helped us." (1 Samuel 7:12)

Throughout my life I have always felt the Lord Jesus Christ's hands guide me, teach me and lead me in His will. He has not only been with me every step of the way in completing this work, but has also blessed me with family, friends, and instructors who assisted and supported me in the course of this research effort. My wife Maggy, my father, mother, and my sister Marina and her husband George have always been the source of love, care and encouragement that sustained me throughout this endeavor. I really appreciate all their kindness and prayers, without which I would have not been able to come this far.

I wish to express my sincere appreciation to my committee members and instructors for all their help and suggestions throughout the research process, and their assistance in distributing the survey in their classes. Thanks to Dr. Stuart Anderson for his guidance on conducting the research, organizing the work, and proofreading all the numerous drafts before getting it right. He led me in arranging and presenting the research in a clear and understandable final product. I also appreciate Dr. Julian Kang for helping me develop the research idea, and directing me in testing and interpreting the research data. He guided me to the point of understanding the research so that I could explain it in a short and concise manner. I wish to thank Dr. Ivan Damnjanovic who provided great insight into the processes and methods associated with this study. Furthermore, my thanks go to Dr. John Walewski for all his valuable support and advice throughout this research work. I also appreciate Mr. Justin Chown for all his time and efforts in working with me throughout the statistical analysis of the data collected, and in showing me how to document and present the research conclusions. I am also grateful to Dr. Zofia Rybkowski and Dr. Boong Ryoo for all their recommendations and assistance in distributing the survey in their classes.

NOMENCLATURE

HGR	Hybrid Graphical Representation
CPM	Critical Path Method
PERT	Program Evaluation and Review Technique
LGC	Linked Gantt Chart
FLG	Flowline Graph
LOB	Line of Balance
LSM	Linear Scheduling Method

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1. INTRODUCTION

1.1 Background

Scheduling is a vital aspect of life in general, and is particularly important for construction projects. The French writer Victor Hugo was quoted to say, "He who every morning plans the transaction of the day and follows out that plan, carries a thread that will guide him through the maze of the most busy life. But where no plan is laid, where the disposal of time is surrendered merely to the chance of incidence, chaos will soon reign."

In essence, one of the main objectives of scheduling is to make sense and communicate data for the purpose of planning and controlling projects. This is accomplished in the construction industry using a variety of scheduling analysis methods like the Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and resource leveling analyses. Another substantial part of scheduling is the visualization aspect of the scheduled data. Many scheduling visualization methods have been developed with the purpose of transforming raw and/or abstract data concerning the project schedule into visual means to amplify cognition. "Although a project schedule can be presented in tabular form, it is more often presented graphically, using one or more … formats." *(PMBOK Guide – Project Time Management).* Linked Gantt Charts (LGC) and precedence diagrams are examples of visualization methods used extensively for this purpose.

The current scheduling techniques and systems available and familiar to the construction industry could be effective in some areas, but research shows that there is a need for more capable and efficient systems. The Linked Gantt Chart (LGC), produced by the activity-based scheduling methods like the Critical Path Method, is currently dominating the construction industry for creating and communicating construction

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This dissertation follows the style of the *Journal of Construction Engineering and Management.*

schedules (Kelleher, 2007). With technological advancements, the activity-based scheduling approach have been developed and improved to capitalize on its intrinsic benefits. However, there are still various documented limitations to these methods (Jaafari, 1984).

Several research projects and case studies show that location-based scheduling methods, like Flowline graphs (FLG), could provide an alternative and a more useful scheduling system for construction projects (Spencer & Lewis, 2005). Despite all the location-based scheduling documented benefits and advantages, it has not being used extensively in the construction industry. This is due, not only to shortcomings and limitations of this scheduling approach, but also to factors like the industry's resistance to change and innovation, the lack of well-developed supporting software programs, and limited knowledge and awareness of the scheduling technique.

Before discussing the advantages and disadvantages of each scheduling technique, it is vital to outline the basic concepts behind each scheduling method. Activity-based project scheduling involves forming an actual or implied network that graphically portrays the relationships between the tasks and milestones in the project. Usually an activity-based schedule would start by dividing the project tasks into work packages to facilitate the scheduling process. These work packages are organized in a Work Breakdown Structure (WBS). Several techniques evolved in the late 1950s for organizing and representing activity-based schedules. The techniques that are currently used by the majority of the industry are the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). The major difference between the two is that CPM assumes that activity times are deterministic, whereas PERT views the time to complete an activity as a random variable that can be characterized by an optimistic, a pessimistic and a most likely estimate of its durations (Shtub et. al, 2005).

Akbas (2004) defined the Critical Path Method (CPM) as a scheduling technique that is "typically used to provide an overall view of the project, activity durations, sequences, milestones and criticality of activities. The CPM model contains activities and precedence relationships. The CPM algorithm defines the path(s) (sequence of activities) that provides the longest project duration among all possible paths." The main outputs generated by CPM schedules are the range of possible activity times, critical activities and floats, and cost and resource information related to activities (Akbas, 2004). Gantt Charts are the major visual representation of the CPM method.

The scheduling of activities is constrained by *precedence relations*. Three common types of precedence relations exist among activities. A lag or time delay can be added to any of these connections. The first and most commonly used is a ***Finish-to-Start*** relationship; it indicates that an activity can start only after its predecessor has been completed. The second is a ***Finish-to-Finish*** connection and it is used when an activity cannot terminate unless another activity is completed. The third is ***Start-to-Start*** relationship, which exists when an activity can start with the beginning of another activity. Figure 1.1 displays examples and describe these three relationships and show the concept of lag between activities. Graphical representations are frequently used to show these precedence relationships. The three models used to communicate and analyze precedence relationships and their effects on the schedule are the Gantt chart, CPM, and PERT (Shtub et. al, 2005).

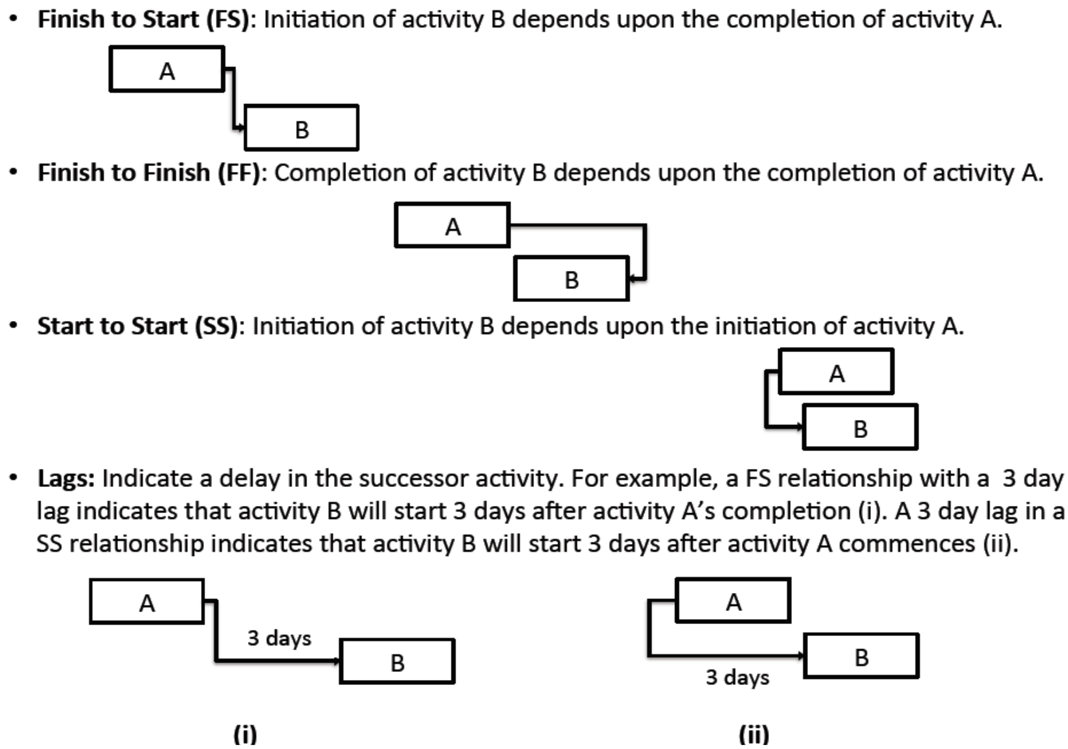

Figure 1.1: The three precedence relationships used in scheduling activities and the concept of lag between activities.

The bar chart (i.e. Gantt Chart) is a two dimensional chart. The x-axis of the chart shows the project timeline. The y-axis of the chart is a list of specific activities that must be accomplished to complete the project. The Gantt Chart uses bars to represent activities, show activity start and end dates, as well as expected durations. The Gantt chart also shows activity date information, and usually presents both the project network logic and the project's critical path activities. Since the tasks are usually arranged from earliest to latest, most bar charts show a pattern of bars that begin in the upper left of the chart and proceed to bars that complete the project displayed in the bottom right of the chart. A Gantt Chart includes bars that do not necessarily show any relationships or dependencies between the scheduled activities. Gantt charts are widely used in the construction industry (Kelleher, 2007) because they are relatively easy to read, and are frequently used in management presentations. Arrows are sometimes used to show the relationships between activities in a Linked Gantt Chart. Linked Gantt Charts are one of three scheduling visualization methods evaluated in this research endeavor.

A range of schedules is generated on the Gantt chart when a combination of early and late starts is applied. The early-start schedule is performed first and yields the earliest finish time of the schedule. That time is then used as the required finish time for the late-start schedule. That is accomplished by shifting each activity to the right as much possible while still starting the project at time 0 and completing it at the earliest finish time. The difference between the start (or finish) times of an activity on the two schedules is called float (or slack) of the activity. Activities that do not have a float are denoted differently (i.e. shaded or in a distinct color) and are termed *critical.* The sequence of critical activities connecting the start and end points of the project is known as the *critical path,* which is the longest path in the schedule. A delay in any activity along the critical path delays the entire project. In other words, the sum of durations for critical activities represents the shortest possible time to complete the project (Shtub et. al, 2005). Activity-based scheduling relies on dividing work into packages and linking them through logical time-based relationships.

The location-based scheduling system is another approach to scheduling projects, it relies on project locations as the main element in organizing the schedule. It includes a variety of scheduling techniques and visualization methods such as Line of Balance scheduling, and the Flowline graph. Similar to the Work Breakdown Structure (WBS) for in the activity-based scheduling approach, in location-based scheduling a Location Breakdown Structure (LBS) is created for a project. An LBS does not divide the project by work packages, but rather by locations (i.e. zones, floor, etc.). Then a Line of Balance or a Flowline schedule could be created. Jongeling and Olofsson (2007) defined Line of Balance (LOB) as "a visual scheduling technique that allows the planner to explicitly account for flow of a project. Line of Balance uses lines in diagrams to represent different types of work performed by various construction crews that work on specific locations in a project."

Jongeling and Olofsson (2007) explained how the first step to generate a LOB schedule is to break down the project in physical sections. For example, the project could be broken down and identified in terms of different locations, such as zones, sections, or floors. Afterwards, tasks (lines) are created in the schedule by using items from the bill of quantities (i.e. bill of materials) or cost estimate in a project, along with information on crews' production rates. The slope of these flow-lines signifies the production rates expected for each activity. Jongeling and Olofsson (2007) presented examples of LOB diagrams with various common errors and time conflicts (see Figure 1.2). In a Line of Balance schedule locations are represented on the Y-axis and project time on the X-axis. The flow-lines represent construction operations by crews. In Figure 1.2, common deviation types that could be identified by using a LOB schedule (areas 1–6) are demonstrated on the left side of the diagram. Typical solutions to these deviations are shown on the right side of the diagram. The deviation types indicate scheduling mistakes and opportunities to plan for a stable and continuous flow of work through locations of a project.

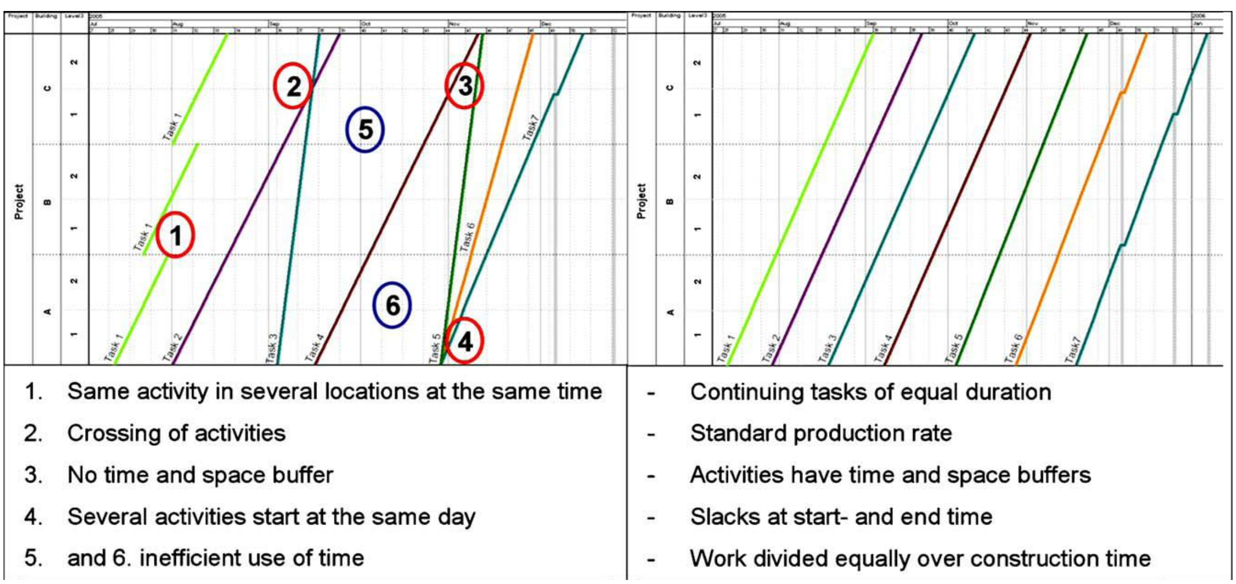

Figure 1.2: Typical solutions to deviations in a Line-of-Balance diagram (Jongeling & Olofsson, 2007).

Literature shows, that location-based scheduling techniques, like Flowline graphs (FLG) and Line of Balance (LOB) schedules, facilitate better resource optimization methods, provide improved visual management, are relatively easier understood and updated, and are an overall more capable scheduling techniques (Spencer & Lewis, 2005). However, there are many reasons behind the industry's reluctance to adopt these scheduling methods. Some are due to shortcomings with the location-based scheduling methods, while others could be attributed to the industry's resistance to innovation and lack of accessibility to location-based scheduling supporting software programs.

With advancements in construction related technologies, theories, and ideas, the need for more effective and efficient scheduling and management tools have grown correspondingly. Research shows location-based scheduling does not only possess intrinsic benefits in its scheduling concepts, but is also more compatible with these new technologies and theories. For example, some studies demonstrate how applying location-based scheduling could aid in implementing Lean Construction concepts and applying Building Information Modeling technologies more effectively (Jongeling & Olofsson, 2007).

Reviewing the available literature, in the area of construction scheduling techniques, one could not help but notice that there is always a tradeoff. Every scheduling approach, whether it is activity-based scheduling, or location-based scheduling, comes with a set of benefits and a subsequent list of limitations. Sometimes the list of advantages and disadvantages from the two different scheduling approaches are complimentary. In other words, the shortcomings of one method, in some cases, are strong points in another method. For example, the activity-based scheduling method provides a clear critical path for the project, and enjoys a wide variety of available supporting software programs (e.g., Primavera®, and Microsoft® Project); yet, it is not efficient in scheduling repetitive work and does not display spatial attributes of scheduled activities. On the other hand, the location-based scheduling approach allows for effective planning of repetitive work, and shows the locations of scheduled activities. However, location-based schedules do not communicate a clear critical path for the project, and are not practical for scheduling activities that are not repeated in the project's location and/or do not have a location (e.g., mobilization, and permits). More on the advantages and disadvantages of both the activity and location-based scheduling approaches are presented in further details in Review of Literature section of this dissertation (Chapter 2).

Cole (1991) conducted a research involving six case studies "two renovation projects and four commercial office buildings, two based on the critical path method, two based on the flowline method, and two that use both models in appropriate sections." He concluded that "Few contractors use planning techniques to their full potential; critical path methods are best suited to non-repetitive projects; flow lines are best suited to repetitive projects; and as most contracts have dual characteristics, no single system can meet all a contractor's requirements for planning and monitoring construction work." (Cole, 1991).

1.2 Research Problem

The process of scheduling usually goes through an iterative cycle shown in Figure 1.3, where a schedule is produced using a scheduling technique (e.g., CPM), visualized through a graphical method (e.g., Linked Gantt Charts), and then analyzed, updated and managed accordingly. For example, a scheduling practitioner could prepare a CPM schedule by entering pertinent data like task names, durations, and relationships in a scheduling software program (e.g., Microsoft® Project or Primavera® P6). The software program then generates some form of visualization interface, like a Linked Gantt Chart and a network diagram. The project stakeholders use the graphical output to meet and discuss the schedule and make modifications. The effects of these changes are evaluated, after entering the changes in the scheduling program, and visualized/analyzed to make further adjustments. This process is performed throughout the project lifetime to consider and assess any updates or changes in the schedule.

This process could proceed in both directions, where a change could be applied visually in the visualization interface, and then the effect of the change is analyzed using the scheduling technique and so on. Furthermore, this process is followed regardless of the scheduling system. In a location-based scheduling approach a schedule is prepared and visualized through a graphical method, like a Flowline graph, and then analyzed, updated and managed accordingly (Figure 1.4).

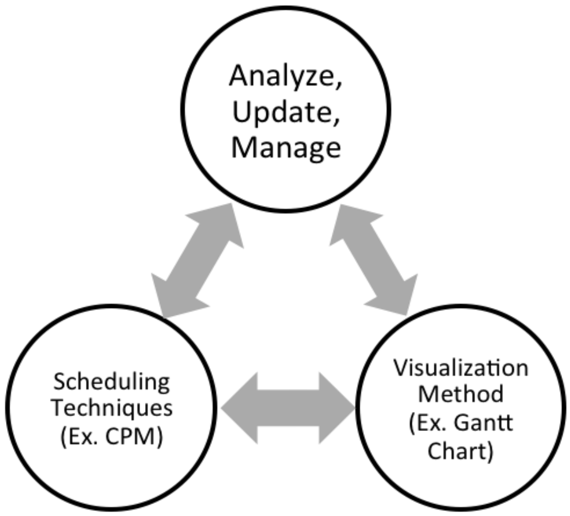

Figure1.3: Scheduling process for the activity-based scheduling approach.

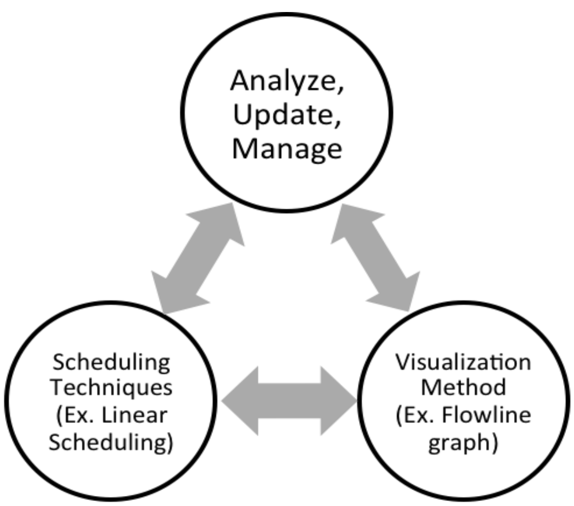

Figure 1.4: Scheduling process for the location-based scheduling approach

Activity-based scheduling and location-based scheduling systems are currently treated as stand-alone and isolated approaches to project management and control, and both have documented intrinsic benefits and limitations. The process shown in Figures 1.3 and 1.4 takes place under each system. Most scheduling practitioners have to make a choice to use one method or the other. Several researchers have attempted to merge the two scheduling approaches with the intention of capturing the combined advantages of both techniques while eliminating/resolving their shortcomings (Suhail & Neale, 2004). However, most of these previous attempts rely heavily on complicated algorithms and mathematical equations (Suhail & Neale, 2004), or combining scheduling techniques from both approaches by alternating their use where it is most beneficial and appropriate (Shoderbek & Digman, 1967). A review of the available literature shows that none have tried to merge the two scheduling methods through their visualization attributes, or by visually relating activity-based scheduling with location-based scheduling. More details on these previous attempts is discussed in Chapter 2.

1.3 Research Questions

Linked Gantt Charts, a product of the activity-based scheduling approach, are limited to providing a graphical visualization tool that communicates *logical relationships* between project activities. Flowline graphs on the other hand, are one of the outputs of the location-based scheduling system, and are a graphical visualization tool that communicates *spatial relationships* between project activities. Each scheduling system (activity or location based) in general, and visualization tool in particular (Linked Gantt Charts or Flowline graphs) comes with a set of benefits and shortcomings. This research endeavor attempts to answer the following research questions:

- Can a graphical tool be developed to show combined Linked Gantt Chart bars from the activity-based scheduling approach, and flow-lines from the location-based scheduling approach, to allow the exploitation of both scheduling methods' visual advantages?

- If so, does using the proposed tool, developed by this research, allow the user to accurately and quickly comprehend the activities' relationships relative to the accuracy and speed of accomplishing the same task using a Linked Gantt Chart from the activity-based scheduling approach?
- If so, does using the proposed tool, developed by this research, allow the user to accurately and quickly identify the activities' locations relative to the accuracy and speed of accomplishing the same task using a Flowline graph from the location-based scheduling approach?

1.4 Research Objective

This research endeavor investigates the possibility to combine the visual advantages of both graphical schedule visualization methods, the Linked Gantt Charts (LGC) and Flowline graphs (FLG), and investigates whether this combination contributes to the human cognitive process. In order to accomplish the goal of the research, a graphical representation system that combines these two scheduling visualization methods is developed. Afterwards, the research attempts to empirically validate the ability of the proposed tool to visually communicate and combine logical and spatial relationships. This is compared to comprehending the same information by looking at a standalone Linked Gantt Chart or Flowline graph. The accuracy and time, of deciphering various details of a sample project schedule, are used as parameters to evaluate the proposed scheduling visualization tool, and compare it to the existing LGC and FLG systems.

1.5 Study Delimitations

The research will be conducted to develop and test the effectiveness of the proposed scheduling visualization tool, in visually merging the Linked Gantt Chart bars, generated from the activity-based scheduling method, and the flow-lines produced by the location-based scheduling technique. However, it will not investigate issues concerning the ability of the proposed tool in creating, updating, tracking, and managing project activities. Furthermore, this research endeavor does not compare the proposed tool's capability in performing these tasks relative to scheduling techniques like the Critical Path Method or Line of Balance scheduling. This research is limited to investigating the user's success in visually attaining the same amount of information, derived from Linked Gantt Charts and Flowline graphs, through the use of the scheduling visualization tool developed. In essence, this research effort is limited to evaluate the theory rather than the application of the proposed visualization tool.

1.6 Document Overview

The research will start by providing a review of the existing literature concerning the strengths and limitations of both the activity-based scheduling and location-based scheduling approaches (Chapter 2). The literature review also presents a summary of some of the previous attempts to merge and combine these two systems. Furthermore, a discussion of the human cognitive process and how visual representations aid human beings in comprehending and deciphering data is provided. Following the literature review an explanation of the development of the proposed scheduling visualization tool is presented (Chapter 3). Then, the research methodology (Chapter 4) followed to reach the research objectives is explained. Finally, the data collected is analyzed (Chapter 5), the findings of the research are documented (Chapter 6), and the research conclusions are discussed (Chapter 7).

2. REVIEW OF LITERATURE

The construction industry has been witnessing numerous research and advancements in various fields. There is a growing need, from construction management professionals, for techniques and methods to schedule and manage projects more effectively and with higher efficiency. They require systems to perform various functions like scheduling, tracking, cost management, resource management, time management and forecasting conflict areas in the project. These systems have to possess certain qualities like ease of understanding and visualization, and simplicity in updating schedule changes during the execution of the project. Furthermore, these scheduling systems are preferred to have the ability to implement and aid in the execution of new construction concepts and technologies like Lean Construction and Building Information Modeling.

The majority of the construction industry is currently relying on activity-based scheduling systems like Linked Gantt Charts (LGC), Program Evaluation and Review Technique (PERT), and the Critical Path Method (CPM) to create, manipulate, and convey project schedules. Activity-based scheduling systems include scheduling techniques (e.g., CPM and PERT) and representation methods (e.g., Linked Gantt Charts) that are currently dominating the construction industry in producing, analyzing, updating and communicating project schedules (Kelleher, 2007).

Using activity-based scheduling techniques like CPM scheduling, and representation methods like Linked Gantt Charts, have been known to be very useful and practical in understanding and communicating construction projects' schedules; however, the system has its fair share of limitations and disadvantages. Many studies have been conducted to document both benefits and shortcomings of activity-based scheduling systems (Jaafari, 1984). For the past ten decades, numerous researchers have demonstrated how an alternative location-based scheduling system could offer solutions to many scheduling related problems and retain various inherent advantages (Seppanen & Aalto, 2005). The following sections highlights and explains some of the major advantages and disadvantages of the two scheduling approaches, the activity-based and location-based approaches.

2.1 Advantages of Activity-Based Scheduling

Activity-based schedules like the Critical Path Method (CPM) are currently the dominant planning and scheduling method in the construction industry. The Linked Gantt Chart (LGC) is usually the result of the activity-based scheduling process and is used to visualize the CPM schedule. Scheduling projects using Gantt Charts is the method taught in construction education programs, utilized by the majority of industry professionals, and benefits from a wide variety of supporting software programs. The Critical Path Method is currently the mainstream scheduling technique in constructing, communicating, managing and updating the majority of construction projects (Kelleher, 2007). Below are three main reasons behind LGC and CPM's wide use by the construction industry.

2.1.1 Displays a Critical Path

The concept of finding a critical path is the major advantage provided by the CPM scheduling technique. Arditi, Tokdemir, and Suh (2001) explained how "In network analysis, at least one critical path exists. Activities which are on the critical path have to be started and completed by their assigned times if the total project duration is not to be extended." The Critical Path Method (CPM) uses the forward and backward paths to identify the critical path of the project. The critical path is defined as the longest path through a sequence of activities. Most construction schedules rely on the critical path to anticipate if the project will be completed on time or not.

The Linear Scheduling Methods could generate a similar path, called the controlling path, but it is not as intuitive or as clear as the critical path generated by the CPM. The controlling path consists of a sequence of activities, if any of these activities' durations are changed, the result will be the change of the total project duration. Similar forward and backward path calculations are used to define this controlling path (Spencer & Lewis, 2005). However, the LOB scheduling method's criticalness is based on time and resources, unlike network scheduling where it is only based on time. As a result of the different rates of production of the individual activities, critical activities in the unit network may or may not coincide with the critical activities in the LOB schedule. (Arditi et al., 2001). This could sometimes cause confusion and miscommunication difficulties when trying to convey the critical path to individuals working on the same project.

The critical path is a very common way to understand the project schedule and is implemented extensively in the construction industry. However, there have been some reported criticisms on its usefulness in applying modern construction theories like resource optimization in projects with a repetitive nature and lean construction concepts. Mendes and Heineck (1998) state "Many researchers discussed the suitability of CPM for construction projects, mainly those repetitive projects, such as railroads and multi-story buildings, and more recently for the lean construction concepts." One major CPM scheduling disadvantage, from a lean construction perspective, is the idea of finding a critical path in of itself. The CPM schedule is developed based on the critical path, and the resource capacity and material requirements are inputs for the project simulation. The emphasis is on project duration shortage and resource leveling. Melles and Welling (1996) point out "The fact of having a 'critical path' implies having non critical ones, which have float time. It means that the planning construction incorporates wastes what significantly diverts from a modern construction philosophy." (as cited in Mendes & Heineck, 1998).

2.1.2 Availability of Well Developed Software Programs

There is a wide variety of software programs that support and enhance the use of Gantt Charts. Akbas (2004) states that "Currently, the most common technique used in practice for macro-level construction planning and scheduling is the critical path method (CPM), a network based project scheduling technique." The author attributes CPM's popularity to the existing CPM supporting scheduling software products, such as

Primavera® Project Planner (2000) and Microsoft® Project (2003). These scheduling software programs allow CPM schedules to generate an overall view of the project with details like activity durations, sequences, milestones and criticality of activities. Akbas (2004) explains that this is part of the reason why CPM is popular in the construction industry. Yamin and Harmenlink (2001) support these conjectures. In their study, they conclude that "LSM (Linear Scheduling Method) is superior to CPM for very specific projects (linear and continuous), but CPM is a more complete scheduling tool than LSM." They explain how that superiority is largely due to the various useful functions that CPM software programs provide "mainly because multiple resource management techniques and statistical analysis have been developed for it (CPM)." (Yamin & Harmenlink, 2001).

2.1.3 Predominant in the Industry

The Critical Path Method (CPM) scheduling technique is the dominant planning and scheduling method in the construction industry. Andrew Kelleher (2004) explains in his research, titled *An Investigation of the Expanding Role of the Critical Path Method by ENR's Top 400 Contractors,* how the "Critical Path Method (CPM) is a widely used tool throughout the construction industry. Since its creation, the use and application of the Critical Path Method has grown tremendously." Kelleher's paper summarizes and builds on two previous studies conducted to investigate the Engineering News Record's (ENR) Top 400 Contractor trends in the use of CPM. Edward Davis performed the first study in 1974, and Amir Tavakoli and Roger Riachi performed the second study in 1990. Kelleher built on these two previous researches and conducted his own study in 2003. Based on his research Kelleher concluded that CPM's use by the Top 400 Contractors is growing and the areas of its use are expanding. "The results from the three studies indicate that CPM use by the Top 400 Contractors is growing with 98% currently using it compared with 90% in 1974. While this growth is not extraordinary, the frequency with which companies use CPM has grown in addition to the application areas of CPM expanding." (Kelleher, 2004). Kelleher (2004) attributed this growth to CPM's expanding use as a planning tool, ability to be updated with minimal effort, the rapid development of supporting software programs, its increased use in estimating and bidding, and use in claims analysis and litigation.

The study showed that detailed planning, before the start of construction, is the number one use of CPM. Due to advances in technology, updating a schedule during construction is becoming easier and faster. This led to the growth in periodic control of construction projects using CPM scheduling. Furthermore, "Another area of CPM growth is estimating and bidding for several reasons: use in this area has jumped from 19% to 54% in the past 30 years." (Kelleher, 2004).

Based on the observed trends of use of CPM scheduling, since its inception in the late 1950's, Kelleher (2004) predicts that there will be new uses and features added to the Critical Path Method allowing it to be used even more. Kelleher anticipates that with more technological advancements, the integration of CPM with other software applications will increase correspondingly. It is interesting to note that the study found that "The techniques used least by the respondents are Line of Balance, Linear Balance Charts, and 4-D planning." (Kelleher, 2004).

2.2 Disadvantages of the Activity-Based Scheduling

It is vital to highlight the reported limitations and shortcomings of activity-based scheduling methods like the Critical Path Method (CPM) scheduling and the Linked Gantt Charts. This will help attain a better understanding of the activity-based schedules, and aid in appreciating the need for alternative scheduling techniques. Furthermore, identifying activity-based schedules' disadvantages explains the motive behind some researchers and scheduling practitioners' desire to develop and consider other scheduling approaches, like location-based scheduling. Furthermore, it demonstrates the significance for merging the CPM with other scheduling techniques as a possible way to resolve these problems, which is the topic of this research.

2.2.1 Scheduling Repetitive Activities

The main reported limitation of the Critical Path Method (CPM) scheduling technique, relative to Line of Balance (LOB) scheduling, is scheduling repetitive activities. This shortcoming was noticed since the time the industry started adopting the scheduling method. CPM is capable of scheduling repetitive activities, however, not as effective or efficient as LOB scheduling. This is highlighted and discussed in numerous research efforts and studies, starting from the early 1970's until the present day. Time and time again, both practitioners and researchers have voiced their disappointment with the CPM application on projects with a repetitive nature. One of the main reasons behind their criticism was the CPM's vulnerability to sequence changes of work between the repetitive typical units, which is, on repetitive projects, a matter of choice and strategy and frequently depends on unforeseen circumstances. (Arditi et. al, 2002)

Critical Path Method scheduling is not oriented towards providing work continuity for the crews of the repetitive activities, which is fundamental in repetitive construction (Suhail and Neale 2004). Furthermore, Rahbar and Rowing (1992) explain in their research how CPM scheduling is unable to distinguish rates of progress of activities and that the number of units that can be completed within any period of duration is not clearly visible.

2.2.2 No Spatial Consideration

The CPM's generated Gantt Charts does not intuitively show the activities' location within the project. To consider any given activity's location the user has to go in and manually add extra information, if the scheduling software has that function. Furthermore, activities and their sequences do not represent spatial characteristics of the work performed, such as the crew workflow directions or the desired spatial buffers between activities. To support such characteristics would require many activities and spatial characteristics implicitly represented via precedence relationships, which makes the definition and maintenance of such a schedule hard. Spatial locations and physical components are not directly related to activities. (Akbas, 2004)

2.2.3 Complexity

Arditi, Sikangwan, and Tokdemir (2002) pointed out that CPM schedules could get very complex and large in size, especially in projects with many repetitive activities. They stated that “In a repetitive project of n units, the network prepared for one unit has to be repeated n times and linked to the others; this results in a huge network that is difficult to manage. This may cause difficulties in communication among the members of the construction management team.” (Arditi, Sikangwan & Tokdemir 2002). Furthermore, the authors explain how the Critical Path Method scheduling is designed for optimizing project duration rather than dealing adequately with the special resource constraints of repetitive projects.

In subsequent sections of this document, the Line of Balance schedule’s capability to ensure a smooth procession of crews from unit to unit with minimal conflicts while decreasing idle time for workers and equipment will be demonstrated. LOB scheduling ability to avoid hiring and procurement problems in issues pertaining to the flow of labor and material used during construction have been documented in previous studies. In Arditi, Sikangwan and Tokdemir (2002) study, the authors explain how some of these problems have been resolved by the development of new generations of modified Gantt Charts and advancement in software programs. However, “Even though this new generation of Gantt charts appears to provide all the advantages of regular CPM networks, they certainly are not of much help in projects of a repetitive nature.” (Arditi et al. 2002).

Jongeling and Olofsson (2007) raise another point of weakness pertaining to the Critical Path Method scheduling. They explain how “Construction planners decompose a project into activities that they associate with one or more building components (e.g. casting of concrete floor 3) that make up the project. Each activity is included in a bar chart and a network that describe the proposed schedule of a project.” Jongeling and Olofsson explain that this practice builds on the assumption that progressive subdivision of the work-scope eventually turns into specification of how construction tasks should be executed. They discuss how some construction planners use the CPM method to integrate the product (i.e. what is to be done) with the process (i.e. how it is done). The problem is that in doing so the schedule becomes very detailed and difficult to use and to update. They explain that the inevitable consequence is that "detailed schedules are often not updated during a construction process and thereby lose their value as an instrument to plan and control work-flow." (Jongeling & Olofsson, 2007).

Another point of complexity when using CPM schedules is updating schedules that involve a large amount of activities. When Gantt Charts are used for operations planning, they become hard to manage, maintain and track because of the increased number of activities and relationships. Increasing the number of sequencing relationships opens the schedule for inconsistencies (Akbas, 2004)

2.2.4 Managing Workflow

Managing the project's workflow is another reported shortcoming of Gantt Chart schedules. CPM networks do not model work continuity for activities that are part of a wider workflow. LOB techniques aim to resolve this for linear or repetitive activities. (Akbas, 2004). Resource allocation and smoothing or leveling procedures are incapable of ensuring full continuity for production crews which are the backbone of operational planning in construction processes, especially in repetitive cases. (Jaafari, 1984)

Jiang & Cheng (2006) performed a case study to investigate the scheduling process of underground utility projects. In their study they compared the Gantt Chart method with the Linear Scheduling method in scheduling these projects. Their research concluded that the Gantt Chart method is inadequate in visibly providing information pertaining to productivity and true project progress based on location. On the other hand, the study showed how linear scheduling focuses on balancing productivity rates of activities in a linear project.

2.2.5 Limited Amount of Information (Difficult to Visualize)

The ability to visualize a construction schedule using Gantt Charts is another limitation of the Critical Path Method scheduling. The early study conducted by Chrzanowski and Johnston (1986) found that "the major disadvantage of CPM is that for complex projects, a CPM schedule becomes extremely detailed." The authors' major complaint was that field personnel, who are usually not trained to understand the methodologies of the Critical Path Method, find the schedule confusing and consequently, less useful. The two authors believed that "In order for a schedule to be beneficial, it should provide a positive visual impact. The reader must be able to easily associate work activity sequences with project times when reviewing the schedule." (Chrzanowski & Johnston, 1986). This problem is magnified in projects consisting of repetitive activities, such as in vertical (high-rise buildings) construction and linear (roadway) construction. Since the same activities are repeated throughout a project's duration, the resultant CPM schedule is cluttered with repetition of information (Chrzanowski & Johnston, 1986).

One would expect with the technological advancement and development of software programs that these limitations would have been overcome. However, in a more recent study comparing the Line of Balance and the Critical Path Method scheduling techniques for high rise building projects, a type of project that includes numerous repetitive activities, Arditi, Sikangwan, and Tokdemir (2002) conclude that "Gantt charts are inadequate, and that there are serious problems with using network methods in such circumstances." The authors claim that Gantt charts, a representation of CPM scheduling, are the most commonly used method of scheduling and control in the construction industry. However, they explain how challenging it is to visually track and comprehend the relationships and scheduling rational of repetitive activities. The authors state that Gantt charts fail to "show interrelationships between the activities of a project. This problem is exacerbated as the project size and complexity increase. Construction managers who use Gantt charts have difficulties in changing or updating the data of a particular activity that may cause additional changes in other related activities." (Arditi, Sikangwan & Tokdemir 2002).

Some studies show that CPM activities do not represent production characteristics for installation. From the flow lines generated by the LOB schedule, the user could visibly identify the productivity rate of a certain activity and comprehend how it compares to other activities on the schedule. However, the bars on the CPM schedule, constituting the basic unit of analysis for the schedule, are aggregations of a set of construction processes that lack information about methods to perform these processes. (Akbas, 2003). The basic assumptions of project activities having fixed time and discrete nature are unrealistic, especially when repetitive units or linear projects are to be constructed (Jaafari, 1984).

2.3 Advantages of Location Based Scheduling

Since the first inception of Line of Balance (LOB) scheduling by the U.S. Navy in 1962, researchers have been investigating the benefits, limitations, and possible improvements of this scheduling technique. This section highlights the major advantages, perceived by researchers and scheduling practitioners, for utilizing location based schedules like Line of Balance and Flowline schedules in construction projects.

Before discussing the benefits of Location Based Scheduling it is important to note that throughout this research effort, the terms Flowline graphs (FLG), Line of Balance (LOB) scheduling and Linear Scheduling Method (LSM) are used interchangeably. There is a difference between these terms; however they all fall under the category of location-based scheduling. For example, the Flowline graph is the primary method for creating and communicating location-based schedules, Line of Balance schedules are a little different in that they show the number of crews working in each activity. The difference between LOB and LSM is cited by Arditi, Tokdemir and Suh (2001); they state that "Any differentiation between Linear Scheduling and the Line-of-Balance (LOB) technique is only a question of emphasis. In LSM, the emphasis is on the graph of time and space, which is similar to the progress chart in LOB. In LOB, the emphasis is on the progress chart and the balance line (Mattila & Abraham, 1998).” For the purposes and aims of this research the difference between these terms is relatively minor and negligible.

2.3.1 Scheduling Repetitive Activities

Line of Balance (LOB) scheduling is best utilized in planning and controlling repetitive activities. Scheduling practitioners and researchers have time and time again demonstrated how (LOB) scheduling is best applied to pipeline, highway, railroad, and utility projects. Linear scheduling is proven to be superior to activity based scheduling when implemented on projects with repetitive activities. Spencer and Lewis (2005) explained how planning and scheduling these types of projects are difficult using the Critical Path Method (CPM). Linear Scheduling is composed of continuous activities, unlike CPM which is composed of discrete activities. The Critical Path Method is dependent on work sequencing while LSM schedules are based upon resource and jobsite availability and are not as dependent on work sequencing as CPM. This allows for more control and resource management for the project (Spencer & Lewis, 2005).

2.3.2 Simplicity in Developing and Understanding the Schedule

Many researchers demonstrated how Line of Balance (LOB) scheduling is a relatively simple method for creating and understanding construction schedules. A relatively early study conducted by Chrzanowski and Johnston in 1986, concluded a number of benefits for using the Linear Scheduling Method. The two researchers affirmed that the most obvious attribute of LSM, is its simplicity. The LSM diagrams easily convey detailed information that is comparable to what may be derived from an equivalent Critical Path Method (CPM) schedule. Furthermore, with LSM, personnel can perform various types of project analyses with relatively little training (Chrzanowski & Johnston, 1986). Spencer and Lewis (2005) claim earned value analysis can be easily conducted and identified from a LOB schedule. Furthermore, schedule delays due to resource productivity, and delays due to weather and site conditions can also be reasonably predicted.

Chrzanowski and Johnston (1986) showed how the Linear Scheduling Method (LSM) allows changes in job progress, resource allocations, and schedule updates to be performed quickly and with minimal difficulty, relative to the more commonly used CPM scheduling. In certain instances, material lists can also be developed. Simplicity and clarity of the whole schedule are major advantages of LSM especially for highly complex linear projects. The authors claim, that after some study of the schedule, the user should be able to understand the flow of work through the project. The user could also comprehend the reasoning for performing the work in the illustrated manner. Chrzanowski and Johnston (1986) illustrated these benefits through an earthwork example, where the user had the ability to quickly ascertain how much material has to be moved and the stations involved in the process. The researchers concluded that the user could receive fairly detailed information without being confronted with the numerical data and degree of abstraction found in network methods.

2.3.3 Incorporating Location in the Schedule

The idea of Line of Balance (LOB) scheduling is based on incorporating location (the Y-axis in a LOB schedule) within the construction schedule. Spencer and Lewis (2005) explained how linear scheduling allows activities to be linked or sequenced spatially or temporally by their physical relationships. In this case, any activity is influenced or impacted by the preceding activity at any location, resulting in a more accurate and realistic schedule.

Spencer and Lewis (2005) present another important advantage concerning the intrinsic nature of Line of Balance scheduling. They explain that, unlike the Critical Path Method, the Linear Scheduling Method (LSM) activities do not need to be continuous over time. This is beneficial because work can be started and stopped at any point in space as long as the space element is made continuous before the project is finished. CPM activities occupy a subset of the entire project time and space and CPM schedules have multiple paths or sequences from the start (in time) of a project to the end. In LSM, the activities span the entire space of the project, but only a subset of the time. (Spencer & Lewis, 2005)

2.3.4 Resource Management

Line of Balance (LOB) scheduling allows for superior visual management for the project resources. Spencer and Lewis (2005) believe that a major advantage for using Linear Scheduling is resource management. They explain how, one of the major restrictions with using the Critical Path Method is assigning resources to activities. Resource constraints in CPM are imposed by time not location or change in condition at a given location. Resources are only assigned to activities. The authors state that in CPM scheduling "resources are usually set up by crews or spreads with multiple limitations or variable production rates. When constraints only have a time component, global restrictions that are time dependent at a location are not possible." (Spencer & Lewis, 2005).

Spencer and Lewis conclude their study by explaining how the Linear Scheduling Method can provide the traditional resource and earned value analysis available with the Critical Path Method schedules. Linear scheduling uses percent complete and incurred costs calculations to measure the actual progress on activities, like CPM. Furthermore, the slope of the flow-lines, produced by a Linear Schedule, is set based on the activities' production. The visual advantage of Linear scheduling in showing the production and resources of scheduled activities, along with the fact that it is a location based scheduling technique, provides additional analysis concerning resource congestions. (Spencer & Lewis, 2005)

2.3.5 Implementation of Lean Constriction Concepts

The theories and ideas behind lean construction initiated in the manufacturing industry, and were developed and improved by the Japanese car company, Toyota. In construction, the application of the lean production model stems from a discussion of Koskela's work (1992), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to reduce wasted value in jobsites (as cited in Conte & Gransberg, 2001). Numerous studies have established the advantages of applying lean concepts in the construction industry. Furthermore, some studies showed that Linear Scheduling helps in enhancing and applying these concepts in construction projects.

In 1998, Mendes and Heineck published a study concerning production control of the construction of multi-story building projects. They stated "using the line of balance technique attempts to solve planning problems by making production processes clearer and simpler." They showed how the Line of Balance (LOB) scheduling technique supports lean construction concepts. Many lean construction issues were complimented and supported by using Line of Balance scheduling, "concepts such as waste elimination, variances minimization, flexible planning and scheduling sequencing." (Mendes & Heineck, 1998).

In the study conducted by Mendes and Heineck (1998), they present "An initial planning strategy which focus on the sequence of work and the rhythm of labor team work is provided by the use of line of balance concepts. This initial planning was applied on several residential multi-story buildings." They planned for the project by grouping together activities that are highly interdependent. The study shows how this grouping methodology resulted in the realization of various lean construction concepts. The method they used allowed for "planning for the whole operations, get advantage of the 'cell production', and matches labor teams and related resources. This approach also makes it possible to take advantage of multiple trades working jointly or of multi-skilled workers." (Mendes & Heineck, 1998). Overall, through their study the authors showed how using LOB scheduling support lean construction principles like eliminating waste, minimizing variances, enabling visual management, and providing flexible plans and sequence of schedule.

Conte and Gransberg (2001) performed a study where they applied the model proposed by lean construction to more than 20 Brazilian construction companies for six years. The researchers defined their activities according to production planning and control of cost, raw materials, labor, equipment and tool consumption. In their research they stated “The line of balance (LOB) technique should be used to optimize the study of the pace of the services to be executed.” Conte and Gransberg (2001) continue to explain how LOB scheduling “provides for the immediate identification of production bottlenecks and eventual buffer insertion points.” They utilized Line of Balance scheduling to offset the differences in pace between the work packages identified for the project. In conclusion, Line of Balance scheduling allowed them to apply lean construction concepts more effectively. They concluded that LOB scheduling aided them in reaching “The ideal situation when all work packages have the same pace, and eliminating inventory that does not really add value to the end product.” (Conte & Gransberg, 2001).

2.3.6 Compatible with Virtual Design and Construction Technology

Activity based planning, like Critical Path Method (CPM) scheduling has been the dominant scheduling technique for 4D Modeling. Jongeling and Olofsson (2007), claim that there are numerous disadvantages to utilizing activity based planning for 4D Modeling.

> Research and application of 4D CAD to date has been dominated by the linkage of 3D CAD building components with activity-based planning approaches, such as CPM schedules. The difficulty of applying flow-based thinking in such models arises from the problem that the models are based around discrete activities. An additional problem is the fact that 4D CAD models often are not organized according to a location-based logic, which further constraints the application of flow-based thinking. (Jongeling & Olofsson, 2007)

Jongeling and Olofsson (2007) concluded in their study that location-based scheduling based on the Line of- Balance technique provide better characteristics to plan work-flow, compared to activity-based scheduling techniques. They claim that using Line of Balance (LOB) scheduling offer a solution to the problem of compatibility between 3D

CAD models and scheduling. Furthermore, their study shows that “location-based scheduling provides a promising alternative to activity-based planning approaches for planning of work-flow with 4D CAD. A location-based approach to 4D CAD could also improve the usability of the 4D CAD models for work-flow analyses.” Jongeling and Olofsson (2007) show how 4D modeling and location based scheduling complement each other and reinforce the various intrinsic benefits they possess individually. So Linear scheduling techniques aid in the application of Building Information Modeling and 4D Modeling technologies and ideas; moreover, the author’s study presented how “4D CAD can enhance the value of location-based schedules.”

In discussing 4D Modeling, Akbas (2003) explains “Its basis on CPM networks and input 3D geometry limits its utilization for operations planning. It carries over some limitations of CPM; it assumes the production rate is constant for the duration of an activity, and it does not capture or visualize the reasons behind an existing plan or any geometric planning parameters, such as workflow directions.”

Throughout their study Jongeling and Olofsson (2007) discuss the various benefits and attributes of utilizing 4D Modeling. One of the advantages of combining LOB schedules with 4D CAD is that it adds “spatial insight in the planning of work-flow that could add to the quality of the process design.” (Jongeling & Olofsson, 2007). However, they show a number of limitations and obstacles that hinder the exploitation of 4D modeling’s full advantages in scheduling processes of construction planning. They conclude their research by stating “The combination of location-based planning by applying the Line-of-Balance technique in combination with 4D CAD could be a promising method in which the strengths of both methods could reinforce each other.”

2.4 Disadvantages of Location-Based Scheduling

As with any scheduling approach, location-based schedules like Line of Balance and Flowline scheduling have their fair share of limitations and weaknesses. This section describes two of the reported disadvantages of Line of Balance and Flowline schedules.

2.4.1 Scheduling Non-Repetitive Activities

The advantages of Line of Balance (LOB) scheduling are especially evident when applied to projects with a repetitive nature. Some researchers argue that this fact could be a two edged sword, and is one of Line of Balance scheduling major limitations. A research conducted by Chrzanowski and Johnston in 1986 concluded that “The main problem with the LSM is that its use is restricted to construction projects consisting of repetitive activities. Discrete activities can be included, but if more detail is required, the activity must be referenced to a network schedule. If repetitive activities in one project have different axis coordinates, then separate schedules must be drawn for them.” This idea is further explained and supported in Suhail and Neale’s study (2004). The two authors refer to “Kavanagh (1985) indicated that the LOB techniques were designed to model simple repetitive production processes and, therefore, do not transplant readily into a complex and capricious construction environment.” (Suhail & Neale, 2004).

2.4.2 Useless if Not Updated

All schedules, regardless of what scheduling method is used would be less useful if not updated. However, Line of Balance (LOB) schedules are built from quantities and productivity rates. If these factors are not updated or do not reflect the real situation in the project, then the schedule could become obscure. Seppanen and Aalto performed a relatively more recent study in 2005 concerning Line of Balance scheduling. They pointed out that “Experiences from using Line-of-Balance in real projects indicate that most of the benefits are currently lost in implementation stage.” This is because of variability of production rates and inadequate control mechanisms on site. The fact that a LOB schedule losses validity if not updated is a weakness shared by any scheduling technique. Like other scheduling methods, to overcome this limitation for LOB scheduling, the project team must be keen on periodically updating the schedule to reflect the true project situation and progress.

2.5 Previous Attempts in Merging Both Scheduling Approaches

Through history and experience the construction industry have identified certain scheduling techniques for different types of projects. Some scheduling methods are believed to be more suitable and could be applied to a certain category or type of project. According to Yamin and Harmenlink (2001) the Linear Scheduling Methods (LSM) "performs optimally when scheduling linear continuous projects, such as highway construction. However, LSM can be very inefficient when scheduling complex discrete projects (bridges, buildings, etc.). The CPM is quite the opposite; it is ineffective and cumbersome for scheduling linear continuous projects but extremely efficient for more complex and discrete type projects." The authors present a table (Table 2.1) summarizing the appropriate scheduling techniques to be used, based on the project type and its main characteristics.

Table 2.1: Recommended scheduling tool for different types of projects. (Adopted from Yamin & Harmenlink, 2001)

Type of project	**Scheduling method**	**Main characteristic**
Linear and continuous projects (pipelines, railroads, tunnels, highways)	LSM	Few activities.
Multiunit repetitive projects (housing complex, buildings)	LOB	Final product a group of similar units.
High-rise buildings	LOB	Repetitive activities.
		Large amount of activities.
		Every floor considered a production unit.
Refineries and other very complex projects	CPM	Extremely large number of activities.
		Complex design.
		Activities discrete in nature.
		Crucial to keep project in critical path.
Simple projects (of any kind)	Bar/Gantt chart	Indicates only time dimension (when to start and end activities).
		Relatively few activities.

As discussed in previous sections and shown in Table 2.1, both the Critical Path Method (CPM) and Line of Balance (LOB) scheduling have intrinsic advantages and uses. The idea of combining the two schedules is not new. For almost four decades, researchers have been trying to find ways to merge these two scheduling techniques and capture the combined benefits provided by each. “This task for combining the two techniques or sometimes combining their merits under different names has been a heavily researched theme for decades. This reinforces the notion that CPM and LOB are complementary.” (Carr & Meyer, 1974).

Schoderbek and Digman (1967) were among the first to merge these two scheduling methods, CPM and LOB. They worked on integrating the planning elements and disciplines of CPM with the control elements of LOB. The idea was to utilize CPM in the development phase(s) and LOB in the production phase(s). Their objective was combining CPM and LOB in a system applicable wherever and whenever CPM or LOB can be of-service. The authors’ approach was based on building an algorithm to accomplish this mergence. Even though the algorithm of scheduling repetitive activities was not shown, it could not be inferred that it was resource driven (Shoderbek & Digman, 1967).

In 1982, Perera introduced a method that addressed multiple branching networks within a project. The method was oriented in computing the duration of the project, and accounted for the float time. However, the method utilized linear programming and was very sophisticated and complex to be applied in real-life project applications. It was challenging to update and use the plan generated. Some researchers criticized it by explaining how “During construction many changes are usually considered, and it is essential that the impact that alternatives have on completion status be quickly assessed (Carr and Meyer 1974). To a large extent, the plan should contain the strength to absorb minor time variations or location variations (Birrell 1980).” (As cited in Suhail & Neale, 2004).

Some later attempts were based on developing mathematical methods to combine the two scheduling techniques. For example, AI-Sarraj (1991) developed a mathematical method for the LOB to facilitate finding the project duration, start and finish times for every activity at every repetitive unit, the available buffer and the information about the intersection place. Al-Sarrag introduced an alternative for drawing a LOB diagram as a means of defining the schedules. The example he presented was for a project of multiple standard units with each standard unit having a series of sequential operations (activities) (Suhail & Neale, 2004).

Some later researchers, following Shoderbek and Digman's model, tried to combine each scheduling technique (CPM and LOB) where it was most practical and useful. Rahbar and Rowing (1992) presented a method were the CPM was used at the summary level of the discrete non-repetitive activities, to avoid a complicated networks with out-of-sequence progress errors, and used LOB at the level of the repetitive activities (Suhail & Neale, 2004). Others, like Russell and Wang (1993), developed construction management software programs, like REPCON, that schedules repetitive activities driven by CPM logic relationships.

In 2004, Suhail and Neale published a paper titled *CPM/LOB: New Methodology to Integrate CPM and Line of Balance*, where they claimed to develop "a new methodology … that adequately integrates the merits of CPM and LOB by attacking the novelty of using resource leveling and the float times calculated by CPM in the LOB. The virtue of the method lies in its invulnerability to changes in the sequence of work and to its ability to maintain work continuity for the working squads of the repetitive activities." (Suhail & Neale, 2004). Their objective was to overcome the main challenges of the Critical Path Method in scheduling repetitive construction projects, handling changes in sequence, and the lack of control on work continuity through combining CPM and LOB in the already developed CPM context.

Previous studies demonstrate how combining and/or merging the Critical Path Method and Linear Scheduling is a challenging task. The outcome should permit the efficient and effective management of "resources needed for repetitive activities, maintains work continuity, preserves the logical relationships in every unit, achieves a desired production rate, and provides a legible presentation of the large data included in a schedule." (Hegazy). It is preferred for the final user interface of this mergence to be presented in a CPM environment. Suhail and Neale (2004) concluded their paper by explaining how there was "intensive research over the past decades to combine the merits of both methods. Unfortunately, the application of the LOB almost vanished and the application of CPM failed to respond to the frequent changes in the sequence of operation between the repetitive units and to maintain work continuity for the working squads." Furthermore, they stressed on how the method they developed was significant because it did not require the user to learn any new scheduling methods beside the common Critical Path Method scheduling technique. "The virtue of CPM/LOB lies in its simplicity of application that enables the user to plan and control effectively using a tool with which he or she is already familiar: CPM. It does not call for training on additional software, which the operation personnel are not expected to welcome… The method harnesses the powerful features of contemporary CPM software and enables the LOB to benefit from the development of the CPM." (Suhail & Neale, 2004).

2.6 Human Visual Cognitive Process

In essence, all scheduling techniques, including the Critical Path Method (CPM) and Line of Balance (LOB), are systems developed to help organize and visualize a set of data. These scheduling techniques could be identified as *Knowledge Visualization* methods. "Knowledge visualization examines the use of visual representations to improve the transfer of knowledge between at least two persons."(Burkhard, 2004). In the case of the CPM, Gantt charts are used to present data concerning the durations of the activities included in any given project and how they are related to each other. Line of Balance scheduling displays the locations and durations of the tasks within the project. The proposed scheduling visualization tool is an extension to the idea of knowledge visualization. The tool is expected to help the user visually link the Gantt chart and Flowline graph through the proposed 3D graph. Understanding the human's visual cognitive process should aid in realizing the significance of the scheduling visualization tool, and appreciate how it could assist the user if applied to construction projects.

Scheduling methods are techniques that transform raw and/or abstract data into visual pictures to amplify cognition so that users could understand and use the data more effectively and efficiently. Research in visualization investigates the mechanisms in humans and computers that allow them to perceive, interpret, use, and communicate visual information. "Information visualization builds on theories in Information Design, Computer Graphics, Human-Computer Interaction, and Cognitive Science." (Burkhard, 2005). These applications allow the user to interactively explore abstract data with visual methods and discover patterns concerning individual items or group of items (e.g. activities with a common resources or taking place in the same location at the same time) with the overall goal to derive new insights. Some visual representations convey certain types of knowledge better than others. This field of study that investigates how people visually extract knowledge from data is referred to as *Visual Cognition* (Lohse et. al, 1990 and Burkhard, 2005).

Several studies discuss the power and benefits of visual representation. In their article *Tube Map Visualization: Evaluation of a Novel Knowledge Visualization Application for the Transfer of Knowledge in Long-Term Project*, Burkhard and Meier (2005) summarize the advantages of utilizing visual representation. According to the authors visual representation helps in:

- Addressing emotions
- Illustrating relations
- Discovering trends, patterns, or outliers
- Getting and keeping the attention of recipients
- Supporting remembrance and recall
- Presenting both overview and detail
- Facilitating learning
- Coordinating individuals
- Motivating people
- Establishing a mutual story
- Energizing people to initiate action by illustrating options to act

Previous research studies have attributed these benefits to a number of aspects like an increased human input capacity when visual abilities are used. Furthermore, studies show that humans' brains have a strong ability to identify patterns, which helps them better decipher data represented visually. Overall, studies conclude that visual representations are superior to textual and/or verbal means of communications and allow for a clearer representation of the data. Tools like scheduling techniques help make abstract concepts accessible, reduce complexity, amplify cognition, explain relationships, and structure information.

The alternative to utilizing visual representation tools and methodologies to communicate construction schedules is to use textual data representing the same knowledge (e.g. lists of activities, durations, relationships, etc.). However, studies show that a large portion of the human brain deals with processing and analyzing visual images. Experts claim that images, like graphs and schedule, are pre-attentive; they are processed before text, and need less energy to be consumed. As a matter of fact a number of studies have shown how visual representations are superior to verbal-sequential representations in different tasks (Burkhard, 2004). For example, they are better in illustrating relations, identifying patterns, presenting both an overview and details, supporting problem solving and communicating different knowledge types. In his article Burkhard (2004) explains the psychological aspects of this phenomenon quoting various sources, he states:

> Miller (1956) reports that a human's input channel capacity is greater when visual abilities are used. Our brain has a strong ability to identify patterns, which is examined in Gestalt psychology (Koffka, 1935). Visual imagery (Kosslyn, 1980, Shepard and Cooper, 1982) suggests that visual recall seems to be better than verbal recall. It is not clear how images are stored and recalled, but it is clear that humans have a natural ability to use images. Instructional psychology and media didactics investigate the learning outcomes of text-alone versus text-picture: (Mandl and Levin, 1989) present different results in knowledge acquisition from text and pictures. Weidenmann (Weidenmann, 1989) explores aspects of illustrations in the learning process. Cognitive neuroscience discusses the underlying cognitive components of picture processing (Farah, 2000).

The literature review discussed in previous sections shows that the Gantt chart, generated by the CPM, is not successful in visually communicating the location of the activities. Some software programs allow inserting data concerning the location of the activities and filtering the data set accordingly. However, the Gantt Chart with the activities listed on the Y-axis and time on the X-axis does not have the ability to show location related information. On the other hand, LOB scheduling is successful in presenting the activities' location but has been criticized on its limitation in displaying the activities' relationships (e.g. lags and SS, FF, FS, etc.). This shortcoming is evident in LOB scheduling inability to clearly present the project's critical path to the user. The objective of this research is to develop and investigate a graphical representation tool that has the ability to visually communicate to the user information concerning both the activities' relationships and locations. The developed tool is explained in further details in the next section (Chapter 3).

3. HYBRID GRAPHICAL REPRESENTATION

3.1 Introduction

This research focuses on two main methodologies for scheduling work: 1) activity-based scheduling; and 2) location-based scheduling. There are many scheduling methods and techniques included under these two main approaches. However, for the purposes of this research two principal scheduling methods, one from each approach are mainly considered. The Critical Path Method (CPM) from the activity-based scheduling approach, and either Line-of-Balance (LOB) or Flowline graphs from the location-based approach. Since the research is concerned with scheduling visualization methods it focuses on Linked Gantt Charts (LGC), which is a method to graphically represent CPM schedules created through the activity-based scheduling approach, and Flowline graphs (FLG) from the location-based scheduling approach.

A number of studies document attempts to merge or combine the activity-based and location-based scheduling techniques with the intention of eliminating their weaknesses and making use of their combined benefits. However, these attempts rely on merging these two scheduling systems through complicated algorithms and mathematical equations or by alternating between them when most useful and suitable. These methods have been criticized as to be relatively complicated and have numerous challenges in practical applications. Up until the development of this research effort no documented research has merged activity-based and location-based scheduling systems using a visualization approach (Suhail & Neale, 2004).

What this research proposes is graphically merging the Linked Gantt Chart and Flowline graph schedules on the same interface to communicate data concerning project activities' sequences, durations and spatial aspects visually. Edward Tufte is one of the well-known researchers in the field of information visualization, and time and time again he highlights in his publications the value of showing more information on the same interface. He explains how portraying multivariate data (multiple values for an observation) on the same system aids in communicating to the user more information (Tufte, 1991). The challenge has always been in maintaining the simplicity, clarity and usability of the visual aid (i.e. chart, table, etc.), while displaying large amounts of information. The idea of combining and visually communicating information concerning sequence, time and locations of activities on the same interface has been a challenge, historically faced by train scheduling specialists. Over the years these specialists have been trying to communicate large amounts of information to a wide variety of audience. Train schedules are intended to show a information concerning trains' time tables, sequences, stops, stations, and numerous other details on a single chart or table, and is meant to be used by conductors, staff members and the general public.

Edward Tufte (1991) gives a historical example of an attempt done by E. J. Marey in 1885 in showing multivariate train schedule data on the same interface. Marey took an interesting new approach to showing the schedule for trains between Paris and Lyon (Figure 3.1). He listed all the stations between Paris and Lyon on the vertical axis (y-axis), and time on the horizontal axis (x-axis). The stations on the y-axis are placed proportionate to their actual distance apart, and each sloping line represents a train going from Lyon (starts towards the bottom left of the graph) to Paris (ends towards the top right of the graph). The slope of the line indicates the train's speed, the steeper the line, the faster the train. From this single graph the user could comprehend information concerning the location of the trains at any given time, their arrival and departure times, and the trains' directions, stops, speeds, and where their paths cross (the intersection of two lines). According to Tufte (1990), Marey's train schedule successfully illustrates the concept of a visualization tool communicating multivariate data. Tufte explains how showing multivariate data is a very valuable advantage in data visualization.

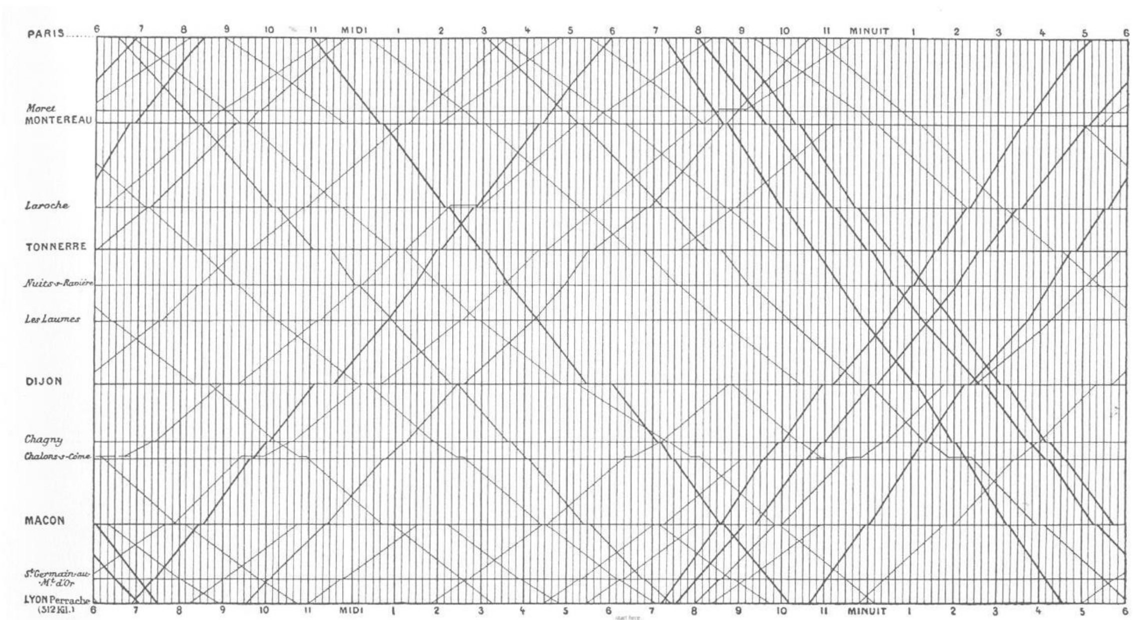

Figure 3.1: The E. J. Marey 1885 Paris-Lyon train schedule (Tufte, 2001).

When Tufte (1990) introduced the challenge of designing train schedules, he described it stating, “The issues of timetable design are at the heart of envisioning data – large arrays of fussily annotated numbers, thick information densities, type and image together, and multivariate techniques for narrating what is a four or five variable story. And the audience for schedules is diverse, ranging from experts at timetables such as travel agents to those who are not travel agents, an audience of uncertain skills, eye power, patience.” The description Tufte (1990) provides of all the difficulties to creating train timetables has many similarities to the challenges inherent in visualizing and communicating construction schedules. A construction schedule contains various data concerning scheduled tasks’ names, order, locations, relationships, etc. and it is used by a wide variety of users. The overcoming of these challenges in the history of building and creating train schedules have been the inspiration for developing a scheduling visualization tool that presents project activities’ dependencies, durations and spatial aspects on the same 3 dimensional interface. This research effort proposes a visualization tool, the *Hybrid Graphical Representation*, hypothesized to visually communicate and combine logical and spatial relationships between activities through a common set of X (time), Y (location), and Z (activities) coordinates.

Hybrid Graphical Representation is the name given to the proposed tool developed and evaluated by this research. The name was chosen due to the nature of the visualization methodology investigated through this research. The Merriam Webster definition of the word Hybrid is “Something heterogeneous in origin or composition.” and/or “Something that has two different types of components performing essentially the same function.” The proposed scheduling visualization technique attempts to merge the Linked Gantt Chart bars produced by the activity-based scheduling process, and the flow-lines generated by the location-based scheduling, by manipulating the flow-lines in a single three-dimensional interface.

The proposed schedule visualization method attempts to graphically merge Gantt bars and flow-lines, by enabling the user to visually comprehend and communicate the same amount of information with comparable accuracy and time, relative to using a standalone Linked Gantt Chart (LGC) produced by the Critical Path Method (CPM) and/or Flowline graph (FLG) from a Line of Balance (LOB) schedule.

3.2 Research Purpose

The purpose of this research is to develop and evaluate the effectiveness of the proposed Hybrid Graphical Representation (HGR) to visually combine and link the two graphical techniques, Linked Gantt Charts and Flowline graphs, derived from the activity-based and location-based scheduling systems, to help resolve some of their shortcomings by capitalizing on their combined strengths. Building on the diagrams shown in Figures 1.3 and 1.4 (Chapter 1), the proposed Hybrid Graphical Representation (HGR) tool attempts to join the two systems (the activity-based scheduling and location-based scheduling systems) in the *visualization* phase, as shown in Figure 3.2 below. This is accomplished by visually allowing the user to seamlessly transition between both scheduling interfaces on a common X, Y, and Z coordinates. More details on how this is accomplished are presented later in this chapter.

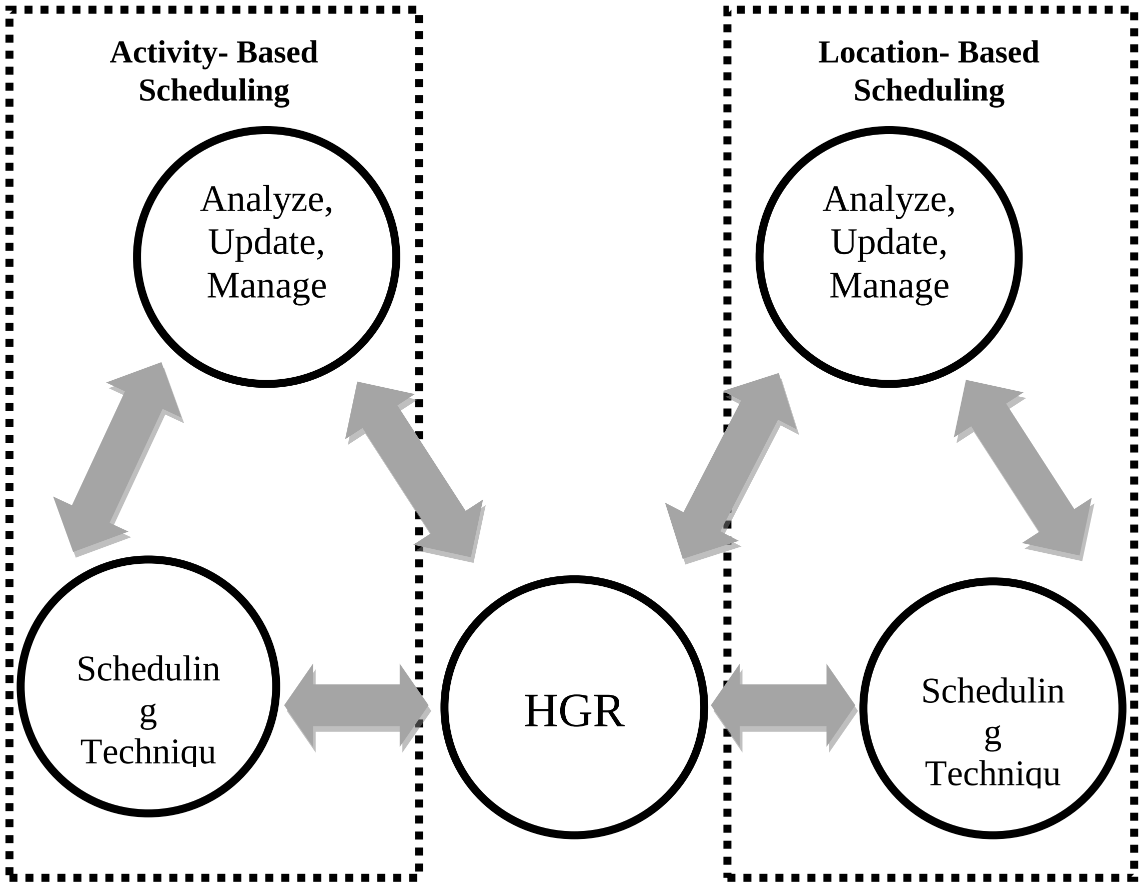

Figure 3.2: Joining the two processes through the proposed scheduling visualization method.

In theory, this method will allow the scheduler to create and communicate a project schedule in both the Linked Gantt Chart and Flowline graph interfaces. Furthermore, the user will have the ability to apply changes to either schedules, and track the effects of these changes in the other scheduling interface. Utilizing the proposed Hybrid Graphical Representation is anticipated to bridge the gap between activity-based and location-based scheduling approaches and realizing the advantages offered by each scheduling system while eliminating some of their shortcomings by graphically combining and linking these two graphical techniques.

While a Linked Gantt Chart and a Flowline graph are successful in showing one aspect of the schedule, logical relationships or spatial relationships of the scheduled activities, the Hybrid Graphical Representation (HGR) tool is anticipated to show both on the same system. The research investigates how successful is the HGR tool in visualizing both features (relationships and locations) on a single system faster and with fewer errors then extracting the same amount of information from a single system, a Linked Gantt Chart or a Flowline graph. The research purpose is not to evaluate which system is better, rather to try to validate the success of the HGR in showing both schedules' attributes.

3.3 Hybrid Graphical Representation Development

The Hybrid Graphical Representation (HGR) is founded on the basic idea that both the Linked Gantt Chart (LGC) and Flowline graph (FLG) visualization methods share a common X-axis, *Time*. The only difference is in a LGC the *Activities* are listed on the Y-axis (Figure 3.3), while the FLG shows *Locations* on the Y-axis (Figure 3.4). This research proposes adding a third dimension to the Flowline graph, listing the project *Activities* on a Z-axis (Figure 3.5). Viewing the Hybrid Graphical Representation schedule from the top, the user will observe a Linked Gantt Chart with *Time* on the X-axis and the *Activities* listed on the Z-axis. Observing the schedule from the front view (Figure 3.6), the user will see the Flowline graph developed through location-based scheduling methods with *Locations* on the Y-axis and *Time* on the X-axis (see Figure 3.7).

The HGR tool is anticipated to facilitate making use of the visualization advantages made available by each individual scheduling visualization method, the LGC and the FLG. The advantages and disadvantages of the LGC and FLG scheduling methods were discussed in the *Literature Review* section of this research (Chapter 2).

From the LGC view (top view), the user will be able to see the activities' relationships, observe a critical path, and be able to communicate the schedule in the familiar and widely known Linked Gantt Chart interface. Switching to the front view of the Hybrid Graphical Representation tool, the user will recognize where each activity is planned to take place (location), manage project resources more efficiently, and schedule repetitive activities more effectively. The HGR tool is anticipated to allow the scheduler to comprehend and communicate the logical and spatial relationships between activities.

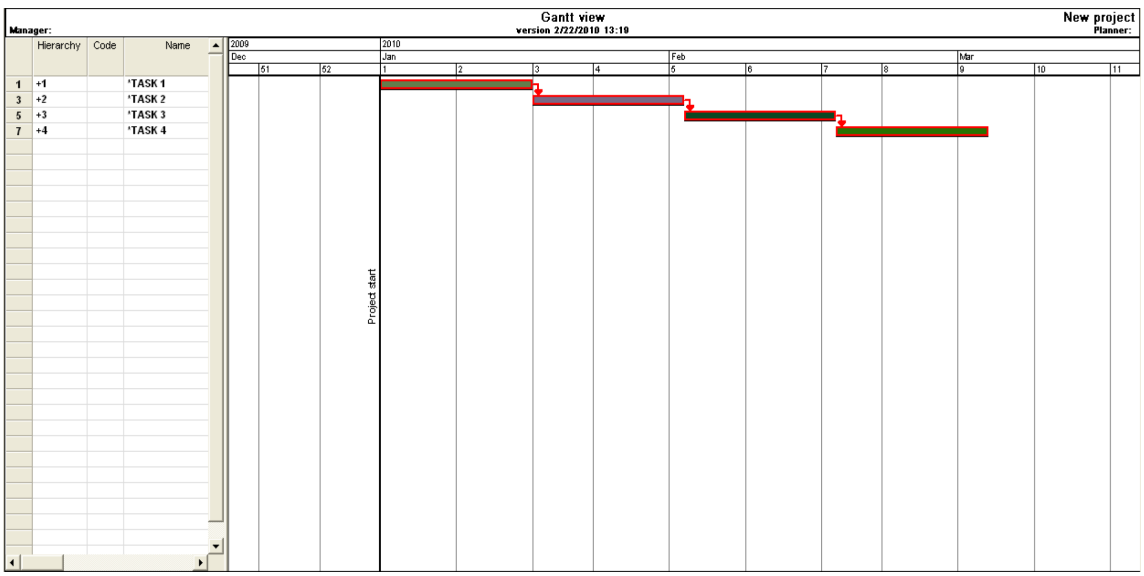

Figure 3.3: A Linked Gantt Chart view produced by the Critical Path Method scheduling technique. *Activities* are listed on the Y-axis and *Time* is on the X-axis.

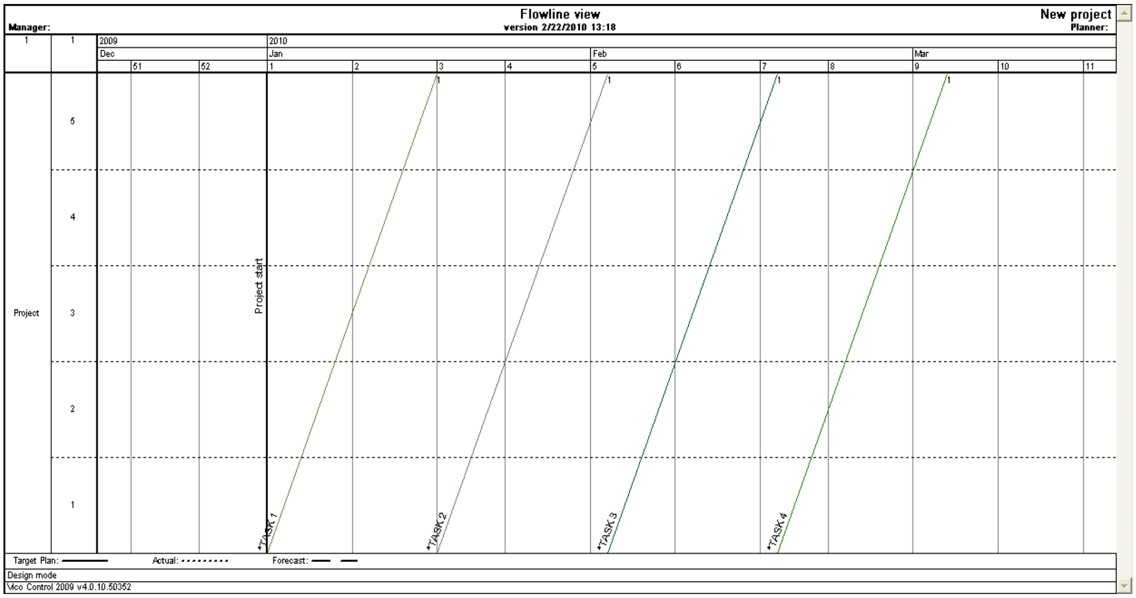

Figure 3.4: A Flowline view produced by the Line of Balance scheduling technique. *Locations* are listed on the Y-axis and *Time* is on the X-axis.

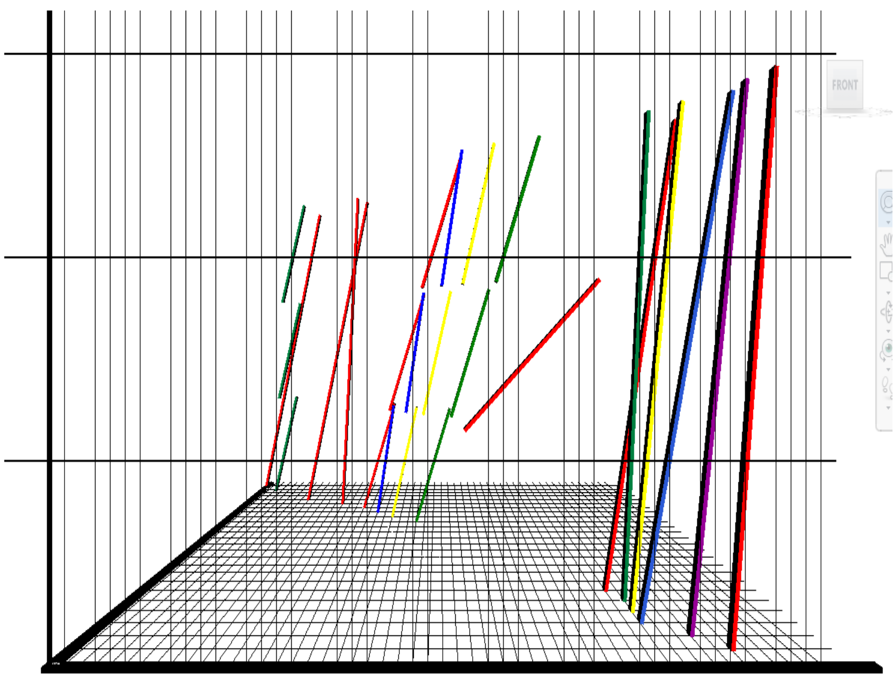

Figure 3.5: A 3D front view of the Hybrid Graphical Representation tool.

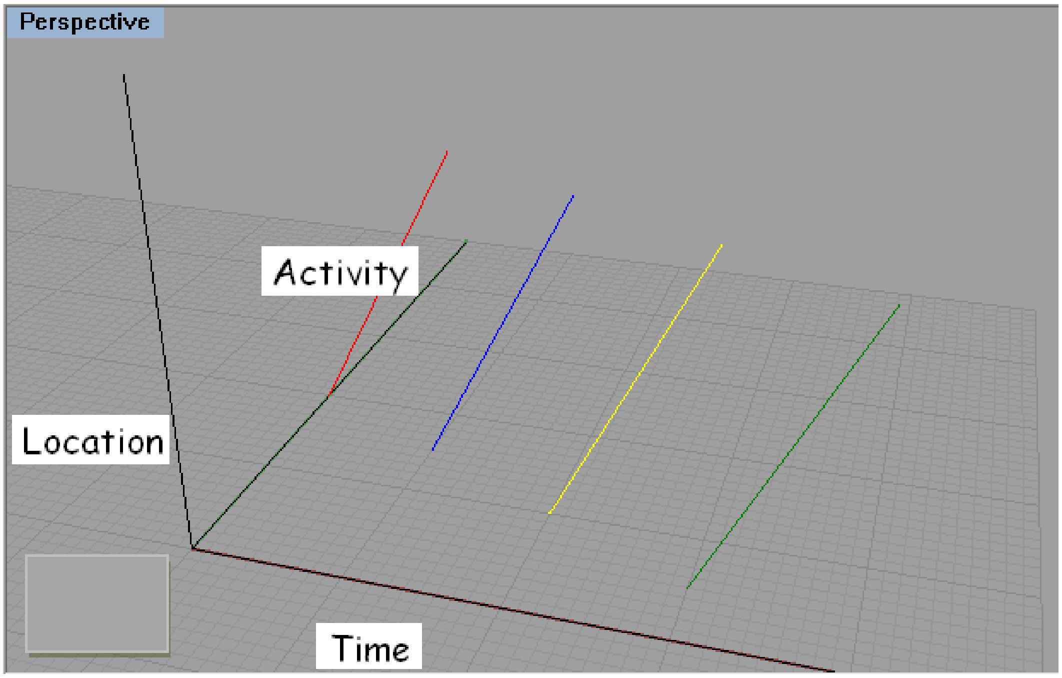

Figure 3.6: A perspective view of the Hybrid Graphical Representation, where *Time* is on the X-axis, *Location* on the y-axis, and *Activities* are on the Z-axis.

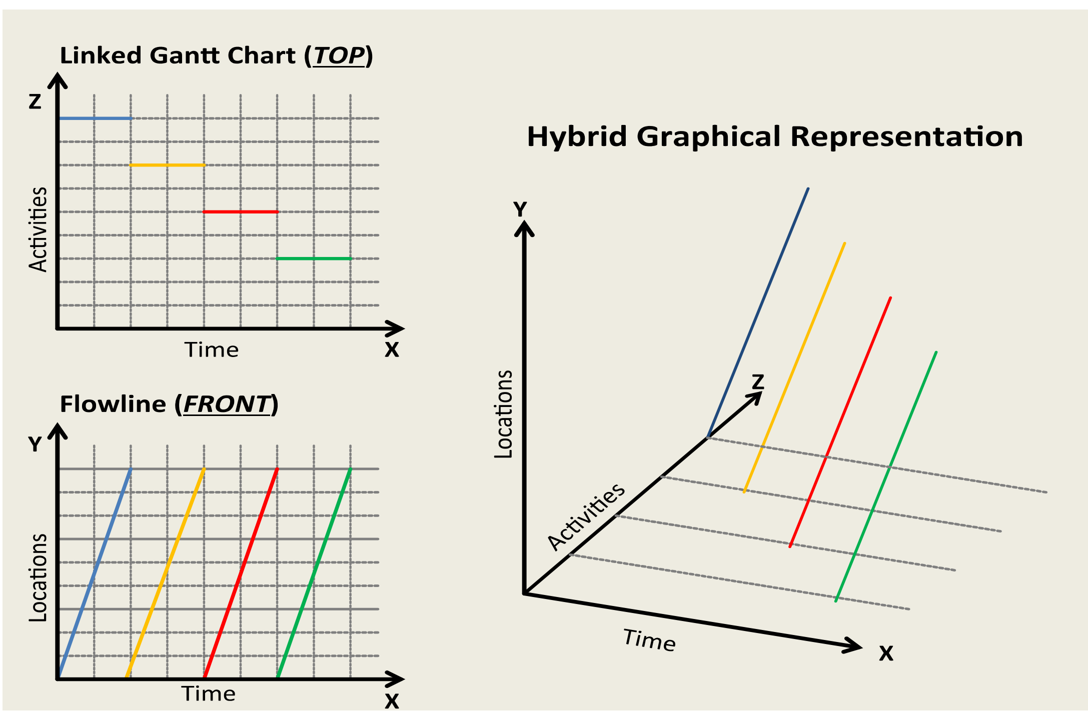

Figure 3.7: The *Perspective* view shows the three axes used to develop the HGR tool. *Top* view shows the Gantt Chart (CPM), and the *Front* view shows the Flowline (LOB).

The Hybrid Graphical Representation is anticipated to give the user the ability of visually making the connection between the location of every activity (by looking at the Flowline graph interface) and the relationship of that activity with other activities (looking at the Linked Gantt Chart interface). Through utilizing Linked Gantt Charts (LGC), generated by the Critical Path Method (CPM) schedule, the user is capable of visually comprehending the relationships between scheduled activities. The Flowline graph (FLG), produced by location-based scheduling techniques, provides visual representation of where each activity will be performed in the project. This research endeavor investigates the effectiveness of the proposed Hybrid Graphical Representation (HGR) tool in showing both, how the activities are related and where they are located on the same 3D interface through a common X, Y, Z coordinates system of *time*, *location* and *activities*.

3.4 Hybrid Graphical Representation Prototype

To answer the research questions and test the Hybrid Graphical Representation (HGR) tool's effectiveness in communicating logical and spatial information concerning project activities, a prototype HGR schedule of a simple project was developed. The schedule had to include aspects from both scheduling approaches, activity and location-based, to aid in examining the HGR's ability in showing and combining both sets of visual data. Figure 3.8 shows the Linked Gantt Chart (LGC) version of the project schedule used for the prototype. The project schedule included a series of activities connected with dependencies and had a critical path. The LGC was generated using the scheduling program, Microsoft® Project. The schedule consisted of 14 activities named alphabetically, from *A* to *M*, with the first activity named *Start*. Furthermore, the sample project schedule consisted of three locations (i.e. floors). Each activity name signifies where it is taking place in the project.

- ***1st*** denotes that the activity is scheduled to take place in the first floor.
- ***2nd*** denotes that the activity is scheduled to take place in the second floor.
- ***3rd*** denotes that the activity is scheduled to take place in the third floor.

- ***All*** denotes that the activity is scheduled to take place in all three floors. The activity will start on the first floor, then second, then third.

Most activities take place in ***All*** project locations (i.e. the three floors), while some activities, like ***M-1st*** for example, is only scheduled in the first floor. Examples of the dependencies included in the sample project schedule are Finish–to-Start relationships between activities ***Start*** & ***D-All***, ***D All*** & ***E-All***, and ***E-All*** & ***G-All***; and Start-to-Start dependencies between ***A-All*** & ***B-All***, ***B All*** & ***C-All***, and ***E-All*** & ***F-1st***.

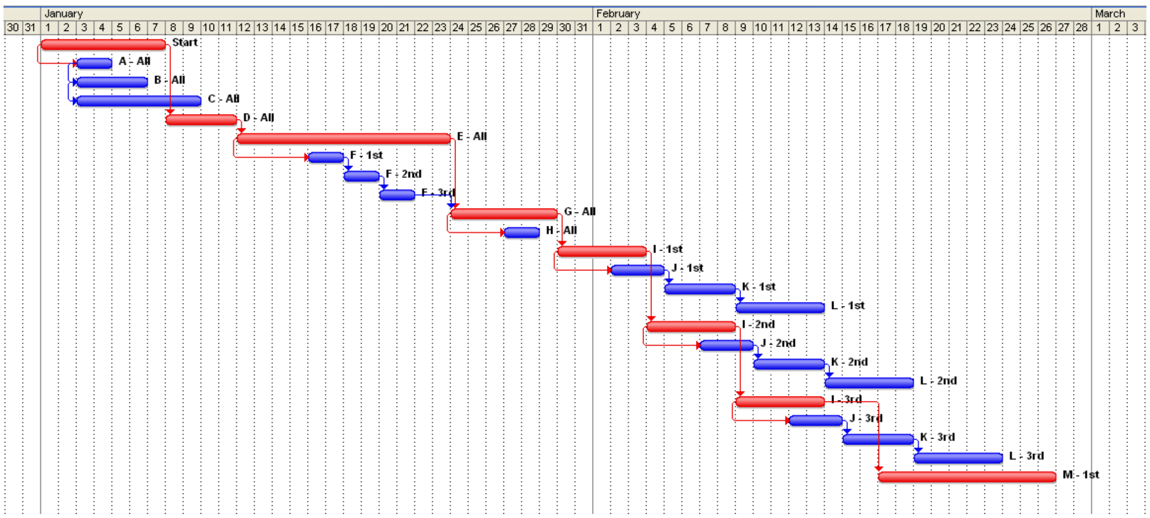

Figure 3.8: The Linked Gantt Chart (LGC) used for the prototype.

A FLG version of the same sample project schedule (Figure 3.9) is generated using the Vico® Control software program. The three locations (1st, 2nd and 3rd floors) floors are shown on the y-axis, and time is shown on the x-axis. The activities progress in the same sequence and based in the same logic shown in the LGC schedule shown in Figure 3.8 (above).

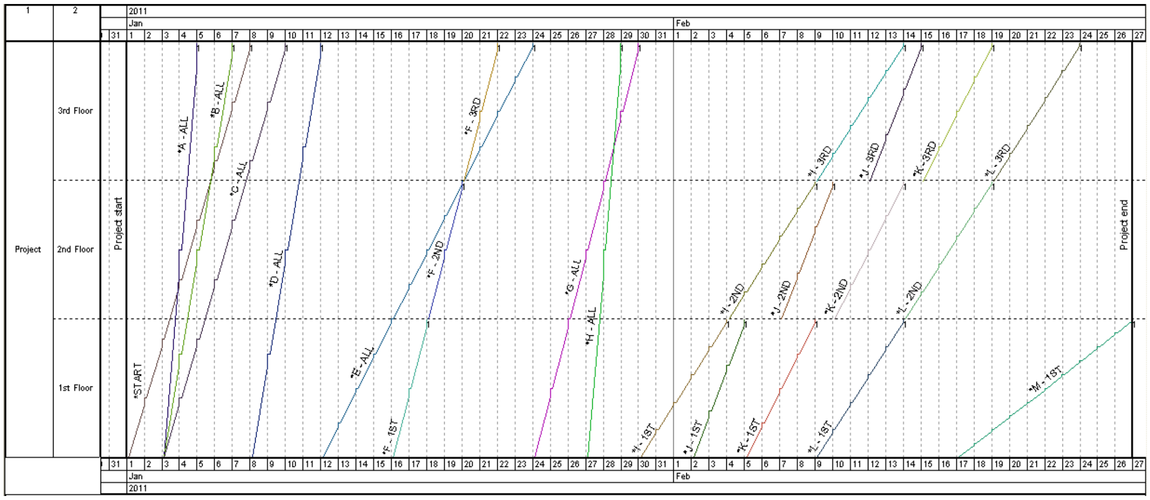

Figure 3.9: The Flowline graph (FLG) used in the online survey.

After developing the sample project schedule and creating a LGC version (Figure 3.8) in Microsoft® Project, and a FLG version (Figure 3.9) in Vico® Control, the HGR prototype model was created. Since the HGR scheduling visualization method is developed and introduced for the first time by this research endeavor, there are no existing scheduling software programs that could generate an HGR schedule. Therefore, a 3D model of the schedule had to be created. The Building Information Modeling (BIM) software program Revit® Architecture was used to model the HGR schedule. Figures 3.10 and 3.11 shows screen shots from the 3D model of the HGR schedule built in Revit®. Figure 3.10 shows a view from the top-left corner, and Figure 3.11 shows the top-right corner of the model. The axis and gridlines are built using structural elements found in the Revit® library like columns (vertical units) and beams (horizontal units). The model had 3 levels resembling the 3 floors in the sample project schedule. The activities on the schedule were created using truss units found in the Revit® library. This enabled control of the color of the units to resemble tasks on the schedule.

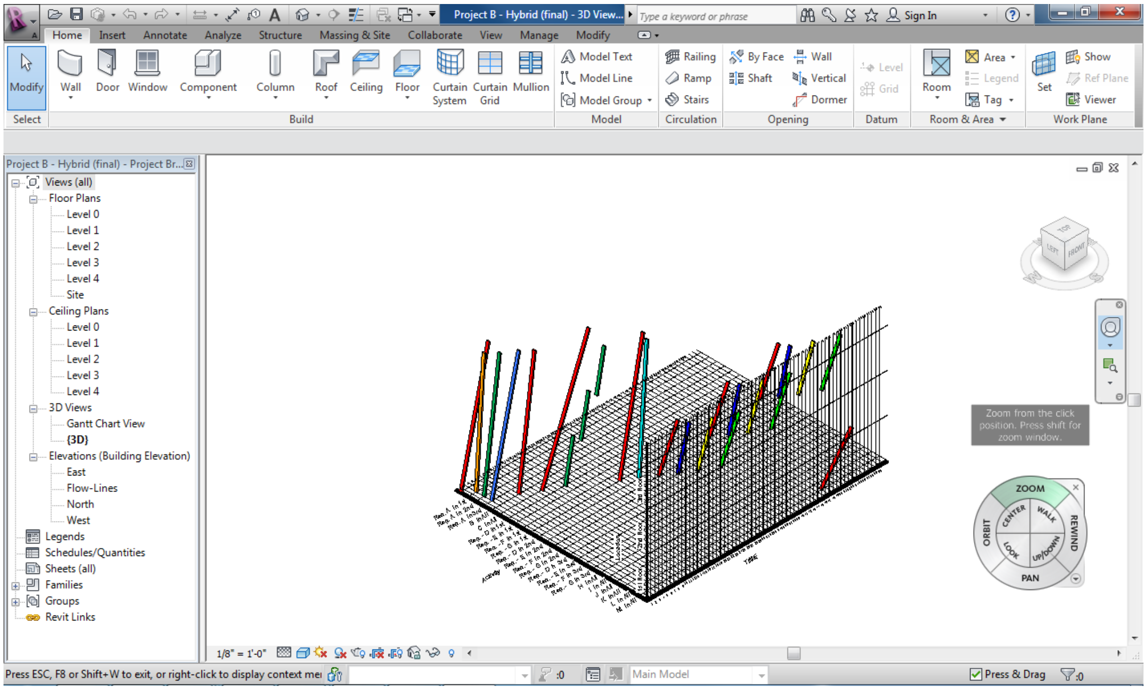

Figure 3.10: Top-Left view of the HGR 3D model from Revit®.

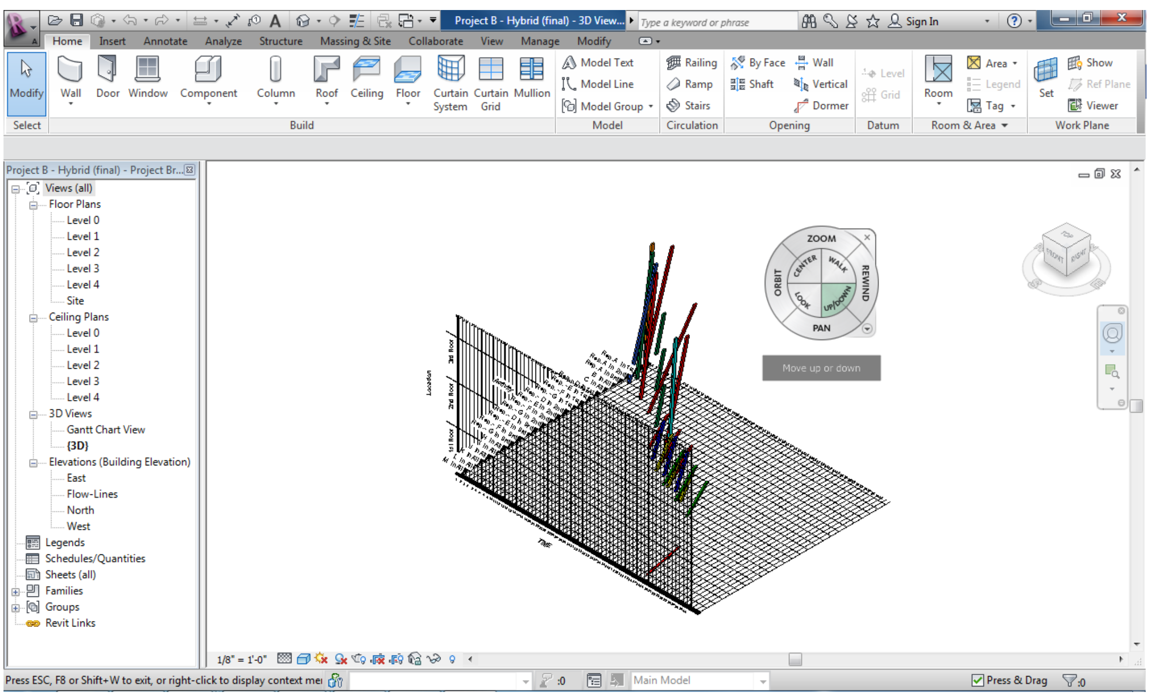

Figure 3.11: Top-Right view of the HGR 3D model from Revit®.

The Revit® model was then exported to Navisworks®, another BIM software program, to generate an animation that shows the transition between the LGC (top view) and FLG (front view). The gradual transition between the top (LGC) and front (FLG) views of the model is captured by Navisworks®, and then the software program generates a video showing the movement from one interface to the next, back and forth. Figures 3.12, 3.13, and 3.14 shows the transition (Figure 3.13) between the LGC view (3.12) and FLG view (Figure 3.14) on Navisworks®. Appendix I provide screen shots of the gradual change between views of the proposed Hybrid Graphical representation tool as shown by the video generated by Navisworks®.

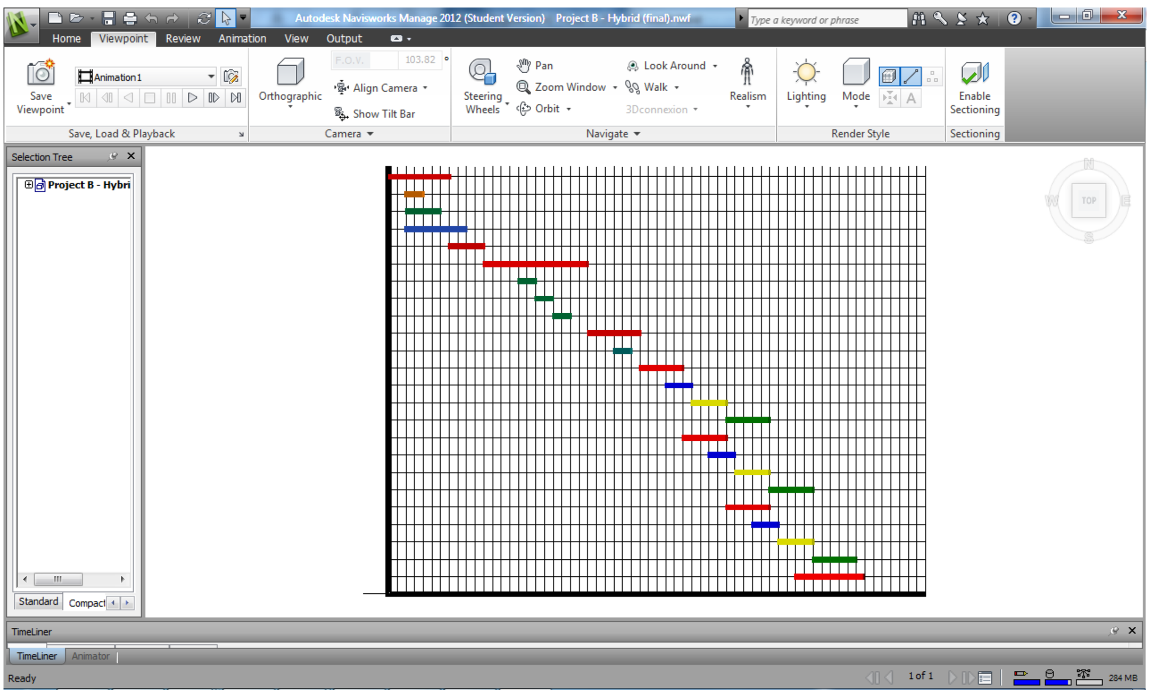

Figure 3.12: Front LGC view of the sample schedule from Navisworks®

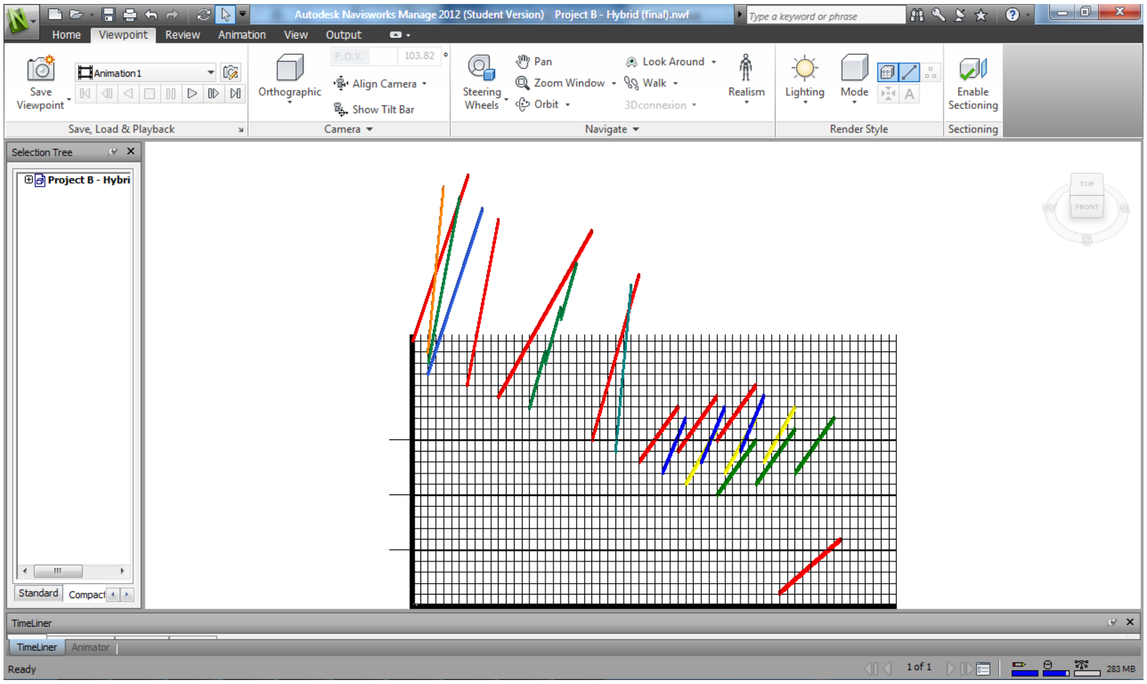

Figure 3.13: A screen shot from Navisworks® showing the transition between the front LGC view and the top FLG view.

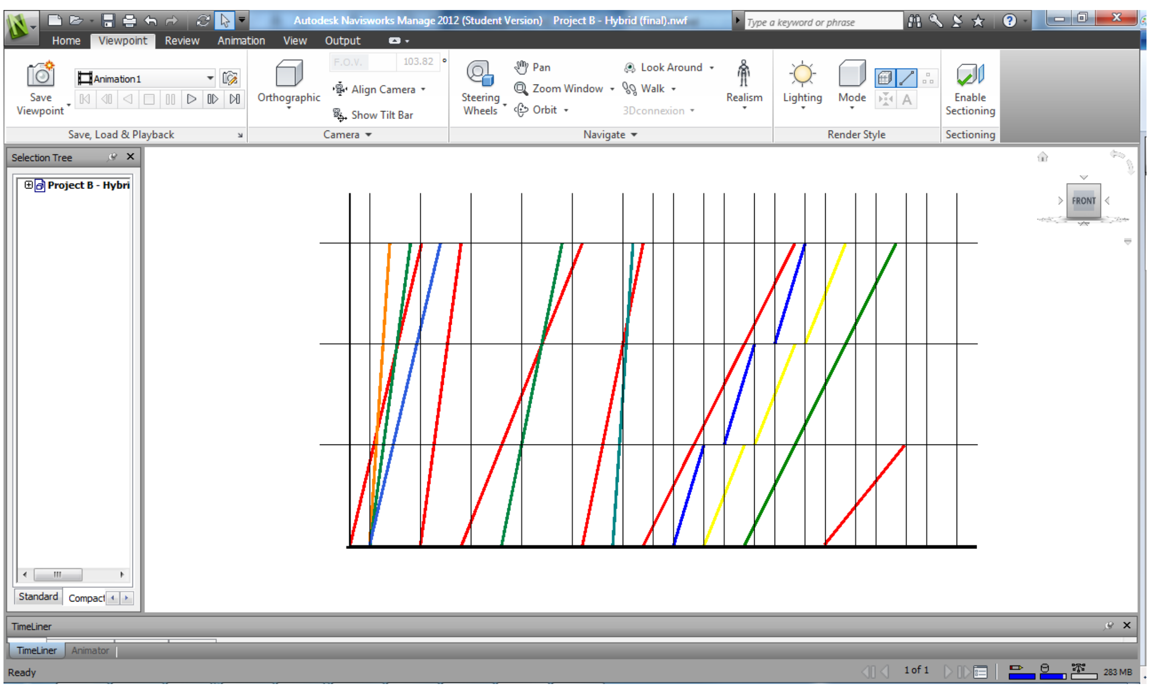

Figure 3.14: Top FLG view of the sample schedule from Navisworks®

Upon the development of the HGR concept, and creating a sample project schedule prototype to test it, research is conducted to evaluate its effectiveness. The next chapter presents the research methodology implemented to examine the HGR's ability to communicate logical and spatial information concerning the scheduled project activities and how it compares to using a LGC or a FLG.

4. RESEARCH METHODOLOGY TO TEST HGR CONCEPT

The proposed Hybrid Graphical Representation (HGR) schedule visualization method is intended to combine the visual and graphical benefits of the Linked Gantt Charts, produced by the activity-based scheduling method, and the Flowline graphs generated by the location-based scheduling method. This is anticipated to resolve some of these scheduling approaches' shortcomings by capitalizing on their combined visual strengths. The merging method under study in this research is based on visually linking both graphical scheduling techniques. The research will attempt to empirically validate the Hybrid Graphical Representation's ability in visually communicating the Linked Gantt Charts and Flowline graphs by seamlessly transitioning between both interfaces through the proposed visual merging methodology.

4.1 Proposed Research

The proposed research to test the HGR tool will rely on quantitative research methodologies in the data collection and analyses processes. Quantitative methods of data collection and analyses are one of the two key approaches to research, the other being qualitative methods. Quantitative research is an inquiry approach useful for describing trends and explaining the relationship among variables under study. To conduct quantitative research, the investigator specifies narrow questions, locates or develops instruments to gather data to answer these questions, and analyzes numerical data from the instruments using statistical methods. From the results of these analyses, the researcher interprets the data using prior predictions and research studies. The results are documented in the final report, which is presented in a standard format, and displays the researcher's objectivity and lack of biasness. This is accomplished in this research through the use of an online survey distributed to students with scheduling backgrounds. The survey measures and compares the participants' accuracy and speed of answering a set of questions using the three scheduling visualization methods Linked Gantt Chart, Flowline graph, and Hybrid Graphical Representation. (Creswell, 2008)

4.2 Research Design and Rationale

The Experimental Research design will be employed to collect, analyze, and interpret data within this quantitative research study. Experimental research designs consist of testing an idea, practice, or procedure. It is used when a researcher wishes to investigate whether a new practice influences an outcome. The experimental research design is the most common approach to conducting quantitative research, and due to the nature of this study it is the most appropriate for this research effort. (Creswell, 2008)

This research will evaluate the Hybrid Graphical Representation (HGR) tool's ability to accurately (accuracy) and quickly (time) communicate the activities' relationships and locations, relative to the accuracy and speed of accomplishing the same task using a Linked Gantt Chart (LGC) or a Flowline graph (FLG). Therefore, accuracy and time will be the variables investigated within the course of the research.

Participants will be shown a Linked Gantt Chart, a Flowline graph, and a HGR of a simple schedule of a construction project and then asked a series of questions requiring the extraction of data concerning the relationships and locations of the activities using the three visualization methods. The participants' accuracy and time in answering these questions using one of the three scheduling visualization methods will be recorded and compared. Each participant will be provided one scheduling version of the project.

The evaluation of the Hybrid Graphical Representation (HGR) is mainly investigated through comparison of the accuracy and time it takes the participants to comprehend the schedule and answer a series of multiple-choice questions. The research will use a list of questions targeting the participants' comprehension of the relationships and locations of the scheduled activities. This will be performed to compare the effectiveness of the HGR tool in communicating the same information relative to the LGC and FL schedules. Table 4.1 shows the questions used in the data collection process and the applicable scheduling visualization method that best displays the pertaining information needed to answer the question. The survey will require the participants to answer these questions using one of the three visualization methods. The intention of each question is discussed in more detail in section 4.3 below.

Table 4.1: Questions used in the data collection tool

	Question	**Question Type**
1	Please identify the first three activities on the critical path of this project.	Linked Gantt Chart (LGC)
2	Which activity on the critical path has the longest duration?	
3	How many activities have a Start-to-Start (SS) relationship with a succeeding activity?	
4	Which activity has a Finish-to-Start (FS) relationship with the longest lag time?	
5	There is a Start-to-Start (SS) relationship between the *Start* activity and the *A-All* activity with a lag time. How long is this lag?	
6	Which of the activities on the 1st floor has the longest duration?	Flowline graph (FLG)
7	How many days on the 3rd floor will involve more than one activity taking place simultaneously?	
8	If activity *G - All* is required to be completed on any given floor before activity *H - All* starts on that floor, looking at the schedule, on which floor would you anticipate a problem may occur?	
9	Which floor will have the longest period of no work taking place in that location (i.e. the floor with the longest idle time)?	
10	The 3rd floor will have the longest period of idle time in the project. Which activity could use that idle time?	

The first five questions are expected to be answered with higher accuracy and in shorter time by visually interpreting a LGC schedule (Figure 4.1), relative to using a Flowline graph. However, a Flowline graph (Figure 4.2) will likely be more suitable for answering questions 6 to 10. The first five questions ask about relationships between activities, independencies, and the critical path. The last five questions target aspects concerning the project locations and spatial considerations. To evaluate the HGR tool, the research will investigate its effectiveness in being utilized to answer all the ten questions. If the participants are successful in answering more questions and/or took a relatively shorter time in answering these questions, this will indicate the ability and efficiency of the HGR tool in showing more information on a single system. An online survey tool is used as a data collection instrument to administer the survey. Further explanation of the data collection tool is presented in subsequent sections.

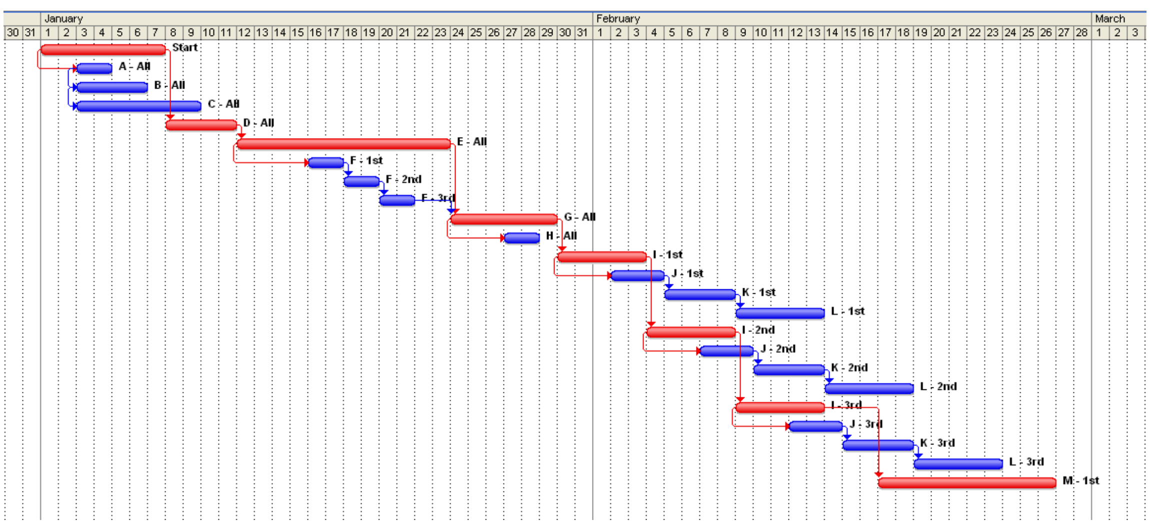

Figure 4.1: The Linked Gantt Chart used in the online survey.

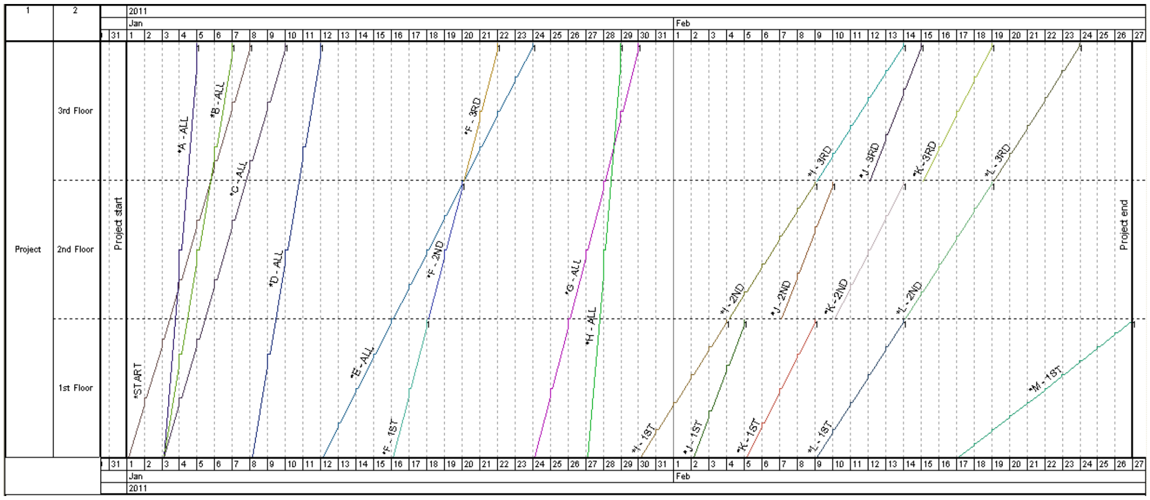

Figure 4.2: The Flowline graph used in the online survey.

The online survey tool will record the accuracy of answering the questions listed in Table 4.1, using the three scheduling visualization techniques, and the time it takes the participants to accomplish this task. Appendix II shows screen shots of the online survey tool. A pilot study was conducted to validate the effectiveness of the survey tool in measuring the required variables to answer the research questions. A discussion of the pilot study is presented in more detail in section 4.5.

4.3 Survey Questions Intentions

This section introduces the intention of each question used in the survey (Table 4.1). Every question was included to evaluate the participants' understanding and visual identification of certain attributes in each of the three graphical scheduling representations under study, Linked Gantt Chart (LGC), Flowline graph (FLG) and Hybrid Graphical Representation (HGR). As previously mentioned, the first five questions are more suitably answered utilizing a Linked Gantt Chart schedule, while the last five are better addressed using a Flowline graph. The research attempts to evaluate the Hybrid Graphical Representation's ability of visually displaying information from both methods. Each question is listed below and a discussion of why it was incorporated in the survey is provided.

1. Please identify the last three activities on the critical path of this project.
2. Which activity on the critical path has the longest duration?

The critical path is a vital concept in scheduling and managing projects. It is used to monitor the overall project's performance and serves as an indicator of possible delays in total project delivery deadlines. The intention of these two questions is to evaluate which visualization method allows the participants to accurately and quickly identify and deduce information about the critical path from each scheduling visualization method, Linked Gantt Chart (LGC), Flowline graph (FLG), and Hybrid Graphical Representation (HGR).

3. How many activities have a Start-to-Start (SS) relationship with a succeeding activity?
4. Which activity has a Finish-to-Start (FS) relationship with the longest lag time?
5. There is a Start-to-Start (SS) relationship between the *Start* activity and the *A-All* activity with a lag time. How long is this lag?

Logical relationships between scheduled activities play a major role in understanding project schedules. Even though, these relationships are used to generate location-based schedules, scheduling representations like the Flowline graph does not retain the ability to show them clearly relative to the activity-based schedules, like the Linked Gantt Chart. These three questions are used to evaluate which visualization method better communicates logical relationships like SS, FS, and lags.

6. Which of the activities on the 1st floor has the longest duration?

A video tutorial explaining the three graphical methods (LGC, FL, and HGR) will be provided to the participants before the survey questions commence. However, most of the participants are expected to have relatively limited exposure to location-based scheduling methods. The intention of this question is to evaluate the participants' understanding and ability to read a Flowline graph by detecting a certain activity on the schedule based on its location (y-axis) and duration (x-axis).

7. How many days on the 3rd floor will involve more than one activity taking place simultaneously?

The ability to visually predict areas that will likely suffer from having more than one activity scheduled to take place simultaneously is important in forecasting problem areas in the project and trying to prevent them in the planning phases. Having more than one activity in the same area during construction could lead to problems like increased crew productivities, and conflicts between crews. To visually identify where there could be possible site congestions is a valuable aspect of Flowline graphs.

8. If activity *G - All* is required to be completed on any given floor before activity *H - All* starts on that floor, looking at the schedule, on which floor would you anticipate a problem may occur?

Scheduling errors is a common problem when developing a schedule for a project. This question is intended to evaluate the participants' ability to visually detect scheduling errors concerning the scheduling logic using the activities' locations.

9. Which floor will have the longest period of no work taking place in that location (i.e. the floor with the longest idle time)?
10. The 3rd floor will have the longest period of idle time in the project. Which activity could use that idle time?

These two questions evaluate the participants' ability to apply location management concepts. The intention is to identify which visualization method allows the participants to optimize the use of the project locations.

4.4 Research Approach

The research approach adopted in this study was inspired from a number of previous research studies involving similar research objectives and questions. Kobsa (2004) performed a comparative experiment concerning five different visualization systems, where subjects performed tasks relating to the structure of a directory hierarchy. The experiment measured task completion times, correctness and user satisfaction. In a study entitled *2D vs. 3D, Implications on Spatial Memory*, Tavanti and Lind (2001) empirically investigated spatial memory performance across different instances of 2D and 3D displays. The authors performed two experiments measuring the number of correct responses of participants using 2D and 3D displays and measured which system helped the participants visually retain more information. Kang, Anderson and Clayton (2007) conducted a study to investigate whether Web-based 4D visualization would expedite the collaborative decision-making process by making the detecting of logical errors in the constriction schedule more explicit. The study measured the time, accuracy and communications of the research participants at different locations in detecting logical errors in a construction schedule. (Kang et. al, 2007)

The research process followed in this research effort will involve the following steps to achieve the research objectives:

- Review previous research works to develop theoretical basis for this research
- Develop a Linked Gantt Chart version, a Flowline version and a Hybrid Graphical Representation version for a sample project.
- Develop an online survey tool that will include the three versions of schedules to collect the data required to test the hypotheses.
- Conduct a pilot test to assure reliability and validity of the experiment.
- Recruit participants and conduct the experiment.
- Analyze the results of the experiments to test the hypotheses. The results will be used to determine if the Hybrid Graphical Representation tool under study could

effectively and efficiently communicate the activities' relationships revealed by the Linked Gantt Chart, and the activities' locations shown in the Flowline graph.

- Develop conclusions and recommend future research efforts.

4.5 Pilot Study

A pilot test study was conducted to assure the reliability, validity, and robustness of the experiment, and to help in anticipating primitive results for the research. The participants of the pilot test were asked to use the online survey to answer the set of 10 questions explained above. Their recommendations and feedback were used to improve the online survey tool, and led to changes in the data collection approach. Initially, in order to reduce the chance of biased results, three different project schedules were to be used (Project A, Project B, and Project C) and each project was to have a Linked Gantt Chart (LGC), Flowline graph (FLG) and Hybrid Graphical Representation (HGR) version of the schedule. As a result there would be nine total surveys to be conducted (Table 4.2). Although, Projects A, B and C were very similar, this was perfromed to cancel the effect of the varying level of difficulty that could be found in using a certain schedule from a given project.

Table 4.2: Three examples of the scheduling versions provided to the participants.

	Project A	**Project B**	**Project C**
Linked Gantt Chart (LGC)	Survey 1	Survey 4	Survey 7
Flowline Graph (FLG)	Survey 2	Survey 5	Survey 8
Hybrid Graphical Representation (HGR)	Survey 3	Survey 6	Survey 9

A total of 36 participants were recruited for the pilot study. Four participants tried each survey (Table 4.2 above). The average accuracy (out of 10) and time (seconds) it took each of the nine groups to finish the pilot surveys are shown in Table 4.3 below. The accuracies of answering the ten questions for each of the three scheduling visualization approaches did not vary much from one project to the other. For LGC the average accuracies (out of 10) from Projects A, B, and C were (7, 6, 6), for the FLG they were (7, 5, 6), and the HGR were (9, 10, 9). There was a variance between the average times. However, considering that the averages were taken from four data points (participants) in each group, it could not be taken as indicative of significant differences between the levels of difficulty of the three project schedules tested (Projects A, B, C). Furthermore, a large number of participants were required to be recruited for the real survey to enable the generation of statistically significance results (around n=30 in each survey). Unfortunately, the number of possible participants was limited. Therefore, keeping all that in mind, and since the accuracy results were close, it was decided to use only one project with three scheduling versions (LGC, FLG, HGR) to maximize the number of participation in each survey. So instead of having nine surveys the decision was made to have a total of three surveys. An LGC, FLG, and HGR surveys from a single project schedule was to be used for data collection.

Table 4.3: Average accuracy and time it took each of the nine groups.

	Project A		**Project B**		**Project C**	
	Accuracy (out of 10)	**Time (sec.)**	**Accuracy (out of 10)**	**Time (sec.)**	**Accuracy (out of 10)**	**Time (sec.)**
Linked Gantt Chart (LGC)	7	346	6	409	6	443
Flowline Graph (FLG)	7	504	5	289	6	428
Hybrid Graphical Representation (HGR)	9	578	10	663	9	406

The pilot test also confirmed that the survey tool was working as intended. Most of the participants were indeed able to answer the majority of the first five questions using the LGC schedule, the last five questions using the FLG schedule, and all the questions using the HGR method.

Initially, the online survey included a section where the participants had to read a written explanation of the three scheduling visualization methods before commencing with the questions part of the survey. However, some of the pilot participants gave negative feedback saying they found going through this process boring and tedious. It was of some concern that students participating in the real survey would overlook this section and start answering the survey questions without learning about each of the three scheduling visualization methods. So a 13 minute video tutorial explaining the LGC, FLG, and HGR techniques was prepared to present that information. It was thought that for the participants to sit and watch/listen to the tutorial would be more interactive and could reduce the risk of them skipping this part and not having the necessary knowledge needed to answer the survey questions. As a result of the pilot participants' comments the online survey was designed to measure the time each participant spent on the tutorial section. If a participant did not spend the duration of the tutorial (13 minutes), then that was an indication they skipped it and their results would be questionable. Furthermore, after watching the tutorial the participants were asked if they felt that they understand LGC, FLG, and HGR scheduling visualization methods or none of the above. This was another way to evaluate the participants' understanding.

4.6 Research Participants

The investigator always starts the quantitative data collecting process by deciding on the group and/or individuals to include in their research. There are two main quantitative sampling strategies, *probabilistic sampling* and *non-probabilistic sampling*. Probabilistic sampling is the form of sampling in quantitative research where the investigator samples individuals who are representative of the population allowing them to make generalizations about the population. In non-probabilistic sampling, the researcher selects individuals because they are available, convenient, and represent some characteristic the investigator seeks to study. Non-probabilistic sampling will be used for this research endeavor. This strategy for sampling is used when the researcher is not interested in studying generalized data of a population, but only in describing a small group of participants, as the case is in this research. (Creswell, 2008)

There are a number of sampling methods within non-probabilistic sampling. Convenience sampling is one of these methods and it will be used to recruit the research participants. This is done since in convenience sampling the researcher can select participants because they are willing and available to be studied. Even though this sampling method does not allow the researcher to say in confidence that the individuals are representative of the population, the sample can provide useful information for answering questions and testing hypotheses. This is in line with the research rationale and will facilitate reaching the research objectives. (Creswell, 2008)

The experiment participants in this research will be students working in the areas of architecture, construction, and civil engineering in the Civil Engineering and Construction Science Departments at Texas A&M University. These students are expected to have a background in construction processes and schedules. Around thirty participants will be included in the data collection process (n=30) to test each of the three scheduling visualization methods. Therefore the total number of participants for the three surveys would be around 90 participants (Montgomery & Runger, 2007).

4.7 Data Collection

The data collection process will be conducted through online surveys using Surveygizmo™ (surveygizmo.com). Surveygizmo will act as the main data-collecting instrument and will measure and record the participants' accuracy and time in answering the experiment questions. The questions shown in Table 4.1 will be used in the online survey, and they are all multiple-choice type questions (mcq). As discussed earlier there will be three versions of the online survey, a Linked Gantt Chart (LGC) survey, a Flowline graph (FLG) survey, and a Hybrid Graphical Representation (HGR) survey. A screen shot of one of the questions (Question number 1) taken from the second survey (FLG) is shown in Figure 4.3 below. The screen shots of the full three online surveys are provided in Appendix II.

The students participating in the research will be offered extra-credit in their courses for taking the online survey. If they choose not to participate they could get the same amount of extra credit by doing the alternative reading assignment. The assignment involves reading an article and writing a paragraph summarizing the article's content, and answering two questions about the article. The alternative reading assignment is also shown in Appendix II. This research study with all its data collection processes have been reviewed by the Human Subjects' Protection Program and the Institutional Review Board at Texas A&M University.

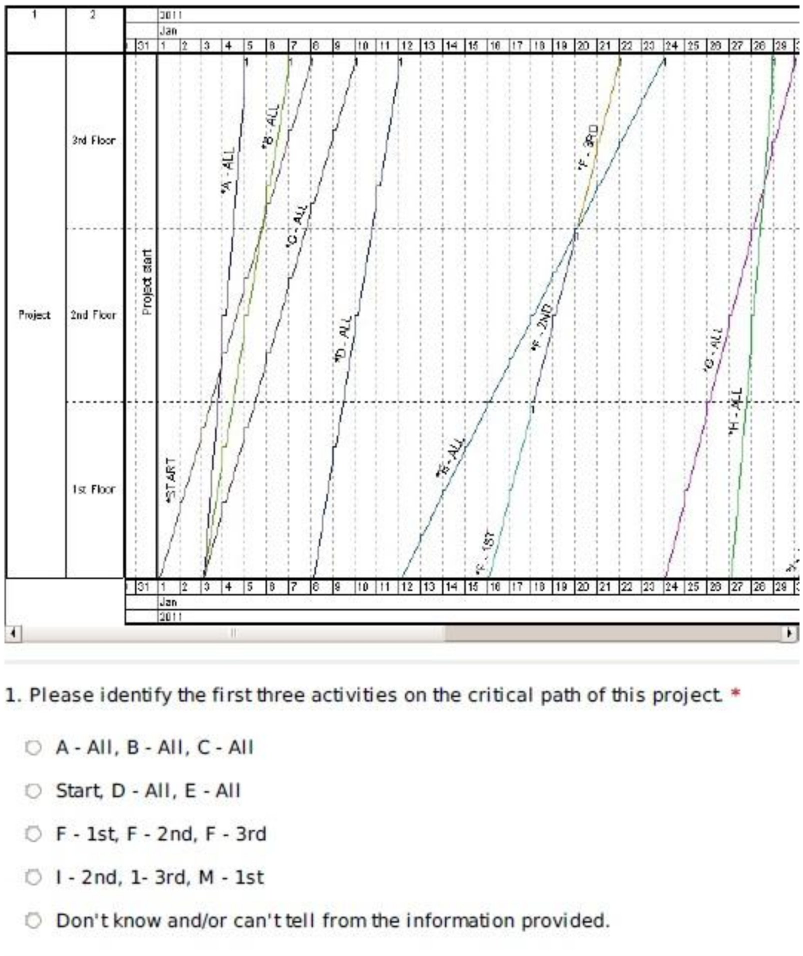

Figure 4.3: A screen shot example of one of the questions taken from the FLG online survey

The outcome of the data collection is the accuracy and time of each participant in answering the list of questions for each scheduling method. The data will be grouped in three tables one for each of the three scheduling visualization methods LGC, FLG and HGR. Table 4.4 shows an example of one of the data collection tables for the Linked Gantt Chart survey. The total accuracy and time of each participant will be summed in the shaded rows shown in Table 4.4. There were be two more data collecting tables like the one shown in Table 4.4, one for FLG and another for HGR.

Table 4.4: The data collection table for Linked Gantt Chart. There will be two similar data collection tables, one for FLG and another for HGR.

Linked Gantt Chart (LGC)								
	Question 1		**Question 2**		**Question …**		**TOTALS**	
	Accu racy	**Time**	**Accu racy**	**Time**	**Accu racy**	**Time**	**∑Accuracy (out of 10)**	**∑Time (seconds)**
Partici pant 1								
Partici pant 2								
Partici pant …								
Partici pant n ≈ 30								

Table 4.5 (shown below) groups the three shaded rows (from Table 4.4) from each scheduling visualization method (i.e. survey) in one table for analyses. The mean of each column is found in the shaded area in the bottom of Table 4.5. These means will be used to test the research hypotheses. This process is discussed in further detail in the next section.

Table 4.5: Grouping the data from the three scheduling visualization methods and finding the means.

	Linked Gantt Chart (LGC)		**Flowline Graph (FLG)**		**Hybrid Graphical Representation (HGR)**	
	∑Accuracy	**∑Time**	**∑Accuracy**	**∑Time**	**∑Accuracy**	**∑Time**
Participant 1						
Participant 2						
Participant …						
Participant n ≈ 30						
	$\mu_{A(LGC)}$	$\mu_{T(LGC)}$	$\mu_{A(FLG)}$	$\mu_{T(FLG)}$	$\mu_{A(HGR)}$	$\mu_{T(HGR)}$

4.8 Data Analysis

Once the data is prepared and organized the analyses process will be ready to commence. The data will be analyzed in a manner that allows addressing the research questions and hypotheses. There are two levels of statistical analysis used in quantitative research, *descriptive statistics* and *inferential statistics*. Descriptive analysis is used when the researcher wishes to describe trends in the data to a single variable or question on their instrument. Descriptive statistics specifies general tendencies in the data (e.g., mean, mode, median), the spread of the scores (e.g., variance, standard deviation, and range), or a comparison of how one score relates to all other scores (e.g., Z-scores, percentile rank). Inferential statistics is used for more in-depth analyses and it characterizes the population. Inferential statistics allows the researcher to analyze data from a sample to draw conclusions about an unknown population. For example, inferential statistics could be used to assess whether the differences of groups (their means) or the relationship among variables is much greater or less than what is expected for the total. Inferential statistics is used when the researcher wishes to compare two or more groups on the independent variable in terms of the dependent variable. Inferential statistics allows the researcher to compare groups or relate variables, furthermore the researcher could make predictions about the variables, and test hypothesis that make predictions comparing groups or relating variables (Creswell, 2008).

Descriptive statistics will be used to present the initial analysis of the experiments' data. Furthermore, inferential statistics will be utilized to compare the groups and the relation between the variables, which is the overall objective of this research. It is suitable because it allows the researcher to look at scores from a sample and use the results to draw inferences or make predictions regarding the population. There are various ways to determine if the sample scores collected by the researcher are a good estimate and indicative of the population scores, hypothesis testing will be used in this study. "Hypothesis testing is a procedure for making decisions about results by comparing an observed value with a population value to determine if no difference or relationship exists between the values. This is the traditional way to test whether the sample mean is a good estimate of the population mean." (Creswell, 2008).

This research endeavor will follow the steps for hypothesis testing to answer the research questions. It includes identifying a null and alternative hypothesis, setting the level of significance or alpha level, collecting the data, computing the sample statistic, and making a decision about rejecting or failing to reject the null hypothesis (Creswell, 2007).

The first step is to identify null and alternative hypotheses. The null hypothesis is a prediction concerning the population, and the alternative hypothesis indicates a difference (or relationship or association). To reach the objectives of this research the data analysis process will evaluate two main hypotheses (i.e. claims) that equate the accuracy and the time, of answering the survey questions using the Hybrid Graphical Representation (HGR) method under study, with utilizing a Linked Gantt Chart (LGC) and the Flowline graph (FLG). The alternative hypothesis here is that there is in fact an accuracy, or time difference between, one or more of these three groups. From the literature review and the results of the pilot study, this difference is expected to be in favor of using the HGR tool for accuracy, however it is unknown which method will result in a shorter time, if any difference exists at all. Therefore, the main research hypothesis is to evaluate if there is a difference between the three groups (LGC, FLG, and HGR) in terms of accuracy and time:

- Accuracy

  H_0: $\mu_{A(LGC)} = \mu_{A(FLG)} = \mu_{A(HGR)}$

  H_1: at least one of the two means is not equal

- Time

  H_0: $\mu_{T(LGC)} = \mu_{T(FLG)} = \mu_{T(HGR)}$

  H_1: at least one of the two means is not equal

Further investigation will be required upon the rejection of one or both these main hypotheses. If the hypotheses are rejected, then there is in fact a difference between one or more of the groups. Thus, further statistical analysis will be required to evaluate which of the group(s) are different, and the statistical significance of this difference. The six conditional hypotheses that will need to be tested as a result of rejecting the above null hypotheses are

- Accuracy

H_0: $\mu_{A(HGR)} = \mu_{A(LGC)}$	**H_0: $\mu_{A(HGR)} = \mu_{A(FLG)}$**	**H_0: $\mu_{A(LGC)} = \mu_{A(FLG)}$**
H_1: $\mu_{A(HGR)} \neq \mu_{A(LGC)}$	**H_1: $\mu_{A(HGR)} \neq \mu_{A(FLG)}$**	**H_1: $\mu_{A(LGC)} \neq \mu_{A(FLG)}$**

- Time

H_0: $\mu_{T(HGR)} = \mu_{T(LGC)}$	**H_0: $\mu_{T(HGR)} = \mu_{T(FLG)}$**	**H_0: $\mu_{T(LGC)} = \mu_{T(FLG)}$**
H_1: $\mu_{T(HGR)} \neq \mu_{T(LGC)}$	**H_1: $\mu_{T(HGR)} \neq \mu_{T(FLG)}$**	**H_1: $\mu_{T(LGC)} \neq \mu_{T(FLG)}$**

To examine the scored data, a statistical analysis computer program, the *SPSS Graduate Pack 16.0 for Mac,* is used to analyze and generate trends from the collected data.

The analysis starts by running the Shapiro-Wilk test for each measurement to check for normality. If the data is normal, then ANOVA is used to evaluate the difference between the means of the groups, and then Tukey's Honest Significance Difference (Tukey HSD) post-hoc analyses is used to group and test the conditional research hypothesis. However, if the data failed the normality test, then non-parametric rank sum tests will be applied (i.e. Kruskal-Wallis and Mann-Whitney). The Kruskal-Wallis analyses will be used to test the main hypotheses. If the main research hypotheses are rejected, then a series of Mann-Whitney tests will be conducted to test the conditional research hypotheses. A similar grouping, to that of the Tukey HSD analyses, will be used for applying the Mann-Whitney analyses. More detailed explanations concerning these tests are described below.

4.8.1 Parametric Tests

Analysis of variance (ANOVA) is used to test the hypothesis that there are no differences between the three groups (i.e. $\mathbf{H_0: \mu_{(LGC)} = \mu_{(FLG)} = \mu_{(HGR)}}$) if the data followed a normal curve. Analysis of variance is a statistical test of the difference of means for two or more groups. ANOVA provides a way to test the null hypothesis that all samples are drawn from the same population and therefore are all equal (H_0: $\mathbf{\mu_1 = \mu_2 = \ldots = \mu_i}$). The alternative hypothesis is that one or more of the sample means are drawn from populations with different means. The possibility that the null hypothesis can be rejected implies one of several alternative possibilities. Either all the population means are different from each other ($\mathbf{\mu_1 \neq \mu_2 \neq \ldots \neq \mu_i}$), some group(s) of the population means differ from one another ($\mathbf{\mu_1}$ differs from $\mathbf{\mu_2}$ but not from $\mathbf{\mu_3}$ and $\mathbf{\mu_4}$), or some of the combination of the means is different from some single mean or from some other combination of means. Therefore, if the null hypothesis is rejected, then the researcher has to explain how the means differ from one another using post-hoc tests, like the Tukey HSD (Bohrnstedt & Knoke, 1988).

There are three treatments (i.e. **i**'s) in this ANOVA test, the Linked Gantt Chart (LGC), Flowline graph (FLG), and the Hybrid Graphical Representation (HGR) schedules. Each treatment group will have around 30 observations (i.e. **j**'s). If the means of the observations for the accuracy or the time, from the three treatments are all equal, then the null hypothesis is true, and $\mu_{(LGC)}=\mu_{(FLG)}=\mu_{(HGR)}$ and they will all equal an overall or grand mean **μ**. The effect of being in a subgroup or one of the three groups (**i**'s) is defined as $\tau_i = (\mu_i - \mu)$. If being in one of the groups has no effect on the dependent variable, **Y**, then $\tau_i = 0$, but if being in a group does have an effect, τ_i will be positive or negative, depending on whether a group's mean is above or below the grand mean, **μ** (Bohrnstedt & Knoke, 1988).

In essence, ANOVA shows how much of the total variation in **Y** could be explained by the independent **i** treatment variables (i.e. LGC, FL, or HGR) and how much is left unexplained. The difference between an observed score and a score predicted by the model is called an error term. So the general model for ANOVA with one independent variable is $Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$ where ε_{ij} is the error term. This formula indicates that the score of observation **j**, which is also a member of group **i** (hence Y_{ij}), is a function of a group effect, τ_i, plus the population mean, **μ**, and random error, ε_{ij}. The error term takes into account and reflects the fact that not every observation in subgroup **i** has the same Y_{ij} (Bohrnstedt & Knoke, 1988).

The ANOVA partitions the total variability in the sample data into two component parts to estimate the proportion of variance in Y_{ij} that is due to the group effects (the τ_i) and due to the error (the ε_{ij}). The total variability in the data is described by the *Total Sum of Squares* (SS_{TOTAL}). The (SS_{TOTAL}) is partitioned into two components, the sum of the squares lying between the means of the groups, called the *Between Sum of Squares* ($SS_{BETWEEN}$), and the sum of squared deviations about the group means, called the *Within Sum of Squares* (SS_{WITHIN}). The partition of the Total Sum of Squares is given by:

$$(SS_{TOTAL}) = (SS_{BETWEEN}) + (SS_{WITHIN}) \qquad \text{or}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{n_i}(Y_{ij} - \bar{Y})^2 = \sum_{i=1}^{I} n_i(\bar{Y}_i - \bar{Y})^2 + \sum_{i=1}^{I}\sum_{j=1}^{n}(Y_{ij} - \bar{Y}_{\cdot})^2$$

where $\bar{Y}$ is the grand mean, and $\bar{Y}_i$ is the mean score of the independent variable category **i** into which observation **j** falls (Bohrnstedt & Knoke, 1988).

The next step in an analysis of variance is to compute the mean squares for $SS_{BETWEEN}$ and SS_{WITHIN}. When the mean squares are computed, two variances are being computed, one due to treatment effects and one due to error. If in fact treatment effects exist, then the between-group variance, or Mean Square Between ($MS_{BETWEEN}$), will be significantly larger than the within-group variance, or the Mean Square Within (MS_{WITHIN}). The variance is an average or mean derived by dividing the sum of squared deviations about the mean by their degree of freedom. In this case the degree of freedom associated with the between-group variance is I-1, and ($MS_{BETWEEN}$) is:

$$(MS_{BETWEEN}) = \frac{SS_{BETWEEN}}{I-1}$$

and to compute MS_{WITHIN} the degree of freedom is N-I

$$(MS_{WITHIN}) = \frac{SS_{WITHIN}}{N-I}$$

If the null hypothesis is true and there are no treatment effects, then $MS_{BETWEEN}$ and MS_{WITHIN} should be roughly equal to each other, and their ratio should be close to 1. However, if the ratio is far greater than 1, this suggests that $MS_{BETWEEN}$ is far greater than MS_{WITHIN}, and the null hypothesis should be rejected. In other words, when $MS_{BETWEEN}$ is substantially larger than MS_{WITHIN}, this suggests that treatment effects exist (Bohrnstedt & Knoke, 1988).

The F-ratio is the ratio of $MS_{BETWEEN}$ to MS_{WITHIN} and it is used to determine how much larger $MS_{BETWEEN}$ must be relative to MS_{WITHIN} to reject the hypothesis of no treatment effects. The F-ratio has a known sampling distribution under the null hypothesis if certain assumptions can be met. The first assumption is that the **J** samples are independently drawn from a normally distributed population. Furthermore, the variance in the population is assumed to be the same for all **I** treatment categories. If these assumptions are met then the F-ratio is distributed according to the F-distribution, with I-1 degrees of freedom associated with the numerator and N-I with the denominator ($F_0 = MS_{BETWEEN}/MS_{WITHIN}$). Since the alternative hypothesis in ANOVA implies that the between-group variance is larger than the within-group variance in the population, a one-tailed test is usually completed to test the significance. An $\boldsymbol{\alpha}$ level is chosen, and if the observed F ratio is larger than the critical value associated with **α**, the null hypothesis is rejected and instead conclude that there indeed are treatment effects. The F value is found from tables included in most statistics books using the **α**, and the degrees of freedom of both the numerator and denominator. Therefore, the null hypothesis is rejected when $F_0 > F_{\alpha, I-1, N-I}$ where F_0 is the computed value, and $F_{\alpha, I-1, N-I}$ is found from the F distribution tables. If after conducting the ANOVA test an overall difference between groups was found, then the Tukey HSD post-hoc test will be used to identify which specific group(s) differed (Bohrnstedt & Knoke, 1988).

A number of steps were taken to satisfy the requirements and assumptions of the statistical tests applied in the data analyses processes. For example, to ensure randomization of the data collected and to cancel the effect of any nuisance variable, the orders of the questions asked in the three online surveys are randomized for each participant. Furthermore, The Levene test is used to check for the homogeneity of the variances. Similar to the ANOVA analyses the Levene test utilizes the F distribution to test the homogeneity of the data.

4.8.2 Non-Parametric Tests

The Mann-Whitney or Wilcoxon Rank Sum test is used to test the hypothesis if the data is not normal. It requires two independent continuous populations (X_1 and X_2) with means μ_1 and μ_2, and both distributions have similar shape and spreads, and differ only in their locations. The test procedure is performed by arranging all $n_1 + n_2$ observations in ascending order of magnitude and assign ranks to them. Then W_1 is defined to be the sum of ranks in the smaller sample (1), and W_2 is defined to be the sum of the ranks in the other sample (2), and $W_2 = [[(n_1 + n_2)(n_1 + n_2 + 1)]/2] – W_1$. Now if the sample means do not differ, then the sum of ranks will consequently come out as nearly equal for both samples. However, if the sum of ranks differs greatly, then this will indicate that the means are not equal. Most statistics textbooks have tables containing the critical values of the rank sums for various alphas (e.g., α= 0.05). The null H_0: $\mu_1 = \mu_2$ is rejected in favor of H_1: $\boldsymbol{\mu_1 \neq \mu_2}$ if either of the observed values $\mathbf{w_1}$ or $\mathbf{w_2}$ is less than or equal to the tabulated critical value $\mathbf{w_\alpha}$

The Kruskal-Wallis Test is the nonparametric test equivalent to ANOVA and an extension of the Mann-Whitney test to allow the comparison of more than two independent groups (i.e. $\mathbf{H_0: \mu_{(LGC)} = \mu_{(FLG)} = \mu_{(HGR)}}$). It is used to compare three or more sets of scores that come from different groups. The Kruskal-Wallis test statistic measures the degree to which the actual observed total ranks $\bar{R}_i^2$ differ from their expected value 3(N+1), where $\bar{R}_i^2$ is the total of the $\mathbf{n_i}$ ranks in the ith treatment. If the difference is large, the null hypothesis H_0 is rejected. The test statistic is:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{a} \frac{R_i^2}{n_i} - 3(N+1)$$

The null hypothesis H_0 should be rejected if the sample data generate a large value for H in the above equation.

5. DATA ANALYSIS

The results of the research methodology, explained in Chapter 4, are documented and discussed in this Chapter. This section presents the data collected through the three online surveys, the procedures followed for the hypothesis tests, and the results of these tests.

5.1 Data Collected

Data was collected from a total of 106 participants using three online surveys. Each of the three surveys measured the accuracy and time of each participant in answering the ten question using the Linked Gantt Chart (LGC) schedule (Survey 1), the Flowline graph (FLG) schedule (Survey 2), or the Hybrid Graphical Representation (HGR) schedule (Survey 3). There were 36 participants for the LGC survey, 35 for the FLG survey, and 35 participants for the HGR survey (Total 106 participants). Table 5.1 shows the number of participants in each survey who said they had previous experience with scheduling. Overall, around 80% of the total survey participants had some kind of scheduling background from previous course work (Table 5.1).

Table 5.1: Number of participants in each survey with previous scheduling experience.

		N	Scheduling Experience	
			Yes	No
Survey 1	**Linked Gantt Chart (LGC)**	36	30	6
Survey 2	**Flowline Graph (FLG)**	35	28	7
Survey 3	**Hybrid Graphical Representation (HGR)**	35	27	8

Table 5.2 below presents all the data collected from the three surveys and organized as explained in section 4.7 (as shown in Table 4.5). Furthermore, the average accuracy and time from each survey are shown in the last row of Table 5.2. Accuracy is shown out of a total score of 10, and time is presented in seconds. The initial descriptive statistics show that in general, the HGR resulted in higher accuracies when compared to the LGC and FLG, but it took the participants a relatively longer time (Table 5.2).

Table 5.2: All the data collected from the three surveys organized as explained in section 4.7 in Table 4.5 (Average Accuracies and Times are shown in the last row)

	Survey 1 - LGC		**Survey 2 - FLG**		**Survey 3 - HGR**	
	Accuracy (out of 10)	**Time (seconds)**	**Accuracy (out of 10)**	**Time (seconds)**	**Accuracy (out of 10)**	**Time (seconds)**
1	9	400	7	721	8	412
2	5	718	7	340	9	424
3	8	234	5	552	7	684
4	4	923	5	289	8	512
5	6	413	3	378	9	537
6	6	373	5	533	8	601
7	5	533	5	307	8	742
8	5	376	7	595	10	498
9	7	515	8	620	7	656
10	5	406	4	448	10	460
11	4	586	6	473	9	530
12	7	562	7	475	9	693
13	8	559	8	374	9	381
14	7	649	5	405	8	817
15	6	523	6	294	10	635
16	5	543	8	631	9	731
17	6	531	8	504	6	679
18	6	427	7	453	6	782
19	5	684	8	396	9	368
20	6	588	6	391	9	549
21	5	527	7	457	10	541
22	5	551	7	299	7	856
23	6	422	6	492	6	740
24	3	291	7	589	10	671
25	5	445	7	561	8	480
26	8	457	6	405	10	704
27	8	426	7	492	7	907
28	6	852	8	489	8	887
29	4	566	7	858	10	732
30	4	691	6	515	7	582
31	3	229	5	362	10	590
32	6	506	5	576	10	224
33	5	386	6	786	9	525
34	6	850	8	431	7	363
35	8	648	5	444	10	673
36	4	312				
MEANS	**5.72**	**520**	**6.34**	**484**	**8.49**	**605**

5.2 Statistical Analysis

Data was first tested for normality to determine whether to utilize parametric or non-parametric statistical tests. If the data satisfied the normality assumption, then the ANOVA test was used to test the hypothesis. Otherwise, nonparametric rank sum tests were conducted (i.e. Kruskal-Wallis and Mann-Whitney). All tests were done at 95% confidence intervals (i.e. alpha is 0.05). Table 5.3 presents the outcomes from the six Shapiro-Wilk normality analyses conducted, and the resulting test method used for analyzing the accuracy and time data. If the p-value is less than 0.05 then the data is not normal. The accuracy data did not follow a normal distribution so the Kruskal-Wallis rank sum test was used, but the time data was normal so ANOVA was utilized to compare the means from the three surveys.

Table 5.3: The outcomes of the six Shapiro-Wilk normality analyses, and the resulting test methods used for analyzing the accuracy and time data.

	Group	**Shapiro-Wilk**		**Normal?**	**Test Method**
		df	**p-value.**		
Accuracy	LGC	36	0.057	No	Kruskal-Wallis
	FLG	35	0.006	No	
	HGR	35	0.001	No	
Time	LGC	36	0.289	Yes	ANOVA
	FLG	35	0.085	Yes	
	HGR	35	0.926	Yes	

5.3 Accuracy Data

The accuracy data failed the normality test so, as explained in Chapter 4, the non-parametric Kruskal-Wallis rank sum test is used to check if there is an overall difference between using the three scheduling techniques in answering the ten survey questions. The Kruskal-Wallis tested the null hypothesis $\mathbf{H_0: \mu_{A(LGC)} = \mu_{A(FLG)} = \mu_{A(HGR)}}$, where $\mathbf{\mu}$ is the group mean accuracy for the three scheduling visualization methods. Table 5.4 shows the mean ranks of the measurements and Table 5.5 shows the results of the test. Table 5.4 illustrates the mean rank of the accuracy for answering the ten survey questions using each of the three scheduling visualization methods. The test statistics table (Table 5.5) presents the Chi-square value, the degree of freedom and the p-value of the Kruskal-Wallis rank sum test. The Kruskal-Wallis test shows that there is a statistically significant difference between the accuracies of the different scheduling visualization methods (P=0.000) with a mean rank of 34.60 for LGC, 45.44 for FLG, and 81.00 for the HGR. Notice that the HGR mean rank sum test is the highest of the three scheduling visualization methods indicating a resulting HGR higher accuracy level in answering the 10 survey questions.

Table 5.4: The Kruskal-Wallis test mean ranks of the measurements

	Group	**N**	**Mean Rank**
Accuracy	**LGC**	36	34.60
	FLG	35	45.44
	HGR	35	81.00
	Total	106	

Table 5.5: Kruskal-Wallis test statistics

	Accuracy
Chi-Square	45.188
df	2
p-value	0.000

To further investigate which specific groups differed, three Mann-Whitney rank sum tests were run comparing the LGC and HGR data, the FLG and HGR data, and the LGC and FLG data. The first two tests were conducted to compare the accuracy of utilizing HGR to the existing scheduling visualization techniques the LGC and FLG. The last test was performed to compare how the accuracies of the participants fared when using LGC compared to FLG in answering the ten survey questions. Table 5.6 shows the mean rank for each of the two scheduling visualization methods compared in each test. The mean ranks indicate which group had the higher accuracy (i.e. the scheduling method with the highest mean rank). According to the first two Mann-Whitney tests run, HGR had a higher mean rank when compared to both LGC (50.7>21.7) and FLG (48.3>22.7), however comparing LGC and FLG show that FLG has a somewhat higher mean rank (40.8>31.4).

Table 5.6: Results of the three Mann-Whitney rank sum tests performed to evaluate the difference between groups

		Mean Rank	**Mann-Whitney U**	**p value**	**Conclusion**
1	**LGC**	21.7	116	0.000	HGR Accuracy is different than LGC
	HGR	50.7			
2	**FLG**	22.7	164	0.000	HGR Accuracy is different than FLG
	HGR	48.3			
3	**LGC**	31.4	463	0.050	LGC Accuracy is ***not*** different than FLG
	FLG	40.8			

The test statistic U, the p-values resulting from the three tests and the conclusions are shown in the last three columns in Table 5.6 (above). There are three groups being compared by this Mann-Whitney analysis (LGC, FLG and HGR). In order to maintain an experiment-wise error rate of 0.05 (i.e. the alpha for the tests) the comparisons were performed utilizing a 0.05/3 alpha to correct for the per-comparison error rate for the three groups (LGC, FLG and HGR). Thus, the alpha used for the three tests is 0.05/3=0.0167 alpha. With that in mind, the results in Table 5.6 shows there is a statistically significant difference between the LGC & HGR (U=116, p=0.000), and FLG & HGR (U=164, p=0.000), both p-values are much less that 0.0167 alpha. As for the LGC and FLG test there is no statistically significant difference (U=463, p=0.050) because the p-value is greater than the 0.0167 alpha. In conclusion, the accuracy of using the Hybrid Graphical Representation (HGR) was statistically higher when compared to the accuracies of using the Linked Gantt Chart (LGC) and Flowline graph (FLG). However, there was no statistically significant difference between the accuracies of the LGC and FLG (not one of the research hypotheses).

More detailed analysis was conducted on the accuracy data to further compare the effectiveness of the Hybrid Graphical Representation (HGR) method in conveying the same amount of information as the two existing scheduling visualization methods LGC and FLG. As explained earlier in Chapter 4, the first five questions in the survey are more appropriately answered using the Linked Gantt Chart (LGC), while the last five questions were better approached using a Flowline graph (FLG). For further investigation, the accuracy data for the first and last five questions were isolated to be evaluated for more detailed analyses (Table 5.7 below). The average accuracy of answering the first five activity-based scheduling questions was almost similar for the LGC (Accuracy = 4.19) and HGR (Accuracy = 4.43) scheduling visualization methods. The average of answering the last five location-based scheduling questions was a little higher for HGR (Accuracy = 4.06) compared to FLG (Accuracy = 3.63).

Table 5.7: Accuracy data of the first five questions from surveys LGC and HGR, and from the last five questions from surveys FLG and HGR)

		First Five Questions (out of 5)	Last Five Questions (out of 5)
1	**Linked Gantt Chart (LGC)**	4.19	
2	**Flowline Graph (FLG)**		3.63
3	**Hybrid Graphical representation (HGR)**	4.43	4.06

Conducting Mann-Whitney rank sum tests on the isolated data (Table 5.8) shows that there is no statistically significant differences between the LGC and HGR accuracies in answering the first five questions (p=0.244), or the FLG and HGR accuracies in answering the last five questions (p=0.137). In other words, the participants were equally successful in answering the activity-based scheduling questions (questions 1-5) using the LGC and the HGR, and in answering the location-based scheduling questions (question 6-10) using the FLG and the HGR. This indicates the HGR's capability of revealing the same amount of information as the LGC and FLG graphical visualization methods combined.

Table 5.8: Results of the Mann-Whitney rank sum test on the isolated Accuracy data

		Mann-Whitney U	p value	Conclusion
First Five Question	**LGC**	532	0.244	HGR Accuracy is ***not*** different than LGC
	HGR			
Last Five Questions	**FLG**	493	0.137	HGR Accuracy is ***not*** different than FLG
	HGR			

In conclusion, comparing the accuracies of the participants in answering the ten survey questions, from the three surveys, showed that the HGR scheduling visualization method led to answering more questions correctly relative to using the LGC or the FLG. Moreover, from the analysis performed by isolating the type of questions, the HGR scheduling visualization method was proven to be as successful in communicating the same amount of information as the stand-alone LGC and FLG schedules.

5.4 Time Data

The time data from the three surveys, testing the duration of the participants in answering the ten survey questions using the Linked Gantt Chart (LGC – Survey 1), Flowline graph (FLG – Survey 2), and Hybrid Graphical Representation (HGR – Survey 3), was found to be normal (see Table 5.3 above). The ANOVA test was used to determine whether there are significant differences between the means of the time from the three surveys. The null hypothesis tested is $\mathbf{H_0: \mu_{T(LGC)} = \mu_{T(FLG)} = \mu_{T(HGR)}}$, where $\boldsymbol{\mu}$ is the group mean time for the three scheduling visualization methods. If the ANOVA test returned a significant result then the alternative hypothesis is accepted, and a conclusion is made that there are at least 2 group mean times are significantly different from each other. As mentioned in Chapter 4 one of the assumptions of the ANOVA test is that the variances of the groups compared are similar. Table 5.9 shows the results of the Levene test of homogeneity of variances. The p-value for this test is greater than 0.05 (0.374>0.05), therefore, the homogeneity of variances assumption is met.

Table 5.9: The Levene test of homogeneity of variance

	Levene Statistic	**df1**	**df2**	**p-value**
Time	.992	2	103	0.374

Table 5.10 shows the output of the ANOVA analysis and whether there is a statistically significance difference between the three groups' time means. The significance p-value is 0.004, which is less than 0.05; therefore, there is a statistically significant difference in the mean length of time to complete the survey questions using the three scheduling visualization methods. To find out which of the specific scheduling visualization methods differed, the Tukey HSD post-hoc test is conducted (see Table 5.11).

Table 5.10: ANOVA analysis of statistical significant difference between the three groups' time means.

	Sum of Squares	**df**	**Mean Square**	**F**	**p-value**
Between Groups	270355.434	2	135177.717	5.765	.004
Within Groups	2.415E6	103	23449.514		
Total	2.686E6	105			

The ANOVA test conducted (Table 5.10 above) led to the conclusion that there are significant differences between the time data collected from the three scheduling visualization methods. Table 5.11 (below) shows the results of the Tukey HSD post-hoc test, which demonstrates how each scheduling visualization method differed by comparing it to the other visualization methods being studied. There was no significant difference in time to complete the ten questions between the LGC and FLG scheduling visualization methods. The p-value is much higher than the 0.05 alpha (p = 0.591). A difference starts to appear when comparing the HGR and LGC time data (p = 0.054), and a significant difference is evident between the HGR and FLG durations (p = 0.004).

Table 5.11: Outcome of the Tukey HSD post-hoc test

		Mean Difference	**p-value**	**Conclusion**
1	**LGC** **FLG**	35.643	.591	LGC Time is ***not*** different than FLG
2	**HGR** **LGC**	85.243	.054	HGR Time is ***not*** different than LGC
3	**HGR** **FLG**	120.886	.004	HGR Time is different than FLG

In conclusion, for the time hypotheses tested by this research, the initial analysis performed on the time data (table 5.2 above), showed that the participants took, on average, more time to answer the ten survey questions using the Hybrid Graphical Representation (HGR = 605 seconds) then the other two scheduling visualization methods. Using the Linked Gantt Chart (LGC = 520 seconds) took a relatively shorter duration, and the Flowline graph (FLG = 480 seconds) allowed for the least amount of time on average to complete the survey. There was a statistically significant difference between the three groups as determined by the ANOVA test (p-value=0.004). A Tukey

HSD post-hoc analysis revealed that the time to complete the ten survey questions was statistically significantly lower for the FLG method when compared to the HGR visualization method under-study (p-value=0.004). Although not one of the hypotheses investigated by the research, but it was interesting to see that there was no significant difference between LGC and FLG (p-value=0.0591). For the comparison between HGR and LGC the Tukey post-hoc analysis shows that there is no statistically significant difference (p-value=0.054), however it is very close to the alpha (alpha=0.05). Therefore, the deduction that there was no time difference between the LGC and HGR methods in answering the survey question is not as conclusive or definitive.

5.5 Summary of Results

Data was collected from 36 participants in the first survey (LGC), 35 participants in the second survey (FLG), and 35 participants on the third survey (HGR). Around 80% of the participants had previous scheduling experience. Based on the normality of the collected data, either the Kruskal-Wallis or the ANOVA test was used to investigate if there is a difference between the accuracy or time data collected in the three surveys. When the Kruskal-Wallis test was used, further investigation was performed using Mann-Whitney tests to investigate the differences between the specific groups. If the ANOVA test was implemented and showed differences between the groups, then the Tukey HSD post-hoc test was used to examine how each method differed.

The Shapiro-Wilk normality test showed that the accuracy data for the three tests are not normally distributed, however the time data had a normal distribution. Table 5.12 below summarizes the data analyses processes undertaken by this research. Table 5.12 shows the average (i.e. mean) accuracy and time for finishing the ten questions in the three surveys conducted using the LGC, FLG and HGR scheduling visualization methods. Furthermore, it presents the results of the overall difference between groups for accuracy and time, and the detailed difference between every two groups. All accuracy data in Table 5.12 is out of 10, and time is in seconds.

Table 5.12: Summary table of data analyses.

			LGC	FLG	HGR	p-value	Conclusion
ACCURACY (out of 10)		MEAN	5.72	6.34	8.49		
	Overall Difference Between All Groups	Kruskal-Wallis	X	X	X	0.000	There is a difference between the three means
	Detailed Difference Between Two Groups	Mann-Whitney	X		X	0.000	There is a difference
				X	X	0.000	There is a difference
			X	X		0.050	There is ***NO*** difference
TIME (Seconds)		MEAN	520	484	605		
	Overall Difference Between All Groups	ANOVA	X	X	X	0.004	There is a difference between the three means
	Detailed Difference Between Two Groups	Tukey HSD post-hoc test	X		X	0.054	There is ***NO*** difference (borderline)
				X	X	0.004	There is difference
			X	X		0.591	There is ***NO*** difference

6. FINDINGS

6.1 Introduction

Three online surveys were developed for each of the three scheduling visualization methods, the Linked Gantt Chart (LGC), Flowline graph (FLG), and the Hybrid Graphical Representation (HGR) method. A simple project schedule with three versions (LGC, FLG, HGR versions) was used in the survey. Each survey recorded the accuracy and time of the participants in answering a series of ten questions using one version of the three scheduling visualization techniques. The first five questions of the survey were placed to measure the comprehension of the activity-based scheduling approach. So questions 1 through 5 were mainly about the project's critical path and the activities' relationships (e.g., Finish-to-Start, Start-to-Start, lags, etc.). The last five questions (i.e. questions 6 through 10) targeted the participants' understanding of the spatial aspects of the project, like locations and spatial considerations concerning the scheduled activities. Using the LGC in the first survey the participants should be able to answer the first five questions with ease, compared to answering the last five questions because of the LGC's inability to show activities' locations. However, in the second survey the opposite would take place, where the participants would find that answering the last five questions using the FLG is visually more practical than answering the first five questions. The premise here is that if the Hybrid Graphical Representation (HGR) method is successful in visually communicating both activity-based and location-based information, then the participants in the third survey would realize which interface to use on the Hybrid schedule, and be able to answer the ten questions. Questions in the three surveys were randomized, and the survey tool recorded the participants' time and accuracy in answering each question.

6.2 Findings

Data was collected from a total of 106 participants; around 80% of them had previous scheduling experience. The test results for the ***accuracy*** data show that the Hybrid Graphical Representation (HGR) scheduling visualization tool enabled the participants to score the highest average accuracy at 8.49 (out of a total of 10). The other two methods led to less accuracy. Participants using the LGC were able to score an average of 5.72 and those using the FLG scored an average of 6.34. Accuracy data was not normal, so the non-parametric Kruskal-Wallis rank sum test was used to test if there was an overall difference between groups. There was a statistically significant difference between the accuracies of the three scheduling visualization methods. Three Mann-Whitney tests were conducted to investigate the detailed differences between the groups. There was a statistically significant difference between the HGR and LGC mean accuracies, and the HGR and FLG mean accuracies. Therefore, the tests conclude that the HGR tool is more accurate and is able to show more information compared to LGC and FGR. As expected, there was no statistically significant difference between the LGC and FLG mean accuracies.

The test results for the ***time*** data show that the participants finished the ten survey questions using the HGR scheduling visualization tool in the longest time period (605 seconds) on average. The other two methods allowed the participants to finish in shorter average durations. Participants using the LGC took 520 seconds, while those using the FLG took 484 seconds. Time data was normal, so the parametric ANOVA test was used to test if there was an overall difference between groups. There was a statistically significant difference between the time durations of the three scheduling visualization methods. The Tukey HSD post-hoc test was conducted to investigate the detailed differences between the groups. There was no statistically significant difference between the HGR and LGC mean times; however the p-value (0.054) was very close to the alpha value (0.050) so the test results is not that definitive. However, there was a statistically significant difference between the HGR and FLG mean times, showing that FLG fared better than HGR in terms of duration.

Therefore, the Hybrid Graphical Representation (HGR) tool enabled the participants to answer the ten survey questions with higher accuracy compared to using the Linked Gantt Chart (LGC) and the Flowline graph (FLG). However, it took the participants a relatively longer time to achieve that higher accuracy. One of the reasons that could have influenced the participants time was that the HGR prototype was presented in the survey as a video clip that starts in the LGC (top view) interface and slowly turns to the FLG (front view). Participants had to play the video or move back and forth through the frames. This could have affected the time it took the participants in answering the survey questions. On the HGR survey, when presented with the HGR schedule, the participants had to click play, sometimes adjust the video settings from 360 to 480 for better resolution, or replay the video if it failed to download. The LGC and FLG schedules were presented as a screen capture of the project schedule, so the participants did not face these issues. So there is a possibility that the time differences between using the HGR versus the LGC or FLG could be attributed to these technical hardships, rather than intrinsic difficulties in reading and understanding the HGR schedule.

Although it was not the initial intent of this study, but it is interesting to note how average times of the Hybrid Graphical Representation tool and the Linked Gantt Chart were fairly close, and the Flowline graph method allowed the participants to finish the fastest (by average). Unlike the Linked Gantt Chart method most of the participants did not have any prior experience with using a Flowline graph. Most scheduling classes concentrate on teaching the LGC method but not the FLG. The research showed that the participants were able to use the FLG successfully with a relatively higher accuracy and in a shorter time (compared to the LGC) just after watching the video tutorial.

6.3 Limitations

There are several limitations to this research. Perhaps the main prevalent limitation was that only a prototype of the Hybrid Graphical Representation (HGR) was used in the data collection and analyses processes of this research. There is always a possibility that, if the HGR system was used on more complex projects and/or to communicate schedules with a larger number of activities, then it would become be more difficult and impractical. Furthermore, the HGR schedule was not developed by a specific software program that could allow the participants to use and explore the schedule. Using the HGR prototype video clip and scrolling through the frames rather than investigating the HGR schedule, as a product of a software program, was one of the main limitations of this research effort.

Another limitation is the fact that the participants had varying degrees of scheduling expertise. Around 80 percent of the participants had already taken a scheduling class and were familiar with the Critical Path Method (CPM) scheduling and comfortable with reading Linked Gantt Charts (LGC). Most everyone was not familiar with location-based scheduling approach and had no previous practice of its application. The majority of the participants had to learn about reading and understanding Flowline graphs through the material presented in the 13 minutes video tutorial at the beginning of each survey. As mentioned in previous sections the video tutorial included a brief explanation about the three scheduling visualization methods included in the study, LGC, FLG, and the HGR. The fact that the survey was conducted in the United States and all the participants were Texas A&M University students located in College Station, Texas could have also played a role in tainting the data and limiting the conclusive quality of the findings.

7. CONCLUSIONS

7.1 Introduction

Linked Gantt Charts (LGC), and the Critical Path Method (CPM) scheduling technique, are part of the broader activity-based scheduling approach and are currently the conventional means to create and communicate schedules in the construction industry. On the other hand, studies show that using Flowline schedules produced by the location-based scheduling system could offer many visual advantages in planning and managing construction projects. The location-based scheduling system's superiority and practicality attributes are especially perceived when implemented on projects with a repetitive nature. Furthermore, some studies demonstrate how the Flowline graph (FLG) improves visual resource optimization and aids in the overall planning and management processes of construction projects.

In many cases, location-based scheduling has proven to be more visually efficient and generate better results when compared to the more popular activity-based scheduling techniques, such as the Critical Path Method and Linked Gantt Charts. For example, some studies have shown that Flowline graphs are better in facilitating the implementation of Lean Construction concepts and applying Building Information Modeling technologies. In using Flowline graphs the user could visually see various activity attributes like location, productivity and flow of resources. Nevertheless, there are many reasons behind the current extensive use of activity-based scheduling methods in the construction industry. Using Linked Gantt Charts, the scheduler is capable to visually identifying the project's critical path, and has more access to well established and developed supporting software programs (e.g., Microsoft® Project and Primavera® P6) allowing them to modify and communicate the schedule with the majority of the industry.

Currently, most scheduling practitioners have to decide between the continued utilization of the more familiar activity-based scheduling approach, or converting to location-based scheduling. Either decision will involve sacrifices of the advantages provided by the method abandoned, and present numerous challenges especially in transitioning and learning the relatively uncommon location-based scheduling approach, if that was the chosen path. Therefore, some researchers attempted to merge these two systems to try and capitalize on their combined advantages. This research develops and investigates the Hybrid Graphical Representation tool's (presented in Chapter 3) ability to visually merge Linked Gantt Charts (LGC) and Flowline graphs (FLG) with the intention to capture the visual advantages provided by both interfaces.

7.2 Review of Research Objectives

The Hybrid Graphical Representation (HGR) method proposed by this study is founded on the basic idea that both Linked Gantt Charts (LGC) and Flowline graphs (FLG) share a common X-axis, *Time*. The only difference is in a Linked Gantt Chart the *Activities* are listed on the Y-axis, while the Flowline graph shows *Locations* on the Y-axis. This research proposes adding a third dimension to the Flowline graph, listing the project Activities on a Z-axis. Viewing the Hybrid 3D graph from the top, the user will observe the Gantt bars with Time on the X-axis and the Activities listed on the Z-axis. Observing the schedule from the front view, the user will see the flow-lines developed through the location-based scheduling method with Locations on the Y-axis and Time on the X-axis. Using the proposed Hybrid Graphical Representation is anticipated to help the user reap the benefits of both scheduling approaches (activity-based and location-based), and visually link and communicate information concerning the activities' logical relationships and where they are taking place in the project.

The objective of the research was to develop and empirically validate the ability of the proposed Hybrid Graphical Representation in visually communicating and combining logical and spatial relationships, compared to comprehending the same information by looking at a standalone Linked Gantt Chart (LGC) or Flowline graph (FLG). The research attempted to answer the questions: Does using the Hybrid Graphical Representation tool allow the user to accurately and quickly comprehend the activities' relationships and locations relative to the accuracy and speed of accomplishing the same task using a Linked Gantt Chart or a Flowline graph? If the HGR is proven successful, then it would provide a new graphical method that is capable of visually communicating the combined information shown by LGC and FLG schedules on a single interface. The research methodology and findings were discussed in previous chapters. This chapter presents the conclusions, study limitations, and suggestions for further research.

7.3 Conclusion

In conclusion, the research shows that a graphical tool that combines Linked Gantt Chart bars from the activity-based scheduling approach, and flow-lines from the location-based scheduling approach, could be developed to allow the exploitation of both scheduling methods' visual advantages. The Hybrid Graphical Representation is successful in visually communicating to the user information found in both, the Linked Gantt Chart and Flowline graph, on the same system. As Tufte (1990) explains, there is always value in showing multivariate information on the same system as long as the clarity and simplicity of the visual tool are not forsaken. For the participants to have the ability to answer more than half of the survey (i.e. 5/10 or more) using the HGR is an indication that the majority of the participants realized which method to utilize for answering each of the ten questions, and went and looked at the appropriate interface on the HGR tool. In other words, this shows that when a participant was given a location based scheduling approach question they identified that the FLG view should be used and was successfully able to turn to that view and extract the needed data to answer the question. This proves that the users had a realization and an understanding of the HGR tool and how it works, and were able to use it effectively. Furthermore, it indicates that the HGR tool was successful in communicating both the Linked Gantt Chart schedule and the Flowline graph. In other words, the research concluded that the HGR tool could communicate both logical relationships from the LGC and spatial relationships from the FLG.

The majority of the construction industry currently treats and thinks of activity-based scheduling and location-based scheduling as two different and distinct scheduling systems. In creating, updating and managing construction processes, they perceive each scheduling method as a separate system, and are forced to choose one over the other. Due to a number of reasons, the choice is usually activity-based scheduling. Factors like the availability of developed supporting software programs and the predominance of activity-based scheduling techniques, like the Critical Path Method (CPM), in the industry play a major role in that decision. Unfortunately, both the activity and location-based scheduling techniques have numerous documented advantages and benefits, when implemented in any given project, which schedulers are forsaking when making a choice of utilizing one and disregarding the other.

What most construction schedules' planners and users overlook is the fact that, in essence, both activity-based and location-based scheduling techniques are linked and show, more or less, the same data in different interfaces. While a CPM schedule presents the relationships between project activities in the form of Gantt bars, the Flowline graph shows the same activities in the form of flow-lines through different project locations. They both share the same X-axis of *time* but have different Y-axis, for a Linked Gantt Chart schedule its *activities*, and for a Flowline graph its *locations*. As a matter of fact, the software company Vico® provides a scheduling software program called Vico® Control that provides users the option of using a Linked Gantt Chart view or a Flowline graph view of the same project schedule. However, looking at the Linked Gantt Chart interface or a Flowline graph interface of the project schedule, a user could not intuitively visualize how the two are linked. Tracking a single activity in both schedules and associating how the activity is related to other activities and where it is planned to take place using shear visual capacities could prove to be a very challenging feat.

The significance of the proposed Hybrid Graphical Representation (HGR) is its ability to visually link Gantt bars from the activity-based scheduling method and flow-lines generated by the location-based scheduling method in one system. The research HGR tool was found to provide better graphical communication of project schedules by showing the user *what* (logical relationships between activities) has to be done and *where* (spatial relationships between activities) it is taking place. So it uses visual representation to improve human cognitive process. With more research and development the HGR could act as a link between activity and location based scheduling methods, and support the growing need for techniques and methods to schedule and manage projects more effectively and efficiently.

7.4 Further Research

Activity-based scheduling and location-based scheduling are currently two stand alone, distinctly different project scheduling and simulation approaches. They are perceived as two unique theories of planning and managing project schedules from inception to turnover. The Linked Gantt Chart (LGC) is the product of activity-based scheduling, while the Flowline graph (FLG) is the product of the location-based scheduling. The findings of this research demonstrated how the Hybrid Graphical Representation (HGR) is capable of visually combining Linked Gantt Charts (LGC) showing logical relationships of scheduled activities, with Flowline graphs (HGR) showing the activities' spatial relationships. Further research could be conducted to investigate the ability of the Hybrid Graphic Representation tool in aiding the user to make a visual connection between the location of every activity (by looking at the Flowline graph interface) and the logical relationship of that activity with other activities (looking at the Linked Gantt Chart interface). Could the HGR user make decisions concerning the logical and spatial attributes of the schedule activities just by studying visually on the HGR interface?

As explained in previous sections there are various benefits for utilizing both scheduling approaches (activity-based and location-based), and having the ability to implement both systems for the same project schedule could prove beneficial. For example, by visualizing the LGC and FLG on the HGR system the user could appreciate how both schedules are different or similar. The user could realize the graphical link between LGC and FLG and how they both present different information about a schedule from the same project. The user could visually comprehend what is inherently different and/or similar in each system. A recommendation for further research would be to explore if the HGR tool could be used as an educational tool (e.g., in scheduling classes) to help explain how the graphical representations of the LGC and FLG are linked and aid in visually understanding the similarities and differences between them. Perhaps even explore if the HGR tool could be used as a transitional tool for individuals or companies who are trying to make the transition from using the more familiar activity-based scheduling approach, to utilizing location-based scheduling systems on their projects, or vise-versa.

Another possibility for further investigation is evaluating the ability of the HGR tool to be used as a communication tool. For example, a professional scheduler could be utilizing the FLG to manage project locations and wish to present their schedule to an audience only familiar with Gantt charts while still explaining their scheduling rationale. Using the HGR schedule could allow the user to explain their scheduling rationale on the FLG view, while showing the audience how it looks like on a Linked Gantt Chart view and help the audience make the visual link between them.

A future study could also involve developing a software program that supports and generates Hybrid Graphical Representation (HGR) schedules. Then, a study could be conducted to evaluate the ability of the HGR tool to merge the LGC with the FLG to the point where a user could seamlessly switch between the two scheduling interfaces, apply changes on both interfaces, have the ability to track and recognize these changes, and use HGR for producing, updating, and managing project schedules. In theory, using the generated 3D output, the user is expected to have the ability to link, understand, track and apply changes to both scheduling interfaces (Linked Gantt Chart and Flowline graph). This is accomplished by seamlessly transitioning between the top and front views of the HGR. Such a software program will really identify if the HGR tool could comprehensively merge both scheduling methods (activity-based and location-based) to the point where it captures their intrinsic advantages by allowing the user to visually understand and manipulate both the LGC and FLG schedules on the HGR's common xyz coordinate system. This will not only lead to the development of better and more accurate schedule, but could also save time, money and effort in constructing, maintaining and improving these schedules in all stages of the project.

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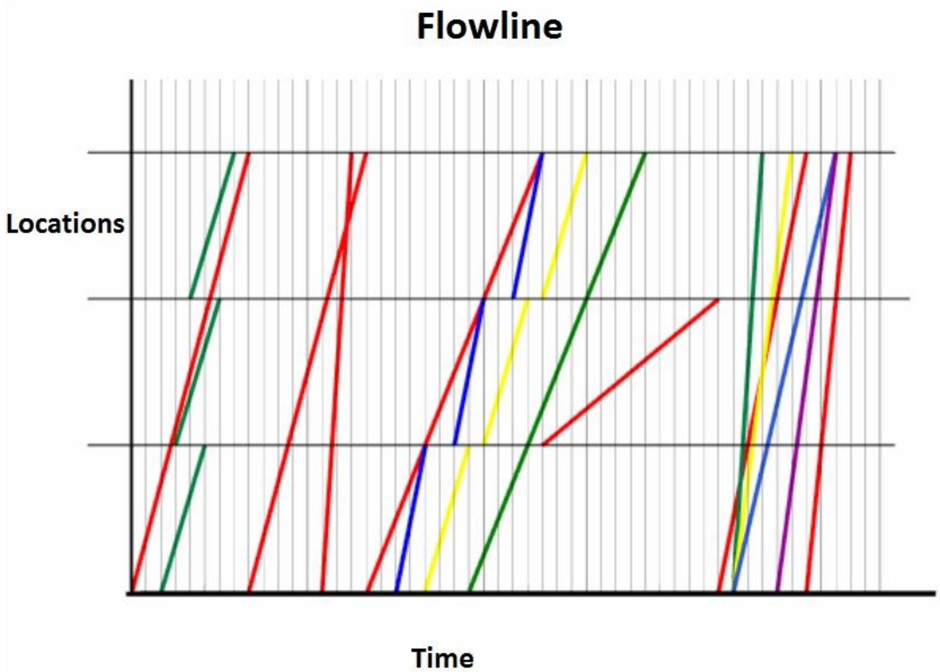
APPENDIX I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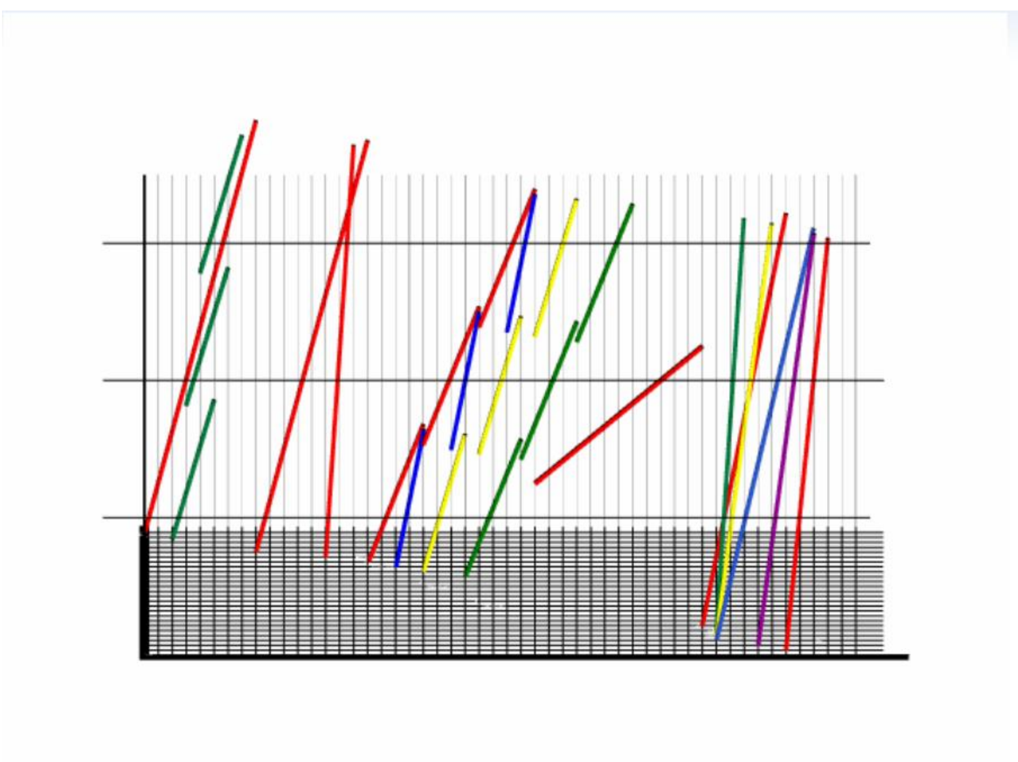
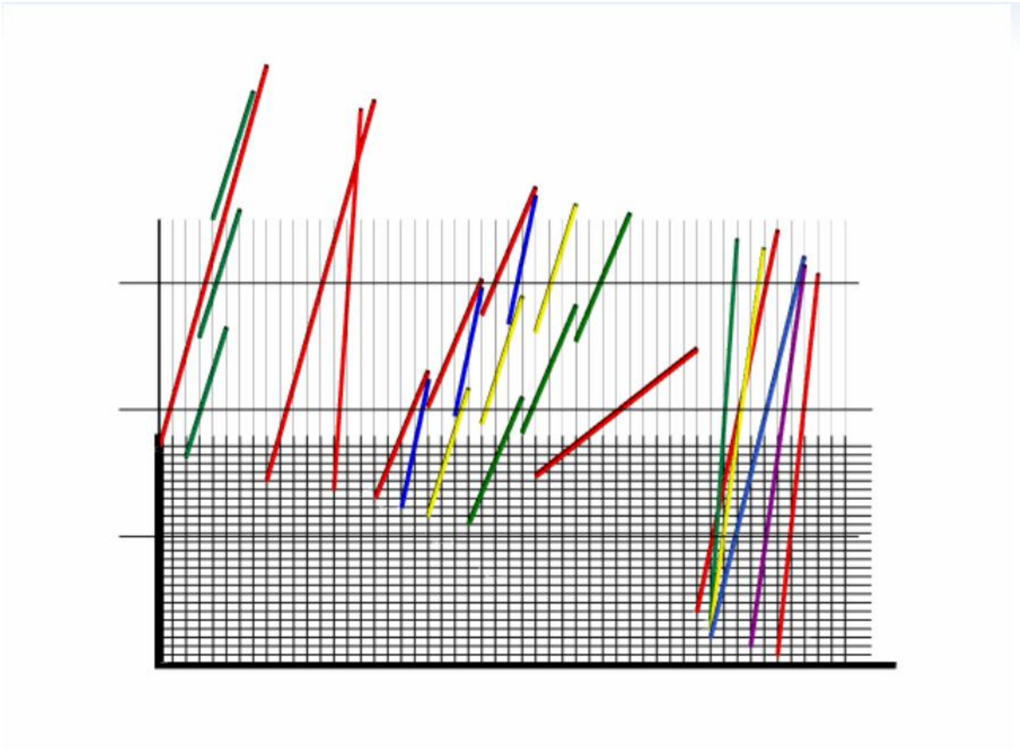
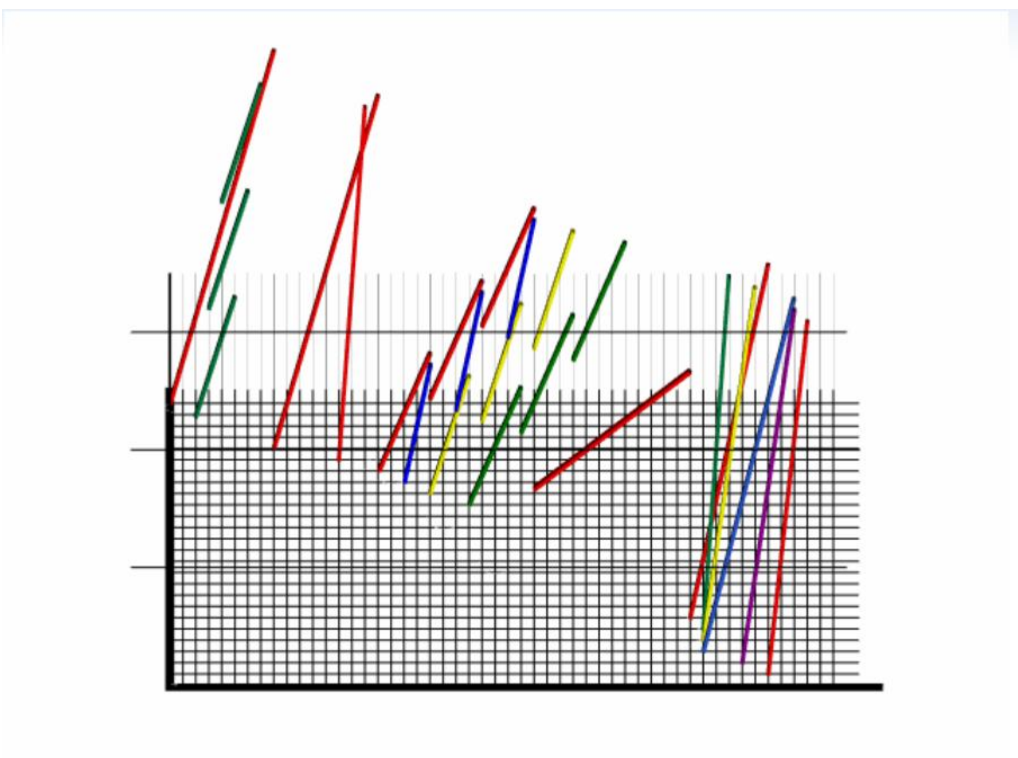
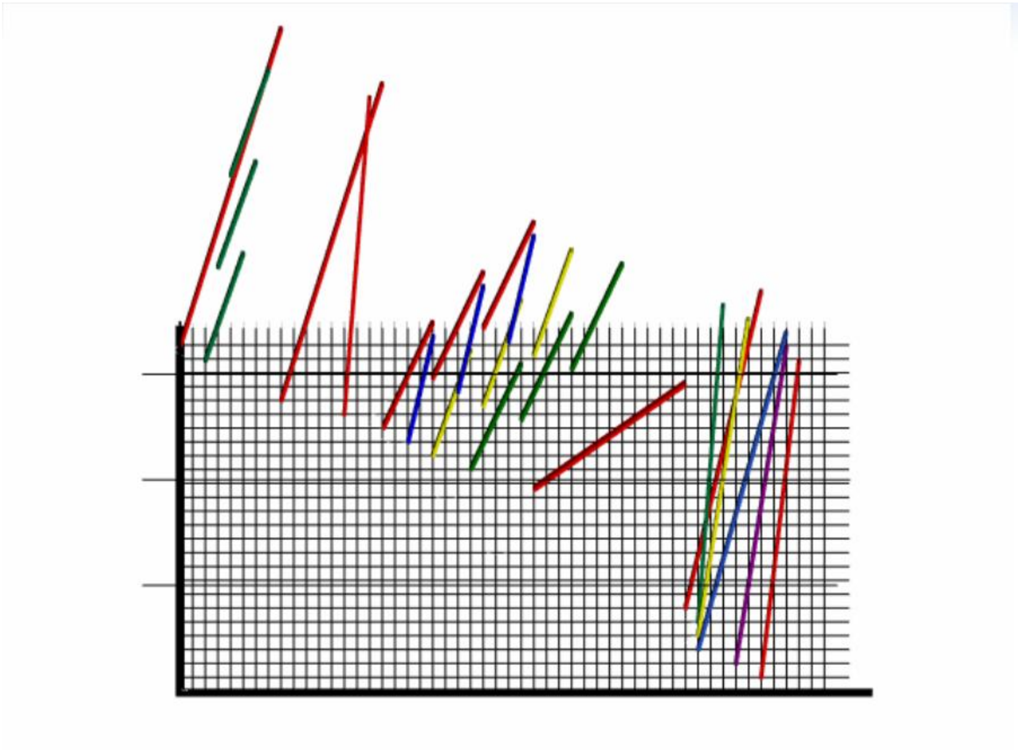
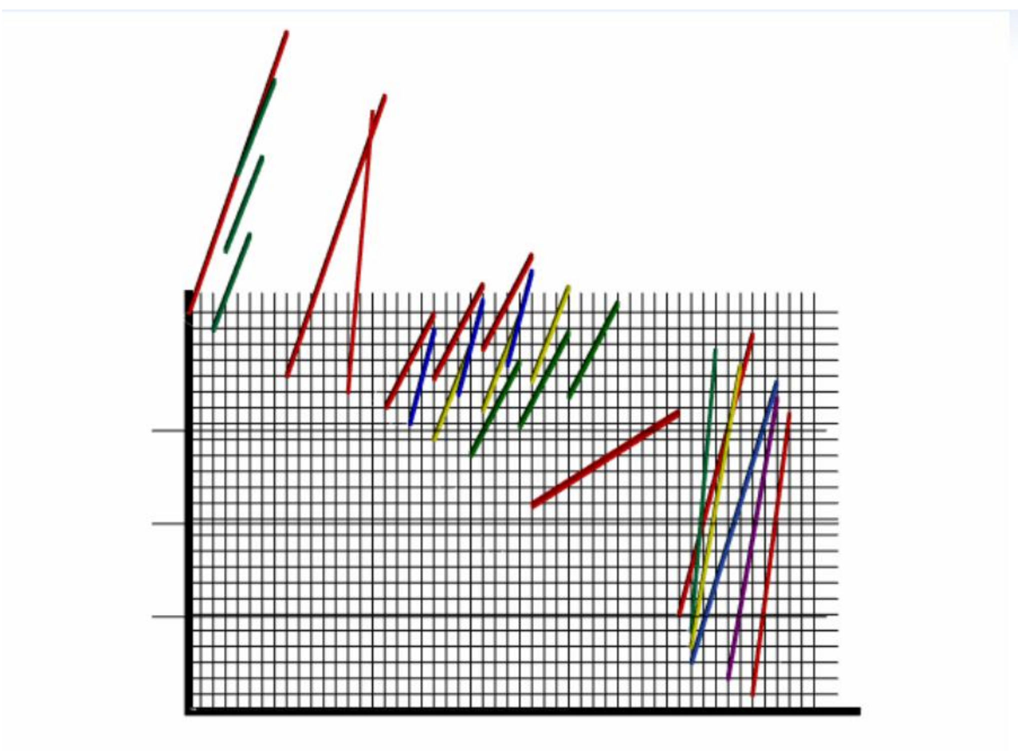
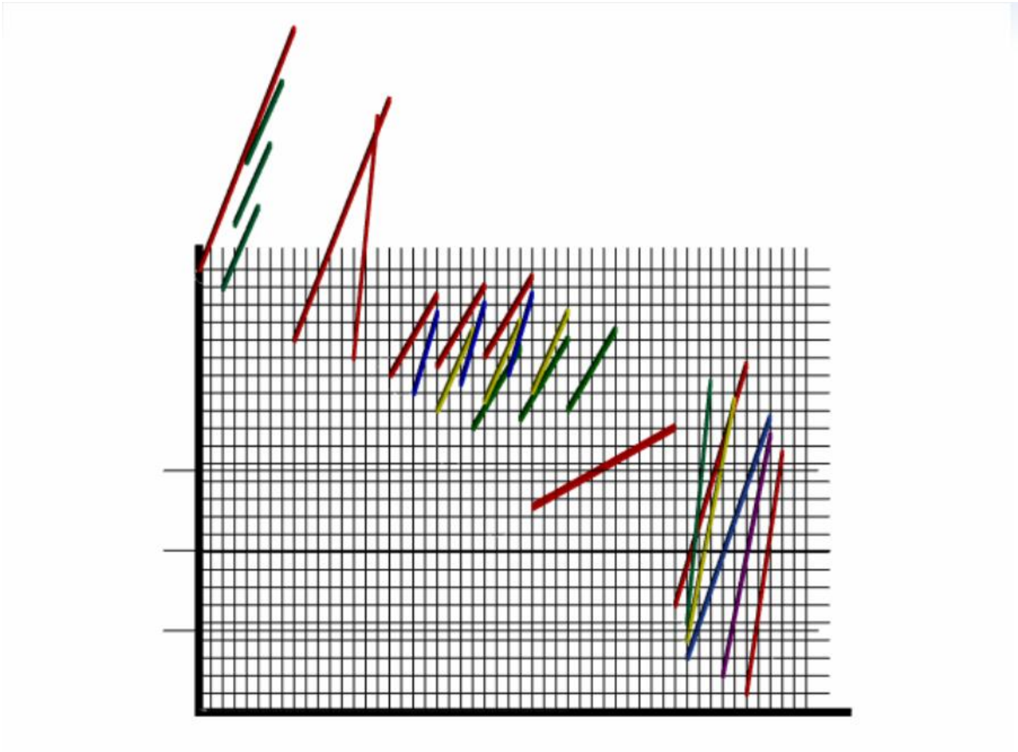


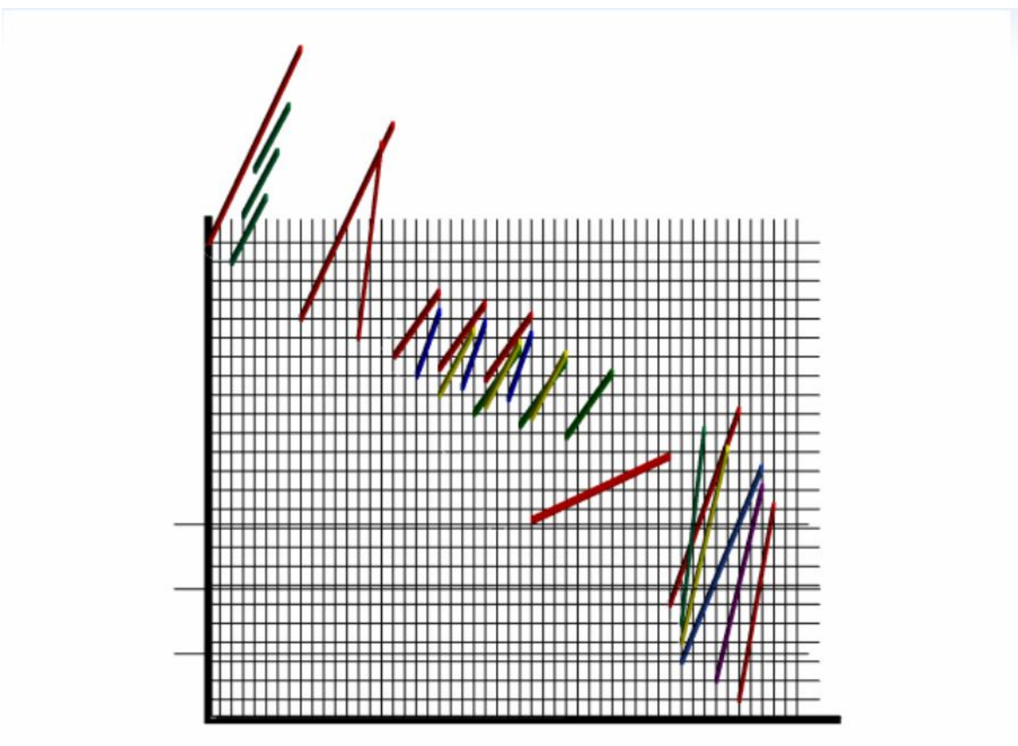


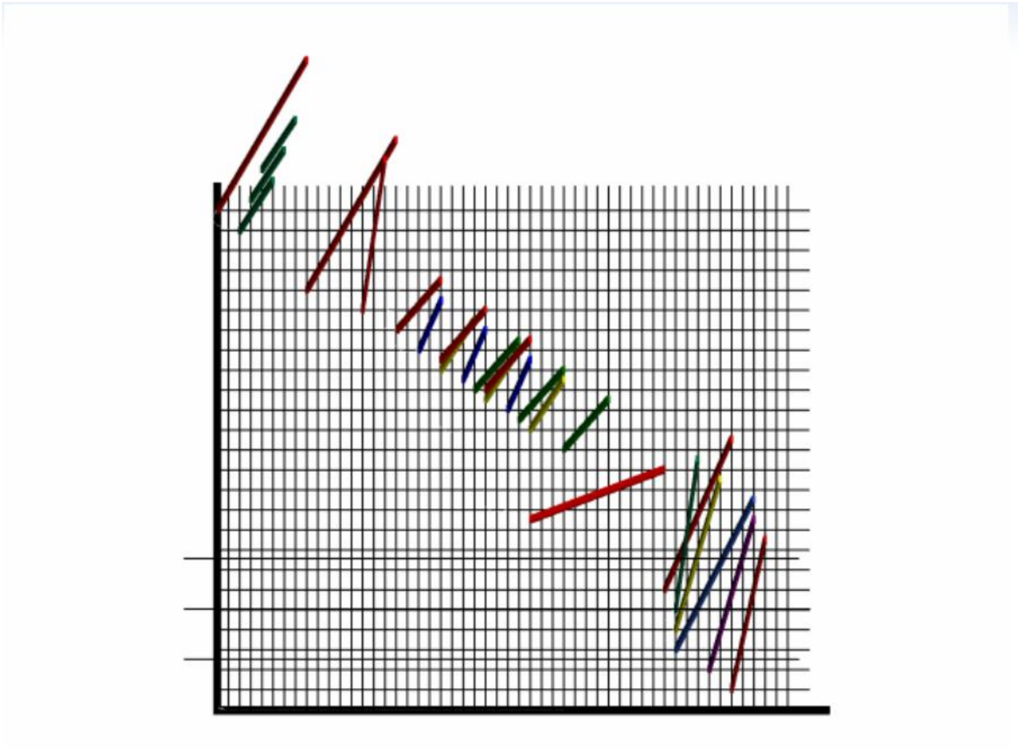


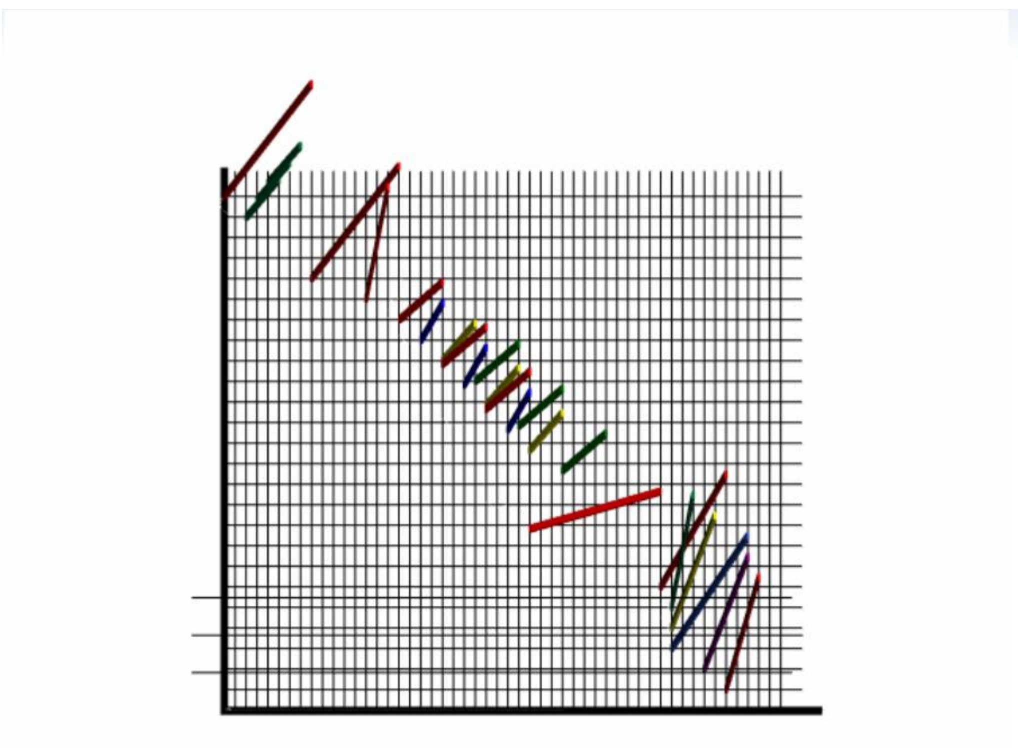


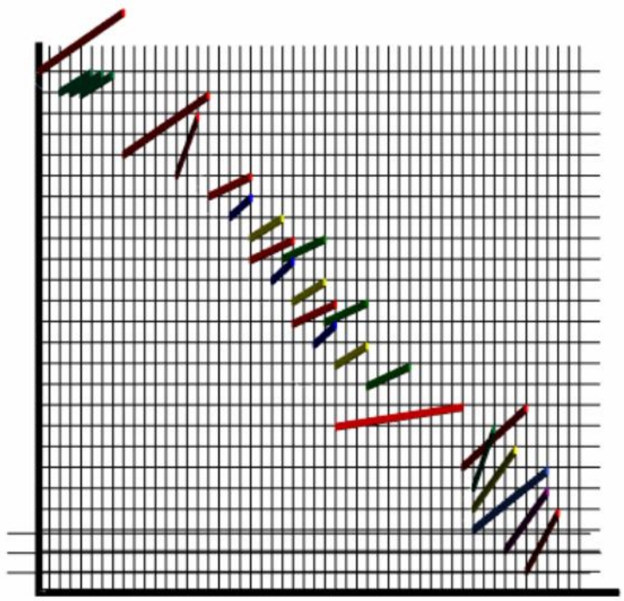


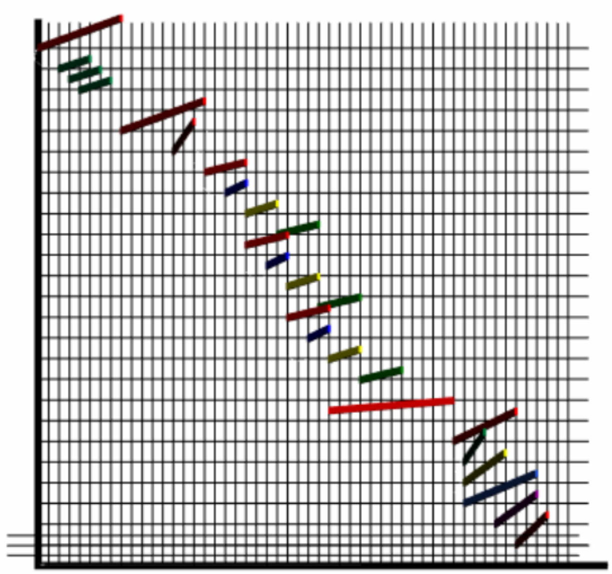


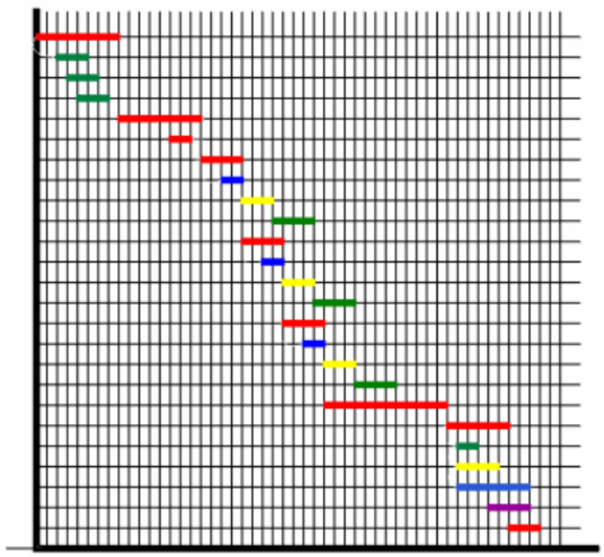




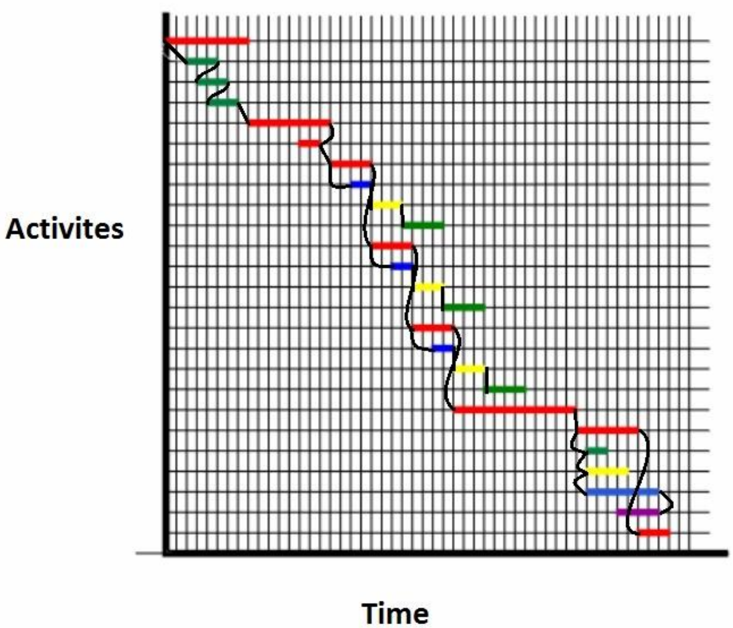








Linked Gantt Chart



APPENDIX II

Survey I – Linked Gantt Chart

Information Sheet

Institutional Review Board (IRB) - Research Information Sheet

Introduction

The purpose of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research.

You have been asked to participate in a research study that evaluates a new proposed visualization scheduling method called the Hybrid Graphical Representation. The purpose of this study is to empirically validate the ability of the proposed Hybrid Graphical Representation (HGR) to visually communicate construction schedules activities' duration, location and relationships, compared to comprehending the same information by looking at Gantt bars produced by the Critical Path Method (CPM) scheduling or flow-lines generated by the Line of Balance (LOB) scheduling technique. You were selected to be a possible participant because you are a student working in the areas of architecture, construction, and civil engineering in the Civil Engineering and Construction Science Departments at Texas A&M University.

What will I be asked to do?

If you agree to participate in this study, you will be asked to fill the emailed online survey to the best of your ability and knowledge. This study will take about an hour to complete. You will be getting extra credit for participating in the survey. You will be asked to provide your email for organization purposes to enable the researcher to track who completed the survey and should receive the extra credit. If you choose not to participate you could get the same amount of extra credit by doing the alternative reading assignment. The assignment involves reading an article and writing a paragraph summarizing the article's content, and answering two questions about the article.

What are the risks involved in this study?

The risks associated with this study are minimal, and are not greater than risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation might include learning new scheduling techniques and getting exposed to new construction scheduling methods.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University being affected.

Who will know about my participation in this research study?

The records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. This study is confidential and records will be stored securely and only I (Meena Nageeb) will have access to the records. Information about you will be kept confidential to the extent permitted or required by law.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Meena R. Nageeb at phone (979) 777 0593 and/or email: meena.nageeb@tamu.edu

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979)458-4067 or irb@tamu.edu.

Participation

Please be sure you have read the above information, asked questions and received answers to your satisfaction. If you would like to be in the study, please check the *I agree* check-box, and click next to start the survey.

[ ] I have read, understood, and agree to the information above.

Background

What is your course number?*

____

What is your email?*

____

Have you ever prepared, used, or seen a project schedule?*

( ) Yes

( ) No

Welcome

Thank you for taking the time to participate in this survey. The survey will begin with a video tutorial to demonstrate and explain the 3 scheduling visualization methods investigated by this study. After watching the tutorial, you will be asked to answer 10 multiple-choice questions using one of the three scheduling visualization methods. The survey will record your accuracy and time in answering each question. The recorded time will not include watching the video tutorial, the time recording will start once you start answering the questions.

After going through the video tutorial, please study the schedule carefully and then click "Next" to start the questions part of the survey. Read each question carefully and consider all the possible choices provided before answering the question.

Please note that each question has a choice of "*Don't know and/or can't tell from the information provided*," choose that answer after considering all the options provided. Some questions could not be answered using a certain scheduling visualization method.

Please note that you could zoom in from the *view* menu in your web browser to enlarge the text and figures included in the survey. The survey is expected to take around 1 hour to complete.

Again, thank you, your participation is greatly appreciated.

The survey will begin with the video tutorial. This is an audio/video presentation so you will need to listen to what is being explained in the tutorial. Please make sure you have your headphones, or any other listening devices ready. Also check that you have all the necessary plugins installed and updated to display media. If your web browser showed a message that "only secure content is displayed," please change it so that it will "show all content."

You could watch the video tutorial more than once, pause the video at any time and/or go back to re-watch certain sections if you wish to do so. When you are done please click "Next" to start the survey.

If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

After watching the tutorial do you feel like you understand the three scheduling visualization techniques? (You can choose more than one answer)*

[ ] I understand the Linked Gantt Chart

[ ] I understand the Flowline graph

[ ] I understand the Hybrid Graphical Representation (HGR)

[ ] I do not understand any of the scheduling visualization methods listed above

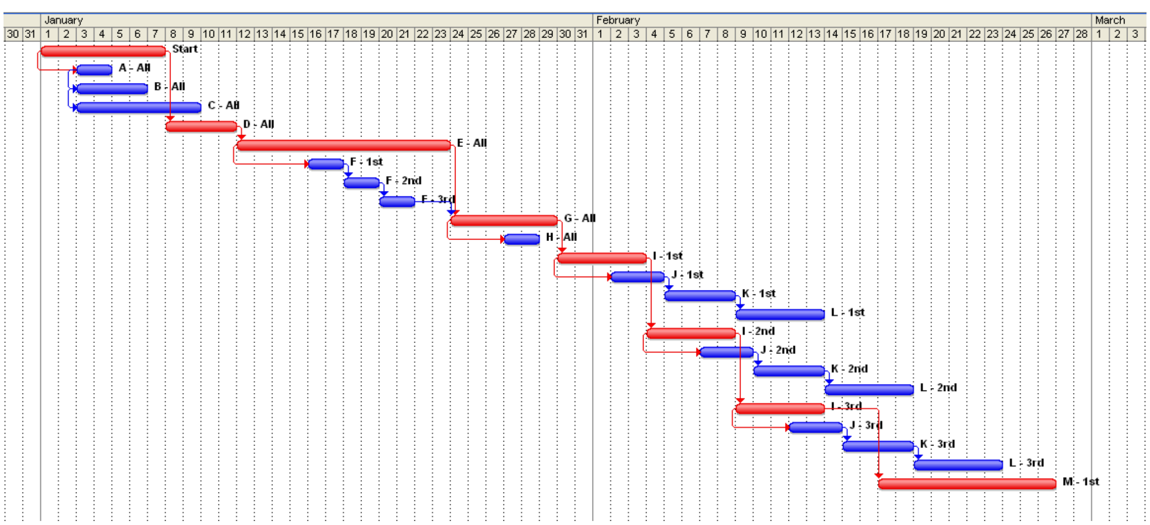
---

Linked Gantt Chart (LGC)

This section is not timed.

Please examine the Linked Gantt Chart (LGC) shown below (produced by Microsoft® Project software program). The activities' names are shown next to each bar. Time is shown on the x-axis on the top side of the chart.

The *critical path* activities (see below) are shown as red bars and non-critical activities are blue bars.



Relationships between activities are shown in the form of arrows (relationships of critical activities are shown as red arrows). You could scroll left and right to see the whole schedule. Please note that the location of each activity is shown as part of the activities' name (e.g., *F-1st* denotes that activity F is taking place in the first floor).

There are 3 floors in this project:

- 1st denotes that the activity is scheduled to take place in the first floor.
- 2nd denotes that the activity is scheduled to take place in the second floor.
- 3rd denotes that the activity is scheduled to take place in the third floor.
- All denotes that the activity is scheduled to take place in all three floors. The activity will start on the first floor, then second, then third.

In the next section you will be asked 10 questions about the Linked Gantt Chart schedule shown below. Please answer the questions to the best of your ability and note that the next section is timed. After examining the schedule click "next" for the questions part of the survey to commence.

Time will start when you click "Next"

---

1) Please identify the first three activities on the critical path of this project.*

( ) A - All, B - All, C - All

( ) Start, D - All, E - All

( ) F - 1st, F - 2nd, F - 3rd

( ) I - 2nd, 1- 3rd, M - 1st

( ) Don't know and/or can't tell from the information provided.

---

2) Which activity on the critical path has the longest duration?*

( ) Start

( ) E - All

( ) G - All

( ) H - All

( ) Don't know and/or can't tell from the information provided.

---

3) How many activities have a Start-to-Start (SS) relationship with a succeeding activity? (Note: Some SS dependencies do not have lags, so they start on the same day)*

( ) 0

( ) 3

( ) 8

( ) 20

( ) Don't know and/or can't tell from the information provided.

---

4) Which activity has a Finish-to-Start (FS) relationship with the longest lag time?*

( ) Start

( ) I - 1st

( ) I - 2nd

( ) I - 3rd

( ) Don't know and/or can't tell from the information provided.

---

5) There is a Start-to-Start (SS) relationship between the Start activity and the A-All activity with a lag time. How long is this lag?*

( ) 0 days

( ) 2 days

( ) 4 days

( ) 6 days

( ) Don't know and/or can't tell from the information provided.

---

6) Which of the activities on the 1st floor has the longest duration?*

( ) E - All

( ) I - 1st

( ) L - 1st

( ) M - 1st

( ) Don't know and/or can't tell from the information provided.

---

7) There are a number of days, on the 3rd floor, where more than one activity is scheduled to take place simultaneously on that given day. For example, day 21 has activities *F-3rd* ***and*** *E-All* ***both scheduled to take place in the 3rd floor concurrently. Having more than one activity scheduled at the same time in the same location could cause problems pertaining to site congestions and lower productivity of crews. About how many days on the 3rd floor will involve more than one activity taking place simultaneously?****

( ) 0 - 5 days

( ) 5 - 10 days

( ) 10 - 15 days

( ) 15 - 20 days

( ) Don't know and/or can't tell from the information provided.

---

8) If activity G-All is required to be completed on any given floor before activity H-All starts on that floor, looking at the schedule, on which floor would you anticipate a problem may occur?*

( ) 1st floor

( ) 2nd floor

( ) 3rd floor

( ) No where

( ) Don't know and/or can't tell from the information provided.

---

9) Which floor will have the longest period of no work scheduled to take place in that location (i.e. the floor with the longest idle time)?*

( ) 1st floor

( ) 2nd floor

( ) 3rd floor

( ) Don't know and/or can't tell from the information provided.

---

10) The 3rd floor will have the longest period of idle time in the project. Which activity if pushed back could use that idle time?*

( ) I - 3rd

( ) J - 3rd

( ) K - 3rd

( ) L - 3rd

( ) Don't know and/or can't tell from the information provided.

Thank You!
Thank you for taking our survey. Your response is highly appreciated.

Survey II – Flowline Graph

Information Sheet

Institutional Review Board (IRB) - Research Information Sheet

Introduction

The purpose of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research.

You have been asked to participate in a research study that evaluates a new proposed visualization scheduling method called the Hybrid Graphical Representation. The purpose of this study is to empirically validate the ability of the proposed Hybrid Graphical Representation (HGR) to visually communicate construction schedules activities' duration, location and relationships, compared to comprehending the same information by looking at Gantt bars produced by the Critical Path Method (CPM) scheduling or flow-lines generated by the Line of Balance (LOB) scheduling technique. You were selected to be a possible participant because you are a student working in the areas of architecture, construction, and civil engineering in the Civil Engineering and Construction Science Departments at Texas A&M University.

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Whom do I contact with questions about the research?

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[ ] I have read, understood, and agree to the information above.

Background

What is your course number?*

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What is your email?*

____

Have you ever prepared, used, or seen a project schedule?*

( ) Yes

( ) No

Welcome

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After watching the tutorial do you feel like you understand the three scheduling visualization techniques? (You can choose more than one answer)*

[ ] I understand the Linked Gantt Chart

[ ] I understand the Flowline graph

[ ] I understand the Hybrid Graphical Representation (HGR)

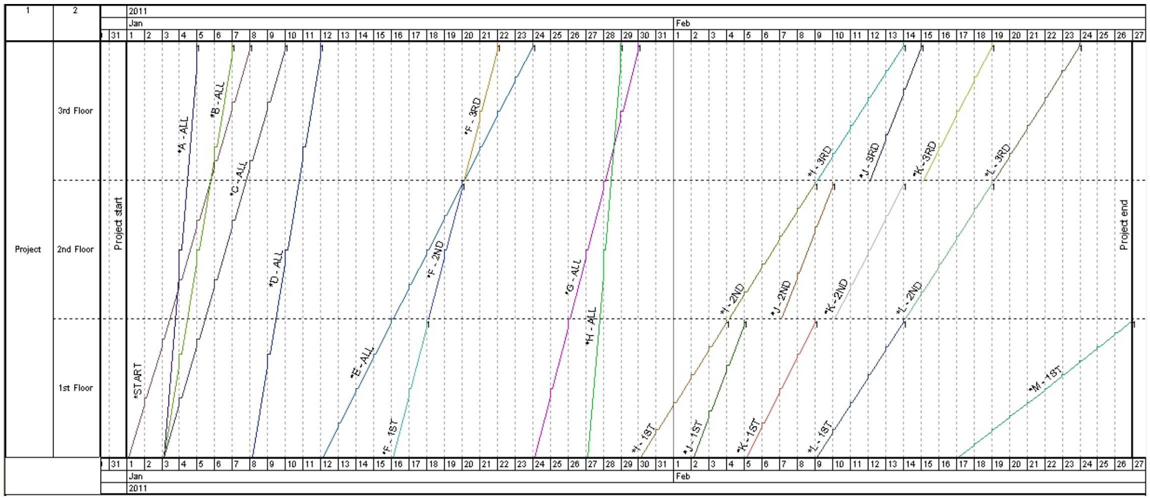
[ ] I do not understand any of the scheduling visualization methods listed above

---

Flowline (FL)

This section is not timed.

Please examine the Flowline schedule shown below (produced by the Vico® Control software program). There are 3 floors shown as locations on the y-axis, and time is shown on the x-axis both on top and below the chart. Activities names are shown on the lines. You could scroll left and right to see the whole schedule.



Please note that the location of each activity is shown as part of the activities' name (e.g., *F-1st* denotes that activity F is taking place in the first floor).

There are 3 floors in this project:

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- 2nd denotes that the activity is scheduled to take place in the second floor.
- 3rd denotes that the activity is scheduled to take place in the third floor.
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Time will start when you click "Next"

---

1) Please identify the first three activities on the critical path of this project.*

( ) A - All, B - All, C - All

( ) Start, D - All, E - All

( ) F - 1st, F - 2nd, F - 3rd

( ) I - 2nd, 1- 3rd, M - 1st

( ) Don't know and/or can't tell from the information provided.

---

2) Which activity on the critical path has the longest duration?*

( ) Start

( ) E - All

( ) G - All

( ) H - All

( ) Don't know and/or can't tell from the information provided.

---

3) How many activities have a Start-to-Start (SS) relationship with a succeeding activity? (Note: Some SS dependencies do not have lags, so they start on the same day)*

( ) 0

( ) 3

( ) 8

( ) 20

( ) Don't know and/or can't tell from the information provided.

---

4) Which activity has a Finish-to-Start (FS) relationship with the longest lag time?*

( ) Start

( ) I - 1st

( ) I - 2nd

( ) I - 3rd

( ) Don't know and/or can't tell from the information provided.

---

5) There is a Start-to-Start (SS) relationship between the Start activity and the A-All activity with a lag time. How long is this lag?*

( ) 0 days

( ) 2 days

( ) 4 days

( ) 6 days

( ) Don't know and/or can't tell from the information provided.

6) Which of the activities on the 1st floor has the longest duration?*

( ) E - All

( ) I - 1st

( ) L - 1st

( ) M - 1st

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7) There are a number of days, on the 3rd floor, where more than one activity is scheduled to take place simultaneously on that given day. For example, day 21 has activities *F-3rd* ***and*** *E-All* ***both scheduled to take place in the 3rd floor concurrently. Having more than one activity scheduled at the same time in the same location could cause problems pertaining to site congestions and lower productivity of crews. About how many days on the 3rd floor will involve more than one activity taking place simultaneously?****

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( ) 15 - 20 days

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( ) 2nd floor

( ) 3rd floor

( ) No where

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9) Which floor will have the longest period of no work scheduled to take place in that location (i.e. the floor with the longest idle time)?*

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( ) 3rd floor

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---

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( ) I - 3rd

( ) J - 3rd

( ) K - 3rd

( ) L - 3rd

( ) Don't know and/or can't tell from the information provided.

Thank You!

Thank you for taking our survey. Your response is highly appreciated.

Survey III – Hybrid Graphical Representation

Information Sheet

Institutional Review Board (IRB) - Research Information Sheet

Introduction

The purpose of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research.

You have been asked to participate in a research study that evaluates a new proposed visualization scheduling method called the Hybrid Graphical Representation. The purpose of this study is to empirically validate the ability of the proposed Hybrid Graphical Representation (HGR) to visually communicate construction schedules activities' duration, location and relationships, compared to comprehending the same information by looking at Gantt bars produced by the Critical Path Method (CPM) scheduling or flow-lines generated by the Line of Balance (LOB) scheduling technique. You were selected to be a possible participant because you are a student working in the areas of architecture, construction, and civil engineering in the Civil Engineering and Construction Science Departments at Texas A&M University.

What will I be asked to do?

If you agree to participate in this study, you will be asked to fill the emailed online survey to the best of your ability and knowledge. This study will take about an hour to complete. You will be getting extra credit for participating in the survey. You will be asked to provide your email for organization purposes to enable the researcher to track who completed the survey and should receive the extra credit. If you choose not to participate you could get the same amount of extra credit by doing the alternative reading assignment. The assignment involves reading an article and writing a paragraph summarizing the article's content, and answering two questions about the article.

What are the risks involved in this study?

The risks associated with this study are minimal, and are not greater than risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation might include learning new scheduling techniques and getting exposed to new construction scheduling methods.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University being affected.

Who will know about my participation in this research study?

The records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. This study is confidential and records will be stored securely and only I (Meena Nageeb) will have access to the records. Information about you will be kept confidential to the extent permitted or required by law.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Meena R. Nageeb at phone (979) 777 0593 and/or email: meena.nageeb@tamu.edu

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979)458-4067 or irb@tamu.edu.

Participation

Please be sure you have read the above information, asked questions and received answers to your satisfaction. If you would like to be in the study, please check the *I agree* check-box, and click next to start the survey.

[ ] I have read, understood, and agree to the information above.

Background

What is your course number?*

____

What is your email?*

____

Have you ever prepared, used, or seen a project schedule?*

( ) Yes

( ) No

Welcome

Thank you for taking the time to participate in this survey. The survey will begin with a video tutorial to demonstrate and explain the 3 scheduling visualization methods investigated by this study. After watching the tutorial, you will be asked to answer 10 multiple-choice questions using one of the three scheduling visualization methods. The survey will record your accuracy and time in answering each question. The recorded time will not include watching the video tutorial, the time recording will start once you start answering the questions.

After going through the video tutorial, please study the schedule carefully and then click "Next" to start the questions part of the survey. Read each question carefully and consider all the possible choices provided before answering the question.

Please note that each question has a choice of "*Don't know and/or can't tell from the information provided*," choose that answer after considering all the options provided. Some questions could not be answered using a certain scheduling visualization method.

Please note that you could zoom in from the view menu in your web browser to enlarge the text and figures included in the survey. The survey is expected to take around 1 hour to complete.

Again, thank you, your participation is greatly appreciated.

The survey will begin with the video tutorial. This is an audio/video presentation so you will need to listen to what is being explained in the tutorial. Please make sure you have your headphones, or any other listening devices ready. Also check that you have all the necessary plugins installed and updated to display media. If your web browser showed a message that "only secure content is displayed," please change it so that it will "show all content."

You could watch the video tutorial more than once, pause the video at any time and/or go back to re-watch certain sections if you wish to do so. When you are done please click "Next" to start the survey.

If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

After watching the tutorial do you feel like you understand the three scheduling visualization techniques? (You can choose more than one answer)*

[ ] I understand the Linked Gantt Chart

[ ] I understand the Flowline graph

[ ] I understand the Hybrid Graphical Representation (HGR)

[ ] I do not understand any of the scheduling visualization methods listed above

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Hybrid Graphical Representation (HGR)

This section is not timed.

As explained in the tutorial, the Hybrid Graphical Representation (HGR) allows the user to see the activities' relationships, observe a critical path, and be able to communicate the schedule in the Linked Gantt Chart method by using the top view. Switching to the front view of the Hybrid Graphical Representation tool, the user will recognize where each activity is planned to take place.

Please play the video below. Notice that the beginning of the video shows a Linked Gantt Chart interface (top view) of the schedule, and towards the end of the clip you should see the Flowline view (front view) of the same schedule. Put the video on pause and slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames. If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

Please examine the Linked Gantt Chart (LGC) shown at the beginning of the video. Notice that the activities names are listed in order on the y-axis with their durations. For example, the first activity's name is *Start* and has a duration of 7 days **7d**. Relationships between activities are shown in the form of arrows.

The *critical path activities* are shown as red bars, and non-critical activities are shown in other colors. Please note that the location of each activity is shown as part of the activities' name (e.g., *F-1st* denotes that activity F is taking place in the first floor).

There are 3 floors in this project:

- 1st denotes that the activity is scheduled to take place in the first floor.
- 2nd denotes that the activity is scheduled to take place in the second floor.
- 3rd denotes that the activity is scheduled to take place in the third floor.
- All denotes that the activity is scheduled to take place in all three floors. The activity will start on the first floor, then second, then third.

Now, please slide the scroller to the end of the video while remaining on pause. You should see a Flowline schedule. Notice that the three locations of the project are shown on the y-axis, and time is shown on the x-axis. The activities names are shown on the lines.

In the next section you will be asked 10 questions about the Hybrid Graphical Representation schedule shown below. Please answer the questions to the best of your ability and note that the next section is timed. After examining the schedule click "next" for the questions part of the survey to commence.

Time will start when you click "Next"

1

Please play the video below, then put it on pause.

Slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames.

The beginning of the video shows a Linked Gantt Chart schedule and the end shows a Flowline schedule.

If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

1) Please identify the first three activities on the critical path of this project.*

( ) A - All, B - All, C - All

( ) Start, D - All, E - All

( ) F - 1st, F - 2nd, F - 3rd

( ) I - 2nd, 1- 3rd, M - 1st

( ) Don't know and/or can't tell from the information provided.

2

Please play the video below, then put it on pause.

Slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames.

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2) Which activity on the critical path has the longest duration?*

( ) Start

( ) E - All

( ) G - All

( ) H - All

( ) Don't know and/or can't tell from the information provided.

3

Please play the video below, then put it on pause.

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3) How many activities have a Start-to-Start (SS) relationship with a succeeding activity? (Note: Some SS dependencies do not have lags, so they start on the same day)*

( ) 0

( ) 3

( ) 8

( ) 20

( ) Don't know and/or can't tell from the information provided.

4

Please play the video below, then put it on pause.

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4) Which activity has a Finish-to-Start (FS) relationship with the longest lag time?*

( ) Start

( ) I - 1st

( ) I - 2nd

( ) I - 3rd

( ) Don't know and/or can't tell from the information provided.

5

Please play the video below, then put it on pause.

Slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames.

The beginning of the video shows a Linked Gantt Chart schedule and the end shows a Flowline schedule.

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5) There is a Start-to-Start (SS) relationship between the Start activity and the A-All activity with a lag time. How long is this lag?*

( ) 0 days

( ) 2 days

( ) 4 days

( ) 6 days

( ) Don't know and/or can't tell from the information provided.

6

Please play the video below, then put it on pause.

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The beginning of the video shows a Linked Gantt Chart schedule and the end shows a Flowline schedule.

If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

6) Which of the activities on the 1st floor has the longest duration?*

( ) E - All

( ) I - 1st

( ) L - 1st

( ) M - 1st

( ) Don't know and/or can't tell from the information provided.

7

Please play the video below, then put it on pause.

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If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

7) There are a number of days, on the 3rd floor, where more than one activity is scheduled to take place simultaneously on that given day. For example, day 21 has activities F-3rd ***and*** E-All ***both scheduled to take place in the 3rd floor concurrently. Having more than one activity scheduled at the same time in the same location could cause problems pertaining to site congestions and lower productivity of crews. About how many days on the 3rd floor will involve more than one activity taking place simultaneously?****

( ) 0 - 5 days

( ) 5 - 10 days

( ) 10 - 15 days

( ) 15 - 20 days

( ) Don't know and/or can't tell from the information provided.

8

Please play the video below, then put it on pause.

Slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames.

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If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

8) If activity G-All is required to be completed on any given floor before activity H-All starts on that floor, looking at the schedule, on which floor would you anticipate a problem may occur?*

( ) 1st floor

( ) 2nd floor

( ) 3rd floor

( ) No where

( ) Don't know and/or can't tell from the information provided.

9

Please play the video below, then put it on pause.

Slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames.

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If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

9) Which floor will have the longest period of no work scheduled to take place in that location (i.e. the floor with the longest idle time)?*

( ) 1st floor

( ) 2nd floor

( ) 3rd floor

( ) Don't know and/or can't tell from the information provided.

10

Please play the video below, then put it on pause.

Slide the scroller slowly to see the transition from one view to the other, or use the left and right arrow keys on your keyboard to move through the frames.

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If you are having a hard time seeing the text you could chose a higher resolution (from 360p to 480p) from the control bar at the bottom of the video.

10) The 3rd floor will have the longest period of idle time in the project. Which activity if pushed back could use that idle time?*

( ) I - 3rd

( ) J - 3rd

( ) K - 3rd

( ) L - 3rd

( ) Don't know and/or can't tell from the information provided.

Thank You!

Thank you for taking our survey. Your response is highly appreciated.

Extra Credit Alternative Assignment

Please read the article titled ***Line of Balance Scheduling: Software Enabled Use in the U.S. Construction Industry (Nageeb & Johnson, 2008)*** and write a half page summary of the main ideas presented by the authors, and answer the following questions.

1. List five of the interviewees' comments regarding the application of Line of Balance scheduling in the construction industry.

2. According to the authors, what are three advantages, and three limitations to using Line of Balance scheduling in the construction industry?

VITA

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