Gantt Resource Management System Applied to Construction

by

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Abstract

The current scheduling techniques such as the Critical Path Method (CPM) do not directly take resources (i.e. material, equipment, manpower) into consideration when producing schedules. As a result resource requirements tend to build up throughout schedules and subsequent conflicts frequently occur. And although contractors normally develop CPM schedules at the planning stages, they frequently manage their project without significant reliance on these schedules during construction. This thesis applies H.L. Gantt's Resource Management System (GRMS), a technique developed in the late 1800's and early 1900's, to the construction brickwork trade on a prototype construction project. This application is then used to demonstrate the potential of the GRMS in addressing practical operational concerns dealing with resource management. In addition, five evaluative criteria are developed and used in making a comparison and contrast between the GRMS of resource management and the current technique utilizing CPM. The results indicate the Gantt Resource Management System best fits the necessary criteria for a successful resource management system.

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Table of Contents

List of Figures

CHAPTER 1

INTRODUCTION

1.1 Background

Although the Critical Path Method (CPM) and the Performance Evaluation and Review Technique (PERT) have been used as planning tools by the construction industry since the 1950's, their effectiveness in use remains an open question. Both methods are built showing interdependencies between activities but often assume no constraints due to resources such as material, equipment, and manpower (Harris 1978). Activity durations are individually estimated independent of resource flow between activities based on contractor's experience, anticipated crew loading, and assumed production rates. With this approach these network techniques can provide reliable schedules for projects under conditions of unfixed deadlines and unrestricted resources. However, project durations in construction are fixed and resource scarce. Consequently, CPM and PERT networks fail to produce realistic project schedules (Hegazy 1990). Moreover, because resource availability is typically not considered in developing CPM or PERT schedules, the demand on resources tend to build up during schedule execution. To alleviate this shortcoming, techniques of resource allocation and leveling were introduced in the 1960's (Harris 1978). Resource allocation schedules necessary resources to execute each scheduled activity. Resource leveling reduces fluctuating demands by adjusting the activities start and finish dates within their slack time. Slack time is the difference between an activity latest and earliest start time.

Using these resource management techniques layered onto an activity scheduling framework means contractors continue to principally manage activity accomplishment without an integrated way of managing resource utilization in the effort. This continued focus on activities rather than resources can be illustrated in that a work disruption would be simply managed as a potential delay in an activity completion and not from the perspective of resource waste, misuse, or idleness, which may potentially led to delays.

To achieve an advantage in the competitive construction market, a management system allowing monitoring and controlling of resources is needed (Hegazy 1999). A system is needed that allows schedules based on required and available resources for executing projects activities more efficiently.

In the late 1800's Henry Laurence Gantt, known to us as the author of the Gantt Chart, developed a resource management system (GRMS) to improve processes in manufacturing by focusing on resources as the basis of production rather than activities. That system can be defined as a management system that produce schedules based on a combination of assigning tasks to the available resources and instruction cards. The conceptual foundations of the Gantt's system are: First, Instruction Card which is a detailed informative schedule of the current best known method of performing a particular task and its estimated or allotted time. Second, scheduling tasks based on the available resources and actively monitoring and controlling resource performance relative to expectations from the bottom to top levels with attributable reasons for deviation from those scheduled. Third, the system provides a visual record of the work achieved overtime. Fourth, it provides an evaluative production tool that enables managers to compare what has been accomplished with what was planned, while also identifying reasons for falling behind by providing the ability to trace the idleness causes and to identify who is responsible.

The GRMS was used to increase the production efficiency within multiple manufacturing industry sectors before and during the World War I. For example, at the Bethlehem steel company, the system was used to reduce the idleness and “unnecessary stoppages”, and assures continuous material and production flows. Another example is, at the Remington Type writer Factory the system was used to assure the workmen’s cooperation in increasing production efficiency by 65% (Alford 1916d). That increase led to a saving of the labor expense by about 18% (Alford 1916d).

Right before World War I, Gantt was asked by General William Crozier, the Chief of Ordnance of the Frankford Arsenal, to install his management system to help organize and manage the production in the shop floors and to assure continuous production flow. Alford (1972) indicated that, when the United States entered the War Gantt was also called by the government to install his management tools to help coordinate and keep track “of the production of the multitudinous and extremely varied orders for artillery, small arms, machine guns, ammunition, and explosives.” According to Alford (1972), the GRMS was able to accomplish the following during the War period: “Controlling the production of rifles, guns, ammunition and other war material for the army, speeding the building of ships for the Emergency Fleet Corporation, improving the operation of ships for the shipping Board.”

The main advantages of the GRMS which differentiate it from the other production management tools, are: First, the system consists of interrelated charts (Man Chart, Machine Chart, Layout Chat, Load Chart, and Progress Chart) that are produced based on the available resources, and as a function of time not quantities. All the operations (i.e. tasks) are assigned to what is available of the resources. Second, these charts are interconnected. For example, if the reason for a workman falling behind is the machine that he is using, the man chart would show that cause and the foreman in his part can trace that cause back to the machine chart. Third, these charts are easy to draw and be understood by all the parties under an executive’s level. Fourth, is the ability to present a lot of details in a single sheet, which will save a great amount of time in exploring and collecting information.

1.2 Problem Statement

Over the last 40 years, construction productivity has lagged the gains that have been made in manufacturing. According to Forbes and Ahmed (2011), over a period of 37 years (1966 to 2003) the construction industry has witnessed a flat increase in the construction productivity with a rate of 0.78% annually while manufacturing has seen gains over that same timeframe of 1.75% annually.

Much of the reason behind failures in construction productivity can be attributed to basic flaws and limitations in the currently used management techniques. The first limitation is the lack of a resource oriented planning approach. The techniques that are currently used lack the ability to present the resource usage at a certain period of time. Therefore, it will become complicated for a project manager to determine if a project ran over budget when the amount of resource used differed from the ones assigned (AGC of America 1994). The second limitation is current management techniques do not equip the workforce with the current state of the knowledge of how to perform the work. Planners assume that the workmen who are supposed to execute the activities know how the work should be performed. The third limitation is the complexity of the procedure used to present the reasons behind delays. Although these reasons might be shown in individual reports, it is hard for a project manager to identify these reasons in big projects where thousands of tasks are scheduled. Delays can be caused by waste/ idleness during the construction process or by disruptions caused by owner interference. Waste could be due to equipment breakdown (i.e. equipment are waiting for repairs), lack of help (i.e. labors are waiting for help), lack of materials, lack of tools, and other disruptions.

Another cause for the inefficiency in productivity is the managers' focus on maximizing profit rather than employing processes and techniques for maximizing resource utilization. The planners think providing the required resources, when needed, is the responsibility of project managers and leave them to deal with the dilemma on site (Meredith & Mantel 2000).

The author believes the application of Gantt's Resource Management System to resource scheduling within the construction industry is both possible and beneficial to eliminate the above mentioned limitations and result in gains in productivity and decreases in construction expenditures. This system builds the schedules based on both the available resources and estimates durations based on instruction cards. Therefore, the managers will be able to compare how much each resource is actually being used. The best methods for work is presented using the instruction cards. Therefore, unnecessary motions, which normally lead to wasted time and potential rework, are going to be eliminated. The system also keeps a visual record of the work accomplished compared with the work planned and presents any reason behind idleness. Therefore, the end product is a schedule that allows projects managers to visualize each construction operations component individually. Such system will help overcome the challenges resulted from applying current scheduling techniques.

1.3 Research Question

Is Gantt's Resource Management System, as developed for the manufacturing sector of the early 1900's, applicable for the construction industry of today? If yes, then would it be preferred to those currently used in the industry to manage and schedule resources?

1.4 Nature of the Study

This study provides a description of the resource management system developed by H. L. Gantt at the turn of the 20th century as described by his writings and those of his associates. Along with its description, examples will be provided of its successful implementation in making full use of the productive capacity of available resources when resources were severely limited. These examples will serve to illustrate its potential in the construction industry. Next, the GRMS will be applied to the brick masonry trade, a trade often used in academic literature when researching construction productivity, on a hypothetical project. In this application, the system will be shown: 1) to be both feasible and effective in initially planning the resource schedule. 2) To allow controlling, and monitoring the project during the execution phase so as to make full productive use of the resources. 3) To indicate the inhibiting obstacles that preventing plan achievement. Finally, the GRMS will be evaluated against current technique in resource scheduling against five developed criteria that are considered critical for proper resource scheduling.

1.5 Research Tasks

There are three main tasks for this research as follows:

1. Describe Gantt's Resource Management System as developed and successfully utilized to increase resource productivity.

2. Apply this system to construction and demonstrate its use for both initial planning and project execution phases.
3. Evaluate Gantt's Resource Management System against current technique of resource scheduling using five developed criteria.

1.6 Thesis Development Plan

Chapter 2 reviews the literature of traditional resource scheduling approaches and productivity measures within the construction and manufacturing industries. It also describe Henry Laurence Gantt work before and during the World War I. Chapter 3 outlines the research methodology of demonstrating the viability and preference of Gantt's Resource Management System within current construction industry over current practice. Chapter 4 describes Gantt's Resource Management System from his writings and those of his associates along with illustrative examples of success in improving resource productivity. Chapter 5 applies Gantt's Resource Management System to the brick masonry trade of an illustrative construction project developed using Building Information Modeling (BIM) software. The system description will include both initial planning of resources, and also monitoring and controlling during an illustrative realistic scenario of work within the construction industry. Chapter 6 evaluates Gantt's Resource Management System against those currently suggested for managing resources on construction projects using five criteria that are critical to the success of any system that proposes to manage resources within the dynamic framework of construction. Chapter 7 serve as the research finding and conclusion along with suggesting topics of further research along this line of inquiry.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews background literature in three parts. The first part addresses heuristic techniques of resource allocation and leveling. The second part reviews work in lean concepts related to construction. The third describes Gantt's work within the manufacturing industry between 1880 and 1920.

2.1 Resource Allocation and Leveling

As developed, CPM and PERT schedules often reflect only the physical, sequential order of activity relationships in their diagrammed logic while largely ignoring resources availability, constraints, or usage. However, resources are central to a productive, profitable project. Allocate too many resources and they are underutilized and burden the project with additional costs. Allocate too few and their activities turn to bottlenecks causing increased wait times for other resources and affect the planned workflow sequencing. To alleviate these CPM and PERT scheduling resource concerns heuristic techniques of resource allocation were developed and appended to the scheduling process. Such techniques serve to plan activities around resource utilization and resource leveling, therefore smoothing the flow of those resources between activities.

2.1.1 Resource Allocation

Being activity planning techniques, CPM and PERT schedules are initially developed for a project without concerns over resource limitations. Consequently, when necessary resources are not available as assumed, the project activities tend to face a considerable amount of delay. To alleviate these problems projects planners turn to resource allocation (resource-constrained scheduling), and resource leveling to mitigate the impact of the resource shortages while producing a minimum duration schedule that complies with the resource limitations. There are numerous academically developed resource allocation approaches such as integer programing (IP), branch-and-bound, dynamic programming, and implicit enumeration (Lu and Li 2003). However, these approaches are considered impractical because it is difficult to dynamically track and adjust these plans during project performance. (Hegazy 1999).

Senouci and Adeli (2001) introduced a mathematical model to reduce overall cost of a projects toward an optimal total construction cost using resource leveling and resource constrained scheduling approaches simultaneously. This is accomplished by applying what they called "the patented neural dynamics model of Adeli and Park'' while taking into account activity precedence relationships, multiple crew-strategies, and time-cost trade-off.

Hegazy (1999) proposes an optimization of the resource allocation and leveling based on using genetic algorithms (GAs). Improvements to the resource allocation and leveling profiles is introduced using random activity priorities generated by traditional heuristic rules. A double moment approach is used to evaluate the resource leveling improvements is two steps: 1) Calculate the minimum moment (M_x) to measure the fluctuations in daily resource requirements 2) Calculate the moment around the resource amount (M_y) in order to take into consideration the resource utilization period. GAs are used to come-up with the ideal set of activity priorities that lead to an optimum solution of a shorter schedule and a suitable resource leveling profile.

Lu and Li (2003) introduces a resource-activity critical path method to overcome the existing limitations and aims to produce a working schedule without attempting to produce a shorter project duration. The technique utilizes what is termed *serial fashion* to prioritize the activities when the resources are limited. The term *serial fashion* means a resource will not be released to the resource pool in order to be reallocated unless the current activity using the resource is completed.

In this technique an activity-on-node is used as the network format. A forward pass determines the early-start-time, early-finish-time, and the idle time. Similarly, a backward pass determines late-finish-time, late-start-time, total float, and free float. *Work content* which is defined as the multiplication of the resource demand times the activities' durations, is used as the main heuristic rule to assign the resources to the planned activities (Lu and Li 2003). The activity with the larger work content will be scheduled first in the event of a resource conflict. The authors indicated that the regular heuristic rules of minimum total slack or latest start prioritization can also be embedded in the method.

2.1.2 Resource Levelling

Schedules are usually developed based on the early start and finish dates of the critical path activities. These activities have a zero total float meaning if one of these activities is delayed, the project duration will be extended. This can lead to a fluctuation of the resource usage. However, non-critical activities have float that enables them to start at a later date without delaying project completion. Therefore, to reduce the amount of resources required at a certain period of time and prevent fluctuation, non-critical activities can be scheduled to start at a time later than their early start. This process is known as resource leveling (Harris 1978).

From a project manager's stand point, there are three major objectives of resource leveling: 1) to satisfy the resource limitation not accounted for in the network, 2) to eliminate the fluctuations in the resource demands, 3) to keep a consistent application flow of resource (i.e. a crane needs to have continuous work to perform because it will add a major cost to the project if it stands idle.). In satisfying these objectives two types of resource leveling approaches are presented in Harris (1978). Both the Traditional and Minimum Moment Methods are discussed below.

2.1.2.1 Traditional Method

The Traditional Method starts with identifying the daily resource demands throughout the project by resource loading each schedule activity. Next, a 'satisfactory' resource allocation level is selected as a target minimum. Resource demands throughout the schedule are then tested day-by-day against the assumed target to determine the variation. Activity periods with resource demands larger than the assumed allocation level are identified. Next, for those periods exceeding allocation an activity will be selected based on priority rules to be shifted one day. Resource demands relative to allocations will be reexamined and if necessary another activity will be chosen and shifted until the demands on that day are below the level. The same procedure is applied for each project day until a total duration is reached.

The advantage of this method is its applicability to situations where resource limitation do exist and planning is performed within this constraint.

There are two major disadvantages relative to the Minimum Moment Method. The first disadvantage is that the resources tend to build-up near the end of the project. The second is that fluctuations are not fully eliminated due to demands that may exist below the assumed allocation level.

2.1.2.2 Minimum Moment Method

This method starts as does the traditional method with resource loading. It differs in that each activity is evaluated against a resource improvement factor rather than a set resource allocation limits. The resource improvement factor for a certain activity represents the moment sum improvement for each day when that activity is shifted. The activity with the highest positive improvement factor will be shifted resulting in a minimum moment and leading to level resource demands.

A rectangular shaped histogram about the x-axis is assumed and the moment is computed for each resource as follows:

$$M = \frac{1}{2} w y_i^2$$

M = moment as objective function

w = width of the rectangle reflecting number of days

y = height of rectangle from x-axis reflecting resource demand

After creating the resource loading for activities, a histogram of the resource loading is then produced. As long as the resource demand is fixed the total area under the graph will remain constant. The following formula can be used to compute the moment for the entire graph:

$$M = \frac{1}{2} \sum_{i=1} yi^2$$

M = moment of a resource histogram

w = width of the rectangle (assumed to be = 1) reflecting a day

y_i = daily resource sum

This method has three main advantages over the traditional method as follows: 1) the project duration does not get extended, 2) resource demands concentrate in the middle of the project rather than the end, and 3) the resources can be adjusted to closely match a contractor's resource availability. However, there are some disadvantages for this method as well. It does not fully eliminate resource fluctuations and it is difficult to apply for complicated projects if the computation process is not automated.

2.2 Lean Construction

The complexity associated with resource constraint scheduling has led to the development of the lean approach within the manufacturing industry and later to its adaptation by the construction industry. The lean approach is a philosophy that aims to best utilize the resources and minimize the waste associated with any production process. The discussion below consists of two major parts. The first describes the origins of the lean approach within the manufacturing industry. The second describes its adaptation to the construction industry (lean construction) and provides two lean construction application.

2.2.1 Lean Philosophy Development

The word 'lean' was introduced as descriptive of a manufacturing philosophy by Krafcik (1988) when he was working as a researcher at the International Motor Vehicle Program (IMVP) to identify the distinctions between the mass production system and the production system used by Toyota. The former is a push system introduced by Henry Ford to focus on making the maximum use of resource in order to produce large quantities of a single type of merchandize and accepting any resulting defects. The latter is a pull system, known as the Toyota Production System (TPS), focusing on making the best use of resources while eliminating potential work disruptions and non-adding value activities in order to provide "what is needed, in the amount needed, when it is needed" (Forbes and Ahmed 2011). The development of the TPS started in the late 1940s when Toyota sent Mr. Eiji Toyoda, Toyota's managing director, and Mr. Taichii Ohno, Toyota's chief engineer, to study the mass production system applied by Henry Ford. They were able to identify significant amount of wasted resources associated with seven categories: production, idle time, transportation, inventory, motion, correction, and processing. The shortcomings of the mass production system did not match their goals and led to the introduction of the TPS between 1948 and 1975 (Strategos Inc. 2007).

There are four elements to the TPS: Just-In-Time (JIT), automation, work flexibility, and creative thinking. As a result, Toyota was able to reduce the time required to produce one car from 15 days to 1 day, reduce inventory levels, and increase resource efficiency (Forbes and Ahmed 2011).

Relentlessly, Toyota continued to enhance the TPS and introduced an advanced form of the system called The Toyota Way, which forms the base for lean construction. The Toyota Way focuses on four foundations and requires the implementation of 13 principles shown in (Figure 2.1) to produce a high quality product with a minimum overall cost.

	Toyota Foundations	Principles
1	Problem Solving (Continuous Improvement and Learning	Continual organizational learning View the situation firsthand to thoroughly understand it Make decisions slowly by consensus—consider all options: Implement rapidly
2	People and Partners (Respect, Challenge, and Grow Them)	Grow Leaders who live the philosophy respect, develop, and challenge people and teams Respect, challenge and help suppliers
3	Process (Eliminate Waste)	Create process 'flow' to reveal problems Use pull system to avoid overproduction Level out workload Stop when there is a quality problem Standardize tasks for continuous improvement Use visual control—transparency Use only reliable, tested technology
4	Philosophy (Long-Term Thinking)	Base management decisions on a long-term philosophy, even at the expense of short-term financial goals

Figure 2.1 Representation of the Toyota Way (Forbes and Ahmed 2011)

2.2.2 Lean Adaptation to Construction

The success attained by the automobile industry using the lean philosophy has led to its expansion to other industrial sectors such as "product development, services, air and sea ship building, software development, and health care delivery, etc." Ballard et al (2007). And, lean philosophy was extended to the construction industry which was facing challenges in delivering projects on time due to the huge amount of waste (i.e. time and resources) during the execution of the activities. According to Pappas (2000), for example, in concrete placement in construction sites "a typical worker spent 63% of the time placing concrete, 29% waiting for material, 4% waiting for supervision, and 4% idle." Significant effort were dedicated to addressing these problems and to maximize the throughput (value) and reduce the waste (i.e. efficient use of resources).

The U.S. Business Roundtable sponsored 23 Construction experts to provide efficiency improvement methods (Blough 1983). They concluded that the traditional project management methods are experiencing three shortcomings. First, the production methods are found to be craft-oriented and executed by various parties with separate contracts. The tasks require long durations performed by craftsmen with a high corresponding cost. Although, these activities may depends on each other, the parties' responsible for their executions have separate contracts. This creates chaos in the construction site, because miscommunication tends to happen when each specialty tries to finish its job as quick as possible without coordinating with other parties creating bottlenecks for the succeeding activities.

Second, the traditional scheduling techniques (i.e. CPM), are found to lack the ability to foresee future disruptions, reduce project uncertainties, and lack the representation of how the work should be performed. Third, the traditional techniques are considered as push methods, since they tend to hand the subcontractor's preplanned schedules that have to be met without considering the resource availability to execute the tasks.

The Construction Competitiveness Committee was founded to address above mentioned shortcomings in depth, which resulted in the formation of the Construction Industry Institute (CII) in 1983. The (CII) created a project team (PT 191) to study the applicability of the lean principles to the construction industry. The team reported that lean can be applied to construction and recommend its application. They introduced the term "lean construction" and defined it as: "the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project." (Ballard et al 2007).

Five lean construction principles were introduced in that report:

1. Customer focus.
2. Culture and people.
3. Workplace organization and standardization.
4. Elimination of waste.
5. Continuous improvement and building quality.

Koskela (1992) studied the feasibility of the implementation of the lean principles to construction. The study was conducted based on the assumption that the construction process is perceived as a production system. Koskela classified the activities in two forms: conversion and flow activities. Flow activities are the activities that do not add-value to the production, such as "material inspection and wait time". The conversion activities are the activities that add-value to the production such as "moving the material from operation to another". Two causes for the non-added value activities were identified: the design procedure (dividing the tasks into subtasks which will lead to the extension of the inspecting, waiting, and moving time), and the lacking of a waste identification and analysis tools. As a solution, Koskela proposed The Transformation Flow Value (TFV) theory of construction (Koskela 1992). The theory uses a set of heuristic rules that aim to increase the conversion activities and reduce the flow activities.

Ballard et al (2007), indicated that the lean business philosophy aims to produce product based on what is demanded, without delays and with least possible waste by principles and available methods. He adapted two of the 14 lean fundamental principles of the Toyota Way and developed The Lean Project Delivery System™, and the Last Planner System®, which they serve as the methods required to accomplish lean objectives.

2.2.2.1 Lean Project Delivery System^{TM}

As it is shown in Figure 2.2, The Lean Project Delivery System (LPDS) is a lean production management system that consist of: 9 modules integrated with four triangles representing four phases (project definition, lean design, lean supply, and lean assembly), along with production control tool, work structuring, and post-occupancy evaluation (Ballard 2000).

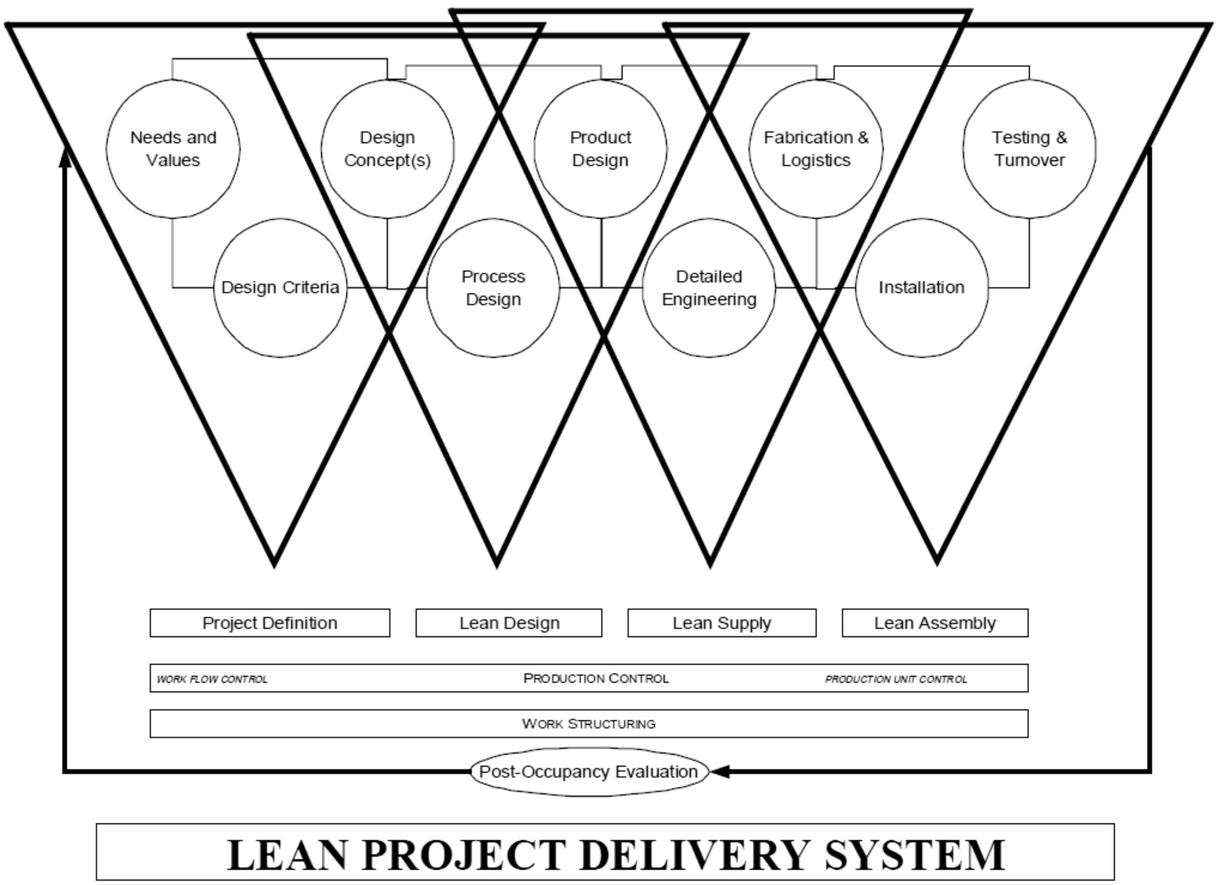


Figure 2.2 Lean Project Delivery System (Ballard 2000)

Starting from the bottom of the Diagram, the *post-occupancy evaluation* is the stage between the end of a project and the beginning of another. It serves as a learning stage that aims to evaluate the system performance in the previous project. Next, *work structuring* and the *production control* are extending throughout all project phases. *Work structuring* aims to assure a smooth information exchange between the project definition, design, supply, and assembly processes. The production control aims to assure plans are executed as scheduled by looking at downstream activities ahead of time and producing weekly work plans (refer to Section 2.2.2.2.3).

The *project definition* phase is carried out by the project manager to assure the project will serve its desired needs and values by developing the design criteria and the design concept. In the decision making process, the project manager needs to work in a close coordination with the client and all the parties involved in the process.

The *lean design* phase consists of: design concept, product design, and process design. The product and process are simultaneously designed in this phase based on the conceptual design while taking into account the project's objectives. An Activity Definition Model (ADM) is used to develop the design process itself. ADM helps to eliminate any potential constraints by determining beforehand that all the prerequisite tasks are done, the resources are available, and the specifications are clear.

The *lean supply* phase uses the data generated from the product design generated in the lean design phase to determine the details required for the engineering work, fabrication, delivery, and inventory (Ballard 2000). It also works toward "reducing the lead time for information and materials, especially those involved in the supply of engineered-to-order products, which typically determine the pace and timing of project delivery." (Ballard and Howell 2003).

The *lean assembly* phase is comprised of three elements: fabrication and logistics, installation, and commissioning. The *fabrication and logistics* component is concerned with delivering the needed materials and fabricated elements when they are needed to the site. The use of fabricated items reduce the amount of waste by simplifying the installation process and reducing the non-add value activities. The installation component is the process of putting all the production elements together to deliver the end product. The testing and turnover component ensures all parts are installed as designed and the owner can now use the facility.

2.2.2.2 Last Planner System®

The Last Planner System (LPS) represent the production control tool that LPDS uses to control the projects. This system aims to reduce downstream uncertainties by giving the authority to set the schedules for achievable activities to the foremen and individuals responsible for performing the work.

Reducing uncertainty leads to the reduction of potential work disruptions and provides a smooth work flow throughout the construction process by planning work ahead of time. In LPS, the work is scheduled by the crew's foreman (last planner) who is directly responsible for performing the work. In the process of producing the schedules the foreman keeps close communication between the contractors and sub-contractors involved in project execution to be able to match the resources requirements with their capabilities. A work buffer (workable backlog) is also used to assure crews have work on hand when constraints occur. Workable backlog is a set of standby assignments that meet all the specifications and do not have constraints but are not on the critical path.

The LPS uses three major components to control production: look-ahead planning, commitment planning (work CAN/ WILL be done), and learning. The *look-ahead planning* aims to schedule activities that are ready to be executed in a 6 to 8 week timeframe. The *commitment planning* aims to identify work that can be done and to select work that will be done. It also involves measuring the production rate by comparing the actual performance as a percent of the work scheduled. In the case of having incomplete activities, root-cause analysis is used to determine the causes. The *learning* component is developed by using the root-cause analysis results as an improvement tool to the work assignment in the subsequent weeks.

The *look-ahead* planning consists of three main parts: 1) *master* schedule. 2) *look-ahead* schedule. 3) *Weekly work* plan (WWP)

2.2.2.2.1 Master Schedule

This is the schedule provided by the contractor at bid time. It includes the overall project duration and presents the main construction phases. In most cases this schedule is considered unrealistic in the field because typically the amount of the work scheduled is beyond crew capacities. They tend to provide subcontractors with schedules without taking into account their resource availability and overall capability. According to Forbes and Ahmed (2011) only 50% of the work scheduled will be completed by the end of a typical week. To resolve this issue, reverse phase planning is subsequently performed, by those involved in work execution, by analyzing the master schedule starting from the final project completion date to "indicate what work SHOULD be done in order to meet the schedule" (Forbes and Ahmed 2011).

2.2.2.2.2 Look-Ahead Schedule

This scheduled is produced from the phase plan with a time horizon of between 6 to 8 weeks and used to control the construction flow. Major activities are identified from the master schedule and a constraint analysis is performed to determine which activates can be done. These constraints are then addressed ahead of time to prevent future disruptions. The *look-ahead* scheduling include three elements which are constraint analysis, activity definition model, and first run studies. These are discussed below.

1. Constraint Analysis

The analysis identifies the constraints that will prevent tasks from being completed downstream and remove them from the schedule. The foreman or last planner starts this analysis by collecting information from project participants and compares the work requirements against the contractor's actual available resources. The constraints analysis is a continuous procedure performed weekly to make sure no constraints will pop up during the construction process. Items with unfinished preceding work or unavailable resources will be taken off the current schedule.

2. Activity Definition Model (ADM)

The *activity definition model* divides tasks into small operations to have a better understanding about their ability to be executed. Figure 2.3 represents the activity definition model for any given process. The inputs to the ADM are directives supplying information about required tolerances or intended use, prerequisite work, and resources. In determining if an operation is ready to be processed three questions are asked "What are the DIRECTIVES governing my output, process, and inputs? What PREREQUISITES do I need from others? What RESOURCES do I need to allocate to this assignment?" (Ballard 2000). In (figure 2.3) the output is tested against the design criteria. If it meets the criteria it will be released to the next process otherwise, either the criteria will be reevaluated or the last product "output" will be revised (Ballard 2000).

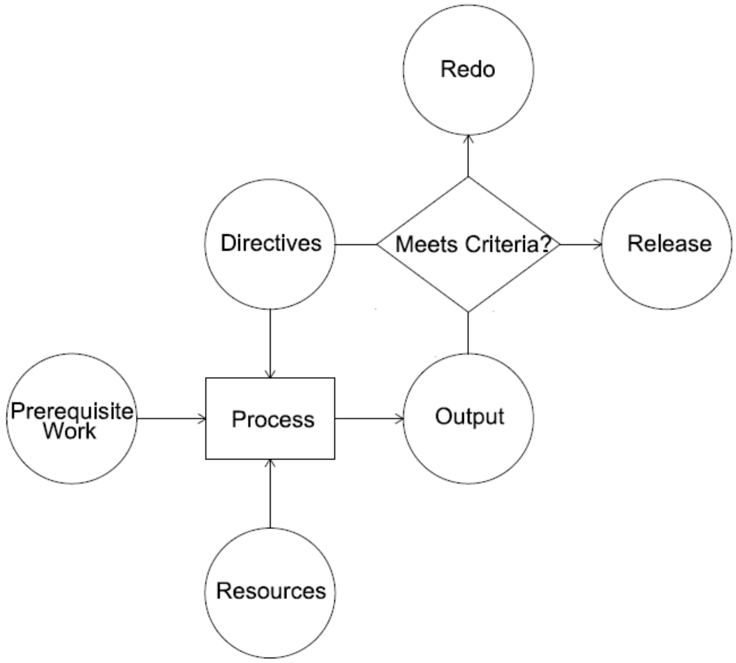


Figure 2.3 Activity Definition Model (redrawn without alterations from Ballard 2000)

3. First Run Studies

These are cyclical studies conducted by those performing the tasks to determine the best methods to do the work and to standardize the execution procedure. These studies cover administrative processes such as (RFIs and change orders) and resource management processes such as "small tool supply and distribution, construction equipment supply and distribution, purchasing, delivery/material handling, etc." (Alarcón 1997). The standard procedures are then taught to the workmen to improve performance.

2.2.2.2.3 Weekly Work Plan (WWP)

The WWP is a weekly schedule produced from the look-ahead schedule. Each trade will have its own WWP produced by their foremen based on information provided by the last planner in the look-ahead schedule. The assignments included in the WWP are considered the promises that will be done having been cleared from any constraints and resource shortages.

2.3 Gantt Work

As stated earlier, the alternative resources scheduling technique proposed here is based on the production management system developed by Gantt between the periods of 1899 to 1917. This section discusses the development stages of the system components (before and after the war), demonstrates its efficiency in dealing with resources during that time period, and present its contributions during the First World War. Most of the historical information provided in this part is based on a bibliography written about Gantt by L. P. Alford (Alford 1972).

2.3.1 Before the War

2.3.1.1 Consulting for Business

According to Alford (1972), Gantt had a career full of technical engineering, administrative, organizational, and management work before to the United States entered the World War in 1917. One of his biggest contributions to the manufacturing industry was the development of the *Task and Bonus System* increasing manufacturing production rates and improving industrial operations. Two examples of this work, Bethlehem Steel Company and Remington Typewriter, are discussed below.

2.3.1.1.1 Bethlehem Steel Company

Gantt developed the *Task and Bonus System* at the Bethlehem Steel Company in 1899. According to Alford (1972), the company was struggling at that time to deliver on promises. Communication between management and shop floor workmen were through sets of instruction cards that specify method, time, and tools for executing each of the elementary operations. The workmen, especially the lower tier, were resistant to the idea of having instruction cards dictating their work, paid little attention to complying with them, and consequently productivity suffered.

The chief engineer at Bethlehem Steel, Frederick Taylor (also known as the father of the scientific management), conducted an investigation to study the reasons behind the inefficiency and to recommend solutions. During this study little attention was given to involve the workmen in the improvement process and to seek their cooperation.

Taylor appointed Gantt in March 1899 to develop methods for increasing labor efficiency. (Alford 1972). Gantt (1913) recommended scientific investigation, instruction cards and a bonus system to increase operational throughput and efficiency. These three elements are discussed below.

1. Scientific Investigation

   Through scientific investigation the best possible knowledge about performing the work and determining how long it should take is acquired. Gantt recommended that scientific investigation should subdividing operations into smaller elements and then study each element separately to have a clear assessment of complicated operations (Gantt 1913).

2. Instructions

   Instruction cards represent a way of communicating the best way for accomplishing the tasks from planner to the workmen responsible for executing the plan. These instructions also direct workmen away from individualized, undisciplined methods of working that may seem suitable to them but are not a product of careful examination. A continuous training program is required according to Gantt to assure all workmen are capable of executing the tasks using the best method within the time frame allowed.

3. Bonus system

   According to Gantt (1913), workmen "prefer to sell their time rather than their labor." They correlate their performance with how much time their wage should buy. But Gantt also recognizes most workmen are willing to perform what a planner ask of them as long as they are compensated.

With this in mind, Gantt (1913) proposes a *Task and Bonus System* as a means to assure the workmen cooperation. Gantt indicates if a workman completes the assigned work for the day based on instruction card estimates he will get his daily wage plus a definite bonus varying between 20 to 60 percent. However, if the workman doesn't finish the daily work set for him by the end of the day he will get no less than his daily wage. If a workman becomes aware he is unable to deliver the work in the allotted time, he reports it to his foreman who reports this to the man preparing the instruction cards. An investigation should be performed to determine the cause of the shortfall. If the instruction card method is flawed or if the expectations of time are too optimistic, then a new instruction card with a new methodology and time is developed and reissued.

According to Gantt (1913), foremen are encouraged to be more engaged with their workmen under this system by each receiving a bonus for each of his men getting a bonus for the day and an extra bonus if all of them do.

Finally, to reduce the machines from becoming a production constraint workmen won't receive a bonus if expectations are not met even if caused by a machine defect. This will encourage workmen to maintain their machines in a good running condition, well lubricated and cleaned.

The benefits of implementing the bonus system according to Gantt (1913) are:

1. An increase of the output (averaging from 200 to 300 percent).
2. A decrease in cost of product.
3. Better workmen attracted by higher wages.

4. Improvement of quality of product due to better workmen and more careful supervision.
5. Falling off in accidents and breakdowns

2.3.1.1.2: Remington Typewriter (1910 to 1917)

Gantt described his work at the Remington Typewriter as “the largest, most pleasant, and most successful job I have ever made.” (Alford, 1972). Gantt was hired in 1910 by Remington Typewriter plants to “improve the industrial operations at the plants”. The task was challenging because the Remington Typewriter Co. consisted of four factories responsible for manufacture 481 different typewriters. Each typewriter consists of 2,500 different parts with as many as 1,113 distinct keyboards with various accessories and supplies. At the time of assembly if there is a missing part typewriter assembly stops. The plants employed around 5000 workers and each factory worked independently. Gantt performed a scientific investigation resulting in the recommendation to install a storekeeping system, timekeeping/production control system, and a task and bonus system. (Alford 1916a, 1916b, 1916c, and 1916d)

The storekeeping system assures the required material, supplies and tools are available when needed and prevents delays caused by their shortages.

The timekeeping and labor control system provides the knowledge required to control labor and production throughout the shop floors by using time cards and instruction cards.

Similar to the Bethlehem Steel Company, Gantt installed the Task and Bonus system at the Remington Typewriter. Mr. Gantt’s contributions to Remington Typewriter production was significant. Some of these contributions are as follows:

1. Unify production so that a workman can be moved from one factory to another with no additional training required.
2. Decreased manufacturing cost.

3. Reduced idleness and "unnecessary stoppages"
4. Assured continuous material and production flow
5. Increased the production rate by 65% with a net saving in labor expense of 18% (Alford 1916d).

2.3.1.2 Consulting for Government

Gantt worked for the government as a consultant prior to the first World War on two occasions (Alford 1972). The first instance was when he was hired by the Secretary of the Navy Mr. George von L. Meyer in 1911, with two other group members to study and provide to recommendations that would increase the efficiency, organization and management of the Navy Yards (Gantt et al 1912)

The second instance was at Frankford Arsenal in 1917when he was hired by General William Crozier, Chief of Ordnance, to help organize and manage production flow on the shop floors at the arsenal (Gantt 1918). There were huge amounts of arsenals and ammunitions orders to fill. However, at any given time the plant managers were struggling to determine if all parts were ready and available with the proper numbers at the time of the assembly (Gantt 1918). The methods that they were using failed to provide full details about what was accomplished and how long did it take. Gantt developed a progress chart that presents the planned and accomplished tasks in their relation to time. The chart provided the production managers with the ability to compare "between promises and performances" (Gantt 1919) and identify the reasons behind delays. Clark (1923), an associate of Gantt, described the chart as simple and understandable to everyone. Gantt's successful at the Frankford Arsenal led to General Crozier extending the progress chart "throughout the Ordnance Department" (Gantt 1919).

Figure 2.4 shows the first progress chart produced at the Frankford Arsenal drawn by one of Gantt's associates, David B. Porter. It shows the weekly schedule for the manufacture of complete rounds of artillery ammunition. The data in this chart is plots as a function of time progress of eight items out of 28 necessary (Alford 1972).

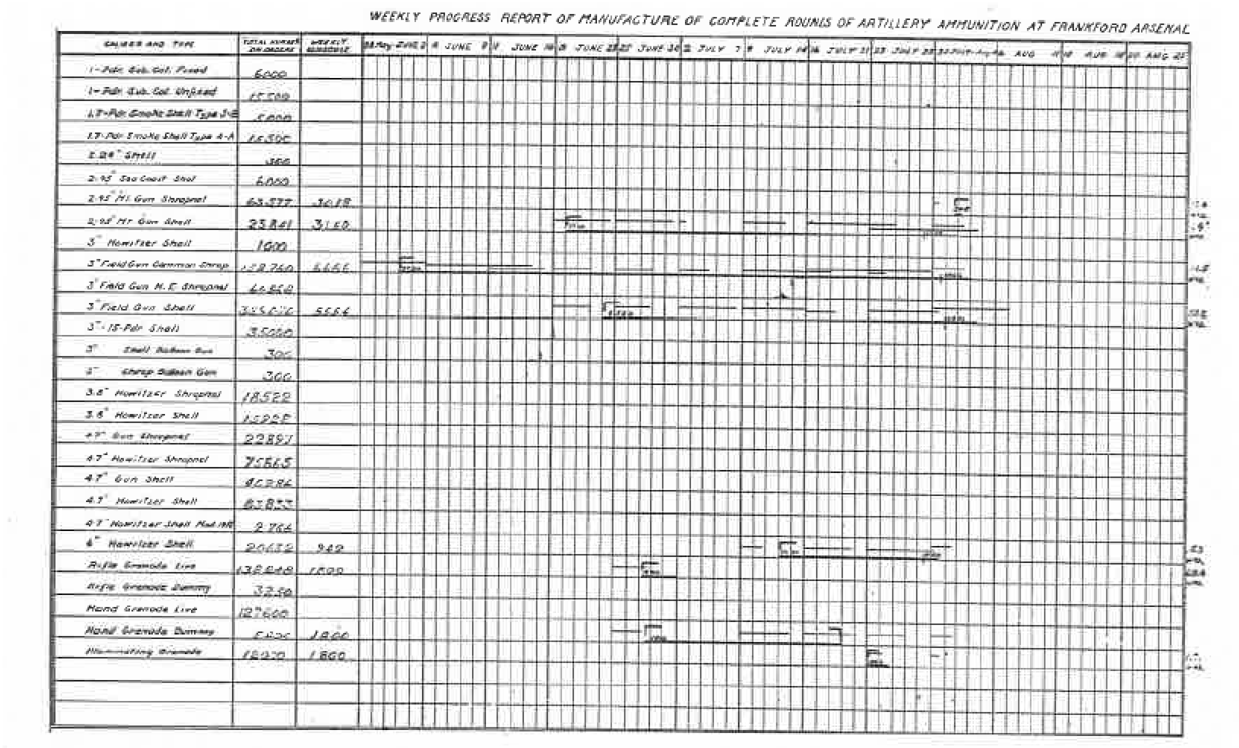


Figure 2.4 First Progress Chart (Alford 1972)

2.3.2 World War I Era

Shortly after the United States entered the First World War against Germany on April 6, 1917, Gantt was called by the Ordnance Bureau of the United States Army to help coordinate and keep track of the production orders for artillery, small arms, machine guns, ammunition, and explosives (Alford 1972). Gantt conducted an investigation in order to assess the situation concluding that working culture at the shop floors should be changed. Gantt indicated that the tendency of the workmen towards doing what they would please should be eliminated instead he suggested they work collaboratively according to scientific knowledge for the sake of the public rather than the individual (Gantt 1919). Gantt developed a set of progress charts presenting the facts in a simpler and clearer form in comparison with the other management tools and provide the ability to determine resources availability, work planned, work performed, and fixes the responsibility. This philosophy did not match how things were managed at that time. According to Alford (1972), Gantt found resistance and opposition and struggled collecting reliable data for his charts because most employees and officers at the Ordnance Bureau did not like the new management approach and did not want the change. The head-office completely supported Gantt and his charts. And as a result of the eventual implementation of the charts, the Ordnance Bureau was able to control and increase the manufacturing of the arms and ammunitions supplied to the army.

According to Alford (1972), the success that Gantt progress charts brought to the Ordnance Bureau led the Emergency Fleet Corporation to adopt the system. When Gantt was hired by the Emergency Fleet Corporation Germany was winning the war. The United States needed desperately to build more ships after the Germans had destroyed *6,618,623 tons of shipping while the world production of new ships over the same time was only 2,703,345 tons with Great Britain and the United States contributing 2,100,000 tons of that total*. (Alford 1972). Similar to the Ordnance Bureau, Gantt saw the need to change changing how the Emergency Fleet is managed. In Gantt (1919), he stated that manufacturing should be directed for the sake of the public. The production had to be financed by the government and not by the "business men" who were seeking to make high profits by selling what they produce to the government. Therefore, according to Clark (1923) the public had to be "aroused" and kept informed about the production progress. Gantt selected the "rivets driven" as the production measurement unit. "*Records of riveting crews were reported daily through the newspapers, with intense rivalry* *between various yards and crews*." (Alford, 1972). The "rivets driven" enabled everyone to see what was actually being accomplished and gave the ability to anticipate the coming demands and helped to produce reliable plans (Alford 1972),. As a result, the production efficiency was increased and the Emergency Fleet Corporation was able to manufacture and deliver 533 ships (3,030,406 tons).

Gantt's central role in building and delivering the ships received no acknowledgment from the newspapers and from the public. That was because no one knew he was the mastermind of the production and the delivery process of the ships and arsenals. According to Alford 1(972), Edward B. Passano (Gantt's friend) stated that:

> *"Gantt's name was never mentioned in the newspapers in connection with this work, and I do not imagine that one in ten thousand knows that he was the "power behind the gun," and that to him is due the credit for much that was done during the latter part of the war period in hurrying the completion of ships."*

This effort with the Emergency Fleet Board laid the ground for Gantt's third participation in the war which was working for the Shipping Board to help operate the ships that were built. According to Alford (1972), the method of tracking ships at that time (sticking pins and flags and card records) were tried and proved to be ineffective in keeping those in charge updated about the locations and the movements of the ships. Moreover, they did not have the ability to visually present the information. The Shipping Board sent for Gantt to help install a technique that would assure operating the ships efficiently. Gantt used the same approach that he used at the Emergency Fleet, and decided to put the "shipping executives" under the public judgment. He chose the "ship hour" as a unit to measure the ships operational efficiency as he explained:

"First, there should be popularized the idea of the "ship hour" as a basis of accountability of each and every ship _ for the ship hour is independent of varying control, size, type, and cost per hour of different ships. On the one hand, ship operators are responsible for their vessels, "ship hours", and on the other hand, the owners of the fleet, whether private or government, should be made to be interested in the performance of ships, ports, or fleets in terms of "ship hours." The American people, the real owners of the American fleet, should be led to have at least a sporting interest in the performance of their ships." (Alford 1972)

Gantt used a set of charts to present the facts (ship hour) in a simple format that could be available and understood for everyone. According to Mr. Dean Herman Schneider and Mr. Edward B. Passano, the usage of these charts provided records of the ships movements between the United States and the other ports, helped organize the movement of the ships in ports, and reduced and identified the causes of the idleness (Clark 1923). And as a result, the time that a ship stayed at docks was reduced from four weeks to two.

Clark (1923) provided multiple illustrations of the ship movement charts used during the war. As an example consider Figure 2.5 which represents a movement chart for the tanker Vesta. The angles open to the right, indicates when the tanker arrived at the port. Similarly, the angles open to the left indicates when the tanker departure the port. The name of the port is posted between the two angles. The name prior to the opening angle indicated its port of origin while that of the closing angle represented its destination port. The load of the tanker, (i.e. Ballast, Oil), is also presented in the chart. Similarly, Figure 2.6 represent a complete ship movement chart. It shows track record information for 18 ships. This chart will inform the managers about the ships locations, and movements.

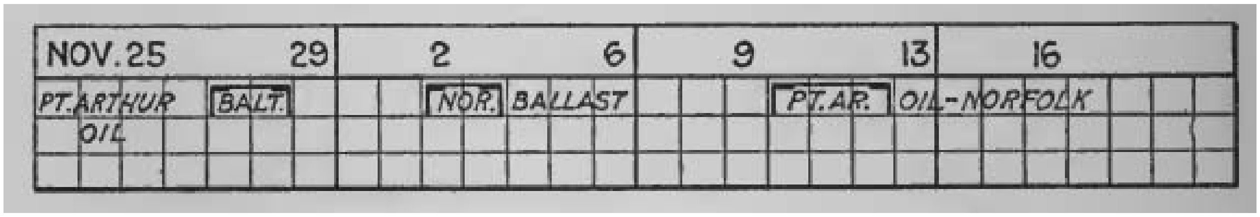


Figure 2.5 Movement Chart Example of Tanker "Vesta" (Clark 1923)

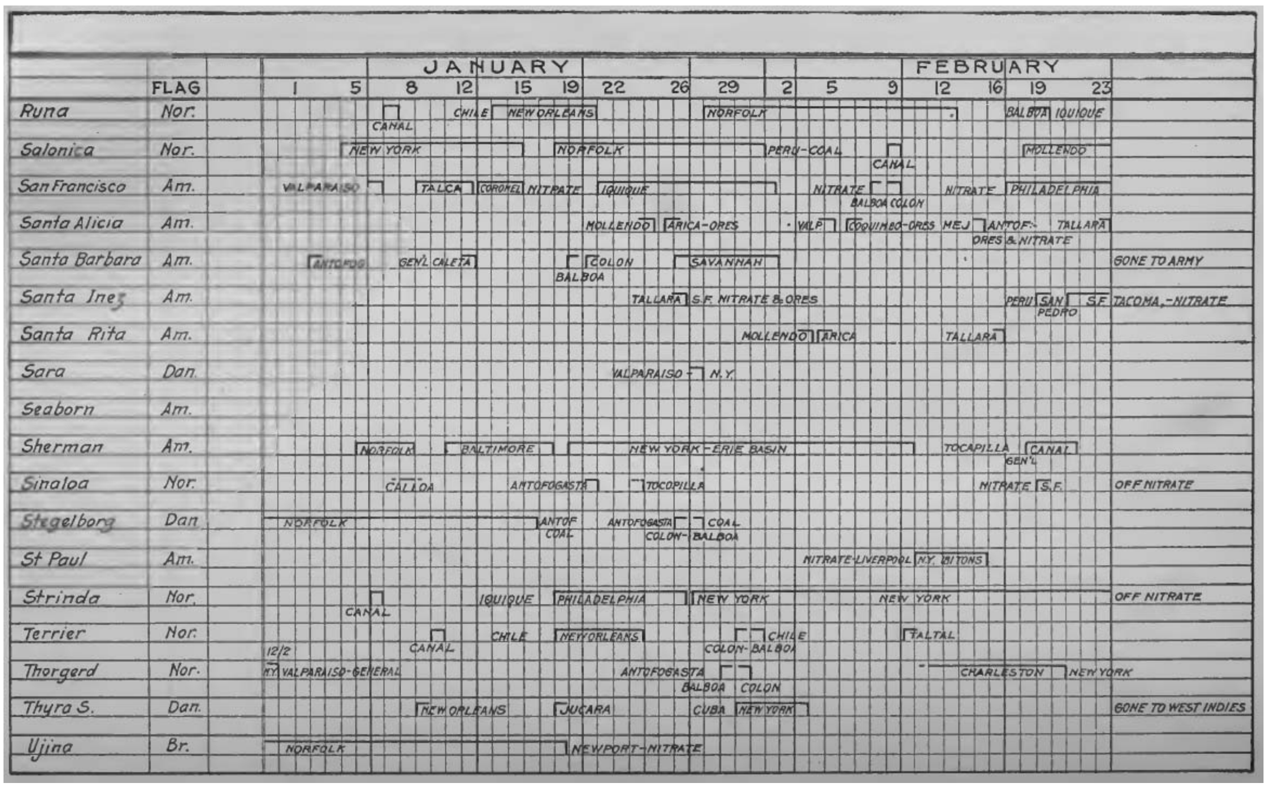


Figure 2.6 Ship Movement Chart (Clark 1923)

According to Clark (1923), after the ship movements were organized (in the sea and at the ports) the Shipping Board sought Gantt's help with another problem. The available vessel capacities were insufficient to undertake the import demands (i.e. 2,000,000 tons of nitrate and 3,000,000 to 4,000,000 tons of sugar). To address this Gantt developed the ship commodity charts to plan supplying these demands using available resources. These charts enabled the planners to determine what to expect from these vessels per month or year by showing the turnarounds and the delivery dates. The commodity chart can be produced either for multiple or individual commodities. Figure 2.7 is an example of a ship commodity chart for Nitrate in 1918. This chart presents the monthly requirements in tons, the estimated deliveries (based on the available vessels), the actual deliveries, and the allocated vessels with their capacities. The requirements are listed at the top of the chart and indicated by figures to the left of each column. Then it is followed by the planned deliveries and actual deliveries respectively. This chart is produced at the end of the month of July. The heavy line in front of the actual deliveries indicates that these vessels are two months behind the schedule. The angles opens to the left in front of each vessels indicates the arrival in port. And the figure inside each angles indicates the actual amount delivered.

According to Clark (1923), the benefits gained from using these charts were:

> "- *Show the progress made toward meeting the requirements.*
>
> *- They emphasized the necessity of allocating vessels to bring in specific commodities; and, when vessels were allocated, they showed what effect that action would have on meeting requirements.*
>
> *- Enabled The Shipping Board to make progress in its task of bringing in the necessary imports with as few ships as possible."*

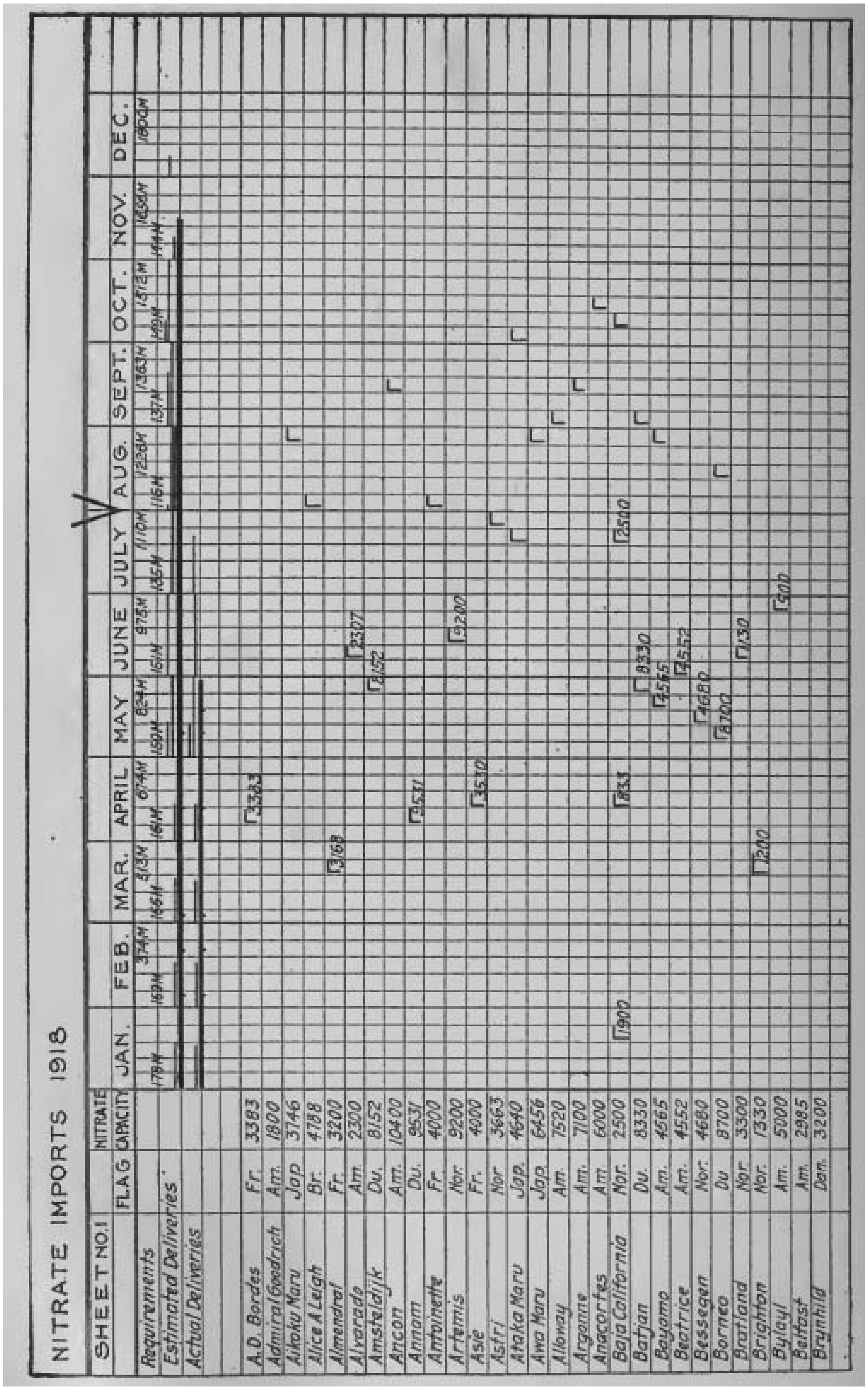


Figure 2.7 Ship Commodity Chart (Clark 1923)

2.4 Summary

This section addressed the current tools and trending philosophies of resource planning in the construction industry, as well as, background literature concerning applications and successes of Gantt's resource management system at the turn of the last century. First, the resource allocation and resource leveling approaches were addressed. The research efforts that had been conducted to optimize the resource constraints were also documented. However, all the resource scheduling approaches were found to be working on the same concept of creating a schedule first based on the tasks and then trying to optimize the resources.

A different construction scheduling approach (Lean Project Delivery System) reflecting a trending philosophy was also considered in this chapter. This philosophy grew out of earlier successes in lean manufacturing. Although LPDS consider the resource availability and the causes of idleness when developing a construction schedule it still is based on the traditional scheduling technique (CPM) where tasks are scheduled rather than available resource.

Finally the work Gantt introduced to the manufacturing industry in the late of 1800s and the beginning of the 1900s in dealing with the resources is also presented. When applied to manufacturing this approach was credited with significant improvements in both production and efficiencies. Many at the time credit his contribution to the success in munitions manufacturing, ship building and commodity imports achieved during the First World War.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter describes the research approach taken in applying the *Gantt Resource Management System* to the construction industry and demonstrating its advantage over what is currently being used in project scheduling. The research method consists of three parts: First, an extensive review of how the *Gantt Resource Management System* components are drawn and used. Second, the adaptation and the application of the system to a construction trade, brick masonry, on a hypothetical project developed for this effort. Third, to provide a comparison and contrast between the proposed technique and the current resource scheduling technique based on a set of developed criteria for this purpose.

3.1 Gantt Resource Management System Components

Chapter 4 provides a description of how to draw and use the Gantt Resource Management System components and establishes the background required to understand the proposed resources scheduling technique. These components are the: instruction card, machine chart, man chart, layout chart, load chart, and progress chart. The chapter is divided into seven parts. The first part uses one of the first instruction cards that Gantt developed at the Bethlehem Steel Company in 1899 to illustrate the process of how to generate and read instruction cards. The second part provides three illustrative figures in describing the general characteristics shared by all GRMS charts. The third part presents the process of generating the machine chart and then uses an example to describe how to interpret information provided in the chart. Similar to the machine chart, the fourth part equips the reader with information needed to develop and read the man chart. The fifth presents the procedure of producing the layout chart and uses an example to show how to read a layout chart. The sixth part describes the load chart and uses an example in order to show its usage. The seventh part presents the characteristics of the progress chart, provides information needed to produce the chart and presents an example of how to interpret information from the chart.

3.2 System Adaptation and Application to construction

According to Clark (1923), the GRMS charts are applicable to "any human activity" and have been in used in "industrial production, commercial fields, and governmental agencies in many countries." Since construction operations can be perceived as a production process the author believes the Gantt Resource Management System is applicable to construction as well. To demonstrate the system applicability to construction, a brickwork project model was created using Revit (Building Information Modeling). The tasks required to be performed were determined and the resources available to accomplish these tasks were listed. Next, a motion study originally developed by Frank Gilbreth, a contemporary of Gantt and pioneer of motion studies, was adapted to determine the best way to perform each bricklaying task. The time required to perform these motions are assumed. Next, a set of instruction cards that contains the methods of accomplishing the work along with the time required to perform each task were produced. These instruction cards were used to develop two as-planned schedules based on the available resources. One of these two was discarded because it was unrealistic due to the over commitment of resources. The as-planned schedule was then broken down into four charts: machine chart, man chart, layout chart, and load chart. Different scenarios were assumed and applied to the charts in order to produce an as-performed schedules. The previous steps are presented in detail in Chapter 5.

3.3 Comparison and Contrast

Chapter 6 provides a comparison and contrast analysis between the proposed technique and the CPM scheduling approach using five developed criteria. These five criteria represent characteristics a resource scheduling technique should possess which are: Transparency, Routine, Continuous Improvement, Simplification, and Dynamic.

CHAPTER 4

Review of the Gantt Resource Management System

This chapter describes the Gantt Resource Management System components. Understanding each of these components is crucial to comprehend the system proposed by this thesis. It should be noted a major factor in producing the workforce cooperation necessary for successful use of this system is a Task and Bonus System as mentioned in Chapter 2. This is beyond the focus of this research and will not be addressed. This chapter is divided into seven sections dealing with the components of the system.

4.1 Instruction Card

Similar to the *First Run Studies* in lean construction, the instruction card provides information regarding the best way to perform a certain task and aims to standardize the process and eliminate unnecessary motion. In order to better understand this process, consider a forging that is to be rough-machined to a finish surface. The work is divided into sub-operations by an expert mechanic based on the available drawings. These operations will then be appointed to the best machines designed for this type of operation. Then, a first-class machinist analyzes the work required, issues instructions specifying the time, tools, feed, and cutting speed, and finally places all these instructions in a card. It should be noted that graphics are also used to insure workmen understand the instructions and are typically drawn and attached to the card.

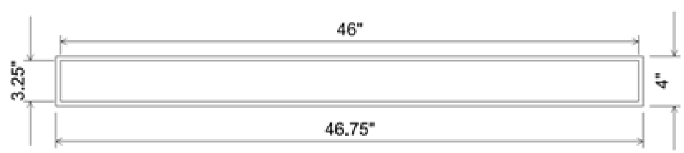
CLASS OF WORK	STANDING ORDER	ORDER NUMBER
Lathe	376	17344

MACHINE NO.	TOOL	CLASS OF METAL	FORGING NUMBER
145	M E	12	14653c 4

MAN'S NAME:	Wm. Jones	SPEED BOSS:	Thos. Smith

DESCRIPTION OF OPERATION	SHAPE OF TOOL	CUT	SPEED	FEED	TIME WORK SHOULD TAKE (min.)	TIME WORK DID TAKE (min.)	RATE
1. Chuck					2.5		
2. Face end	P V M			2 B F	4.0		
3.Turn half way	P V M		J	2 B F	12.0		
4.Turn end for end					5.0		
5.Turn half way	P V M		J	2 B F	12.0		
6. Face end	P V M			2 B F	4.0		
7. Remove form machine					2.5		
					42.0		

Inside lines in sketch represent machined, and outside lines forged, sizes



INSTRUCTION CARD NO.	SHEET DRAWING NO.	B. S. Co DRAWING No.	MONTH	DAY	YEAR	SIGNED
4327		266271/4 c	6	1	1901	Buckley

Figure 4.1 Gantt Instruction Card used at Bethlehem Steel Company (redrawn without alterations from Gantt 1902)

Figure 4.1 is a redrawn version of an instruction card Gantt introduced at Bethlehem Steel Company in June 1899 for the Machine Shop No. 2. He described it as follows:

"*This card represents instructions given to William Jones, whose boss is Thomas Smith, to do work on forging No. 14653C4, Manufacturing Order No. 17344, in Lathe No. 145, according to Standing Order No. 376. The hardness of the metal is represented by Class 12. He must use tools made of "M E" steel, of the shape designated in the column calling for shape of tool. The approximate depth of cut* *in turning is (3/16) inch. "J" represents a combination of feed gears, and "2-BF" a cone speed which he must use. Opposite each operation are speeds that must be used in order to accomplish the work in the time set. The total time for turning and facing this forging is shown to be forty-two minutes. At the bottom of this card is given, first its number, then the drawing number of the assembling sheet, if we have such a sheet; then the detail drawing for this particular piece, and next the date and signature of the man who made out the card. The note at the bottom, namely: (When machine cannot be run as ordered, speed boss must at once report to the man, who signed this slip,) is put in red ink and should be observed to the letter"* (Gantt, 1902).

The speed boss is the Forman responsible for making sure that the instructions provided in the card is being followed (Taylor 1911).

4.2 General Chart Concepts

The process of drawing a Gantt chart starts with dividing the working hours into smaller time periods. For example, if you are working five days a week, a sheet is divided into five equal columns. Each space is assumed to be equal to the amount of work that should be done within the specific time period. Figure 4.2 is an example of a daily work schedule (from Monday to Friday) at a manufacturing plant. The numbers on the left of each column represent the amount of work to be performed on each day.

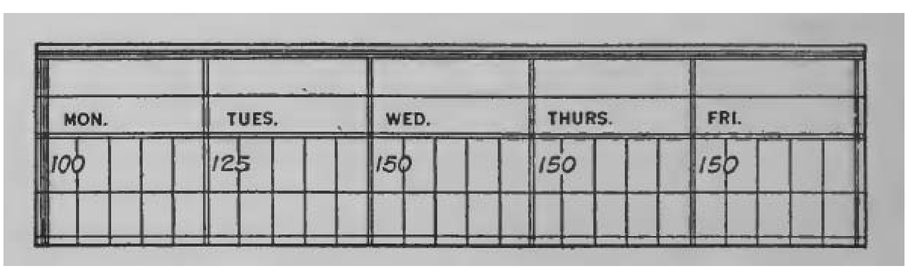


Figure 4.2 Gantt Chart showing Daily Work Scheduled (Clark 1923)

Figure 4.3 shows the percentage of work actually completed in relation to the work scheduled. This is accomplished by drawing a light horizontal line within the specific time period. For instance, on Monday, the amount of work to be accomplished is 100 units. However, only 75 units of work were accomplished. Therefore, a line through 75% of the space is drawn. On Thursday 180 units were accomplished instead of the 150 units that were scheduled. Therefore, the horizontal line was drawn all the way across Thursday and a second additional line with a length of the extra 30 units (20%) was also drawn across the same time period. Similarly, the work performed on Wednesday was 150 units which is exactly as scheduled. Therefore, the light line is drawn all the way across that day.

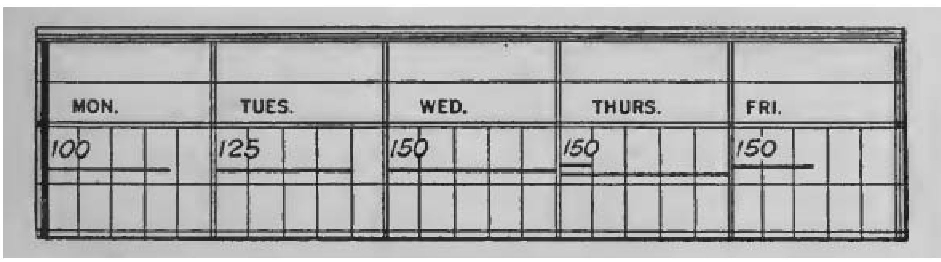


Figure 4.3 Gantt Chart Showing Work Performed (Clark 1923)

The cumulative work scheduled to be completed at the end of each day's contribution is placed on the right side of each column (see Figure 4.4). For example, the cumulative work scheduled to be completed by Wednesday is 375 units, which represents the summation of the work scheduled for Monday, Tuesday, and Wednesday. The heavy line in Figure 4.4 represents the summation of all the actual work performed in respective to the total work planned. The total work performed during the week is 580 units, which is 86% of the total work planned. Therefore, the heavy line represents 86% of the total space between Monday morning and the end of Friday.

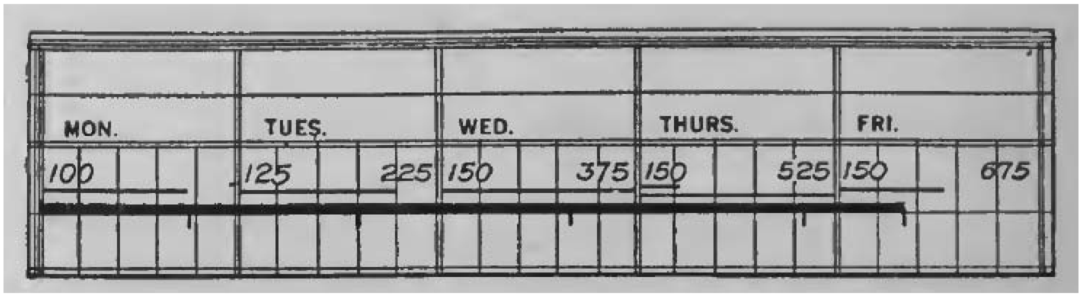


Figure 4.4 Gantt Chart Showing Performed Work Accomplished Daily and Weekly (Clark 1923)

In all Gantt charts, the reasons behind delays reflected by shortfalls in production are shown on the charts next to each accomplished tasks and represented by letters to indicate the cause. For example, Figure 4.5 shows lower than expected production attributed to the operator being new to the job. Therefore, the foreman put the letter G to indicate that the cause for delay was “Green Operator”.

Figure 4.5 Chart Element Illustrating “Green Labor” cause of Idleness (Clark 1923)

4.3 Machine Chart

The Machine Chart is a tool used by shop managers to measure their machine efficiencies and judge plant performance. The chart consists of the number of machine operating hours each day, the number of machine operating hours each week, and the cause if a machine was idle.

To draw a machine chart, the foreman uses a sheet with working days represented by columns. Each day is then divided into the number of working hours. For example, if the working hours were 8 hours, he divides the column into four smaller columns, each representing 2 hours. And if they works 9 hours, he divides the day into five columns, 4 columns of 2 hours and 1 narrow column of 1 hour. The foreman categorizes the machines based on the tasks performed and lists them in the first column. A light line is drawn to represent the number of hours a machine was operated. Thus, a column without a line indicates a machine was not operated and the reasons are then represented by symbols (see Figure 4.6). The letter (R) in the Figure below indicates that the reason for the idleness is “Repairs”.

Figure 4.6 Chart Element Illustrating “Repairs” cause of Idleness (Clark 1923)

The chart legend will list all causes for idleness and its correspond symbol. A heavy line is drawn under each machine to represent the cumulative time that each machine has run within the charted period. To indicate the performance of a certain machine group the heavy lines under the group are summed and averaged. Likewise, for the department, the group performance lines are averaged.

Consider Figure 4.7 below representing a machine chart in a machine shop. The first column represents the categories of the machines at the shop floor. The second column represents the resources available under each category in the shop at that time. The chart shows the actual number of working hours for two weeks. Each column represents working days within the charting period. The daily shop working hours are 8 hours. Therefore, each day is divided to four smaller columns, each one representing 2 hours. As mentioned earlier, light lines represent the number of hours that a machine was operated. The heavy lines represent the cumulative working hours of each machine. The heavy lines in front of the main machine categories represent the average cumulative working hours of the machines under that category. Similarly, the heavy line in the top of the chart represents the average of the heavy lines of the machine categories in the machine shop. The letters represent the reasons associated with under performance. Take for example milling machine 273 which is the last machine in that group. On Monday the 13th, the machine was operated for 5.5 hours and could not continue working because there a lack of Help. Therefore, the light line was drawn with a length of approximately 70% (5.5/8) of the total space. Because the idleness cause was lack of help, the letter (**H**) was put in the empty space. The cumulative heavy line for the milling machine 273 indicates that the machine is around 4 days behind the schedule. The legend to the chart that shows the reasons for idleness is presented in Figure 4.8.

As evidenced in the example above, it is easy for a foreman to dissect the information of the shop from just a glance at the chart. Since the chart provides him with the ability to visualize the performances of the available resources, he can identify right away what is holding the shop from keeping up with the promises. This enables the foreman to tackle each problem at its roots.

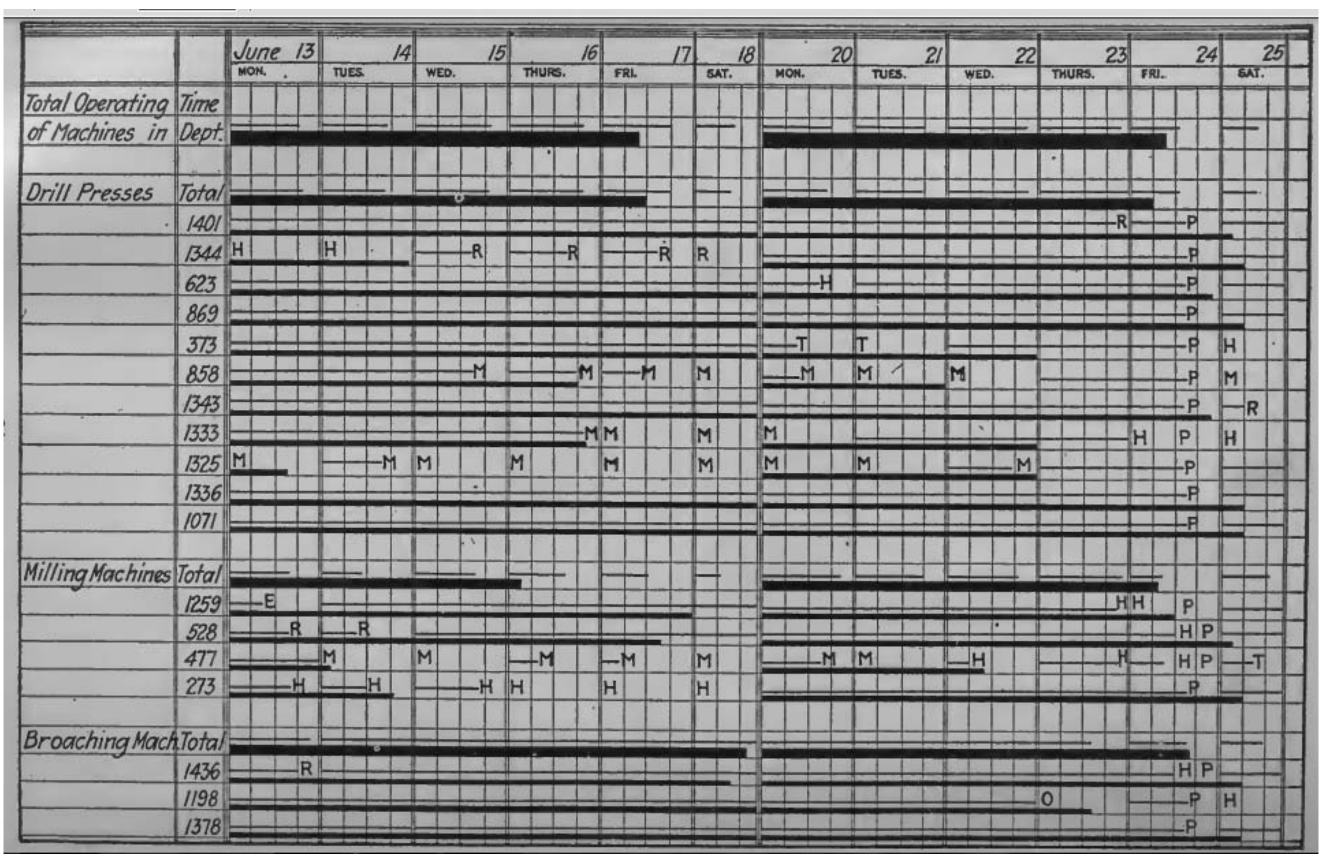


Figure 4.7 Machine Chart Example for a Shop Floor (Clark 1923)

LEGEND

Width of daily space represents working hours of the plant.

Time machine was running.

Weekly total of individual machine.

Weekly total of group of machines.

Weekly total of all machines in department.

The portion of the daily space through which no line is drawn represents the time the machine was idle.

In order to prevent future idleness, it is necessary to know the reasons for the idleness which has occurred in the past so that responsibility can be fixed. Therefore, wherever there is no line on the chart, a letter is entered in the space to indicate the reason for idleness.

REASONS FOR IDLENESS

E—Waiting for set-up.
H—Lack of help.
M—Lack of material.
O—Lack of orders.
P—Lack of power.
R—Repairs.
T—Lack of tools.
V—Holiday.

When there is more than one reason for idleness, the reason entered on the chart is determined by asking questions in the following order:

R—Is the machine ready to run?
O—Is there an order for the machine?
M—Is there material ready to be worked on?
T—Are there tools?
P—Is there power to run the machine?
H—Is there an operator for the machine?

Circumstances sometimes change the relative importance of the reasons for idleness and it is then necessary to change the sequence of these questions.

Figure 4.8 Machine Chart Legend Enumerating Selectable Categories Causing Idleness (Clark 1923)

4.4 Man Chart

One way that Gantt's system increases production capacity is through the motivation of workmen without making them feel as if they are being driven. By keeping a record of what has been done, what might have been done, and the reason for falling behind, obstacles become easily detected. This allows tasks to be completed more efficiently. According to Gantt, most of the workmen have shown willingness to learn from their mistakes to become better workers and have welcomed any help that might be given to them by the foreman.

There are many benefits and applications of the Man Chart. First, the Man Chart is used as a tool to evaluate the worker output by comparing their actual daily performances with the work expected to be accomplishing during that day. Second, the chart helps to increase the efficiency by providing the ability to identify the causes for idleness. By providing a line at the top of the chart representing the average performance achieved by the workmen, the system allows for the assessment of a foreman's efficiency based on the average of his men's performance. Similarly, a superintendent could be judged through the average performance of his foremen. To draw a Man Chart the foreman uses the same technique used to draw the Machine Chart discussed above. A sheet has the working days divided into columns. Each day is then divided into the number of working hours. Each space represents the work that should be done in that day in terms of time spaced columns. Next, the foreman categorizes his workmen (available resources) and lists them in the first column. A horizontal light line is used to represent the work that has been done. For example, if a workman did 75 percent of the work that was expected to be done in a certain day, the light line will cross 75 percent of that day as shown in Figure 4.9a. If the foreman doesn't have an exact estimate for the time the assigned work should take a dashed line is drawn instead of a continuous one reflected in see Figure 4.9b. In the case of delays, the foreman uses symbols to represent the reasons that prevented the workmen from accomplishing their jobs. Similar to the machine chart, the foreman lists the reasons behind delays in a legend and attaches them to the chart (see Figure 4.10). It should be noted that the reasons behind delays may vary between the Machine Chart and Man Chart.

Figure 9a Actual Work Performed Illustrated using Lightly Drawn Line (Clark 1923)

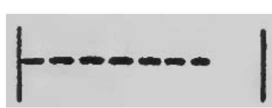
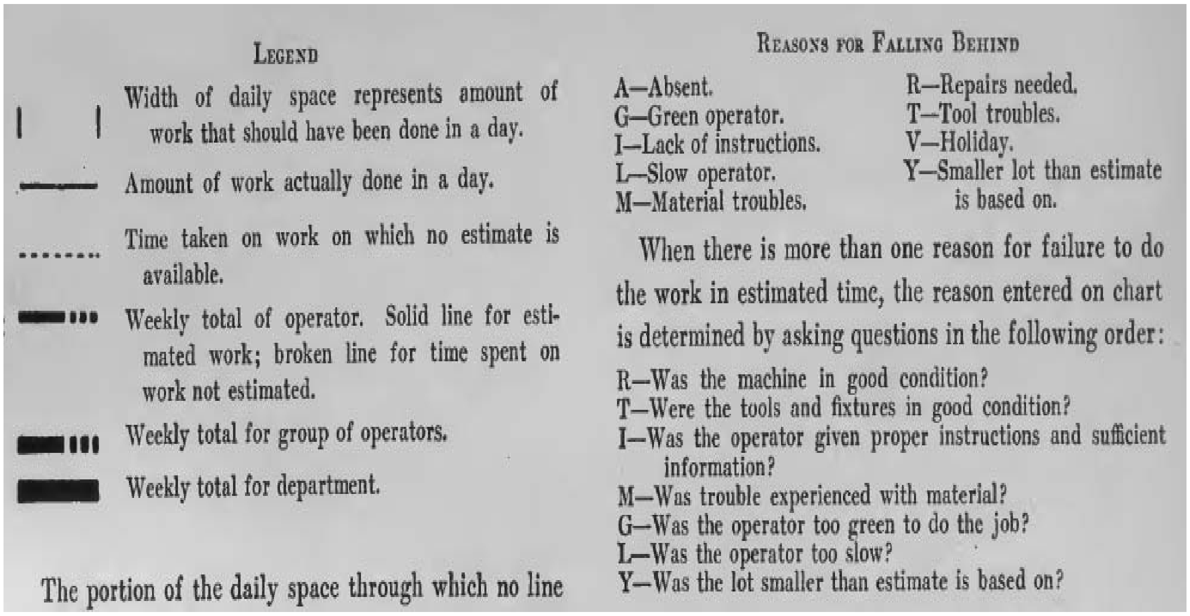


Figure 9b Chart Element Illustrating Work Performed without Prior Time Estimates (Clark 1923)



LEGEND

Width of daily space represents amount of work that should have been done in a day.

Amount of work actually done in a day.

Time taken on work on which no estimate is available.

Weekly total of operator. Solid line for estimated work; broken line for time spent on work not estimated.

Weekly total for group of operators.

Weekly total for department.

The portion of the daily space through which no line

REASONS FOR FALLING BEHIND

A—Absent.
G—Green operator.
I—Lack of instructions.
L—Slow operator.
M—Material troubles.
R—Repairs needed.
T—Tool troubles.
V—Holiday.
Y—Smaller lot than estimate is based on.

When there is more than one reason for failure to do the work in estimated time, the reason entered on chart is determined by asking questions in the following order:

R—Was the machine in good condition?
T—Were the tools and fixtures in good condition?
I—Was the operator given proper instructions and sufficient information?
M—Was trouble experienced with material?
G—Was the operator too green to do the job?
L—Was the operator too slow?
Y—Was the lot smaller than estimate is based on?

Figure 10 Man Chart Legend Enumerating Selectable Categories Causing Idleness (Clark 1923)

The total work a workman has done in a week (the summation of the light lines) is indicated by a heavy horizontal line. This makes it easy to estimate the performance of each workman category, by averaging the heavy lines of all the workmen under that category a group total is provided by a 1/8 inch wide line. Similarly, the department can be evaluated by averaging the performances of all categories under that department with a 1/6 inch wide line for departmental totals.

Consider Figure 4.11 which represents a Man Chart in a shop floor. The chart presents an as-performed schedule for two consecutive weeks. The shop floor is controlled by one foreman, who in turn supervises two sub-foremen. The first sub-foreman (Kloth) is responsible for 7 workmen and were almost two days behind the schedule for the first week. That is indicated by the heavy line drawn in front of that sub-foreman. The shop floor overall was two days behind the schedule for the first week. That is indicated by the heavy line drawn in front of the foreman. This heavy line is the result of averaging the two heavy lines of the two sub-foremen. The reason behind delays are indicated by symbols placed across each space. For example, on Monday, July 11th, workman Schmidt completed just 80% of the work assigned to him due to material troubles indicated by the letter ‘M’.

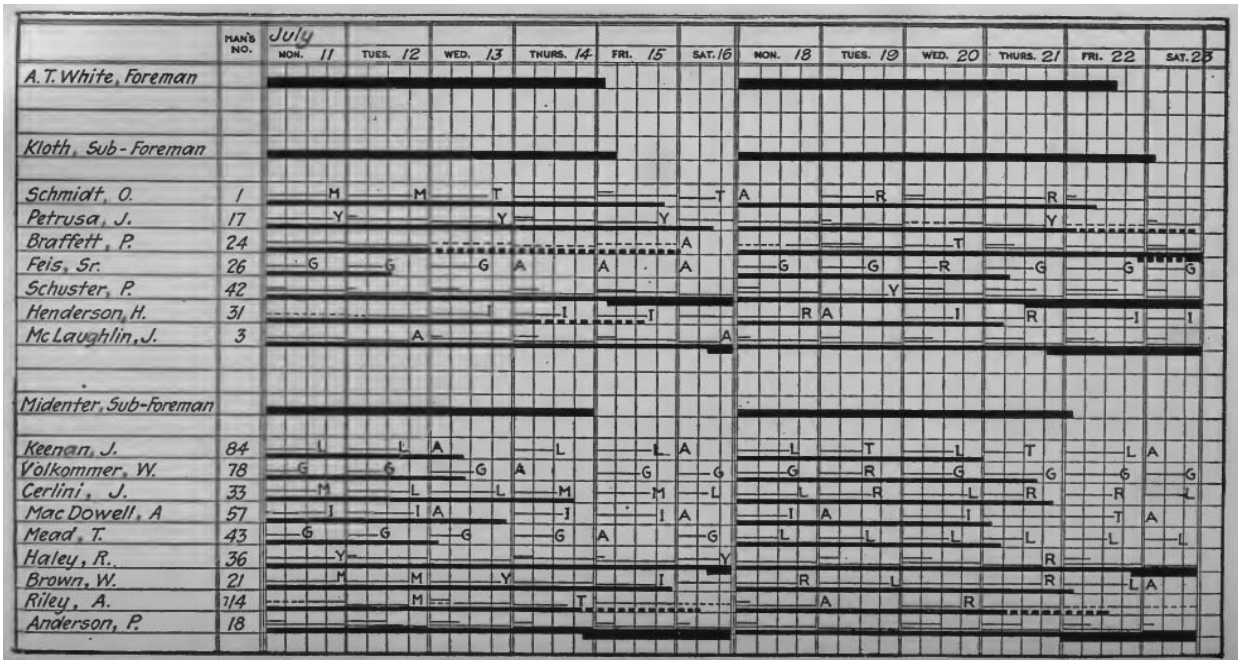


Figure 4.11 A Man Chart Example for Shop Floor (Clark 1923)

By using the chart a foreman can monitor and control the departments under his responsibility. For example, he can identify the department that is not performing as planned by simply looking at the department cumulative line. He can then look at the subgroups under that department and identify the group that needs more attention. This enables him to identify the workmen who are struggling to perform the work under that subgroup by looking at the reasons for the idleness. Sometimes, the origin of a delay or failure is the foreman. For example, the workmen could lose time (idle time) because of “improper sharpening of tools, defects in materials which should have been caught by the inspectors, the unsatisfactory condition of machines, and the lack of proper instructions on new work” (Clark 1923).

4.5 Layout Chart

The Layout Chart is used to make a plan that best utilizes the available resources (machines and men) in order to get the current work done. The Layout Chart provides the opportunity to present the starting time of the work, the time required to perform the work, and the person responsible for the work. In this section, two examples will be presented in order to provide better understanding to the layout chart mechanism. The first example will show a simple form of the chart for a stenographic department. The second example presents a more complex form of a layout chart in a machine shop.

4.5.1 Stenographic Department Example

Stenography is a writing method that uses shorthand techniques, such as acronyms, symbols, and abbreviations, to quickly record spoken words. The head of the stenographers uses a Layout Chart to assign the work to his/her stenographers. This chart enables the head of the stenographers to see the work that has or has not been completed so that when he/she wants to assign a job, they know who is available. To make a layout chart, the head of stenographer divides a sheet into the number of the hours in the workday divides each hour into subsections. For example, consider Figure 4.12. The first column has a list of the available stenographers. The next column represents the time it should take to write one page. This stenographic department works from 9:00 am to 5:00 pm. Each hour was ruled to four subsections (15 min each). This sheet was reported at 3:15 pm as indicated by the symbol (**V**) shown at that time. The lines starting at 9:00 am indicate that Miss. Gray and Miss. White are the only stenographers who have work left from the day before. Miss. Green started her work at 9:30 and the work should take about an hour and a half. At the report time, Miss. Brown and Miss. Black had still work to finish which is indicated by the lines extending beyond the reporting time.

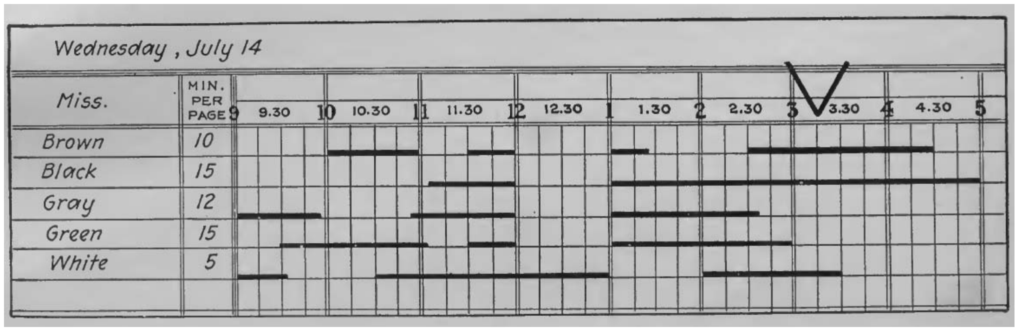


Figure 4.12 Layout Chart Example for Stenographic Department (Clark 1923)

4.5.2 Machine Shop Example

The Layout chart in a machine shop enables the managers to see the status of the machines whenever there is a job to be assigned. To make a layout chart, a sheet is divided into columns and sub-columns. If the shop work is laid out for several weeks, the sheet is divided into weeks and then to days. If the shop will be working less than a week, the sheet is divided into days and then into hours. In the chart, the first column represents a list of the available machines in that shop. A symbol (┌) indicates when the work should be started. A symbol (┐) indicates when the work should be finished. The total period of the work to be performed is represented by a light line between the two angles (see Figure 4.13a). The work completed is represented by a heavy line under the light line (see Figure 4.13b). When there is a new operation to be assigned and there is a delay in a past operation for a certain machine, the delay is represented by a cross between the two angles (see Figure 4.14).

Figure 4.13a Scheduled Work Illustrated using Lightly Drawn Line between Opening/Closing Angles (Clark 1923)

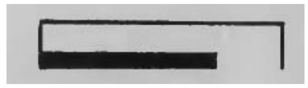


Figure 4.13b Performed Work Illustrated using Heavily Drawn Line between Opening/Closing Angles (Clark 1923)

Figure 4.14 Chart Illustrating Time Allocated for Performing Delayed Work (Clark 1923)

The work status can be determined by the location of the heavy line. If the heavy line aligns with the reporting date and time the schedule is on track. If the heavy line is ahead of the reporting date and time the work is ahead of schedule. Take Figure 4.15 for example. The chart is reported at the end of Monday as indicated by the symbol (**V**). The heavy line is extended until the end of Tuesday. It can be seen that the work is a day ahead of the schedule. Moreover, if a new operation needs to be assigned to a machine and that machine is ahead of schedule by one day, the new operation will be scheduled to start before that machine is scheduled to finish the old operation. For example, in Figure 4.15 the machine is one day ahead of the schedule in performing operation number A423. Therefore, the foreman schedules the machine to start operation A424 on Thursday morning instead of Friday morning. The reason behind delays will be represented by symbols right next to the heavy line, and a legend containing the symbol notation will be attached to the chart.

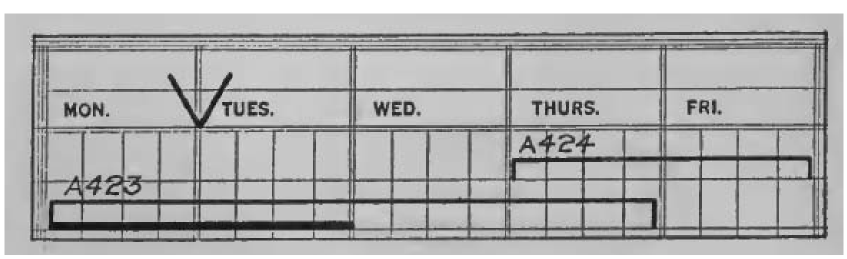


Figure 4.15 Layout Chart Depicting Ahead-of-Schedule Work (Clark 1923)

Figure 4.16, is an example of a Layout chart in a machine shop. This chart can be described as follows:

> "For the operation No. 11191-CE, according to the foreman's estimate, was to have been finished Tuesday noon, but had been completed on Monday and another order was begun, No. 61427. That job was also finished ahead estimate and the third order was begun Thursday afternoon instead of Friday. When the chart was copied on Wednesday, the 16th, the work was just on schedule. On the second machine, the work was already 3 days behind schedule when it was carried over from a previous sheet. At that time, order X6842 was scheduled to begin Thursday morning and completed Monday afternoon, but it was necessary to run in a repair job, a ring for a motor, so that 4 hours had to be allowed for the delay (indicated by crossed lines) before No. 16842 could be begun. When the chart was copied, Wednesday night, the work on this machine was 4 hours behind schedule" (Clark 1952).

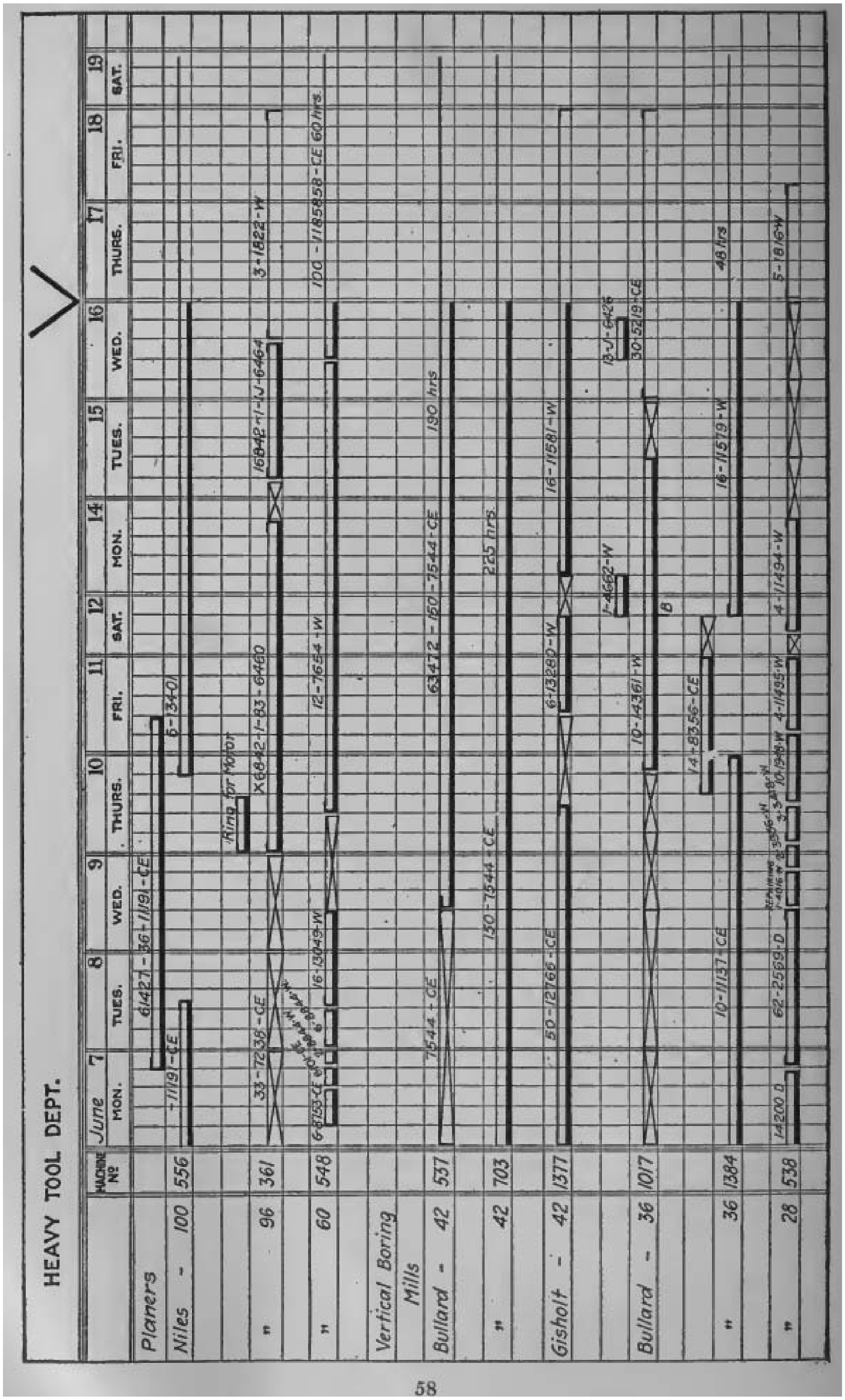


Figure 4.16 Layout Chart Example for a machine shop (Clark 1923)

4.6 Load Chart

The Load Chart presents work that still has to be done for each available resource (machine class, operators, floors, etc.), and the work that has been assigned as a function of time periods. The orders in front of each resource are obtained from the Layout Chart. The Load Chart provides a complete picture of the amount of work planned for each resource ahead of time. Therefore, when a manager/executive looks at the Load Chart and sees what tasks remain for each resource, he can easily assign new tasks.

Figure 4.17 is an example of a foundry load chart. The first column represents all of the machines available at the foundry, listed in groups. The second column represents the number of molders in each floor. The heavy dashed line indicates the amount of hours of work behind schedule. The light lines on the Layout Chart indicates the work scheduled from the past week. The heavy lines represent the total time that has been assigned to the floors for a given task. When a superintendent looks at this chart will be able to see the amount of work ahead of each group. For instance, the iron foundry has 48 molders, divided into four different types of floors. Take the crane floors as an example. Each molder is scheduled to work 40 hours per week. There are 16 molders which means the cumulative number of molding hours per week is 640. The work was behind schedule by 320 hours (indicated by the heavy broken line in the beginning of the first week). The light line indicates the work scheduled for the first week was a day and a half. The time allocated to accomplish the work scheduled is presented by the heavy line planned to take 2.5 weeks. It can be seen from the chart that the work assigned to the steel foundry is more than the available molders' capacity. For example, the four molders at the side floors have three weeks of work (indicated by the dashed lines) before they can start the work scheduled for them. The work assigned to this floor is supposed to finish on November 3rd (indicated by the light lines). However, the work completion will be delayed until December 3rd if the plant manager does not assign more molders. “This chart emphasizes the unbalanced condition of work in this foundry and the need for shifting workmen in such a way that all promises of delivery could be met" (Clark 1923).

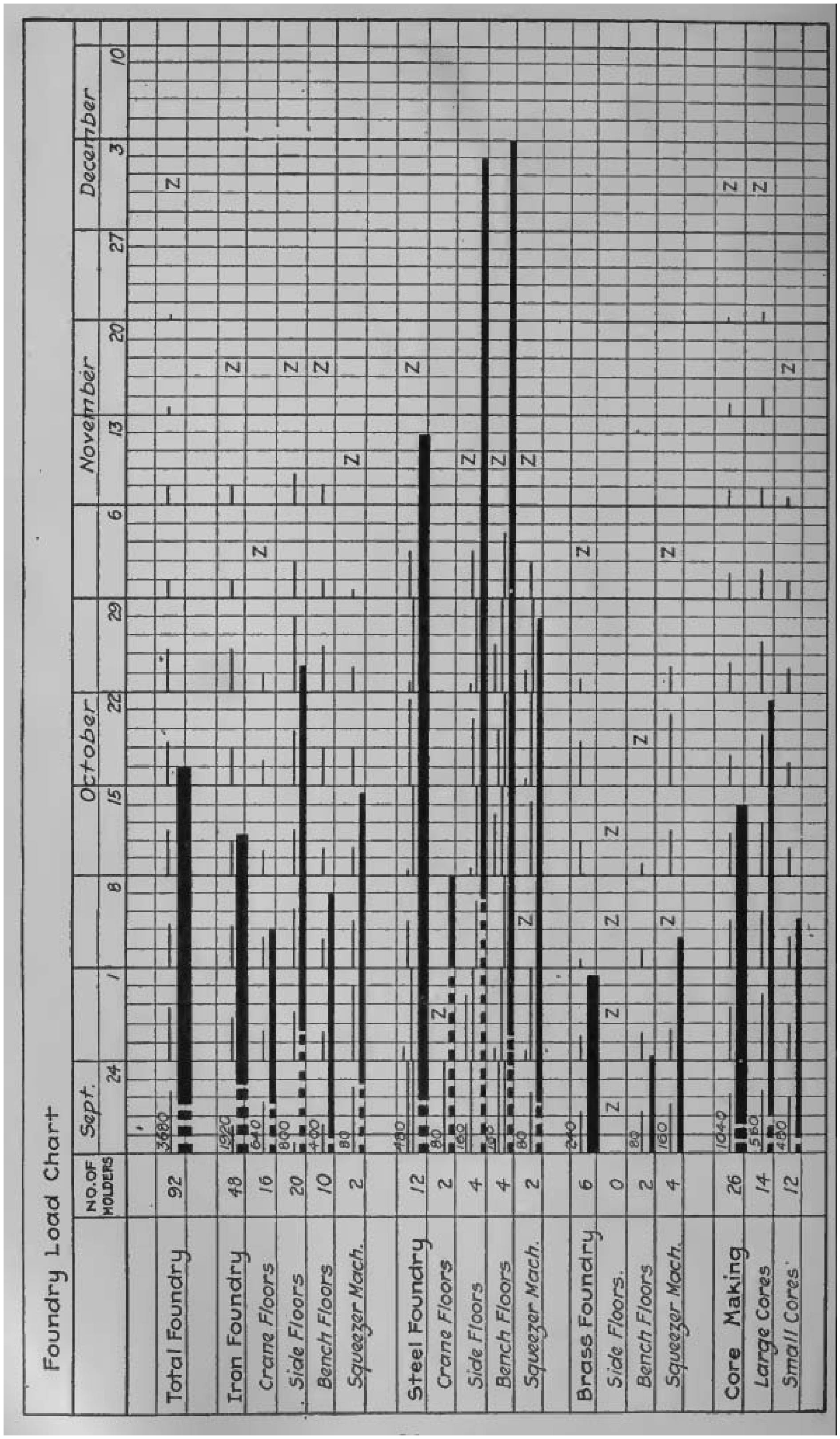


Figure 4.17 Load Chart Example for Foundry (Clark 1923)

4.7 Progress Chart

The Progress Chart compares actual performance with promised performance and gives the executives a mechanism to see if the orders/instructions associated with a certain plan have been carried out. Also, the Progress Chart gives executives the opportunity to keep records of their accomplishments and what they believed to be possible and compare it with the current situation. Therefore, it will be easy for executives to determine the degree of satisfaction in actual performance. The Progress Chart can be used within the manufacturing industry for various purposes such as comparing operations, organizing office work, sales quotas, budgets and expenses, and store-keeping.

A typical progress chart has the following characteristics:

1. It is easily understood in detail by the sub-managers.
2. It compares the actual performance with the anticipated performance, allowing the executive to foresee future happenings accurately.
3. It enables the managers to monitor the operations by the amount of work completed, as well as any reasons for delays.
4. It enables managers to see if their promises are going to be kept.

When drawing the progress chart the work being scheduled is presented by a number to the left of the space. The cumulative work scheduled is presented by a number to the right of the space. A light line across the space represents the work done at that specific time period. Similarly, a heavy line represents the cumulative work accomplished to date. A number in the middle of the space represents the work done without a preplanned schedule (See Figure 4.18). When a light line is drawn across a certain space more than one time, it indicates that more work has been performed than was originally scheduled (See Figure 4.19). A letter Z (zero) in the middle of a space indicates that no work was accomplished within that time period (See Figure 4.20). If the work is performed is more than three times the work scheduled, a number will indicate how many times the work exceeded what is scheduled as shown in Figure 4.21.

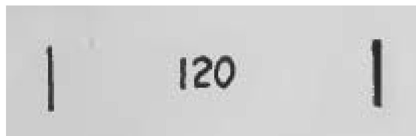


Figure 4.18 Chart Element Illustrating Work Performed without Preplanned Schedule (Clark 1923)

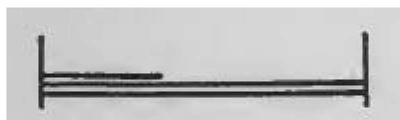


Figure 4.19 Chart Element Illustrating Performed Work in Excess of Scheduled (Clark 1923)

Figure 4.20 Chart Element Illustrating No Work Performed (Clark 1923)

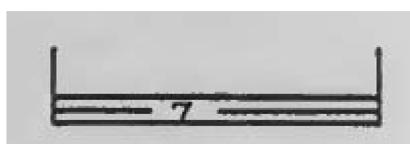


Figure 4.21 Chart Element Illustrating Performed Work Exceeded Seven Times the Schedule (Clark 1923)

Figure 4.22 is an example of a Progress Chart on a plant that manufactures on orders. The chart represents all the operations that were scheduled at that plant for a given time period. The angles to the right indicate when the materials are to be released from the stores. The angles to the left indicate the date in which the parts are to be shipped. The numbers indicate when each operation began, and the heavy lines indicate that an operation was completed. The reasons for idleness are indicated by letters under the lines where the work is underperformed. The date the chart was reported is indicated by the symbol **V** which in this case is March 3rd. If the work is performed according to the schedule, the heavy line will extend until the date of the report. And if the work is underperformed, the heavy line will be short from the reported date. For example, order number 59043 is a week and a half short of the schedule. That can be seen by the heavy line stopping on February the 23rd, which is a week and a half shorter than the reported date (March 3rd). The reason for that delay was lack of tools, indicated by the letter ‘T’.

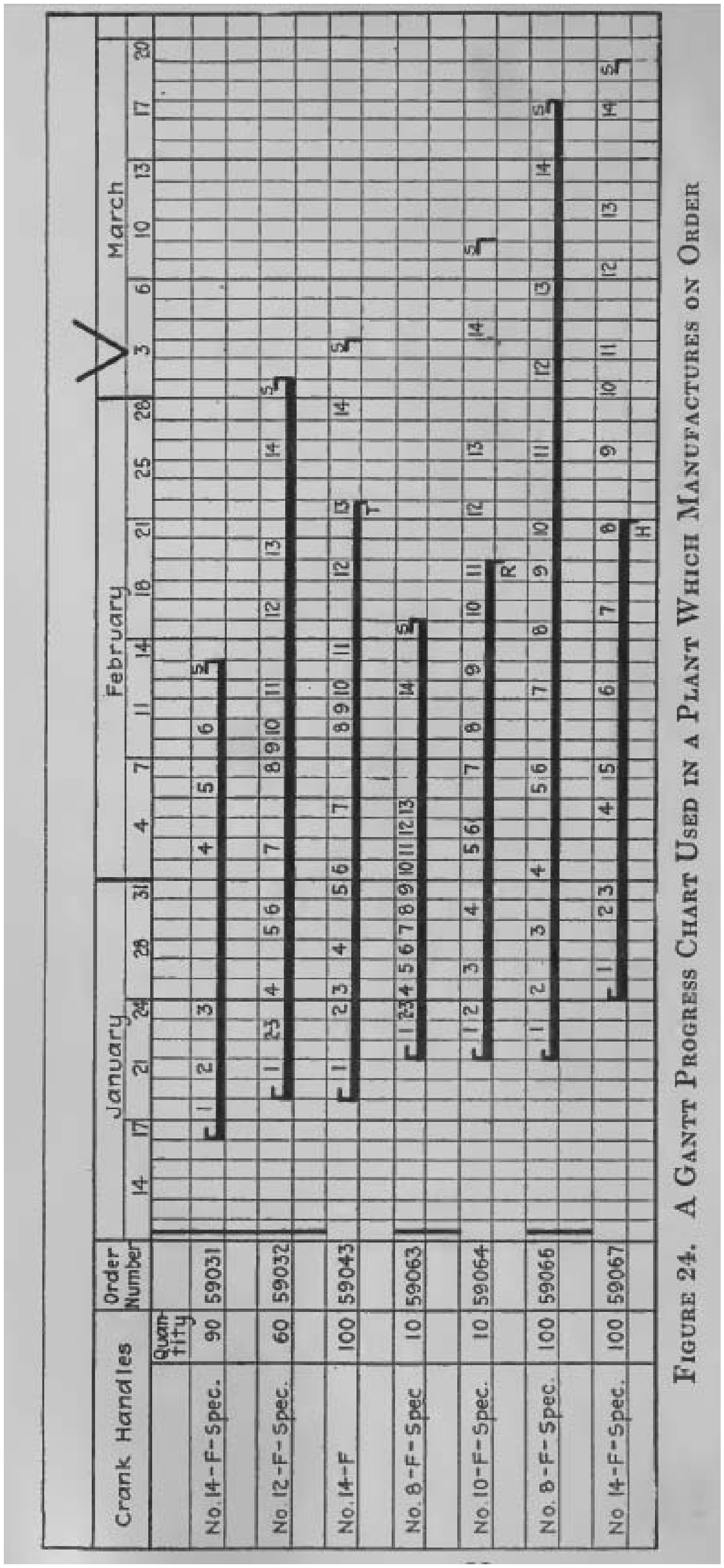


Figure 4.22 Progress Chart Example for Order Driven Manufacturing Plant (Clark 1923)

Another example of the progress chart is shown on Figure 4.23. This chart presents a comparison between the plan (quotas) and the performance (sales) for Article A in 8 regions in the United States. The monthly planned quotas are represented by figures on the left side of each column. The figure on the right side represents the cumulative amount of work required in the end of every month. At the time of reporting the chart (end of July), the United States total sales were behind schedule. This is indicated by the heavy line at the top of the chart. The two major regions underperforming are the Southern and Southwestern regions.

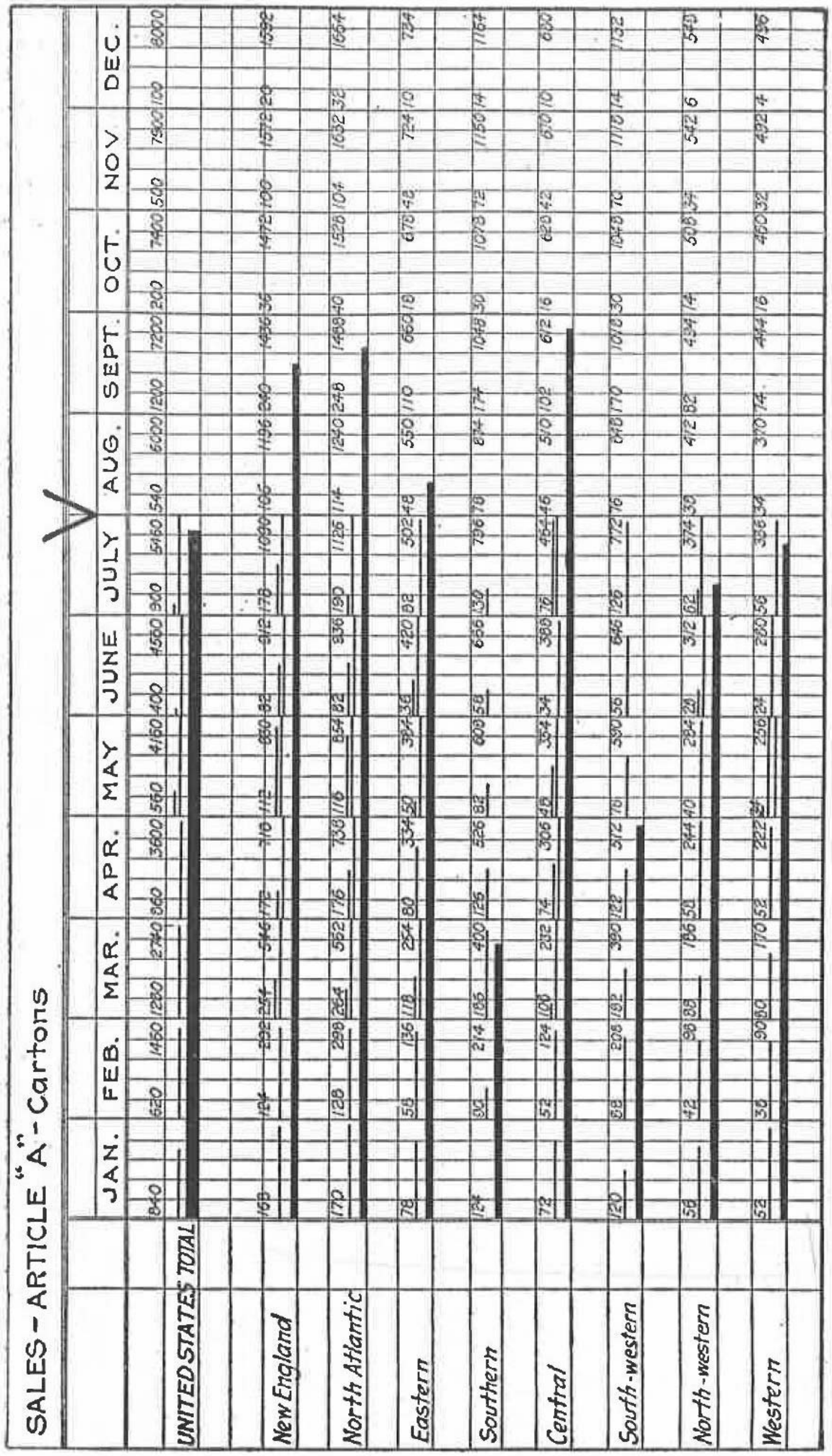


Figure 4.23 Progress Chart Example for Quota Driven Pursuits (Clark 1923)

4.8 Summary

In this chapter, the process of producing the Gantt Resource Management System components is described. The chapter is dived into seven sections. The first section provided the steps required to issue an instruction card. The second section described the main themes shared by the different Gantt charts. The third section explained the process of how to draw and use the machine chart. It also provided an example of how to interpret the information from the chart. The fourth section described how to draw and use the man chart and used an example to help demonstrate its usage. The fifth section provided the information regarding the production of the layout chart and how to use it. Two charts were used as illustrations. The sixth section used a chart produced at a foundry to describe the load chart. The seventh section illustrated how to draw and use the progress chart and provided an example.

CHAPTER 5

Application to Construction

The focus of this chapter is to apply the Gantt Resource Management System to the construction industry. To demonstrate this adaptation the brickwork trade was selected and a theoretical project model was developed to provide an example with activities that need to be executed. These activities were optimized using an existing motion study. The following sections will explain the example selected, present the adapted motion study, and describe the application of the Gantt Resource Management System.

5.1 Selected Construction Trade and Design Model

Brickwork was selected because it has the potential to increase efficiency and productivity if proper planning methods are applied. It can also be considered as a standard approach with subroutine tasks similar to an assembly process. Therefore, the brickwork gives a great opportunity to allow the adaptation of a manufacturing management system. The writer believes that what can be demonstrated on brick work can be applied to other construction trades.

The digital model of a hypothetical brickwork project was created using Revit 2013. The idea is to create a small model that is complicated enough to challenge the capabilities of the proposed system. The model consists of four different features: corners, solid walls, walls with openings, and curved walls. Each requires issuing a different instruction card because it requires a different methodology to perform the work. The model was created using Revit because the software has the potential to incorporate the proposed resource management system. Revit 2013 allows managers to plug in activities with their relations to each other, and link each activity with design model to produce a construction schedules. Therefore, if the computer is provided code (similar to the design code) that includes information such as generic schedule, techniques to develop time, lag feature, the tasks relationships the human element can then be eliminated and the process of producing schedules can be automated. The information provided by the GRMS is well developed to an extent that a computer code is possible to be written to automate the system as a next step in its implementation.

5.2 Motion Study

In the early 1900s, Frank Gilbreth conducted a motion study to determine the best way to lay bricks. Frank Gilbreth is a brick/concrete contractor that is considered as the father of the motion study for the art of bricklaying. He was able to cut the number of motions by 75% and "the workman's output has been doubled." (Gilbreth 1911). The motion study took the variables that affect the work efficiency into account: variables of the workmen, surrounding, equipment, tools, and the motion. The variables of the workmen captures an individual worker's productivity factors, such as: anatomy, fatigue, experience, health, mode of living, etc. For example, with anatomy if the mason is left-handed the brick piles should be stacked on his left side. The variables of the surrounding include: appliances, clothes, heating, cooling, ventilation, tools, union rules, etc. The variables of motions are: acceleration, direction, effectiveness, speed, etc.

From studying these variables Gilbreth introduced a "fountain mortar trowel" that is big enough to carry mortar for more than 4 bricks. He also developed a scaffolding system consisting of three platforms (See Figure 5.1): The first platform, the mason platform, provides space for the bricklayer to stand. A width of 1 foot and 5 inches was found to be the ideal width that will enable a mason to move comfortably. The material platform is placed at an elevation 2 ft. higher than the mason's platform. In that way the mason will not need to stoop over to reach for the material and therefore reduce the fatigue resulting from the bending movement and also accelerate the placement of the bricks and mortar on the wall. The third platform is the laborers platform. It enables the tenders to load and unload materials from the stock platform in a very efficient way without interfering with the masons because it is a separate platform. All three platforms are jacked simultaneously by a jacking arm attached to the scaffolding horses to keep the wall height at the same level as the mason's waist (see Figure 5.2).

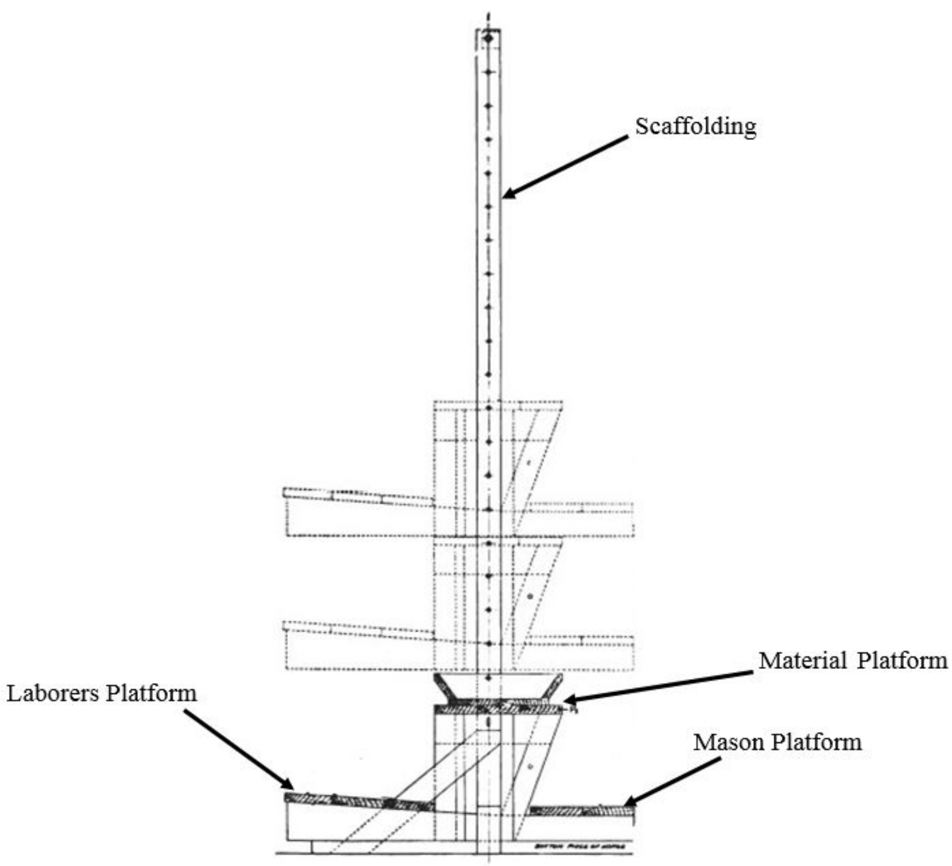


Figure 5.1 Gilbreth Scaffolding Side Elevation (Gilbreth 1911)

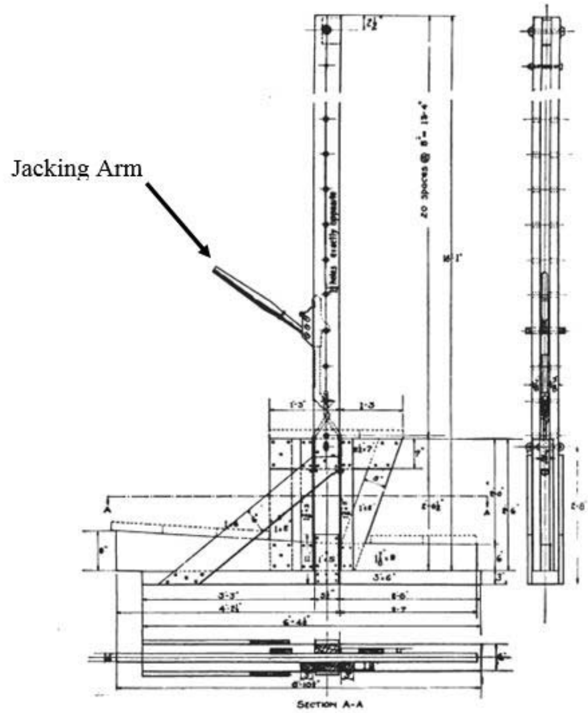


Figure 5.2 Gilbreth Scaffolding Side Elevation showing the Jacking Arm (Gilbreth 1911)

In order to eliminate the unnecessary motions resulting from reaching for far materials, Gilbreth suggested that two mortar boxes with a brick pile in between should be placed per scaffolding bay on the material platform (the bay is the distance between two scaffolding horses, 10ft) (see Figure 5.3). The tenders should load the bricks with their face-up, see Figures 5.4 and 5.5, in order to eliminate the unnecessary motion done by the mason if the brick laid on its width.

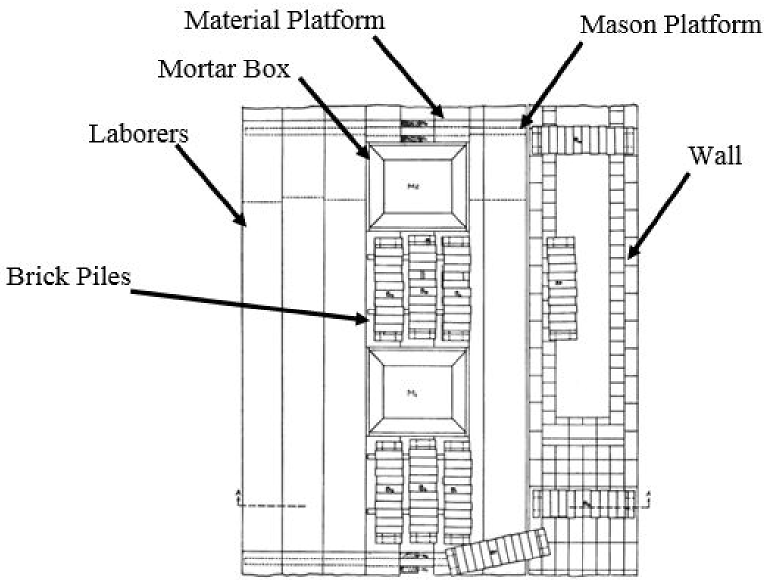


Figure 5.3 Mortar Box and Brick Pile Locations Shown on Material Platform (Gilbreth 1911)

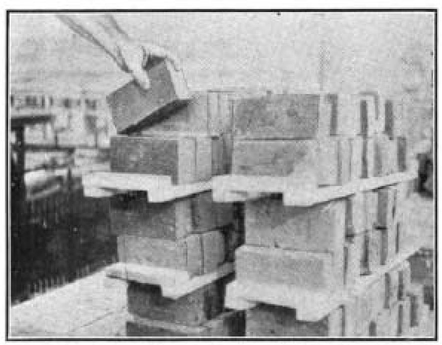


Figure 5.4 Instructed Method of Picking up Brick from Upper Tier (Gilbreth 1911)

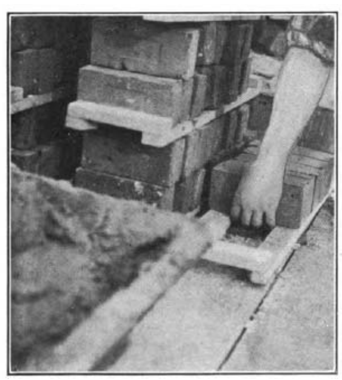


Figure 5.5 Instructed Method of Picking up Brick from Lower Tier (Gilbreth 1911)

After the introduction of the fountain trowel concept and the scaffolding system, Gilbreth was able to reduce the number of motions required to lay one brick from 18 motions to 4.5 motions. Figure 5.6 is an example of the instructions required to lay one brick using the stringing mortar method which requires spreading enough mortar for four bricks before laying down any brick. The figure also show the wrong way to lay brick which the workmen might have considered typical of current practice.

The scaffold system and the material setup plays a key role in omitting some of the unnecessary operations. For example, placing the mortar boxes and the brick piles in the material platform eliminated operations 1 and 4. That's because stepping for the mortar and reaching for the mortar should be done at the same time. Similarly, stepping for brick and reaching for brick should be done simultaneously. The time required to reach the material is also reduced because the bricklayer does not have to bend over to pick materials since the material platform is elevated 2 ft. The brick tenders are responsible for delivering mortar with the right consistency, transporting bricks, stacking bricks face up, and keeping the bricks in the right wetness. As a result the masons are left to focus solely on their job. Therefore, steps like operations 3 and 6 are eliminated.

Operation No.	The Wrong Way. Motions per Brick. ¼ ½ ¾ 1	The Right Way. Motions per Brick. ¼ ½ ¾ 1	STRINGING MORTAR METHOD. THE EXTERIOR 4-INCHES (LAYING TO THE LINE.)
1	Step for Mortar.	Omit.	
2	Reaching for Mortar.	¼	As a large trowel holds mortar enough for four brick, ¼ of a motion is the right amount to allow for one brick.
3	Working up Mortar.	Omit.	Have a laborer keep the mortar at the right consistency by tempering.
4	Step for Brick.	Omit.	If the mortar boxes are not over 4 ft. apart no stepping is necessary.
5	Reach for Brick.	1	
6	Pick up Right Brick.	Omit.	
7	Mortar, Box to Wall.	¼	Conveying mortar for four brick, equals ¼ motion per brick.
8	Brick, Pile to Wall.	½	Brick in each hand = ½ motion per brick.
9	Deposit Mortar on Wall.	¼	Depositing mortar for four brick at once = ¼ motion per brick.
10	Spreading Mortar.	¼	Spreading mortar for four brick per motion = ¼ motion per brick.
11	Cutting off Mortar.	Omit.	Do not cut off any mortar until brick is deposited on mortar.
12	Disposing of Mortar.	Omit.	
13	Laying Brick on Mortar.	Included in 5.	
14	Cutting off Mortar.	1	
15	Disposing of Mortar.	1	Butter the end of last brick laid.
16	Tapping Down Brick.	Omit.	
17	Cutting off Mortar.	Omit.	
18	Disposing of Mortar.	Omit.	
	18	4½	Total Number of Motions per Brick.

Figure 5.6 Laying Single Brick using "Stringing Mortar" Method (Gilbreth 1909)

5.3 Brickwork Project

Figures 5.7, 5.8a, and 5.8b below shows the plan view and the 3D snapshots respectively for the brick model. The building total perimeter is 525 ft and the height is 10 ft. It consists of 14 corners and three wall types. The first wall type is walls with openings. These are the two walls located on the west side of the building (W1 and W3) with a total area of 616 SF. The second type is the curved walls (W2 and W12) with a total area of 632 SF and 30 ft. in radius. The third type is solid walls without openings with a total area of 3844 SF (W4 - W11 and W13 - W17). The building has 14 corners (C1 – C14).

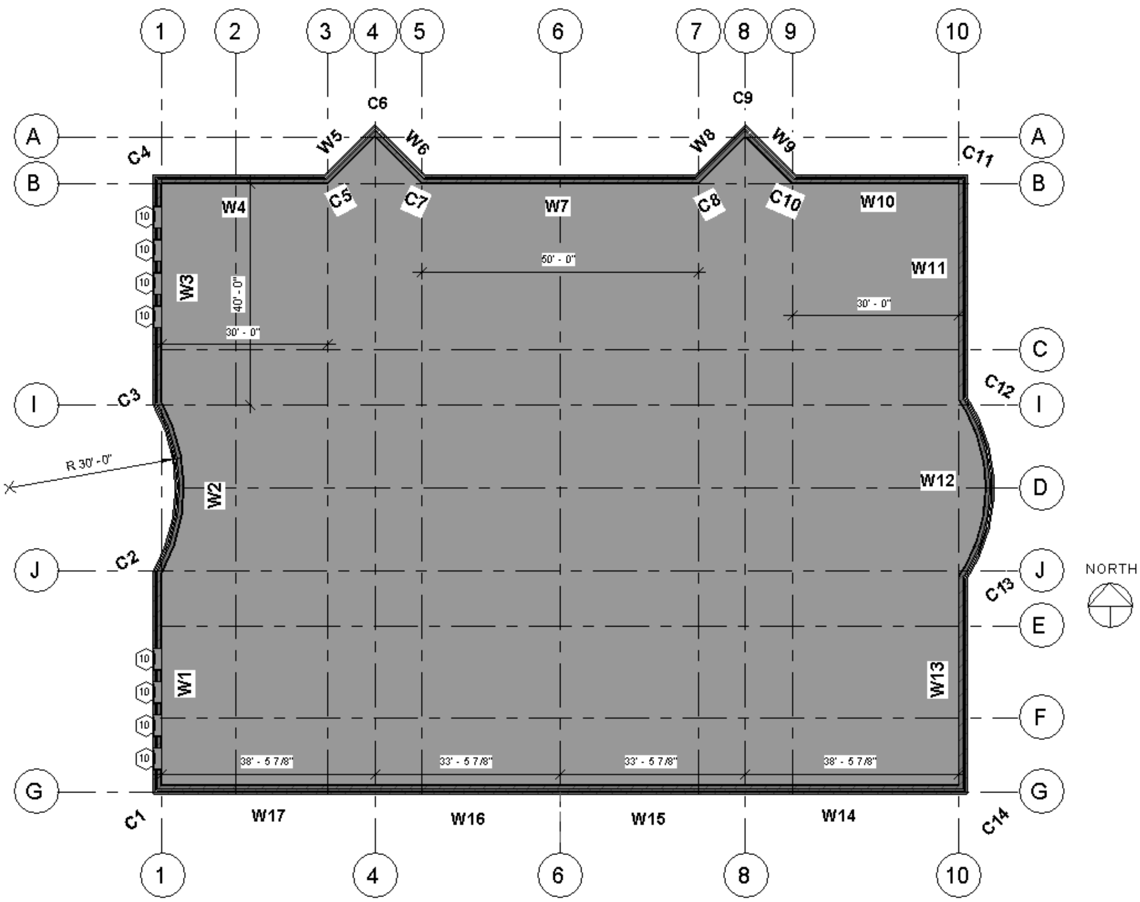


Figure 5.7 Prototype Project Plan View

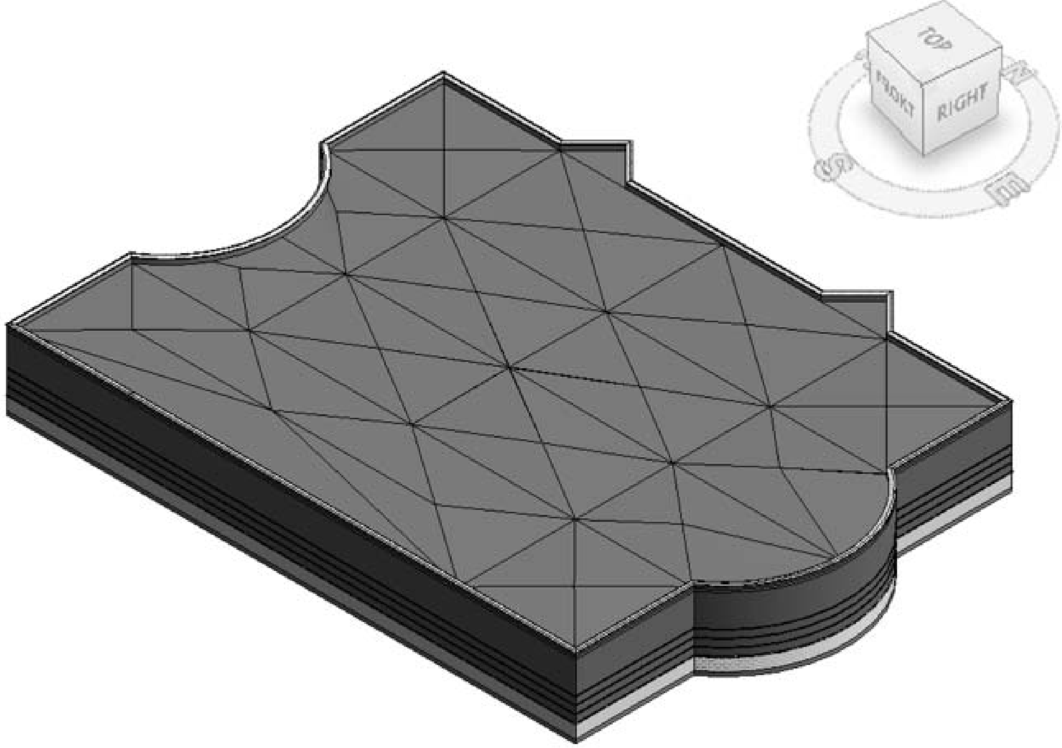


Figure 5.8a Project 3D View from Southeast

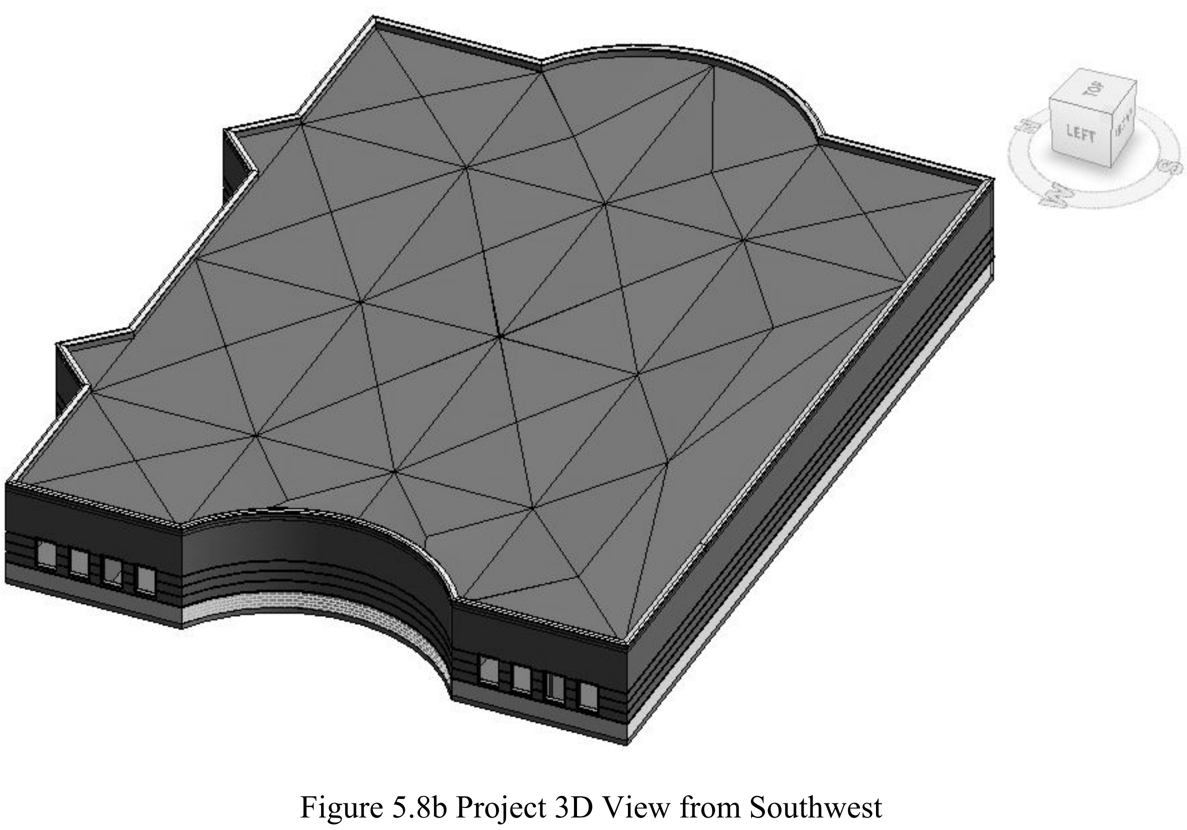


Figure 5.8b Project 3D View from Southwest

5.4 Gantt Resource Management System Development

This section is divided into four parts. The first describes the process of producing four different instruction cards by adapting Gilbreth's motion study. The second describes the scaffolding system used with the motion study. The third presents the preliminary planning schedules which consisted of an as-planned schedule produced before the work is actually started, a Machine Chart, and a Load Chart and a Layout Chart. The fourth part provides an example of an assumed actual work scenario, an as-performed schedule.

5.4.1 Instruction Cards

To produce an instruction card the task needs to be identified and then a scientific investigation performed to determine the best way to perform the work. In the example project the tasks are divided into seven categories, each requires the production of a separate instructions card. These categories are: Corners, Walls with openings, Walls without openings, Curved Walls, Expansion joints, Scaffolding, and Mortar preparation. The motion study, developed by Gilbreth, for the stringing mortar method is adapted and used. The duration of how long each activity should take is estimated based on the number of motions required to lay four bricks and based on the brick mason's capacity to lay bricks per day. According to RSMeans (2008), the productivity of a crew consist of three masons and two brick helpers is 1500 bricks per day. Therefore, in the production of the instruction cards and construction schedules for the example model, a crew of three brick masons and two brick helpers is assigned to perform the work. This number is used to determine the time required per motion on all the instruction cards. For the example model, seven instruction cards are produced, which are: how to build a corner, a wall without openings, a curved wall, a wall with openings, an expansion joint, erect scaffolding system, and how to prepare the mortar. For the sake of this discussion, the corners, the walls without openings, and the curved walls are presented as example instruction cards. The rest of the instruction cards are attached in the Appendix A.

5.4.1.1 How to Build a Corner

The process of issuing an instruction card starts with studying how to efficiently build a corner by using the necessary motions. The second step is to convert the total number of motions to a time that indicates how long it should take to build the corner. Figure 5.9 is an instruction card representing how to build a corner consisting of 7 courses. As it can be seen the card heading contains the description of the work to performed, the location of the job on the project site, the foreman responsible to supervise the work, the brick mason identification numbers, the bond pattern required to be used, and the method required to lay the brick. It should be noted that laying a corner requires a skilled, experienced journeyman mason. General notes are attached to the instruction card to help the mason better understand the overall procedure and to provide general guidelines.

In Figure 5.9, the first column presents the operations to be followed by the bricklayer in building one corner with 29 operations. The second column presents the number of motions required in each operation. There are a total of 46 total motions. The third column contains notes to explain some specific operations and to refer to supporting illustration figures. With that being said, the instruction card should contain some figures that will help the brick mason to visualize and understand how the work should be performed. These figures should be attached to the card as would Figures 5.9a to 5.9k. The fourth column contains the total time taken to perform each motion. In this example the writer has provided summative total time to perform the 46 motions. The fourth column would contain the actual time taken to perform the work.

Class of Work: Corners. Location: All corners. Responsible Foreman: Mark

Journeyman number: 1&2. Bond Pattern: Stretcher Bond. Method to be use in laying the brick: Stringing Mortar Method.

Operation Description	Motions	Notes	T Req.	T Took
1- Lay dawn dry four bricks in one direction and three bricks on the other direction. The bonding pattern (stretcher bond).	3			
2- Take out these bricks	3			
3- With the foreman mark the gauge control point from the datum peg.		See Figure 5.9a		
4- Lay the first brick, gauge it and level it with the eye.	1	See figure 5.9b, Use the most accurate bricks.		
5- For the first course, the level is based on the corner brick.		See Figure 5.9c		
6- Reaching for Mortar	1/4	With a large trowel holds mortar for 4 bricks.		
7- Mortar = Box to Wall	1/4	Conveying mortar for four bricks at once.		
8- Deposit Mortar on Wall	1/4	Depositing mortar for four bricks at once.		
9- Spreading mortar	1/4	Spreading mortar for four bricks at once.		
10- Reach for Brick (1st time)	4/4	Rub brick into the mortar		
11- Brick = Pile to Wall (1st time)	1/2	Brick in each hand.		
12- Reach for Brick (2nd time)	4/4	Rub brick into the mortar		
13- Brick = Pile to Wall (2nd time)	1/2	Brick in each hand.		
14- Reach for Brick (1st time) on the other direction.	4/4	Rub brick into the mortar		
15- Brick = Pile to Wall (1st time) on the other direction.	1/2	Brick in each hand.		
16- Reach for Brick (2nd time) on the other direction.	4/4	Rub brick into the mortar		
17- Brick = Pile to Wall (2nd time) on the other direction.	1/2	Brick in each hand.		
18- Cutting off mortar	4/4			
19- Disposing off mortar	4/4	Butter the end of last brick laid.		
20- For the second course, lay the corner brick first.	8	Use the same procedure for laying the first course.		
21- Lay the third course	6			
22- Lay the fourth course	4			
23- Lay the fifth course	2			
24- Lay the sixth course	2			
25- Lay the seventh course	1			
26- Check the gauge before you start leveling and plumbing	1			
27- When plumbing the bricks, support it with your foot from the bottom and hold it with your hand from the top.	2	See Figures 5.9d and 5.9e; make sure it is always leveled.		
28- Tap the brick with the trowel either away or toward the level.	1	See Figures 5.9d and 5.9e		
29- Check for the face alignment by swinging the spirit level over the face that you want to check.	2	See Figure 4.9f		
Total Number of Motions/ Corner	46	Time per motion = 1 min	46 min	46 min

Figure 5.9 Instruction Card for Building a Corner

General Notes:

- Corners should be built racked back.
- Do not racks back more than 1.2 ft. (Because it is going to be noticeable in the finished work)
- Corners should be 7 courses high.
- Lay the first course dry (to make sure the positions of the corner bricks are correct and to set up the right bonding pattern.)
- Each course should be leveled after it is laid.
- To have an accurate brick alignment, always sight corner bricks when you lay them. Sight one side of the corner at time:
    1. Align your eye with the corner from the top.
    2. Move your eye back and forth two times on the plan, that you want to align your brick with, and on a direction away from the plan.
- Use a spirit plumb rule to correct and level any projection on the bricks.
- To plumb a corner, the best location to put the plumb rule is the edge of the corner brick. See Figure 5.9c
- Install a datum peg with an elevation equal to the ground floor elevation. See Figure 5.9g.
- Use the storey rod see figure 5.9h, provided by the foreman, to check the height of the courses. (Every course you lay). `
- Gauging should be taken from the fixed datum in the wall. See Figures 5.9g.
- On laying the corner brick, check the brick for the gauge first before the plumbing and leveling see Figures 5.9i and 5.9j.
- Gauge plumbing for corners should be based on the corner bricks.

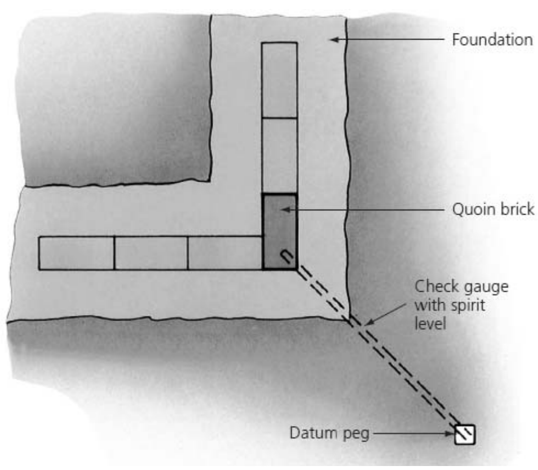


Figure 5.9a Setting Gauge Control Point from Datum Peg (The Brick Development Association 2005)

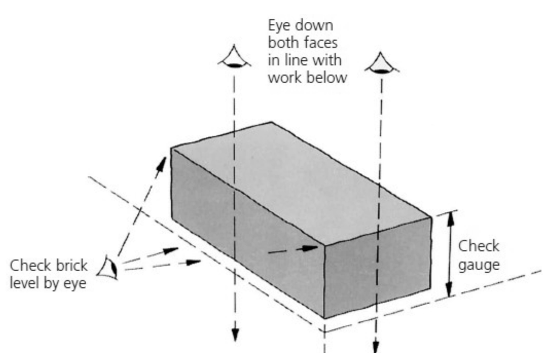


Figure 5.9b Eyeing Corner Brick (The Brick Development Association 2005)

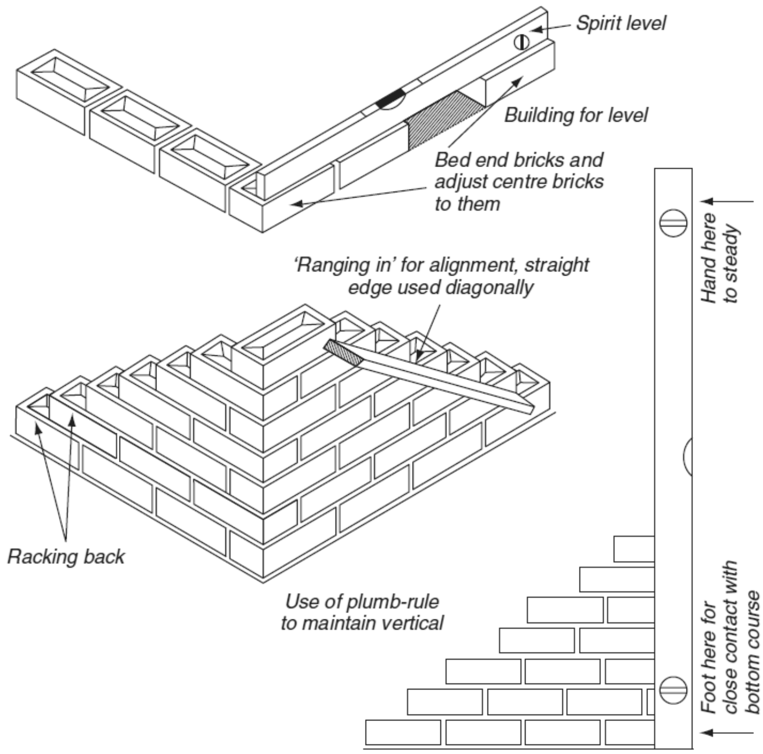


Figure 5.9c Raising Corners in Half Brick Walls (Hodge and Thorpe 2006)

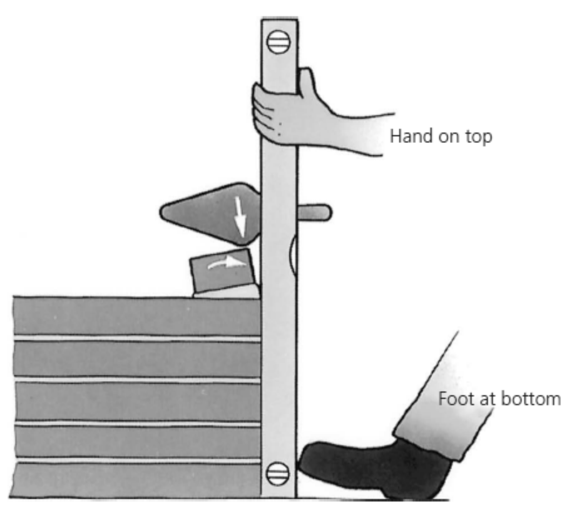


Figure 5.9d Tapping Brick to Level (The Brick Development Association 2005)

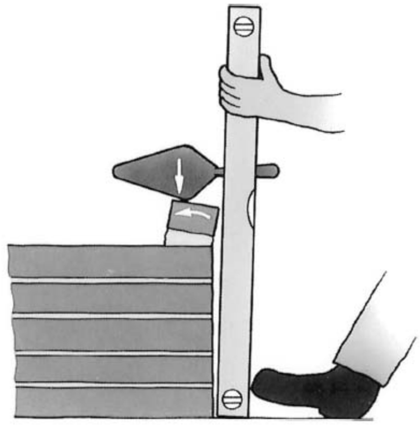


Figure 5.9de Tapping Brick Back (The Brick Development Association 2005)

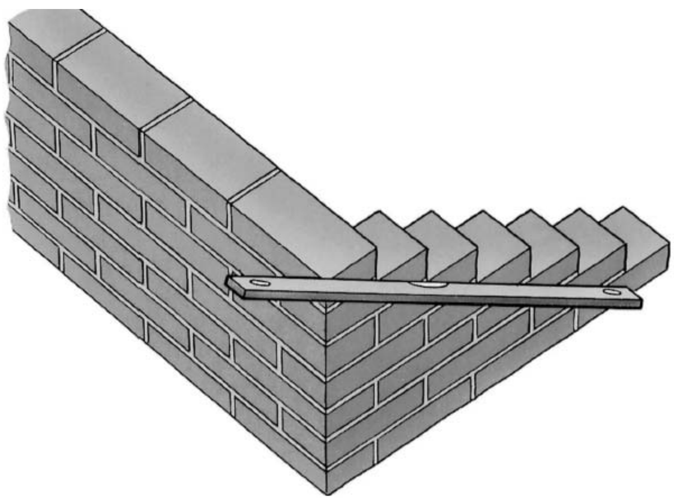


Figure 5.9f Checking for the Face Alignment (The Brick Development Association 2005)

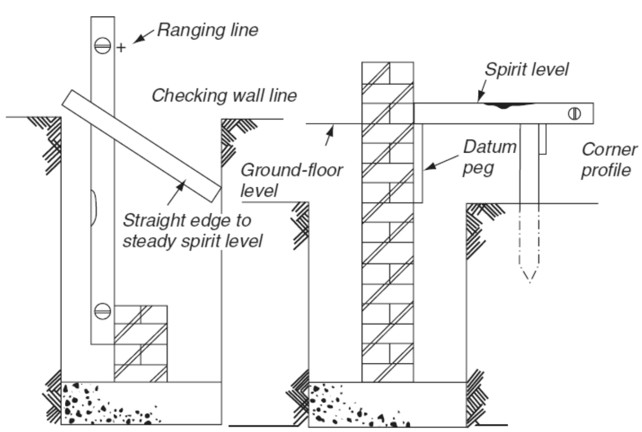


Figure 5.9g Setting Datum Peg Elevation equal to the Ground Floor (Hodge and Thorpe 2006)

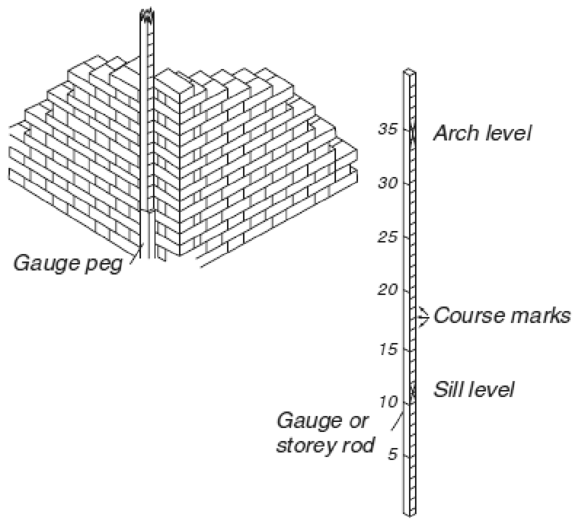


Figure 5.9h Using a Storey Rod (Hodge and Thorpe 2006)

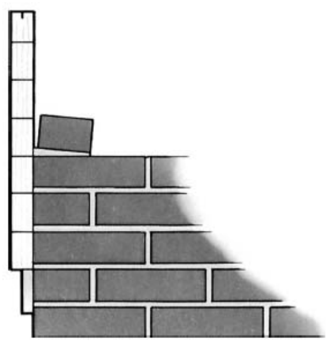


Figure 5.9i Checking Gauge of Corner Brick (The Brick Development Association 2005)

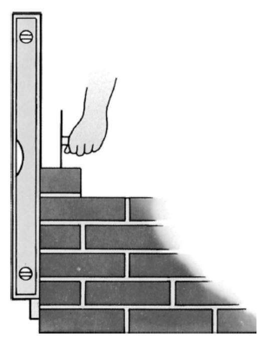


Figure 5.9j Plumbing corner brick (The Brick Development Association 2005)

5.4.1.2 How to Build a Wall without Openings

Similar to the instruction card issued for the corners, Figure 5.10 represents an instruction card of how to build a solid straight wall between two corners. The card is using the same corner instruction card format but containing different information. The information provided and the number of motions presented in this card reflect the construction of a typical straight wall on the east side of the building. A spreadsheet (see Appendix A) is developed based on the number of the motions on this card to estimate the equivalent number of motions and time required to construct the rest of the solid walls in the building. It should be noted that the construction of a wall between two corners does not required a first class mason therefore a brick apprentice is assigned as a third mason with the other two journeymen to lay bricks between these walls . The total number of motions required building one of the typical walls on the west side of the building with a length of 40 feet and a height of seven courses is estimated to be equal to 1074 motions. The time required to do these motions by one mason is estimated to be 8 hours.

Class of Work: Wall without openings   Location: Typical solid straight wall on west side.

Responsible Foreman: Mark   Brick Mason number: J1, J2, and apprentice

Method of laying the brick: Stringing Mortar.   Bond Pattern: Stretcher Bond.

Operation Description	Motions	Notes	T Req.	T Took
String the line between the two corners.	2			
Sight the line	1			
Total Motions before laying the first course	3			
Laying 4 bricks				
Reaching For Mortar	1/4	With a large trowel holds mortar for 4 bricks.		
Reach for brick	2	For 4 bricks (2 bricks at a time)		
Mortar = Box to Wall	1/4	Conveying mortar for four bricks at once.		
Brick = Pile to Wall	1/2	Brick on each hand.		
Deposit Mortar on Wall	1/4	Depositing mortar for four bricks at once.		
Spreading mortar	1/4	Spreading mortar for four bricks at once.		
Cutting of mortar	4/4 per brick			
Disposing of mortar	4/4 per brick	Butter the end of last brick laid.		
Total motions for laying four bricks	8.5			
Total motions for laying the first course (72 bricks)	153			
Total motions for laying the Seven course	1071			
Total motions for laying a wall between two corners	1074	It take 0.45 minute per one motion.	8 hrs	

Figure 5.10 Instruction Card Methods for Building Wall without Openings

General Notes:

- Using a wooden block and a pin (see Figure 5.10a) string a line between the plumbed corners (see Figure 5.10b) for each course you want to lay. (1/8 inch should be between the line and the face of the wall).
- Insure the line is pulled tight enough to prevent it from sag.
- Sight the line from one end (corner) to ensure it is positioned correctly.
- After you lay every course check it with a plumb rule to make sure the line was not disrupted while laying the brick course.
- Use half bond with brick of subsequent courses bridging the halves of lower bricks.
- At T junctions with the internal walls: use ¾ bats and ¼ bats as bonds.
- Plumb every fourth or fifth perpends (see Figure 5.10c). ‘’Perpends are the positions of the vertical joints between the bricks.’’(Ibstock Brick 2000).

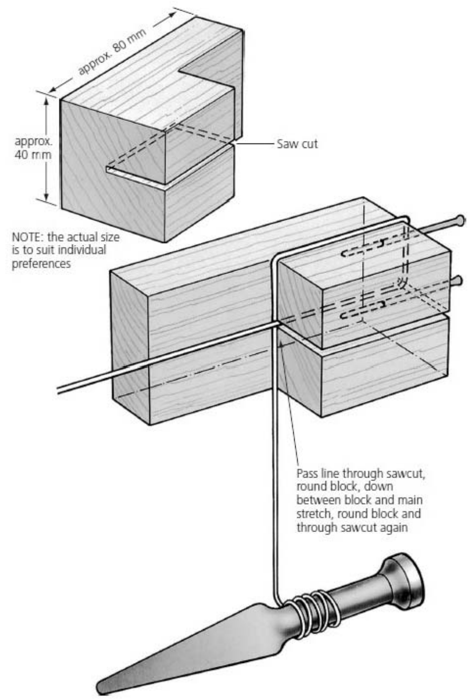


Figure 5.10a Using Wooden Block and a Pin to get a Straight Line between two Corners (The Brick Development Association 2005)

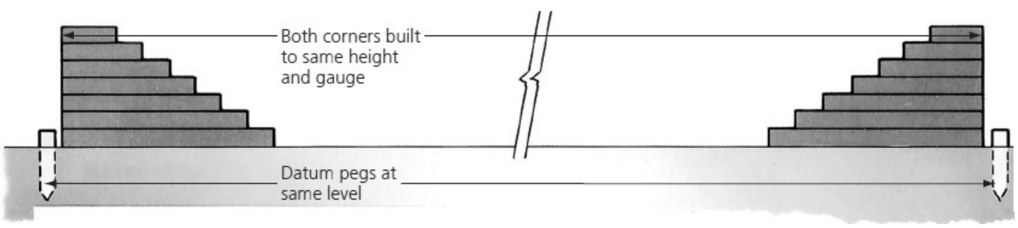


Figure 5.10b Stringing Line between Plumbed Corners (The Brick Development Association 2005)

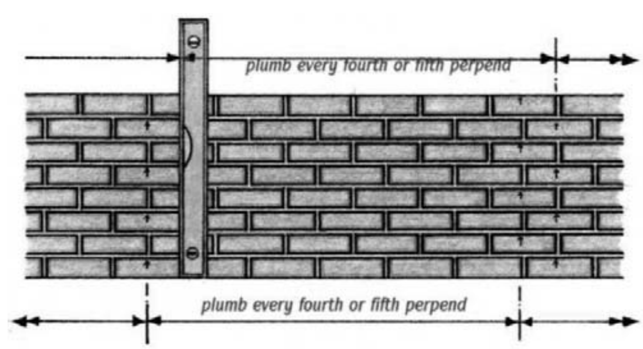


Figure 5.10c Plumbing every Fourth or Fifth Perpends (Ibstock Brick 2000)

5.4.1.3 How to Build a Curved Wall

Figure 5.11 represents an instruction card for how to build a curved wall between two corners with a height of seven courses on the east and west side of the building. The card follows the same format as the instruction card issued for building a corner. It should be noted that the building of a curved wall involves details that requires skills and experience. However, the brick apprentice is assigned to do one of the walls in the model in order to show the flexibility of the instruction card. The curved wall size is 25% less than the straight wall size presented in the previous instruction card. Therefore, as it is shown in Figure 5.11, it takes the same amount of time to be constructed. That is because the time estimate of the motions presented in the curved wall instruction card is adjusted based on a rate of a second class bricklayer rather than a first class mason. The total number of motions required to lay one curved wall seven courses high between two corners is estimated to be 881 motions. The time required is estimated to be 8 hours. General Notes and supporting illustration figures are attached to the card in order to demonstrate some specific operations. Another instruction card for how to build a curved wall between corners by a journeyman has been produced and attached in Appendix B.

Class of Work: Curved Wall. Location: East and west side of the building.

Responsible Foreman: Mark Brick Mason number: Apprentice

Bond Pattern: Stretcher Bond. Method to be use in laying the brick: Stringing Mortar.

Construction Method: Full Template.

Operation Description	Motions	Notes	T Req.	T Took
A. With the foreman, install the template in the right place.				
B. Laying four bricks				
Reach for Brick	2	For 4 bricks (2 bricks at a time)		
1- Reaching For Mortar	1/4 per brick	With a large trowel holds mortar for 4 bricks.		
2- Reach for Brick	4/4 per brick			
3- Mortar = Box to Wall	1/4 per brick	Conveying mortar for four bricks at once.		
4- Brick = Pile to Wall	1/2 per brick	Brick in each hand.		
5- Deposit mortar on wall	1/4 per brick	Depositing mortar for four bricks at once.		
6- Spreading mortar	1/4 per brick	Spreading mortar for four bricks at once.		
7- Cutting off mortar	4/4 per brick			
8- Disposing off mortar	4/4 per brick	Butter the end of last brick laid.		
Total Motions for laying four bricks	6.5			
Total Motions for laying the first course (53 bricks).	86			
Total Motions for laying the seven courses	603			
9- Horizontal Leveling between plumbing points.	18 motions/ course 126 motions	There are 20 plumbing points 18 motions * 7 courses = 126		
10- Check for curvature between the plumbing points.	18 motions/ course 72 motions	There are four courses that will need this step. 18*4= 72		
11- Vertical plumbing	20 motions/ course 80 motions	There are four courses that will need this step. 20*4= 80		
Total motions	881	0.54 of a minute per one motion	8 hrs	

Figure 5.11 Instructions Card Methods for Building Curved Wall

General Notes:

- Use half bond
- Use the template, provided by the foreman, to lay the first three courses.
- Around the curve, mark a number of plumbing points. See Figure 5.11a.
- Use the wooden template to check the curvature between these plumbing points. See Figure 5.11b
- Vertical plumbing should be taken from the plumbing points at the first course. See Figure 5.11b.
- Horizontal leveling is very important while you are laying the course. Check the horizontal leveling between the plumbing points. See Figure 5.11b.

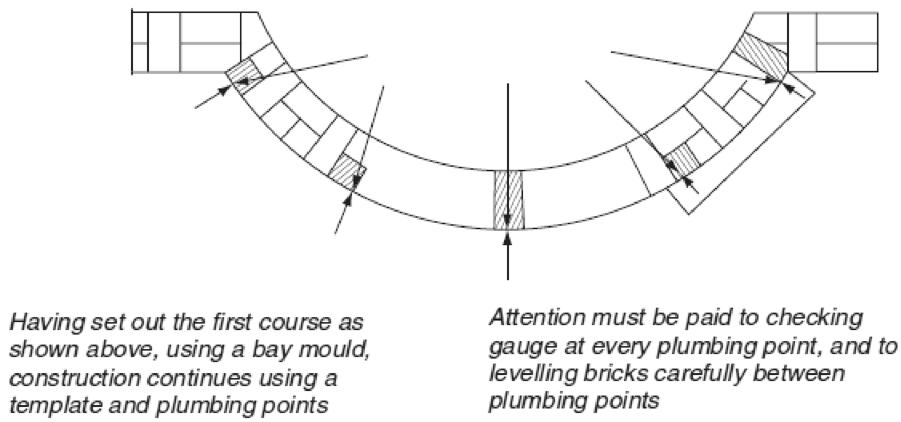


Figure 5.11a Plan View of Plumbing Points Locations. (Hodge and Thorpe 2006)

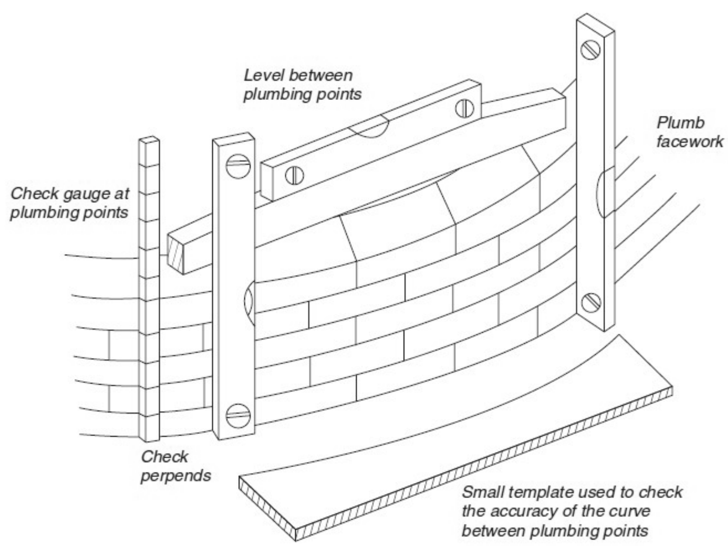


Figure 5.11b Checking Curvature between Plumbing Points (Hodge and Thorpe 2006)

As can be seen the instruction card leaves no chance for wasted motions. The instructions control the production operation and who is responsible to perform the work. One of the big advantages of using such a card is the ability to be updated. For instance, if the temperature is abnormal and preventing the workmen from keeping up with the time estimate the card can be updated and adjusted to allow the adjustment for such a reason.

5.4.2 Scaffolding System

The success of methodology used in developing these instruction cards depends on the installation of a scaffolding system similar to the one developed by Gilbreth. In order to do so a scaffolding system (the workhorse scaffolding) produced by Non-Stop Scaffolding Inc. has been used for the construction of the brickwork model. Figure 5.12 represent a section elevation view of a workhorse scaffolding. As can be seen, the scaffolding contains three platforms similar to the scaffolding system that Frank Gilbreth developed. These platforms are the mason platform (placed on the side of the wall), material platform with a capacity up to 3,800 lbs, and labor platform. These platforms can be adjusted as the wall rises.

There are two main advantages of this type of scaffolding: First, the system parts are simple and light weight and can be taken down and reinstalled very fast (20 minutes). Second, according to Non-Stop Scaffolding Inc., the system proved to increase the labors efficiency by 25%. An instruction card that describes how to setup such a system is produced and attached in Appendix A.

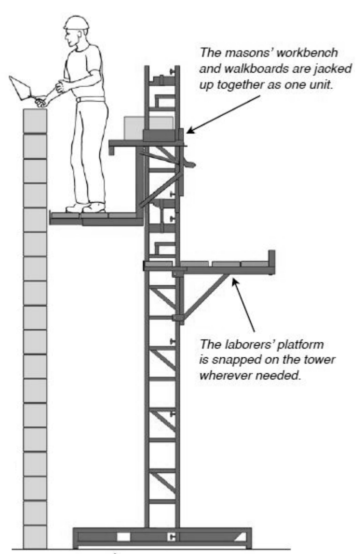


Figure 5.12 Workhorse scaffolding. (Non-Stop Scaffolding Inc. 2008)

5.4.3 Preliminary Schedules

This section discusses the schedule produced during the planning stage. Before work commences, an as-planned schedule, a Machine Chart, and a Load Chart are developed for planning purposes. This discussion is followed by an example of a layout chart that shows the work planned for one day.

5.4.3.1 As-planned Scheduled

Figure 5.13 represent an as-planned schedule for the example project with an estimated duration of 30 days. The schedule consists of the same elements of the GRMS charts used in the manufacturing industry. As can be seen the available resources are assumed to be a crew of three bricklayers and two brick helpers (taken from m the RSMeans 2008). The bricklayers are divided into two categories. The first is the high skilled masons (journeyman 1 and 2). The second represents a less skilled mason (apprentice). The two labors are listed under the brick-helper category. The chart also shows two workmen who are going to install the scaffolding system between Wednesday the 27th and Friday the 29th. These resources are listed on the first column of the chart. The activities to be performed are assigned to each one of the masons and plotted on the chart. The contractor is expected to work five days per week (8 hours per day). Therefore, each day is divided into four small columns each one representing 2 working hours. The width of each working day column represents the expected work to be performed each day. The light lines shown in this chart are drawn to show the work scheduled for each day.

As Planned Schedule

	Nov. 2013					Nov. 2013				
	Mon 11th	Tue 12th	Wed 13th	Thu 14th	Fri 15th	Mon 18th	Tue 19th	Wed 20th	Thu 21st	Fri 22nd
Corner Mason										
Journeyman 1	C_1, C_2 W1	$C_5 \rightarrow C_9$ W6	W7	W12	W15	C_1, C_2 W1	$C_5 \rightarrow C_9$	W7	W12	W15
Journeyman 2	C_3, C_4 W3	$C_{10} \rightarrow C_{14}$ W8	W11	W13	W16	C_3, C_4 W3	$C_{10} \rightarrow C_{14}$ W8	W11	W13	W16
Wall Mason										
Apprentice	W2	W4 W5	W9 W10	W14	W17	W2	W4 W5	W9 W10	W14	W17
Brick-Helper										
Mortar Tender	30	20	30	30	30	30	20	30	30	30
Brick Tender	1320	1000	1400	1350	1400	1320	1000	1400	1350	1400
Scaffold										
1										
2										

	Nov. 2013					Dec. 2013				
	Mon 25th	Tue 26th	Wed 27th	Thu28st	Fri 29th	Mon 2nd	Tue 3rd	Wed 4th	Thu 5st	Fri 6th
Corner Mason										
Journeyman 1	C_1, C_2 W1	$C_5 \rightarrow C_9$	W7	W12	W15	C_1, C_2 W1	$C_5 \rightarrow C_9$	W7	W12	W15
Journeyman 2	C_3, C_4 W3	$C_{10} \rightarrow C_{14}$ W8	W11	W13	W16	C_3, C_4 W3	$C_{10} \rightarrow C_{14}$ W8	W11	W13	W16
Wall Mason										
Apprentice	W2	W4 W5	W9 W10	W14	W17	W2	W4 W5	W9 W10	W14	W17
Brick-Helper										
Mortar Tender	30	20	30	30	30	30	20	30	30	30
Brick Tender	1320	1000	1400	1350	1400	1320	1000	1400	1350	1400
Scaffold										
1										
2										

	Dec. 2013					Dec. 2013				
	Mon 9th	Tue 10th	Wed 11th	Thu 12th	Fri 13th	Mon 16th	Tue 17th	Wed18th	Thu 19th	Fri 20th
Corner Mason										
Journeyman 1	C_1, C_2 W1	$C_5 \rightarrow C_9$	W7	W12	W15	C_1, C_2 W1	$C_5 \rightarrow C_9$	W7	W12	W15
Journeyman 2	C_3, C_4 W3	$C_{10} \rightarrow C_{14}$ W8	W11	W13	W16	C_3, C_4 W3	$C_{10} \rightarrow C_{14}$ W8	W11	W13	W16
Wall Mason										
Apprentice	W2	W4 W5	W9 W10	W14	W17	W2	W4 W5	W9 W10	W14	W17
Brick-Helper										
Mortar Tender	30	20	30	30	30	30	20	30	30	30
Brick Tender	1320	1000	1400	1350	1400	1320	1000	1400	1350	1400
Scaffold										
1										
2										

Legend:

(box)	Width of daily space represents amount of work that should have been done in a day
(line)	Amount of work actually done in a day
W_i	Wall number i
$C_5 \rightarrow C_9$	Corners 5,6,7,8,9
$C_{10} \rightarrow C_{14}$	Corners 10,11,12,13,14
C_1, C_2	Corners 10,11,12,13,15
C_3, C_4	Corners 10,11,12,13,16

Figures in front of the mortar tender indicates cf of mortar required per day

Figures in front of the brick tender indicates numbers of bricks required per day

Figure 5.13 As-planned Schedule for the Brick Project

5.4.3.2 Machine Chart

Figure 5.14 represents the machine chart for the as-planned schedule. The chart shows the machine and equipment that will be used in the project. The chart time frame is divided the same way as the as-planned schedule (five days a week, and 8 hours per day). In this chart, the light lines indicate the number of hours available for the machine each day. Similarly, the length of the heavy lines represent the cumulative total numbers of hours for the machine to work per week.

5.4.3.3 Load Chart

As indicated previously in Chapter 4, the load chart provides the managers with the ability to see how much of the available resources are being used. Figure 5.15 presents the load chart produced for the as-planned schedule. This chart shows the usage percentages of the available resources per week. The first column presents all of the available resources in the construction site. The second column contains the quantities of each resource. The third column represent the working hours per week for each resource. Because the data presented in this chart is for weekly assignments, the light lines across each week represent the percent of the resource being used out of its full capacity. For example, the corner brick masons journeyman 1 and 2 are being used 84% of their full capacity set to a 50 minute-hour. The heavy lines represent the cumulative total resource usage for the entire schedule. The numbers on the left side of each light line represent the total amount of the working hours per category. For example, there are two corner masons (journeymen 1 and 2) working 40 hours per week, therefore the figure placed on the left side of each line is 80 hours.

5.4.3.4 Layout Chart

The layout chart shows the status of the work assigned to each available resource and also presents the work ahead. In order to show how the layout chart will look for a construction schedule consider Figure 5.16. The chart has the same features of the layout chart presented earlier in Chapter 4. The angles open to the right indicate when the work will start, while the angles open to the left shows when the work will finish. The light line between the two angles represents how long each operation should take. This chart presents the work assigned to the available resources on Tuesday the 12th. The day is divided into hours and the hours are divided into 15 minutes intervals.

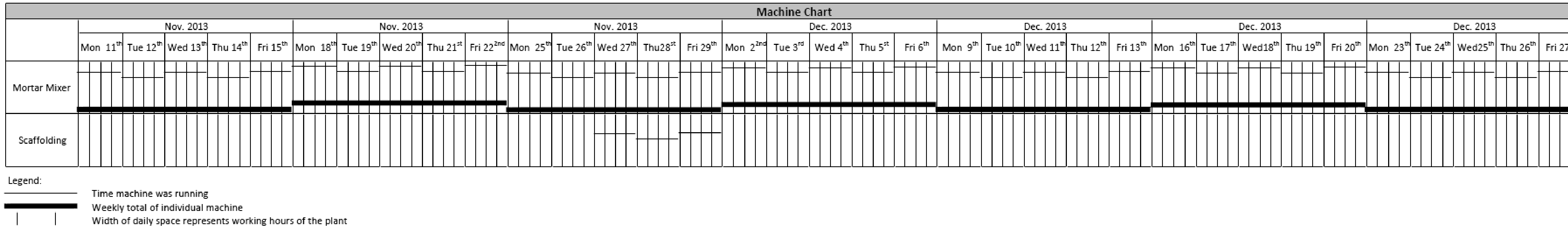


Figure 5.14 Machine Chart for the As-planned Schedule

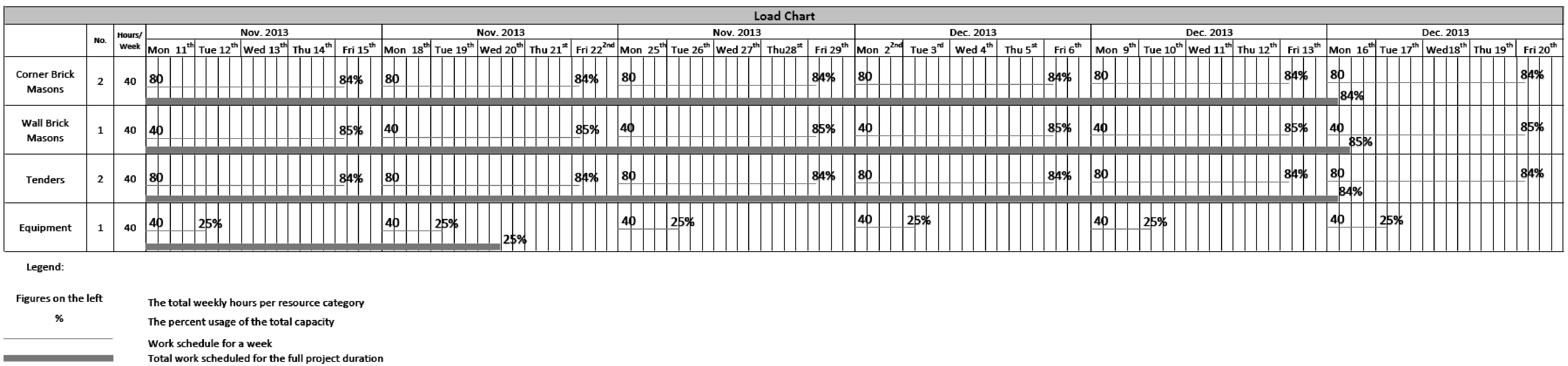


Figure 5.15 Load Chart for the As-planned Schedule

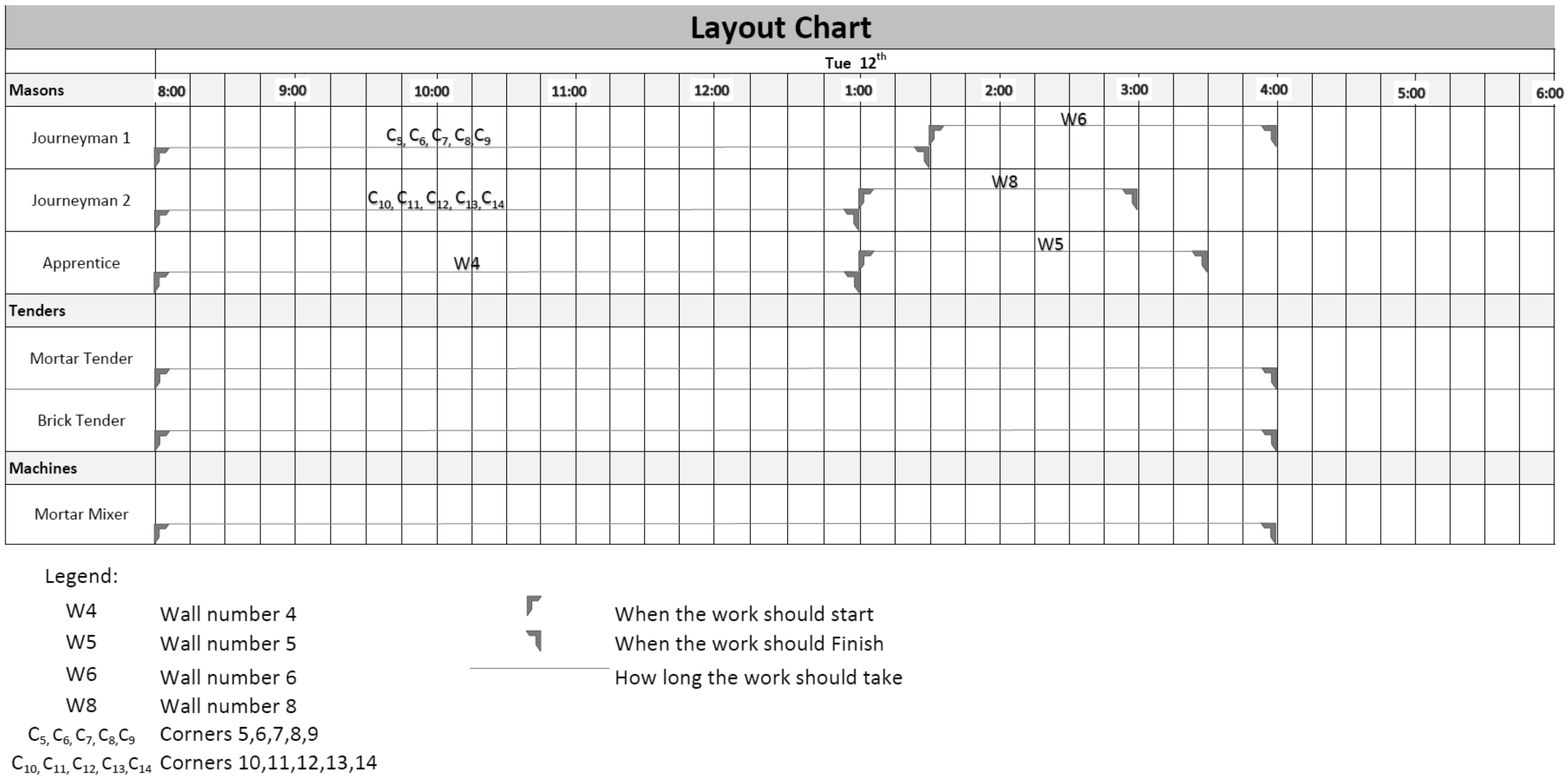


Figure 5.16 Layout Chart Showing the Planned Work for Tuesday the 12th

5.4.4 As-Performed Schedule

To show the versatility of the Gantt Resource Management Charts a scenario that represents actually working conditions is applied to the first week of the project schedule. This scenario considers the absence of the journeyman 1 on Tuesday the 12^{th}. This section is divided into two sections. The first section presents the Man Chart, Machine Chart, Layout Chart and the Progress Chart showing the impact of this idleness. The second section presents the Charts after management took actions as a response to potential idleness. Charts are plotted in order to show the impact of the decisions made. A second scenario attached in Appendix B is also used to further demonstrate the Gantt Resource Management Charts. The scenario uses the absence of the journeyman 1(on Tuesday the 12^{th}) in addition to the mortar mixer breakdown (Thursday the 14^{th}) as idleness causes.

5.4.4.1 Absent Workman Scenario before Manager Action

Because the idleness is a manpower resource the first chart to plot is the Man Chart shown in Figure 5.17 representing the first week of the schedule. The light lines represent the daily work performed by the workmen. The heavy lines represent the cumulative work performed throughout the week. The chart shows that at the end of the week the work is one day behind the schedule. That is indicated by the fact that the heavy lines are drawn until the end of Thursday instead of the end of Friday which is the reporting date. The reason behind the idleness is attributed to the absence of journeyman 1 on Tuesday the 12^{th} indicated by the letter A. that had effects on the performance of the journeyman 2, the apprentice, and the brick-helpers indicated by J1.

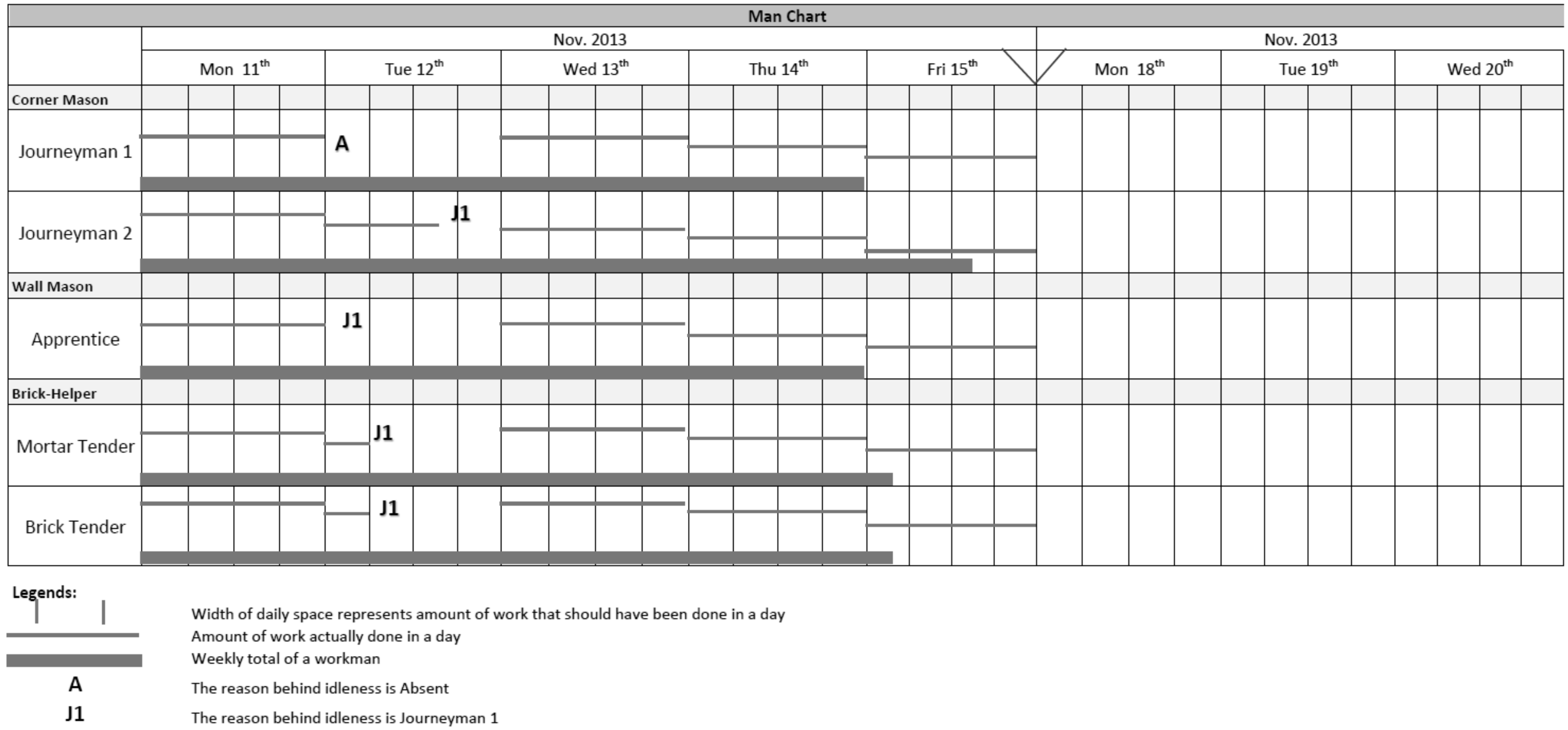


Figure 5.17 Man Chart Showing the Effect of the Absence of Journeyman1 on the First Week of the Schedule

The impact of the absence of the journeyman 1 can be reflected also on the machine chart plotted on Figure 5.18showinghow much time the machines have for week 1. The first column on the chart contains the machines used in the first week. The week is divided into five days and the days are divided into 2 hours intervals. As can be seen the chart shows two types of idleness. The first is the lack of work indicated by the letter L. As it was stated in Chapter 4, the machine chart show how many hours a machine was working and if not working shows the reason why. The lack of work idleness indicates that the work assigned to that machine will only keep it in operation for a total of 4 hours per day. The second idleness indicated by J1 refers to the journeyman 1 absence on the second day. The heavy line indicates that the machine has worked 45% of the total time by the end of the week.

The project manager also plots a Layout Chart at 4:30 pm on Tuesday 12^{th}, shown in Figure 5.19, to see the status of the assigned work. The manager is able to see that journeyman 1 was absent. As a consequence of this absence, journeyman 2 was not able to do wall number 8 since its construction depends on laying corners number 9 and 10 which are supposed to be done by journeyman 1. The apprentice also was not able to do any one of the tasks assigned to him since their construction depends on the corners to have been laid by journeyman 1.

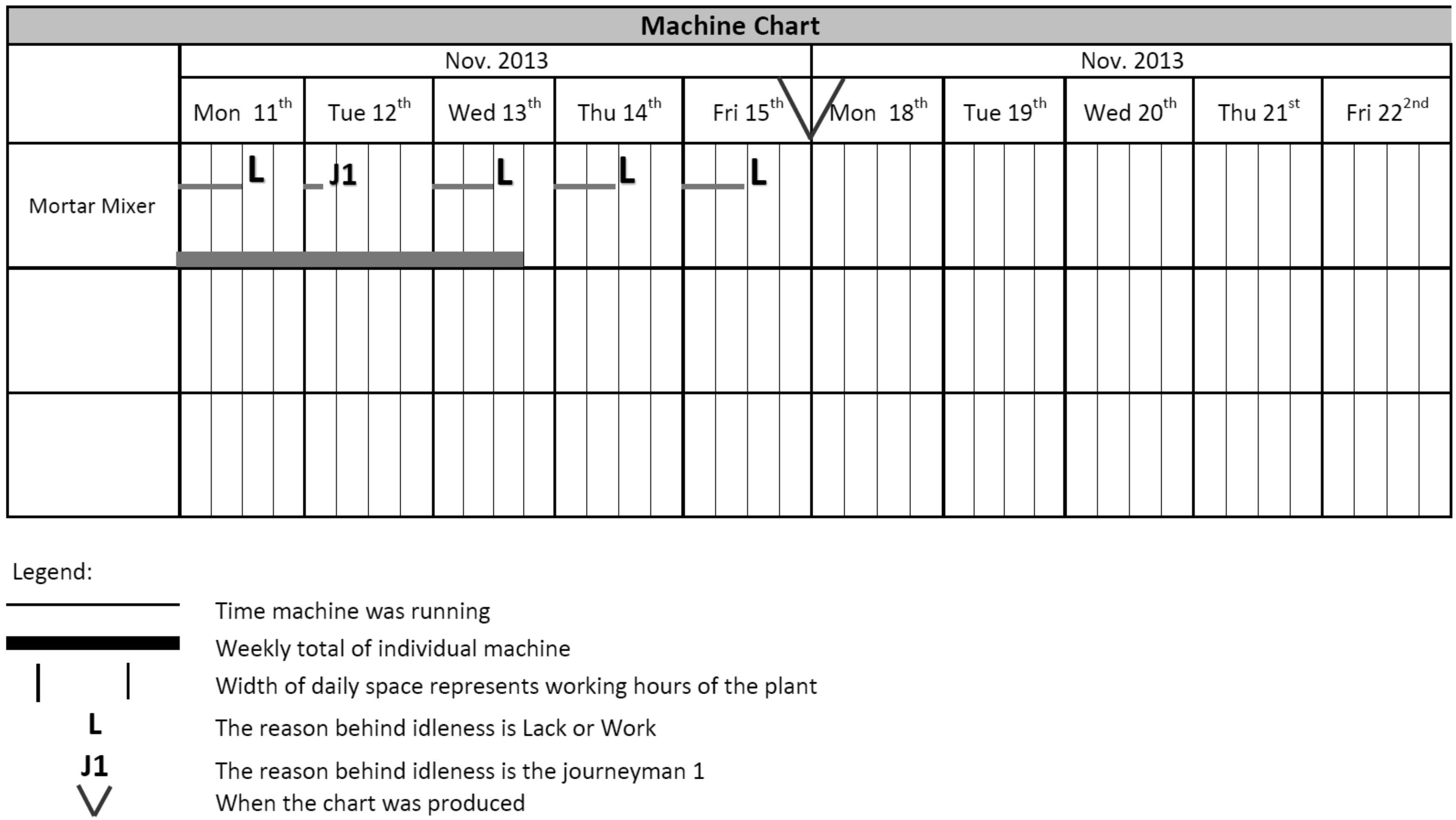


Figure 5.18 Machine Chart Showing the Effect of the Absence of Journeyman1 on the First Week of the Schedule

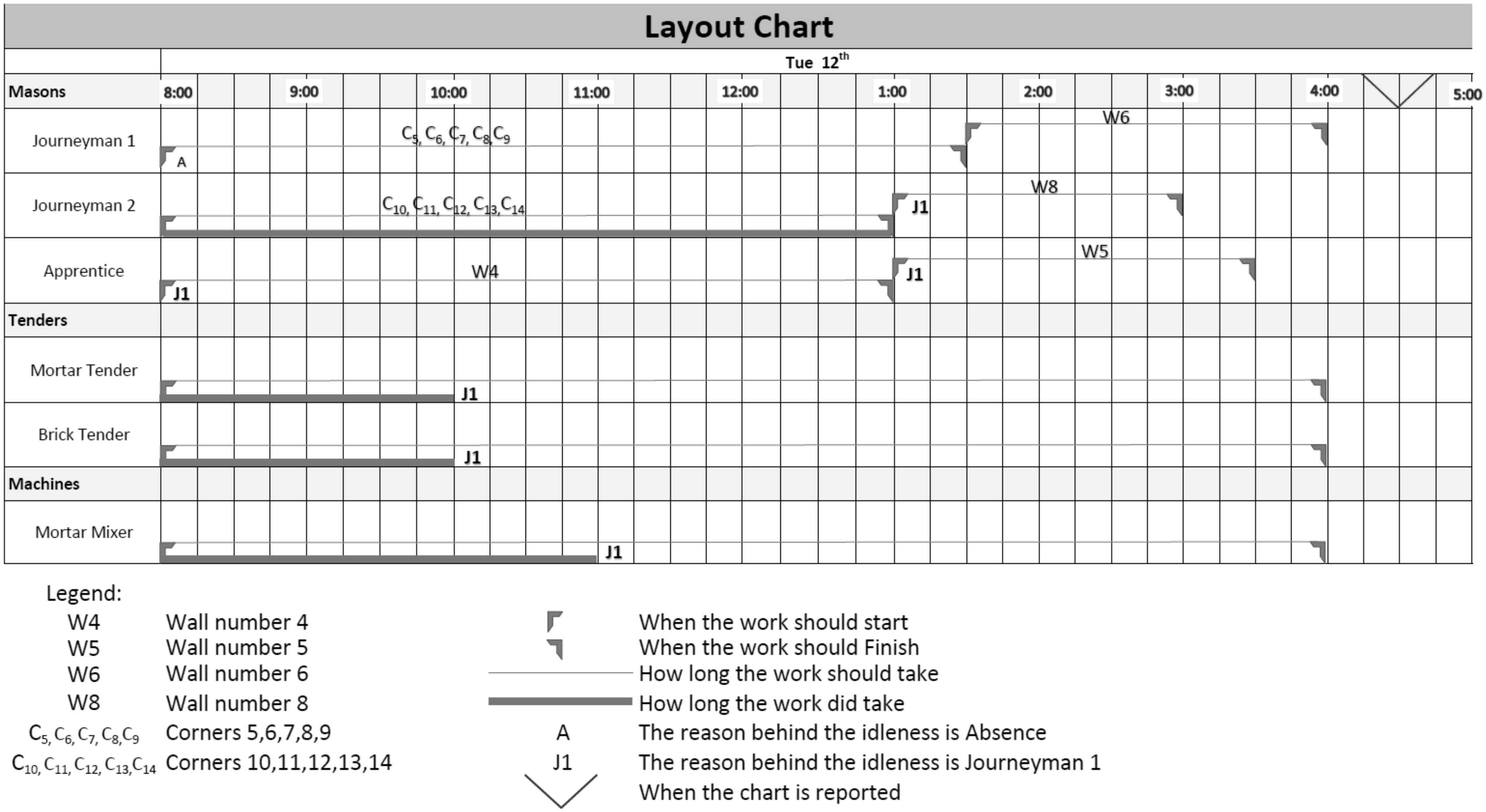


Figure 5.19 Layout Chart Showing the Effect of the Absence of Journeyman1 on Tuesday the 12th

A progress chart is also plotted at the close of business for week 1 (Figure 5.20) to compare the actual work performed with the as-planned schedule for that week. The first column contains the available resources for the planned schedule. The numbers written on the left side of each column represents the total amount of work scheduled for a certain day. It should be noted that the numbers in front of the mortar tender represents quantities for cubic feet of mortar. Similarly, the numbers in front of the bricklayers and the brick tender represents the quantities of bricks. The numbers written on the right side of each day's column represents the cumulative amount of work scheduled to that day. A light line represents the percentage of the work actually performed during the day. The heavy lines indicate the cumulative work performed throughout the week. For example, the work assigned to the masons laying corners on Monday the 11th is 927 bricks. The masons were able to do 100% of that work which is represented by a light line drawn throughout the width of that day. However, the absence of the journeyman 1 Tuesday 12th prevented accomplishing all the work assigned (561 bricks) and the journeyman2 did only 30% of the work assigned. Similarly, on Tuesday the 12th, the apprentice was supposed to lay 420 bricks between corners, however since his work is relying on the corners to be laid by the journeyman1 he was not able to perform the work and J1 was placed inside the column corresponding to that date to indicate the reason preventing work to be accomplished.

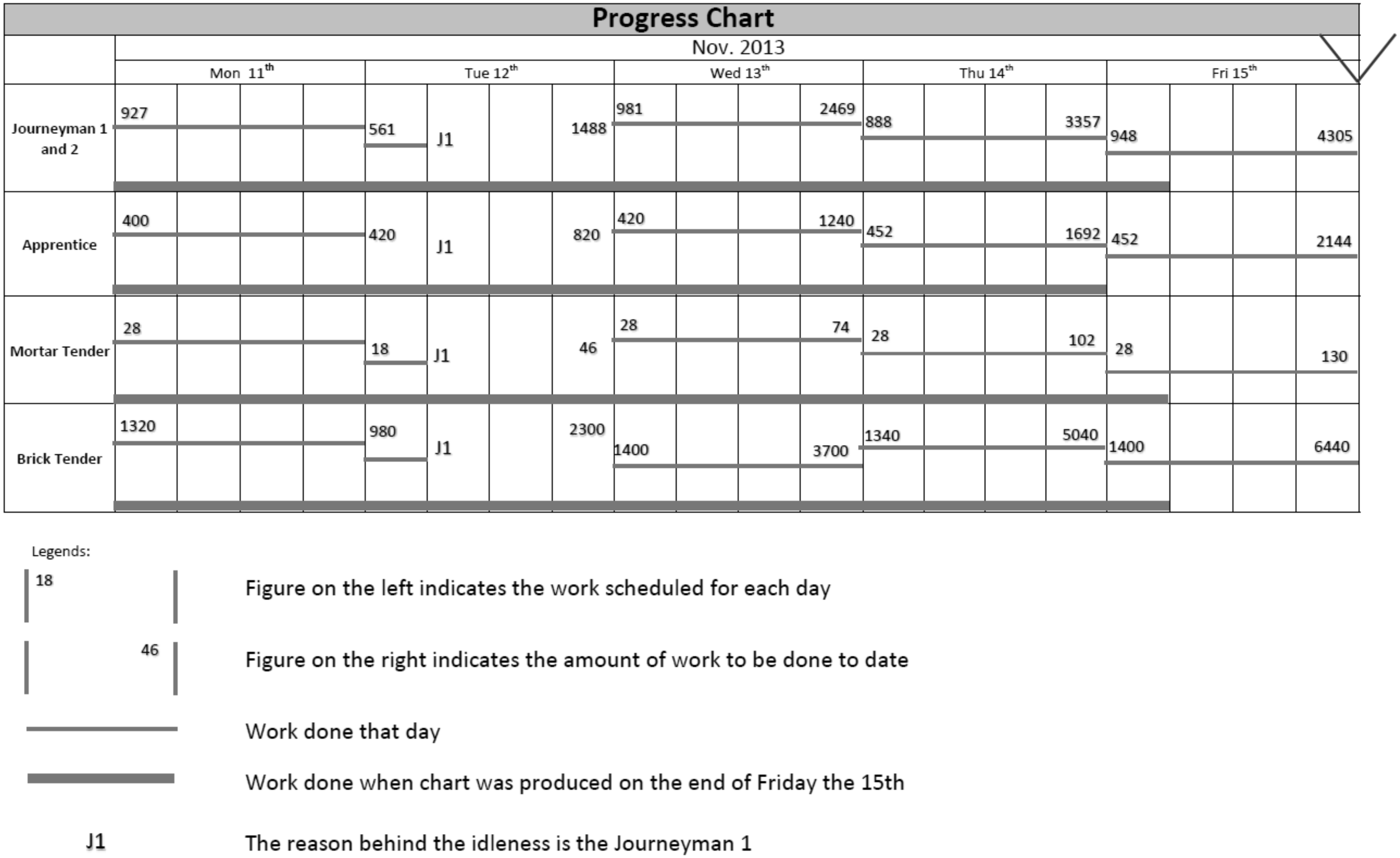


Figure 5.20 Progress Chart Showing the Effect of the Absence of Journeyman1 on the First Week of the Schedule

5.4.4.2 Manager reaction to the idleness

The previous charts reflect the consequences of the project manager not reacting to the absence of one of the brick masons on the jobsite. The next case will be the assumption that the manager has reacted to the idleness and proposed a solution. Figure 5.21 represent the Man Chart for the first week of the schedule. As can be seen the absence of the journeyman 1 did not affect the overall duration of the schedule. That was because the manger assigned the task of performing corners 5, 6, 8, and 9 (they were supposed to be performed by the journeyman 1) to the other available resource (journeyman 2). Corners 5 and 6 are needed to be built to allow the apprentice to build walls 4 and 5. Corners 8 and 9were needed by the journeyman 2 to build wall 8. As it is indicated on the corner instruction card, it takes 45 minutes to build a corner with a height of 7 courses. The decision of assigning these corners to the journeyman 2 was based on knowing he has surplus time of 2 hours on that day on the original plan (refer to the Layout Chart Figure 5.19). Therefore, as can be seen on Figure 5.21, the extra work journeyman 2 accomplished on Tuesday 12th is indicated by drawing an extra line. Therefore, the apprentice was able to perform the work assigned to him. The previous details can be shown by plotting a Layout Chart for the week shown in Figure 5.22. At the time of reporting the chart, the two available brick masons were on schedule. As can be seen journeyman 2 has successfully performed the corners assigned to journeyman 1. Notice the apprentice started laying wall 4 at 9:00 am instead of 8:00 am. That was because he had to wait for journeyman 2 to lay corner 5 before he could start laying wall 4.

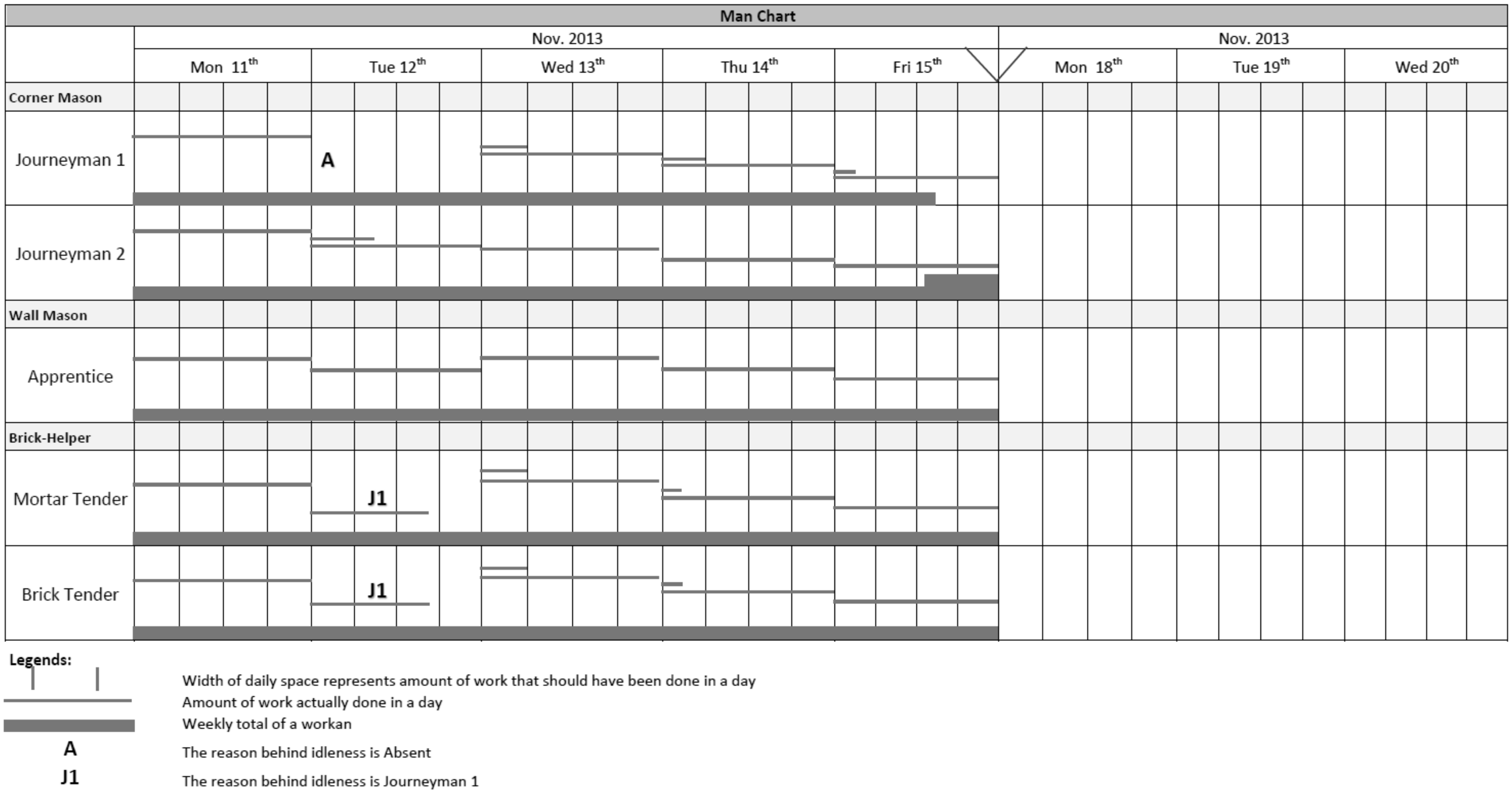


Figure 5.21 Man Chart Depicting Immediate Resource Reallocation Response to Journeyman1 Absence

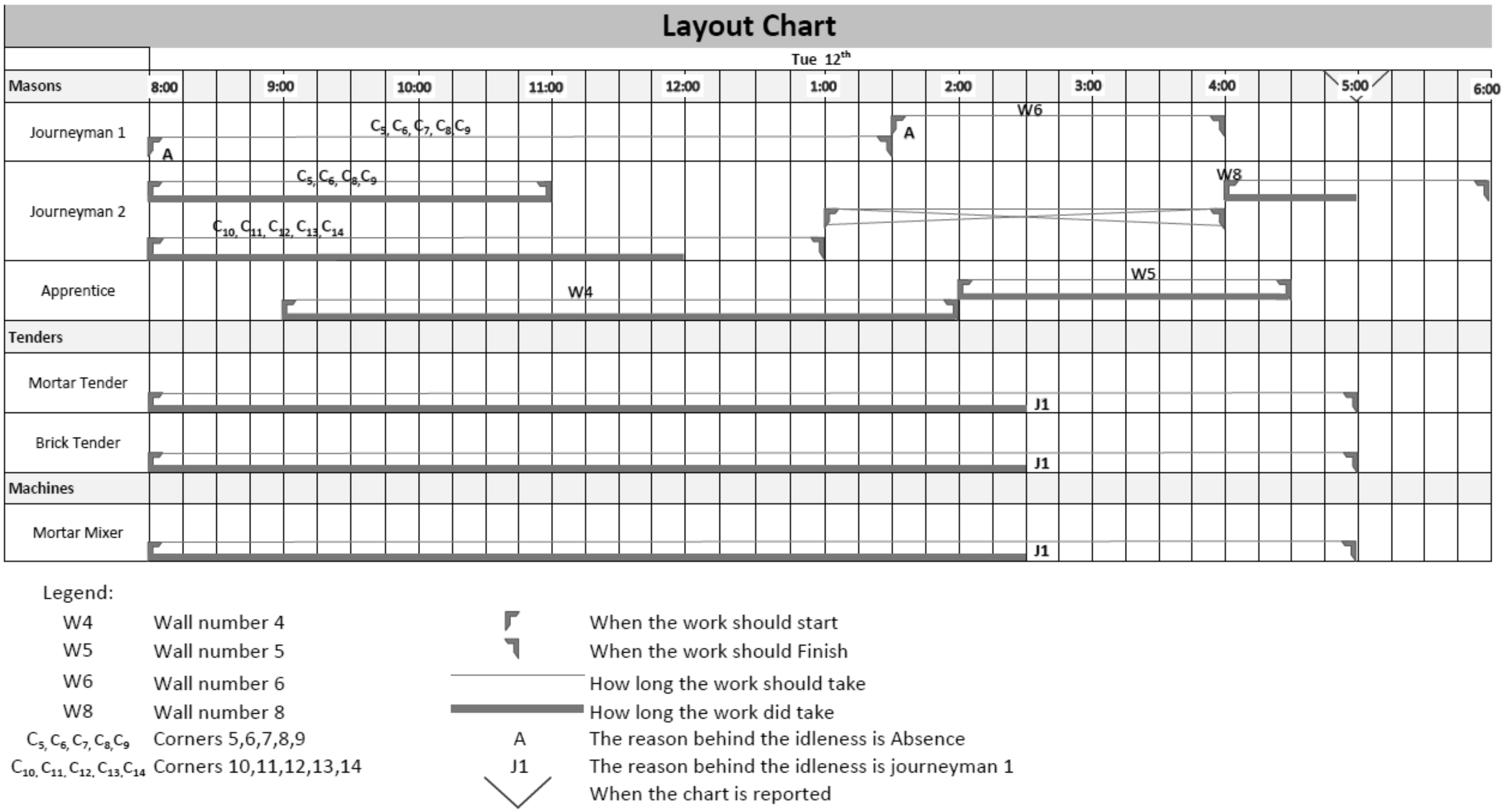


Figure 5.22 Layout Chart Depicting Immediate Response to Journeyman1 Absence

5.5 Summary

In this chapter the Gantt Resource Management System applicability to construction is demonstrated. In order to do so, four steps were taken. First, a trade from the construction industry is chosen and a project model is then developed using a building information modeling software. The second step is adapting a motion study to apply the best way to do the different project activities. Third, the developed brickwork project is then described. Fourth, the Gant system tools are then used to produce a construction schedule for the project and then a hypothetical scenario is developed in order to demonstrate how a project manager can use these tools to deal with an idleness situation.

CHAPTER 6

Comparison and Contrast

6.1 Resource Management System Criteria

This chapter provides a comparison and contrast between the Gantt resource scheduling chart and the CPM scheduling approach. The comparison and contrast is built based on five criteria representing attributes a resource scheduling technique should accomplish. These criteria are Transparency, continuous improvement, routine, simplification, and dynamic. Therefore, the chapter is divided into two sections. The first section describes each one of these criteria. The second section measure each of the two resource scheduling techniques against each these criteria.

6.2 Criteria Development and Discussion

6.2.1 Transparency

Transparency is defined as the ability of a production system to make the process visible and observable to everyone involved (Koskela 1992). Its aim is to provide the people who are doing the work with mechanisms that allows them to understand the process without having someone explaining it and therefore, it facilitate control and improvement.

Transparency is an essential component resource management systems should include because it leads to increases in productivity. According to Formoso et al (2002), sharing information between managers and their subordinates has a positive impact on productivity.

They indicated that transparency works the same as lean philosophy towards minimizing the waste, and reducing the non-added value activities. Koskela (1992) indicates lack of transparency will increase the tendency of producing defects, reduce the ability to identify them, and "diminishes motivation for improvement."

Koskela (1992) indicates transparency can be achieved "through organizational or physical means, measurements, and public display of information." The display of the information is assured by using visual system that best describes the process and the tasks at hand rather than relying on verbal communication. According to Formoso et al (2002), transparency is increased by using six approaches:

1. Reduce the interdependence between the activities:

This approach increase transparency by isolating identified tasks within multiple operations. Therefore, it shows who is responsible to perform each operation. The managers will have the ability to see the underperformance and identify the reason behind the idleness.

2. Enable immediate recognition of process status:

This is achieved by installing visual tools that shows the work status, the problems preventing the process from being completed. That is because in dynamic non-standardized environments like construction, the execution of activities require a continuous movement of resources (labors, materials, and equipment).

3. Making the process directly observable:

This approach aims to provide the multiple actors responsible for execution of the tasks with the ability to see how the different work stations are laid out, and how the materials are being transferred throughout the site. This will lead to better understanding of the production flow. This is facilitated by "removing visual obstacles, appropriate planning of the work station flow, or through an adequate layout design." Formoso et al (2002). They indicate on construction sites sometimes obstacles cannot be removed. Because some of the obstacles are part of the process such as walls, and slabs. The work flow planning and layout designs are important because they affect the material deliveries, storage, and batch transfers.

4. Incorporating information into the process:

That means presenting the correct way to do the work, the specifications, and work assignments by using visual devices. According to Formoso et al (2002), in most cases workers do not know management expectations and are having a hard time understanding how the overall process is being handled. They express the lack information related to "equipment maintenance, workstations flow, and the purpose of some activities they were assigned to."

5. Maintaining a clean and orderly workplace:

Transparency is increased by showing the material waste in storage designated areas on the site. This will lead workmen to reduce the tendency to produce waste during their execution of the tasks. Formoso et al (2002) indicates that having a clean and orderly workplace will eliminate the unnecessary time workers spend searching for tools, materials, and information thus increasing production efficiency.

6. Rendering invisible attributes visible through measurements:

That is achieved by installing visual performance measurement tools for the workmen to see how management is going to measure their performance. Formoso et al (2002) indicates that there is a lack of shared information between the managers and their subordinates regarding how performances are being measured. This creates a lack of trust between the managers and the workmen because they are not aware of how their organizations are measuring their performances.

6.2.2 Continuous Improvement

Continuous improvement is defined as “an organization-wide process of focused and sustained incremental innovation.” (Bessant and Francis, 1999). Continuous improvement is considered a dynamic characteristic that deals with the uncertainties involved in the construction process. It positively contributes to the knowledge of the staff within organizations and works to facilitate the process standardization.

Continuous improvement is considered an essential element for resource management systems because it provides the momentum required to accomplish organizations strategies. According to Kaye and Anderson (1999), it changes the organization behavior toward responding to changing demands of the market and involves the entire workforce in the innovation and improvement process.

Kaye and Anderson (1999) indicated that continuous improvement consists of three interrelated parts (Figure 6.1). The first part is the drivers which are the factors that assure attaining and sustaining continuous improvements. The second is the enablers which are the essential factors needed by the drivers in order to achieve continuous improvement. And the third is the results which are the reflections of the implementation of the continuous improvement.

1. Drivers:

There are five drivers that keep the momentum required for continuous improvement which are: the role of the senior management, leadership by all managers, stakeholder focus, measurement and feedback, and learning. The role of the senior management starts with defining the organization vision, mission, aims, and setting the success factors. And then communicate them to the staff members.

The second driver factor is the leadership by all mangers. It starts with the managers being able to understand the organization objectives and then "coaching" these goals to their subordinates.

The third driver is stakeholder focus. The ability to be able to identify the customer's changing demands, point out their satisfaction, and then adjust to these changes.

The fourth driver is measurement and feedback which is the ability to install mechanisms that allow measuring the performance against the identified success factors and then project these performances to the staff members.

The fifth driver is learning from the results which consists of capturing the learning and experience of individuals, comparing the performance of the organization's different sections, and then performing analysis and planning process to assure a continuously improving process.

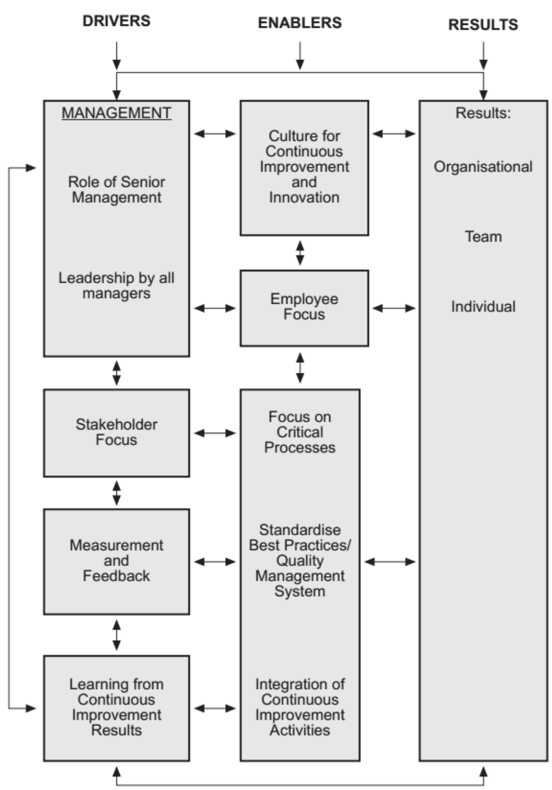


Figure 6.1. Continuous Improvements Elements (Kaye and Anderson 1999)

2. Enablers:

There are five enablers required to achieve continuous improvements. The first enabler is a culture for continuous improvement and innovation. This is the factor that will enable the senior management to achieve their goals by installing tools to assure employees understand the performance and quality expectation and installing effective communication systems.

The second enabler required by the leadership is having an employee focus. This is achieved by using tools that show employees how their performance relates to others and then involving them in the improvement identification process (brain storming/ suggestions).

The third enabler is the focus on critical processes. This characteristic starts by identifying the process required to deliver the stakeholder demands and then checks if these process will also satisfy the organization objectives (mentioned in the senior management driver). It also consists of identifying the best way to perform these processes in order to eliminate the "non-value adding activities."

The fourth enabler is the quality management system. This part calls for a standardized and a simple quality management system.

The fifth enabler is the integration of continuous improvement activities. That is through having a "self-assessment" mechanism to identify the areas of improvements.

Results:

The results play an essential element to measure the effectiveness of the continuous improvement process. This part requires showing the performances at the organizational level, at the team level, and at the individual level.

6.2.3 Organizational Routine

Routine is defined as “a pattern of behavior that is followed repeatedly, but is subject to change if conditions changes” (Sidney 1964). This pattern aims to standardize the process, organize the interaction between the resources, and therefore facilitate the tasks accomplishment. The facilitation comes from the fact that resources do not have to worry about the other factors affecting the work accomplishment and just focus on their tasks.

Resource management systems should have the ability to standardize the construction process and turn it into a routine. According to Becker (2004), routine works at the organizational level to direct people’s behavior to work collectively towards achieving the organization goals and plans through a mechanism that provide instructions of how these plans should be performed. He indicates routine takes two forms which are “mindlessness” or “Effortful”. Mindlessness means following the process without putting much intellectual effort because of the previously provided instructions. Effortful indicates the effort taken to produce the instructions whenever the conditions change (Becker 2004).

According to Becker (2004), routine systems have four main effects on organizations, which are: coordination and control, economizing on cognitive resources, reducing uncertainty, and stability.

1. Coordination and control:

Becker indicated that the standardization nature of the routines makes the process easy to “monitor and measure” and therefore easier to control. Routine facilitates coordination through providing the ability to conduct simultaneous activities and presenting the staff members with the information enabling them to compare other team members’ behaviors (performances), and providing instructions (Becker 2004).

2. Economize on cognitive resources:

Because “mindlessness” is one of routine characteristics, the amount of the processed information by the people in the organization will be limited and the decision making complexity will be reduced leading to increasing the time devoted to the non-routine activities. Becker (2004) also indicates that “routines also economize on the time necessary for reaching a solution and allowing for spontaneous reaction even under constraint situations, such as time constraints.”

3. Reduce uncertainty:

Becker (2004) indicated that having a system that is routine leads to known outcomes and therefore reducing uncertainties. He indicates that routines provide the organizations with two factors that reduce uncertainty which are fixing the variables in the process which will increase predictability and limiting the cognitive resources.

4. Provide stability:

Routine provide stability through the process standardization and fixing the ways of how the work is performed. According to Becker (2004), if the way to perform the work produces results that elevate expectations then no effort will be put towards finding other ways and therefore leads to stabilize the process.

6.2.4 Simplification

Simplification is defined as the ability to provide information in a way that facilitates decision making and problem solving process at all levels. It aims to provide the people involved with the ability to better understand the information regarding the multiple variables contributing to construction.

In dynamic environments, resource management techniques should be able to simplify the information management process. According to Tezel et al (2009), complex information will negatively impact the performance and increase the misunderstanding and conflicts which will create chaotic environments and makes decision making and problem solving more difficult.

There are two steps to simplification of the information. The first is using tools that best describe the information. According to Vessey (1991), the decision making process will be more efficient and the problem solving process more accurate if the tools used to present the information match the tasks needed to be accomplished. There are two formats to present information which are tabled or graphical representations. Tables present "symbolic information" which are separate information (values) that requires an analytical process in order to be understood. Graphs present "spatial related information" which is information that "assess the problem area as a whole." Vessey (1991) indicates that the information presented using graphs allow "summarizing data, showing trends and relationships over time, comparing data points and relationships of variables, and detecting deviations or differences in data."

The second step is installing tools that enable people making sense of information. Thiry (2001) indicates being able to make sense of the information coming from the surrounding environment will lead to a more effective decision making and problem solving strategies while reducing the ambiguity and uncertainty.

Sensemaking provides information to staff members in a way that enables them to make sense of it. The amount and the quality of the information plays a major role in sense making. For a given problem, too much information will lead to an over complication and hence will create uncertainty. Similarly, too little information will create oversimplification and also creates ambiguity. Therefore, there should be a balance in providing information. It should be directed towards assisting the staff members to better assess a certain situation, compare their performance with others, and therefore better decisions. Choo (1996) states "through sensemaking, people in an organization give meaning to the events and actions of the organization."

6.2.5 Dynamic

Dynamic is defined as the ability of a scheduling technique to be adjusted whenever work disruptions occur. This ability is considered the main factor to the success of any schedule. Static schedules are considered unrealistic and normally end up on the shelf. This will leave managers to deal with day-to-day events spontaneously without having a mechanism that enables them to see the impacts of the situation nor their decisions.

Techniques used to produce resource schedules need to be able to respond to the dynamic nature of the construction environment. Herroelan and Leus (2004) expresses the need for techniques that can handle the uncertainties facing baseline schedules. The baseline schedule is the initial schedule generated to set up the project objectives, expectations, and deadlines for the material procurement.

Ouelhadj and Petrovic (2009) also stresses the need for dynamic scheduling approaches that are able to produce "schedules in the presence of the real time events." Once the process starts, baseline schedules become susceptible to unavoidable resource and job related disruptions such involving equipment, tools and manpower difficulties rush jobs, job cancelation, and due date changes. While the authors indicate there are three categories for dynamic scheduling, only one is applicable to construction which is the robust predictive-reactive scheduling technique.

This type uses the original baseline schedule and targets performance "shop efficiency" as the controlling factors for scheduling changes. Schedules are updated by shifting the activity assignments when disruptions occurs while taking the original schedule duration and the resource efficiency into consideration.

6.3 Comparison and Contrasts Analysis

This section presents the comparison and contrast analysis between the Gantt Resource Management System and the CPM scheduling approach based on the developed five criteria.

6.3.1 Transparency

As stated earlier a system will be transparent if it has six characteristics:

1. Reduce the interdependence between the activities.
2. Enable immediate recognition of process status.
3. Make the process directly observable.
4. Incorporate information into the process.
5. Maintain a clean and orderly workplace.
6. Render invisible attributes visible through measurements.

6.3.1.1 Gantt Resource Management System

1. Reduce the interdependence between the activities:

From the discussions provided in Chapters 4 and 5 the Gantt Resource Management System supports this approach. It shows the operations contributing to the production of a certain process as independent activities. For example, Figure 5.16 shows the different work assignments to each resource as independent activities although they are related to each other.

2. Enable immediate recognition of process status:

From the charts produced for the absent workman scenario in Chapter 5 it can be seen that the GRMS supports this approach. For example in Figure 5.19 the manager can see that the work execution throughout the site is negatively impacted by the absence of the journeyman1.

3. Making the process directly observable:

This approach is concerned with making the multiple actors on a job site to be able to see the operations at different work stations. For example, a brick mason on a site should be able to see the work of other bricklayers at their stations. This approach is not a scheduling capability. It is considered one of the responsibilities of the management office on the site. Therefore, Gantt resource management system does not possess this capability nor should it have.

4. Incorporate information into the process:

This approach requires showing the workmen the best way to do the work, the specifications, and the work assignments/ expectations. The Gantt Resource Management System supports this approach by producing the instruction cards and the progress chart. For example, the card presented in Figure 5.9 describes the instructions required to lay a corner consisting of seven tiers. The progress charts presented in Figure 5.20 shows the expectations for each resource per day.

5. Maintaining a clean and orderly workplace:

The adapted Gantt Resource Management System presented in this thesis does not directly support this approach. However, it should be noted that when Gantt introduced the task and bonus system and combined it with his multiple resource management charts the workmen began to take care of their machines and organize their tools that they were using which led to an organized and clean shop floor.

6. Rendering invisible attributes visible through measurements:

Gantt Resource Management System supports this approach by using the progress charts. For example, in Figure 5.20 the workmen can see from the progress chart how their performance is to be measured. If they finished what is planned for a certain day a light line will be drawn for the full width of the column of that day to indicate a 100% work completion.

6.3.1.2: CPM Scheduling:

1. Reduce the interdependence between the activities:

   The CPM does not support this approach. People can only see the activities without knowing what operations are contributing to the execution of these activities.

2. Enable immediate recognition of process status:

   Because CPM does not reduce the interdependence between the activities, it does not have the capability to support this approach. If there is a delay in the execution of a certain activity all the managers see is an activity that is behind the schedule without being able to identify what caused the idleness.

3. Making the process directly observable:

   Similar to the Gantt Resource Management System, CPM does not support this approach because making the work station layout and the material movements plans are not the responsibility of the scheduling techniques.

4. Incorporate information into the process:

   The CPM does not show how the work should be performed nor the resources assigned to the work. Therefore, it does not support this approach.

5. Maintaining a clean and orderly workplace:

   This approach is a managerial responsibility not a scheduling capability. The CPM does not support this approach nor does it encourage it.

6. Rendering invisible attributes visible through measurements:

CPM scheduling lacks the ability to sharing the information between management and the people in the organization. Therefore, the CPM scheduling does not support this approach.

Figure 6.2 below summarize the comparison and contrast between the Gantt resource management system and CPM scheduling for this criteria.

Approach	Gantt Resource Management System	CPM Scheduling
Reduce the interdependence between the activities.	☑	☒
Enable immediate recognition of process status.	☑	☒
Making the process directly observable.	☒	☒
Incorporate information into the process.	☑	☒
Maintaining a clean and orderly workplace.	☒	☒
Rendering invisible attributes visible through measurements.	☑	☒

Figure 6.2. Transparency Comparison and Contrast.

6.3.2 Continuous Improvement

A system will support this criterion if the “drivers” have the enablers required to achieve the improvements and maintain their continuity. It also needs to show the result of these improvements at the organizational, team, and individual levels. Therefore, in this section the enablers will be the criteria used to perform the comparison and contrasts. Figure 6.3 below, shows each driver and its enabler.

Drivers	Enablers
The role of the senior management	Culture for continuous improvement and innovation
Leadership by all managers	Having an employee focus
Stakeholder focus	Focus on critical process
Measurement and feedback	Quality management system
Learning	Integration of continuous improvement activities

Figure 6.3. Continuous Improvements Drivers and their Enablers

6.3.2.1 Gantt Resource Management System

1. Culture for Continuous Improvement:

Driver: The role of the senior management starts with defining the organization vision, mission, aims, and setting the success factors. And then communicates them to the staff members.

Enabler: This is enabled by installing tools to assure that the employees understands the performance and quality expectation, and installing "effective communication systems."

Gantt Resource Management System support this approach. It breaks down the overall plan into multiple charts directed towards each resource category to assure a clear understanding of these plans. For instance, after the as-planned schedule is produced for the brick project in Chapter 5, a man chart and a layout chart were drawn in order for the bricklaying crew members to understand their work expectations, work assignments, and see how their performances is to be projected in these charts.

2. Having an employee focus:

Driver: The leadership by all the mangers. It starts with the managers being able to understand the organization objectives and then "coaching" these goals to their subordinates.

Enabler: This is enabled by using tools that show employees how their performance relates to others and then involving them in the improvement identification process (brain storming/ suggestions).

Gantt Resource Management System supports this criteria. It provides the tools required to coach the workmen which are: 1) Teach the workmen the best way to do their work by using instructions cards. 2) Allow the workmen to compare their performances to each other. For example, Figure 5.9 presents the instructions required to build a corner by a journeyman. The involvement of the workmen comes from the steps taken to produce these instructions. For instance, the project manager might bring a first class bricklayer and ask him to build a corner the best way he can. And then the manager can record the motions and the times taken by that bricklayer to build the corner, and then produce the instruction card based on these information. Gantt's system also gives the workmen the ability to see their performance and compare it with others. For example, in the Man Chart presented in Figure 5.17 the heavy line indicates the summation of the cumulative work accomplished by each worker. At a glance each workman can determine the amount of work that he accomplished and compare it with his co-workers.

3. Focus on Critical Process:

Driver: It is the ability to be able to identify the customer's changing demands, point out their satisfaction, and then adjust to these changes.

Enabler: This is enabled by identifying the processes required to deliver the stakeholders demands and then check if these process will also satisfy the organization objectives (identified by the senior management). It also consists of identifying the best way to perform these processes in order to eliminate the "non-value adding activities."

The Gantt Resource Management System satisfies this enabler by using the instruction cards. These instructions eliminate the unnecessary motions and aims to produce the required product from the first time. Therefore, the extra cost related to the wasted time and rework will be eliminated. Therefore, this will increase the organization's ability to deliver in the promised time. For example, the instruction cards provided in Chapter 5uses a motion study developed by Frank Gilbreth in the early 1900s that cut the motion required to lay one brick by 75%.

4. Quality management system:

Driver: It is the ability to install mechanisms that allow measuring the performances against the identified success factors and then project these performances to the staff members.

Enabler: This is enabled by having a standardized and a simple quality management system.

The GRMS allows a quality management system using standardized dynamic production processes. The standardization is generated by controlling how the work is performed and not allowing each actor involved to do the work in a method of their choosing. The system also has the ability to update the instructions in the case of changing the product design or a feedback that there is a better way to do the work.

5. Integration of continuous improvement activities:

Driver: It is the process of "capture the learning and experience of individuals", compare the performances of the organization different sections, and then perform analysis and planning process to assure a continuously improving process.

Enabler: This is enabled by having a "self-assessment" mechanism to identify the areas of improvements.

The GRMS supports this criterion by showing the reasons behind the idleness and the total work performed by each worker/ machine/ department. For example, let us assume that the bricklaying crew is placing bricks on the second floor and a particular brick tender is starting to fall short in delivering the required amount of bricks per day which led to a schedule delay. The project manager will capture from the man chart that the brick tender is the reason behind the idleness. He can decide to assign him overtime work to stack the brick in smaller pallets and closer to the scaffolding. The extra amount of work that will be performed by the brick-helper is presented on the man chart by drawing an extra line within the width of the column for that day.

6.3.2.2 CPM Scheduling

Figure 6.4 below represents how a brick work activity will be shown in a CPM network and represents an illustrative example to reference in performing the comparison and contrast against the continuous improvement criterion.

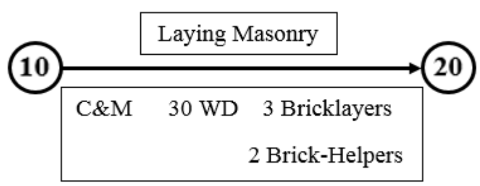


Figure 6.4 Brickwork as it will appear in a CPM network

1. Culture for Continuous Improvement:

Driver: The role of the senior management starts with defining the organization vision, mission, aims, and setting the success factors. And then communicate them to the staff members.

Enabler: This is enabled by installing tools to assure that the employees understands the performance and quality expectation, and installing "effective communication systems."

CPM does not support this criteria. As can be seen from Figure 6.4 above, the network is showing just the activity and its duration. The workmen will not be able to see any individual work expectations.

2. Having an employee focus:

Driver: The leadership by all mangers. It starts with the managers being able to understand the organizational objectives and then “coaching” these goals to their subordinates.

Enabler: This is enabled by using tools that show employees how their performance relates to others and then involving them in the improvement identification process (brain storming/ suggestions).

The CPM does not support this criteria. It focuses on the activities not resources. These resources are addressed in terms of resource loading which is a crew consisted of 3 bricklayers and 2 brick-helpers. Therefore, it does not have the tools required to train nor coach the staff members.

3. Focus on Critical Process:

Driver: It is the ability to be able to identify the customer’s changing demands, point out their satisfaction, and then adjust to these changes.

Enabler: This is enabled by identifying the processes required to deliver the stakeholders demands and then check if these process will also satisfy the organization objectives (identified by the senior management). It also consists of identifying the best way to perform these processes in order to eliminate the “non-value adding activities.”

CPM does not support this criteria. As can be seen from Figure 6.4 the CPM networks does not show the resources that will be used, the time it took performing each activity, and how much did it take for the tasks to be executed.

4. Quality management system:

Driver: It is the ability to install mechanisms that allow measuring the performances against the identified success factors and then project these performances to the staff members.

Enabler: This is enabled by having standardized and simple quality management system.

CPM does not support this criterion. It does not have a standardized process in executing the activities. The execution of the activities is left to the experience of the workmen and the quality control depends on the consultant on the job site.

5. Integration of continuous improvement activities:

Driver: It is the process of "capture the learning and experience of individuals", comparing the performances of the organization different sections, and then performing analysis and planning processes to assure a continuously improving process.

Enabler: This is enabled through having a "self-assessment" mechanism in order to identify the areas of improvements.

CPM does not support this criterion. As shown in Figure 6.4 CPM does not have a self-assessment mechanism to show the areas for improvements. All people see is an activity and its duration.

Figure 6.5 below summarizes the comparison and contrast between the Gantt resource management system and CPM scheduling for this criteria.

Enabler	Gantt Resource Management System	CPM Scheduling
Culture for Continuous Improvement	☑	☒
Having an employee focus	☑	☒
Focus on Critical Process	☑	☒
Quality management system	☑	☒
Integration of continuous improvement activities	☑	☒

Figure 6.5. Continuous Improvement Comparison and Contrast

6.3.3 Organization Routine

It is stated earlier that the routine criterion facilitate coordination and control, economize cognitive resources, reduce uncertainty, and provide stability.

6.3.3.1 Gantt Resource Management System

1. Coordination and Control:

The GRMS supports this criterion. It facilitates the monitoring and the controlling process by providing the charts required to see what every resource did and compare it with what was planned. The comparability combined with the instructions allow managers the ability to coordinate between the activities. For instance, in the Man Chart presented in Figure 5.17 it can be seen the bricklayers and tenders were not able to do their work on Tuesday the 12th because of the absence of the journeyman 1. That is projected by drawing a light line presenting the work performed against what is planned onto the width of the column for that day. In order to control this situation, the manager uses the layout chart to help him make a better decision in handling the situation. The Layout Chart in Figure 5.19 is then plotted to show the impact of that absence on the resources and the overall schedule for that day. The chart shows that if some of the work assigned to the journeyman1 is shifted to journeyman2 then the brick apprentice and the brick-helpers will be able to do their work for that day.

2. Economize on Cognitive resources:

The GRMS supports the economization on cognitive resources. The thinking process is eliminated because everyone involved in the process is provided with a clear plan of what is expected and the best methods to perform the work. For instance, the brick tender will not have to worry about preparing the mortar since there is someone (the mortar tender) that will be held accountable for that task.

3. Reduce Uncertainty and provide stability:

The Gantt Resource Management System reduces uncertainties and provides stability through producing plans based on the available resources and having the capability of presenting the reason behind idleness. For example, in the brick model provided in Chapter 5the project manager was notified of journeyman1 absence and was able to see its impact on the overall schedule because the as-planned schedule (Figure 5.13) was produced based on the available resources. When reacting to this idleness he is able to see how his decision is going to impact the schedule (Figure 5.22). Therefore, uncertainty was eliminated because the charts enabled him to actually see the impact of that decision. The stability is created through having a standardized process and fixing the ways of how the work is performed.

6.3.3.2 CPM Scheduling

1. Coordination and Control:

CPM schedules do not provide the capability to control nor coordinate between the activities. For example, in the case of the absence of one of the bricklaying crew the manager will not be able to see who was responsible for the idleness. He is not going to be notified because the responsibilities are not fixed. Therefore, what he will see at the end of the week/ month is just the brickwork is behind the schedule. Therefore, he does not have the tools required to coordinate nor control the process.

2. Economize on Cognitive resources:

CPM does not economize on cognitive resources. Because CPM is a task driven technique, it does not provide any information regarding resources. Therefore, there is no resource information to be economized which will increase the complexity of the decision making process and reduce the ability to spontaneous react under constraints.

3. Reduce Uncertainty and provide stability:

CPM scheduling does not reduce the uncertainty nor provide stability. The uncertainty level is high when a schedule is to be produced using CPM. The planners normally do not know the outcomes of the schedule they produced and must assume the actual resources to be used in the process. Therefore, these schedules normally tends to be unrealistic and sometimes revised on site when the work is about to begin. The CPM scheduling technique does not possess a standardize process nor instructions on how the work should be executed.

Figure 6.6 below summarize the comparison and contrast between the Gantt resource management system and CPM scheduling for this criteria.

Effects	**Gantt Resource Management System**	**CPM Scheduling**
Coordination and Control	☑	☒
Economize on Cognitive resources	☑	☒
Reduce Uncertainty and provide stability	☑	☒

Figure 6.6. Routine Comparison and Contrast

6.3.4 Simplification

It has been discussed that simplification is attained by two factors: presenting the information in a format that describes it the best and having a sense making mechanism enabling people to understand information without having someone describe it to them.

6.3.4.1 Gantt Resource Management System

1. Provide tools to describe the tasks to be performed:

From the discussion provided in Chapters 4and 5, the Gantt Resource Management System supports this criterion. Because it uses graphical representation to show information regarding work expectations, work performance, and available resources. This will help people who are doing the work to understand expectations and how their performance is measured. For example, in the Progress Chart presented in Figure 5.20 the mortar tenders can see how many cubic feet of mortar is required from him each day and at the same time he can see the effect of his production on others.

2. Provide tools that help the workmen to make sense of the available information:

GRMS provides sense making by breaking the activities into multiple operations, identify those responsibility, and provide instructions of how to execute each one of these operations. For example, the Progress Chart presented in Figure 5.20 shows workmen expectation concerning not only their work for each day but also those of others involved in the work as well. Doing this will allow each workman to understand if he fails to deliver what is planned it will impact the work of others and that of overall schedule as well. Therefore, they can make sense of the information provided in this chart.

6.3.4.2 CPM Scheduling

1. Provide tools to describe the tasks to be performed:

Although CPM scheduling can be formatted as a bar chart to show the schedule and activities durations, it does not contain capabilities required from a graph to simplify the presented information. It does not show the relationship between the operations contributing to production of a certain activity and hence does not allow the comparison between these operations.

2. Provide tools that help the workmen to make sense of the available information:

CPM scheduling does not support this criterion. It does not have the ability to graphically communicate the plans to the people in the bottom level of the organization. The plans are activity driven and are presented and kept in the management office. For example, brick masons will not have access to these plans on the jobsite.

Figure 6.7 below summarize the comparison and contrast between the Gantt resource management system and CPM scheduling for this criteria.

Tools	Gantt Resource Management System	CPM Scheduling
Tools that best describe the tasks to be performed	☑	☒
Sense Making	☑	☒

Figure 6.7. Simplification Comparison and Contrast.

6.3.5 Dynamic robust predictive-reactive scheduling

6.3.5.1 Gantt Resource Management System

The Gantt resource management system can be considered dynamic under the “robust predictive-reactive scheduling” category. That can be seen from the brick model example when the idleness of having journeyman1 absent. The schedule was adjusted by shifting some of his work to the journeyman 2 in order to keep the schedule as planned and maintain the maximum performance since the activity sequence are maintained. The Gantt Man Chart (Figures 5.17 and 5.21), Layout Chart (Figures 5.19 and 5.22), and Progress Chart (Figure 5.20) were able to present the idleness and its significant impact on the overall schedule. The system provides the project manager with capability to determine which mason to be shifted in order to keep the schedule as planned. Therefore, this system can be considered dynamic.

6.3.5.2 CPM Scheduling

Current scheduling techniques contain updating procedure for determining project status or likely completion dates and establishing project historical records. The update frequency depends on the degree of the project complexity, when a disruption occurs, or if it’s specified in the project specifications. However, the update process is activity driven focus and does not include resource in the process.

Figure 6.8 below summarize the comparison and contrast between the Gantt resource management system and CPM scheduling for this criteria.

Schedule Type	Gantt Resource Management System	CPM Scheduling
Robust predictive-reactive scheduling	☑	☒

Figure 6.8. Dynamic Criteria Comparison and Contrast.

6.4: Summary:

Chapter5 discusses the five developed criteria used in the comparison and contrast analysis between the Gantt Resource Management System and CPM scheduling technique which represents the current technique of resource management in the construction industry. The five criteria are developed in this research effort from literature with the focus on characteristics that a resource scheduling technique should possess. A whole by whole type comparison and contrast style is then used.

The Gantt resource management system is found to be satisfactory in meeting all the five criteria. That is because the GRMS is a resource driven and originally developed to increase resources efficiency. It creates a transparent environment throughout the organizational levels, encourages the establishment of continuous improvements and sustain it within the process. It also uses the instructions and the interrelated charts to standardize and simplify the process.

The CPM scheduling does not match any of the criteria. The reason is that CPM is designed to produce activity driven schedules with the objective of informing the mangers of the dependence between projects activities and does not contain any form of communication tool to the people who are doing the work. It also does not have the ability to present to these people how the performance is being measured or even how to do the work. That is because the main focus is the activities not the people or the machines utilized in accomplishing the work.. Therefore, CPM does not support any of the criteria developed in this chapter. A summary demonstrating the criteria matching in listed in Figure 6.9.

Criteria	**Gantt Resource Management System**	**CPM Scheduling**
Transparency	☑	☒
Continuous Improvement	☑	☒
Routine	☑	☒
Simplification	☑	☒
Dynamic	☑	☒

Figure 6.9. Resource Management Comparison and Contrast Criteria.

CHAPTER 7

Summary, Conclusion, & Suggestions for future research

7.1 Summary

Current scheduling techniques such as CPM are considered activity driven in their nature. They produce schedules based on activities relationship without taking into consideration the resources limitation. Resources are dealt with after the schedules are produced in the form of resource allocation and resources leveling. Research has been done to deal with this limitation and a lot of optimizing techniques have been introduced. However, these techniques are usually complicated and are seldom put into meaningful practice. Therefore, projects are continually falling short of promises and resources are dealt with on day-to-day basis without knowing how much money has been spent on resources to accomplish certain activities.

In the late 1800s and early 1900s the manufacturing industry faced similar difficulties in dealing with resources. A resource driven management system was then developed by H. Gantt to prevent the chaos resulting from produced schedules based on just the activities dependencies. His system identifies reasons behind delays and helps monitor and control the production process. It consists of instruction cards and five charts which are: Man Chart, Machine Chart, Layout Chart, Load Chart, and Progress Chart.

The aim of this thesis is to accomplish three major goals. First, fully describe the resource management system developed by Henry Gantt and emphasize its success in increase the production efficiency before and during the World War I. Using his system, Gantt was able to help organize and manage the production in the shop floors at the Frankford Arsenals by developing the Progress Chart. After the United States entered the World War I, Gantt was successfully able to install his tools at the Ordnance Bureau of the United States Army, the War Industries Board, the Emergency Fleet Corporation, Shipping Board, and the production of naval aircraft. Second, apply the GRMS to the construction industry and demonstrate its use. In accomplishing this a brick project model is developed using building information modeling software where an as-planned schedule is developed dealing with the brick masonry trade. Then an actual construction scenario for the first week of schedule was assumed in order to produce the Gantt's multiple charts to demonstrate how they can be used during construction.

Third is to compare and contrast the Gantt resource management system with a current scheduling technique based on a set of developed criteria. Five criteria which are necessary for a resource scheduling approach were developed and include: Transparency, Continuous Improvements, Routine, Simplification, and Dynamic. Transparency uses five approaches to make the process visible to all the parties involved in the process. Continuous Improvement require the installation of five enablers that provide the momentum required to accomplish organizations strategies, change the organization behavior toward how to respond to the market changing demands, and involve all the organization workforce in the innovation and improvement process. Routine is the ability to standardize the construction process and works at the organizational level to direct people's behavior to work collectively towards achieving the promises. Simplification aims to achieve decision making and problem solving processes along with enabling people involved in the construction process to make sense of the strategic information provided by the top managerial levels. Dynamic allows resource scheduling techniques to deal with the uncertainties (disruptions) that faces Base line schedules. The Gantt management system is found to satisfy all the five criteria while the CPM failed to comply any. Therefore, a conclusion can be drawn that the proposed technique in this thesis is more effective than what is currently being used.

7.2 Conclusion

The techniques used to produce schedules for construction projects should be resource driven while maintaining the activities sequences. Producing schedule based on just the activities and then assigning resources to these activities have proven ineffective. Contractors need tools that, make the construction process visible and understandable to all those involved. Second, facilitate the production of the stakeholder’s demands while achieving the organizations goals through incremental innovations. Third, standardized processes that organize the interaction between the available resources involved in order to facilitate coordination and control, economize on the cognitive resources, reduce uncertainty, and provide stability. Fourth, best describe the information collected from not just the surrounding environments but the variables involved in the construction process. It should also help all actors involved in a certain process to make sense of available information. Fifth, contractors needs scheduling techniques that can show and adjust to work disruptions dynamically.

Three goals are achieved through this thesis. First, the effectiveness of the GRMS during the World War I have led to a tremendous increase in the production rates at the shop floors that implemented the system. Second, the GRMS is found to be applicable to construction and has the potential to be automated and applied to any project. Third, the system is found to be more effective than CPM in producing reliable resource schedules.

7.3 Suggestions for Future Research

The GRMS system applicability to the construction industry has been discussed in this thesis. But, further work needs to be performed in order to fully apply the system to the industry for general use. That work is envisioned along three components:

1- Adapt Gantt's Task and Bonus System to the construction industry

The question here is: what are the benefits that will be gained from adapting and applying the Task and Bonus System to construction. The answer could be that in order to avoid potential resistance from the workmen to the GRMS when applied to construction, a bonus is paid if the tasks performed as-planned. Task and Bonus charts need to be plotted and posted regularly so the workmen can see how many times they have made a bonus and compare it with their contemporaries. Therefore, it will work as a motivation for the workmen to increase their productivity.

2- The GRMS should be used on an actual project as a research trial in order to identify and correct any potential deficiencies

While the GRMS is proved to be both applicable to construction and efficient in managing the resources, the example provided in this thesis is considered hypothetical and the system need to be applied to an actual project to answer the following questions: How is the construction productivity compared before and after the application of the GRMS? How does the construction cost is compared pre and post the GRMS? Is the system applicable to construction trades other than brickwork? Is the system able to project the potential work disruptions related to interrelated activities? What are the system deficiencies that were not seen in this thesis? How long does it take to update each chart from the time an as-performed site report is received? How long does it take the management office to learn the system?

3- Computer code needs to be written and added to a building information modeling software to automate the system

BIM has the potential to incorporate the GRMS. However, a computer code needs to be written in order to produce instruction cards, the as-planned schedule, and the as-performed schedules. When developing that code, two questions need to be in mind: First, can the instruction cards be loaded in a form of a video to the designed model and then link it with each task? What automated mechanism will allow people in the field to update actual work performed relative to the plan?

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Appendix A

Instruction Cards

Class of Work: Walls with opening. Location: W1, W3 Responsible Foreman: Mark

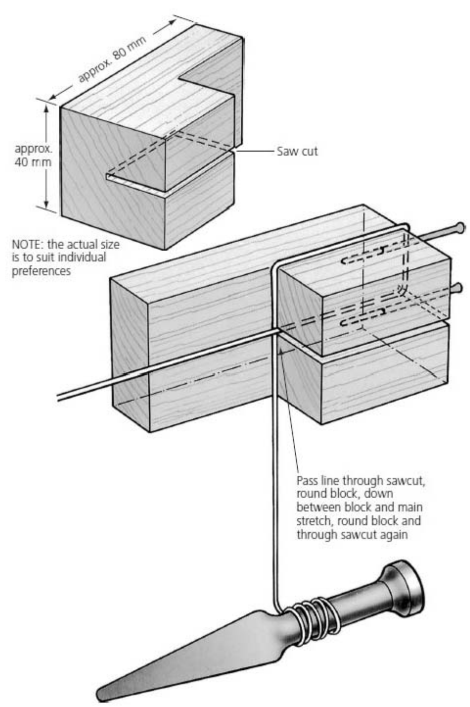
Journeyman number: 1&2. Bond Pattern: Stretcher Bond. Method to be use in laying the brick: Stringing Mortar Method.

Operation Description	Motions	Notes	T Req.	T Took
String the line between the two corners.	2			
Sight the line	1			
Install the reveal bricks				
Mark the reveal bricks locations	8			
Reach for bricks	4			
Install the reveal bricks	4			
Total Motions before laying the first course	19			
Laying 4 bricks				
Reach for Brick	2	For 4 bricks (2 bricks at a time)		
Reaching For Mortar	1/4 per brick	With a large trowel holds mortar for 4 bricks.		
Reach for Brick	4/4 per brick			
Mortar = Box to Wall	1/4 per brick	Conveying mortar for four bricks at once.		
Brick = Pile to Wall	1/2 per brick	Brick in each hand.		
Deposit Mortar on Wall	1/4 per brick	Depositing Mortar for four bricks at once.		
Spreading mortar	1/4 per brick	Spreading Mortar for four bricks at once.		
Cutting off mortar	4/4 per brick			
Disposing off mortar	4/4 per brick	Butter the end of last Bick laid.		
As building up the courses: plumb the perpends of each reveal brick	1 per reveal brick=8	There are 6 reveal bricks. This way you would have the vertical sides ready for every window.		
Total Motions for laying four bricks	17			
Total Motions for laying the first course (56 bricks)	238			
Total Motions for laying the Seven course	1666			
Total Motions for laying a wall between two corners with 4 windows openings	1685	It take 0.27 of a minute per one motion.	7.5 hrs	

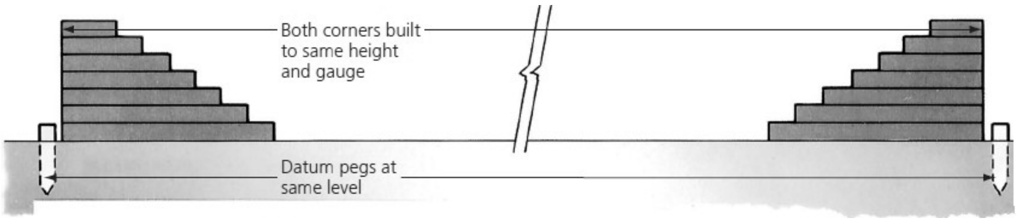
A-1 Instruction Card for how lay bricks in a wall with openings

General Notes:

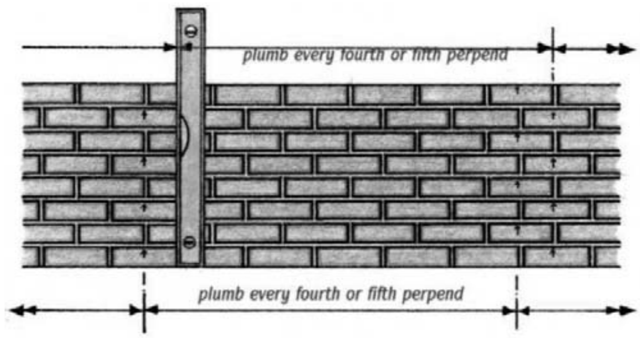
- Using a wooden block and a pin (see A1-1), String a line between the plumbed corners (see A1-2), for each course you want to lay. (1/8 in should be between the line and the face of the wall).
- Insure the line is pulled tight enough to prevent it from sag.
- Sight the line from one end (corner) to ensure that is positioned correctly.
- After you lay every course, check it with a plumb rule. To make sure that the line was not disrupted while laying the brick course.
- Use half bond.
- At the T junctions with the internal walls: use ¾ bats and ¼ bats as bonds.
- Plumb every fourth or fifth perpends (see A1-3). ''Perpends are the positions of the vertical joints between the bricks.'', ibstock building sustainability.
- Mark the locations of the windows (the two edges of the window) on the ground: This is done with a help from the foreman.
- Install, dry, the reveal bricks on the edge of these marks (see A1-4).
- In the case of wall openings that are not multiple of the brick's coordination dimensions; use the gauge rod to determine any broken bond between the reveal bricks.
- Broken bonds should be located centrally under window's openings.
- Broken bonds can be manipulated by playing with the cut of the bricks (see A1-5).



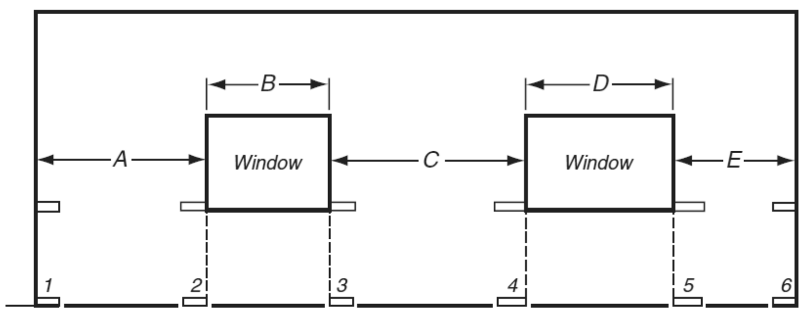
A-1-1 Wooden block and a pin used to get a straight line between two corners (The Brick Development Association 2005)



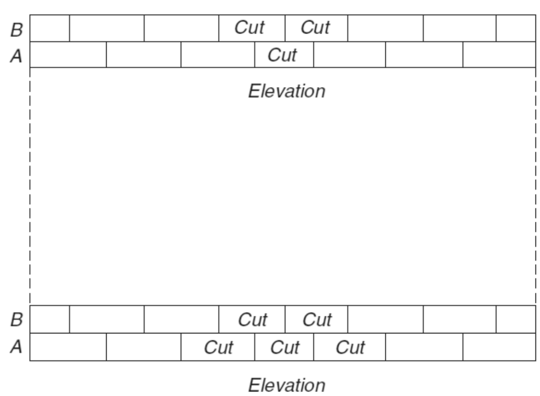
A-1-2 String line between the plumbed corners (The Brick Development Association 2005)



A-1-3 Plumb every fourth or fifth perpends (ibstock building sustainability)



A-1-4 Elevation view Shows the reveal Bricks locations (Hodge and Thorpe 2006).



A-1-5 Manipulating the Broken Bonds (Hodge and Thorpe 2006)

Class of Work: Curved Wall. Location: East and West Side of the Building.

Responsible Foreman: Mark Brick Mason: Journeyman1

Bond Pattern: Stretcher Bond. Method to be use in laying the brick: Stringing Mortar.

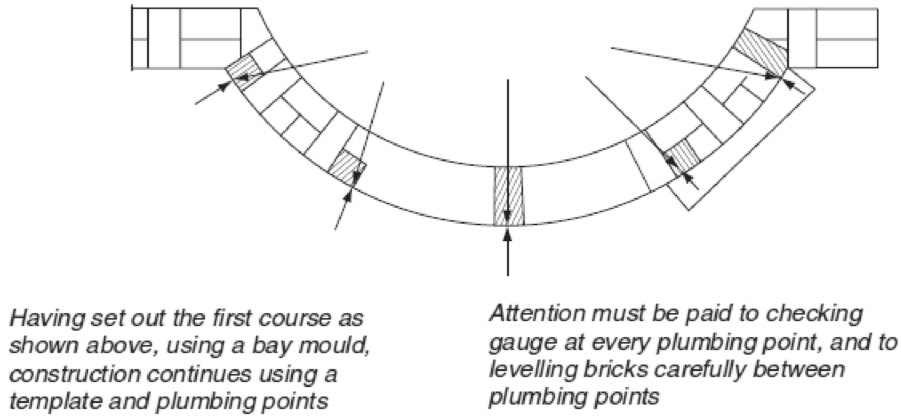
Construction Method: Full Template.

Operation Description	Motions	Notes	T Req.	T Took
C. With the foreman, install the template in the right place.				
D. Laying four bricks				
Reach for Brick	2	For 4 bricks (2 bricks at a time)		
1. Reaching For Mortar	1/4 per brick	With a large trowel holds mortar for 4 bricks.		
2. Reach for Brick	4/4 per brick			
3. Mortar = Box to Wall	1/4 per brick	Conveying mortar for four bricks at once.		
4. Brick = Pile to Wall	1/2 per brick	Brick in each hand.		
5. Deposit Mortar on Wall	1/4 per brick	Depositing Mortar for four bricks at once.		
6. Spreading mortar	1/4 per brick	Spreading Mortar for four bricks at once.		
7. Cutting off mortar	4/4 per brick			
8. Disposing off mortar	4/4 per brick	Butter the end of last Bick laid.		
Total Motions for laying four bricks	6.5			
Total Motions for laying the first course (53 bricks).	86			
Total Motions for laying the Seven courses	603			
9. Horizontal Leveling between plumbing points.	18 motions/ course 126 motions	There are 20 plumbing points 18 motions * 7 courses = 126		
10. Check for curvature between the plumbing points.	18 motions/ course 72 motions	There are four courses that will need this step. 18*4= 72		
11. Vertical Plumbing	20 motions/ course 80 motions	There are four courses that will need this step. 20*4= 80		
Total Motions	881	0.50 of a minute per one motion	7 hrs	

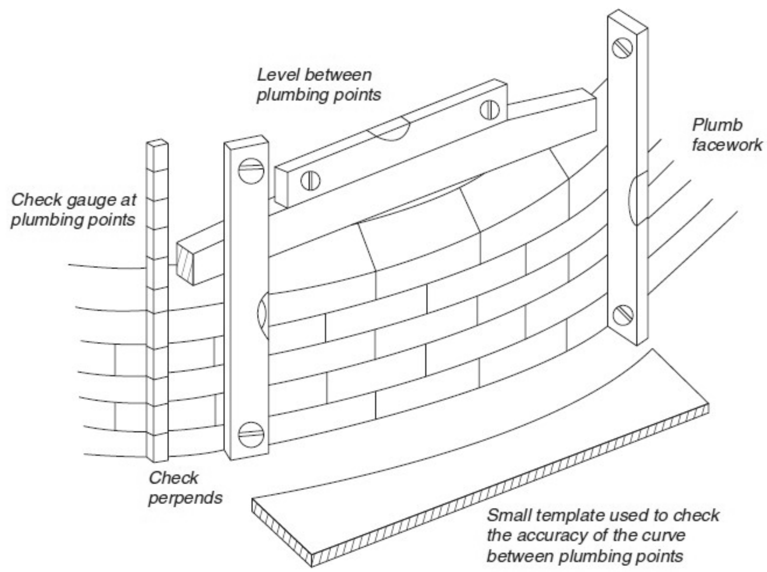
A-2 Instructions card of how to build a curved wall

General Notes:

- Use half bond
- Use the template, provided by the foreman, to lay the first three courses.
- Around the curve, mark a number of plumbing points (see A-2-1).
- Use the wooden template to check the curvature between these plumbing points (see A-2-2).
- Vertical plumbing should be taken from the plumbing points at the first course (see A-2-2).
- Horizontal leveling is very important while you are laying the course. Check the horizontal leveling between the plumbing points (see A-2-2).



A-2-1 Plan view of plumbing points locations. (Hodge and Thorpe 2006)



A-2-2 Checking Curvature between plumbing points (Hodge and Thorpe 2006)

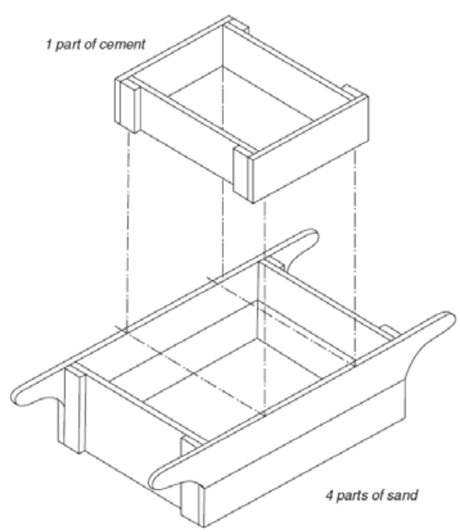
Class of Work: Mortar. Location: The project site.

Responsible Foreman: John Brick-helper: Mortar Tender

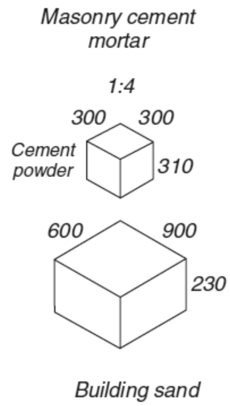
Mortar Type: Masonry Cement/Sand Mortar

General Notes:

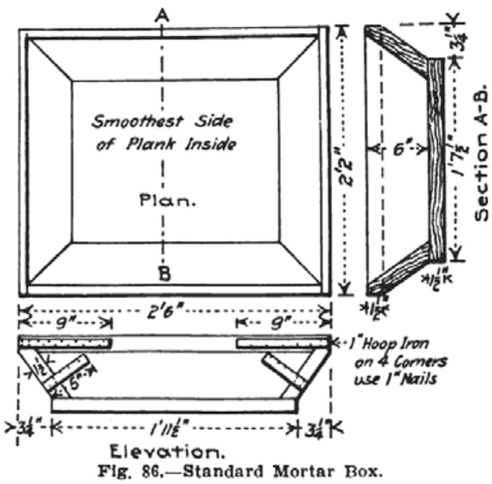
- This type of mortar uses ‘’1 volume of OPC to 3 or 4 equal volumes of sand.’’ (Hodge and Thorpe 2006). (See A-3-1).
- Gauge boxes should be used in measuring the quantities of the dry materials in each batch (see A-3-2).
- Boxes should be placed behind the mixer.
- Do not batch using a shovel.
- A light roof should be installed above the mortar bed to protect the mortar makers from the rain the sun. (Bricklaying System p. 107).
- It is advisable to have more than one mortar bed in the site. They should be typical from each other so the foreman can assign a same number of mortar makers to each mortar bed. (Bricklaying System p. 107-108).
- A-3-3 show how a typical mortar box should look like.
- A brick tender should always located in the stock platform with the following responsibilities:
    1. ‘’To keep the mortar at the right consistency.’’ (Bricklaying System p. 108). For example, He should have a water bucket ready to temper the mortar.
    2. Fill the mortar boxes.
    3. Take any hard mortar and temper it with a shovel and a water bucket or a hoe.
- A pail of lime patty to every cement barrel can be added to increase the workability and decrease the ‘’set of the cement.’’
- The brick tender should use a square shovel not a round-pointed shovel.



A-3-1 Sand and Cement Volume boxes (Hodge and Thorpe 2006)



A-3-2 Gauge boxes (Hodge and Thorpe 2006)



A-3-3 Mortar Box (Gilbreth 1911)

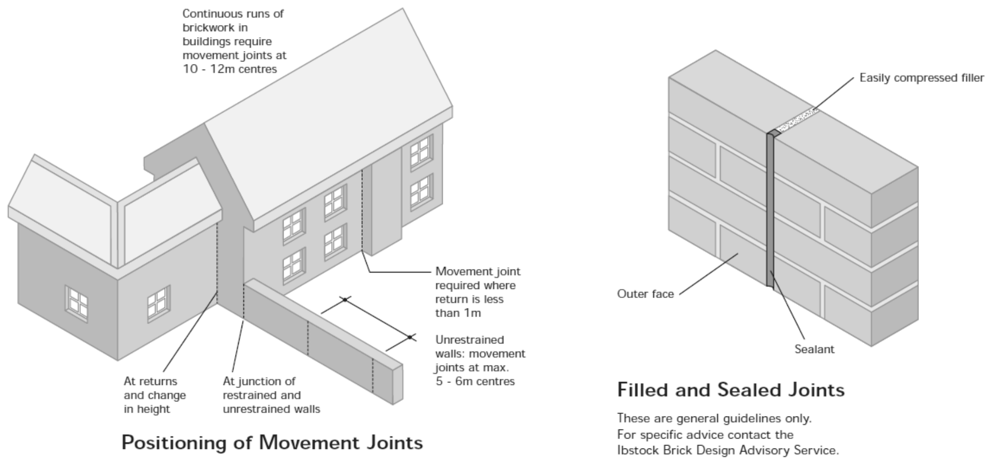
<u>Class of Work:</u> Movement Joints. <u>Location:</u> All Walls

<u>Responsible Foreman:</u> John <u>Brick Mason:</u> Journeymen 1&2, Brick Apprentice

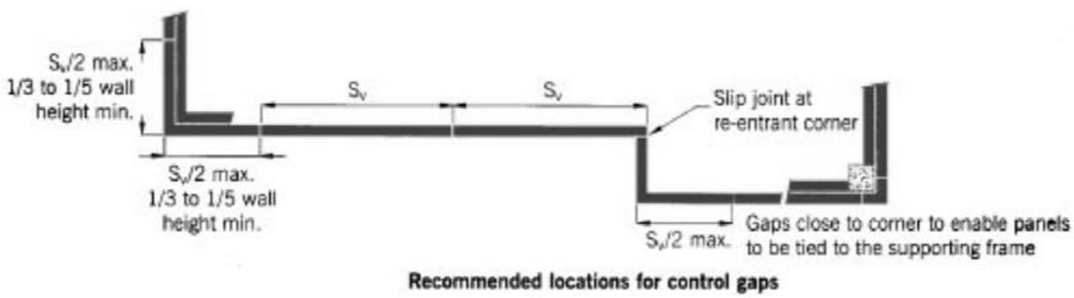
<u>Type of the Joint:</u> Vertical Joint

- Walls without openings: The spacing between the joints should not exceed 25 ft.
- Walls with multiple openings: The spacing between the joints should not exceed 20 ft.
- Unrestrained walls (i.e. Parapet): The spacing between the joints should not exceed 15 ft., if it exceeded that distance increase the joint width.
- From A-4-1 & A-4-2, the joints are placed:
  "
  1. at or near corners
  2. at offsets and setbacks
  3. at wall intersections
  4. at changes in wall height
  5. where wall backing system changes
  6. where support of brick veneer changes
  7. where wall function or climatic exposure changes
  8. Extend to top of brickwork, including parapets.'' (Brick Industry Association 2006).
- "The width of the joint width in (mm) is equal to the joint spacing in (m) plus allowance of typically 30% to allow for the compressibility of the filler and the performance of appropriate sealant. '' (ibstock brick 2000).
- Movement Joints should be clear from any mortar.
- Joints will be filled with ''a round polythene-foam backing rod squeezed into the gap, and a gunned-in mastic sealant.''(Holland and Smith). See A-4-3.
- Also ''a pre-molded foam or neoprene pad that extends through the full Wythe thickness.''(Brick Industry Association 2006), can be used to prevent any mortar from filling the joint (see A-4-4).

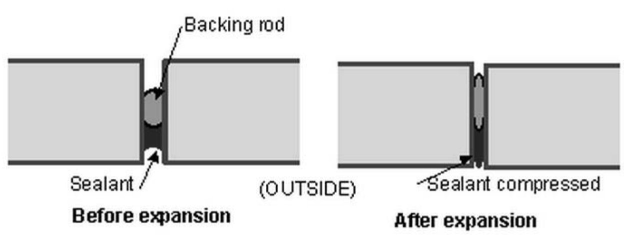
Operation Description	Motions	Notes	T Req.	T Took
1. String a line between the two corners.				
2. Install reveal bricks at the edge of the expansion joint openings.				
3. Determine the correct bond.				



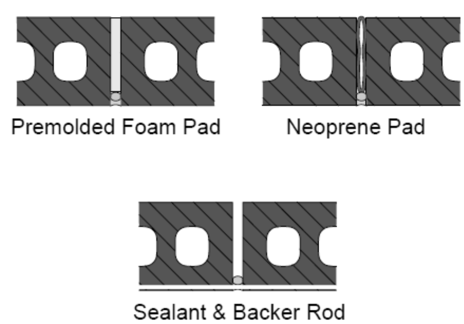
A-4-1 Expansion Joints Locations (ibstock brick 2000)



A-4-2 Expansion Joints Locations (Holland and Smith)



A-4-3 Joints Filling (Holland and Smith)



A-4-4 (Brick Industry Association 2006)

Class of Work: Jointing

Location: All Walls

Responsible Foreman: John

Brick Mason: Journeymen 1&2, Brick Apprentice

Jointing Notes:

1. Jointing time is based on two factors; “brick suction rate and the weather condition.”(The Brick Development Association 2005)
2. At high temperature conditions, jointing should be done by the bricklayer every three courses.
3. In cold temperature, jointing should be done “twice only in a lift of brickwork may be appropriate.”(The Brick Development Association 2005).
4. Finishing a joint while the mortar is too dry, will leave a dark mark on the joint and ‘’Leave crumbly face.”(The Brick Development Association 2005)
5. Finishing a joint while the mortar is still wet, will lead the mortar to spread and leave a rougher surface.
6. Finish the cross joints first.
7. To get a bucket handle finishing joint, use the same tool throughout the joint and “the jointing tool must remain in contact with brick arises above and below the bed joints and each side of cross joints.”(The Brick Development Association 2005). See A-5-1.
8. In finishing the internal corner joints, pay attention to emphasize the bond pattern. “Finish alternately to left and right.”(The Brick Development Association 2005). For an incorrect method example (see A-5-2). For correct method example (see A-5-3).
9. To avoid the mouse’s ears at the movement joints, make sure to finish the joint till the edge of the brick and “do not leave gaps at the ends of the bed joints.”(The Brick Development Association 2005).

A-5-1 How to use jointing tool (The Brick Development Association 2005)

A-5-2 Incorrect method of finishing a corner (The Brick Development Association 2005)

A-5-3 The correct way to finish a corner (The Brick Development Association 2005)

Class of Work: Scaffolding

Location: All the site

Responsible Foreman: John

Brick Mason: Scaffold labor 1&2

Workhorse Scaffolding System

1. Install a steel plate under the scaffolding and attach a leveling jack to the base towers, if the scaffolding will be on unstable ground).
2. ''Connect two base towers with carriages using x-braces.'' Carriages should be on both sides of the platform.
3. To connect the towers together use the straight braces.
4. To lift the scaffold as desirable, use the jack handle. Any scaffold leg should not be lifted 4 notches higher than the other leg tied to it.
5. In loading the materials '' Do not land more than 1000 pounds per 7-foot bay on the workbench.''
6. As the scaffold go up, install the laborers bracket. '' Do not land more than 2500 pounds per 7-foot bay on the laborers bracket.''
7. Use extension towers as needed. Do not exceed 25 feet in height. For work plat form higher than 20 feet, tie the scaffold legs to the wall using ''the Non-Stop Wall Tie-In Bracket or #9 wire. Tie every 14 feet horizontally.''
8. Use the guardrail posts and panels as a protection in the end of the platform.
9. Platform should be unloaded from men and materials before lowering the scaffold.

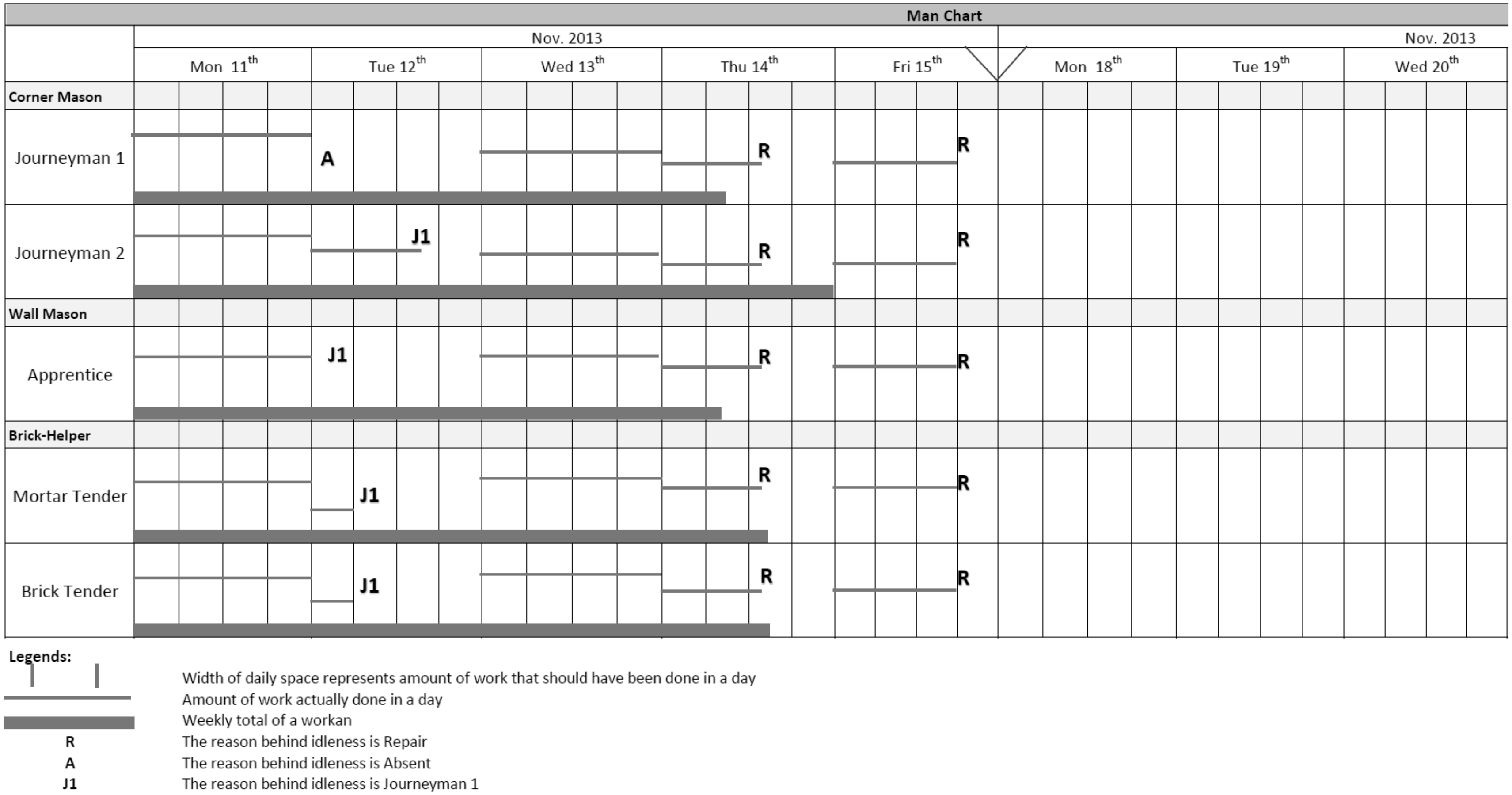
Total number of motions per 1 tower per 1 labor = 12 motions
The width of one tower = 12'
The model length to cover = 524'
Required number of towers to be installed = 44 towers
Total number of motions if one labor is going to install = 528 motions
Time required to install one tower = 24 min per 12 motions
Time required for 44 towers = 24*44 = 1056 min or 17.5 hours (two working days)

	Targeted Productivity/ day					
	Wall without oppening					
	# bricks/ day	# motions/4 bricks	# motions/500 bricks	time (min)/ per motion	Total time(min)/ bricks between corners	Total time(hr)/ bricks between corners
Standard wall	500	8.5	1062.5	0.451764706	480	8
W4	285	8.5	605	0.451764706	273	4.6
W5	135	8.5	286	0.451764706	129	2.2
W6	135	8.5	286	0.451764706	129	2.2
W7	453	8.5	962	0.451764706	435	7.2
W8	135	8.5	286	0.451764706	129	2.2
W9	135	8.5	286	0.451764706	129	2.2
W10	285	8.5	605	0.451764706	273	4.6
W11	493	8.5	1047	0.451764706	473	7.9
W13	493	8.5	1047	0.451764706	473	7.9
W14	452	8.5	960	0.451764706	434	7.2
W15	452	8.5	960	0.451764706	434	7.2
W16	452	8.5	960	0.451764706	434	7.2
W17	452	8.5	960	0.451764706	434	7.2

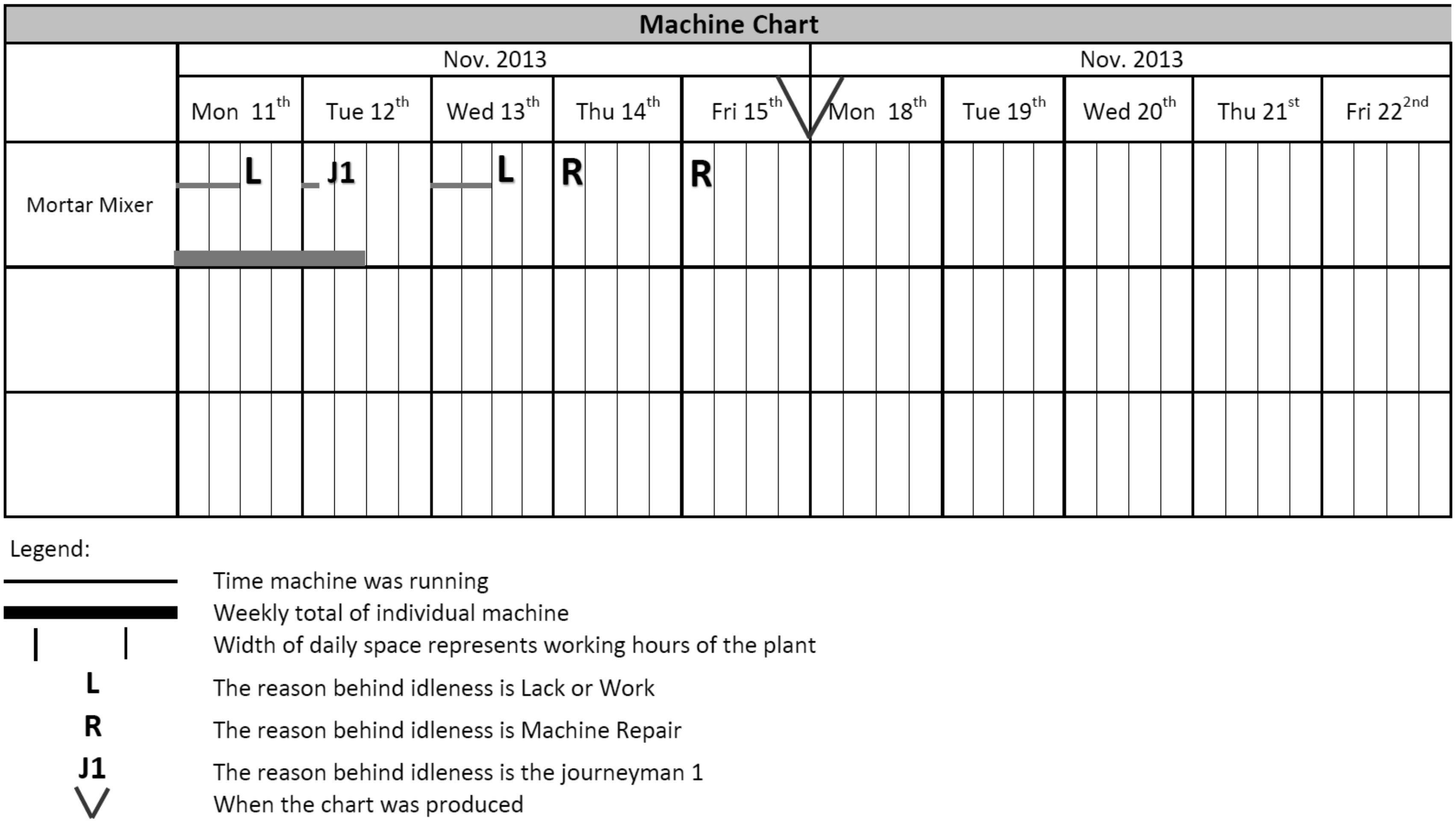
A-6 Time Estimates of the Walls without Openings

Appendix B

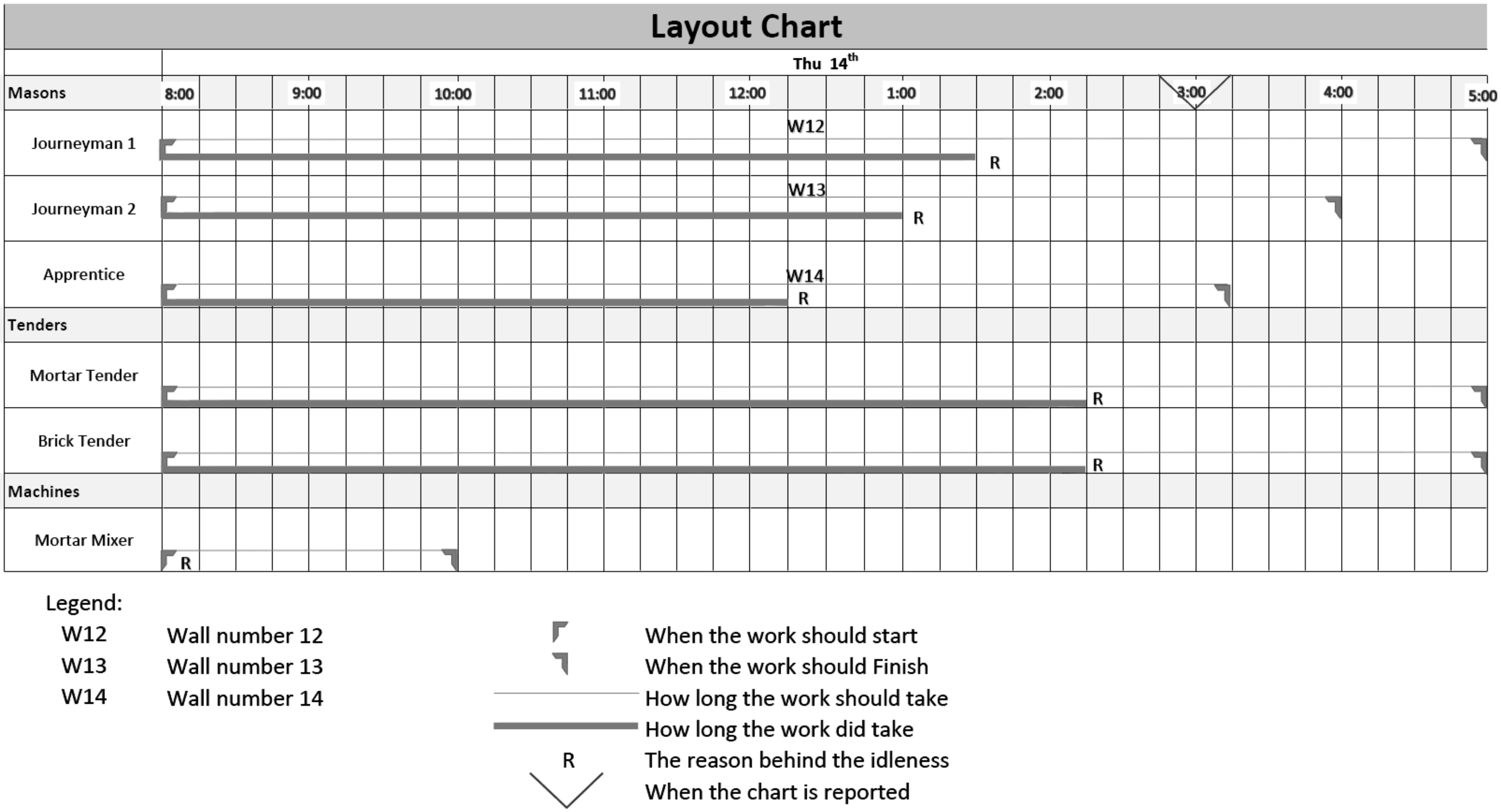
The Brick Project Second Scenario



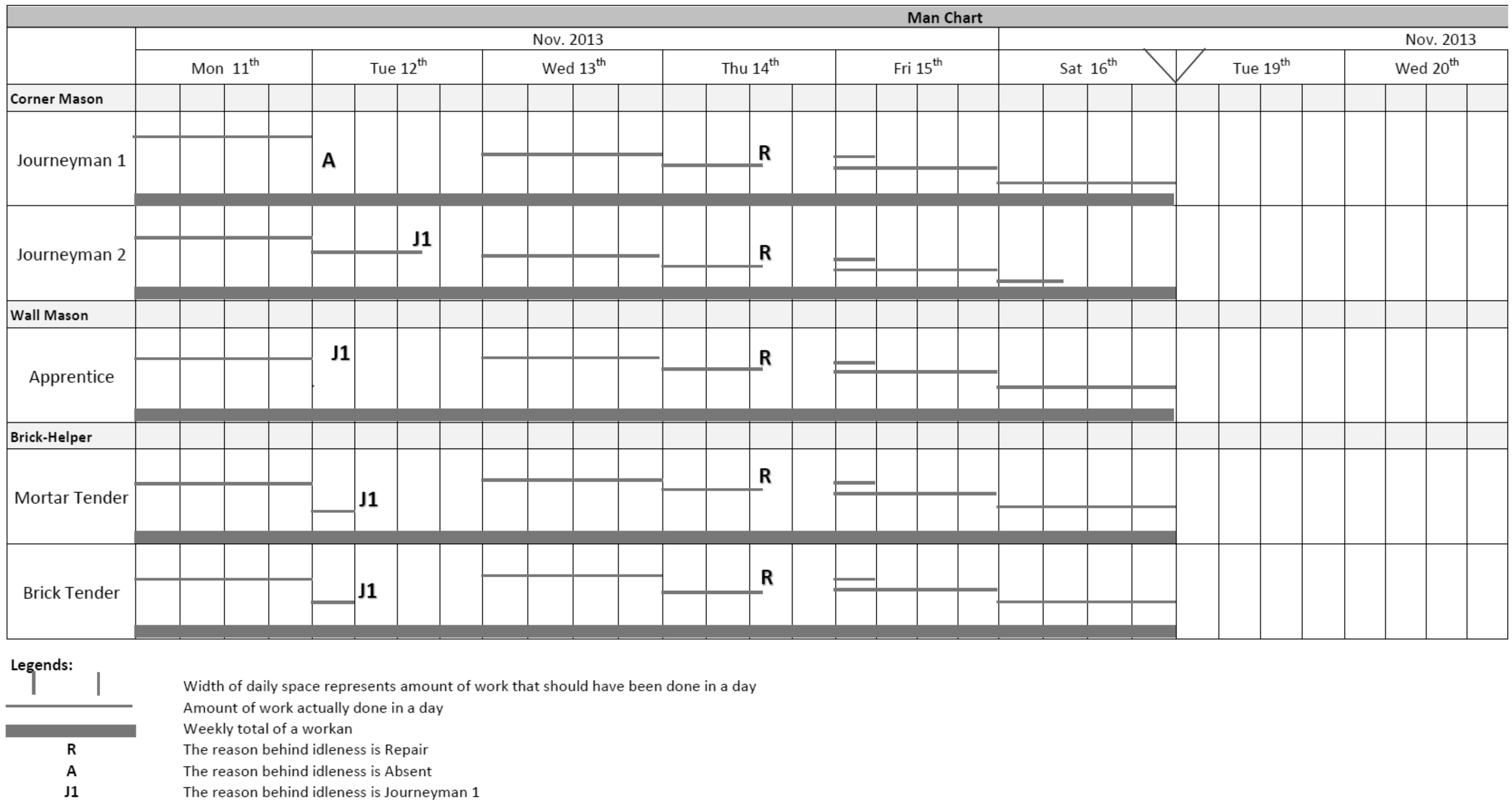
B-1 Man chart shwoing the second scenario ideness



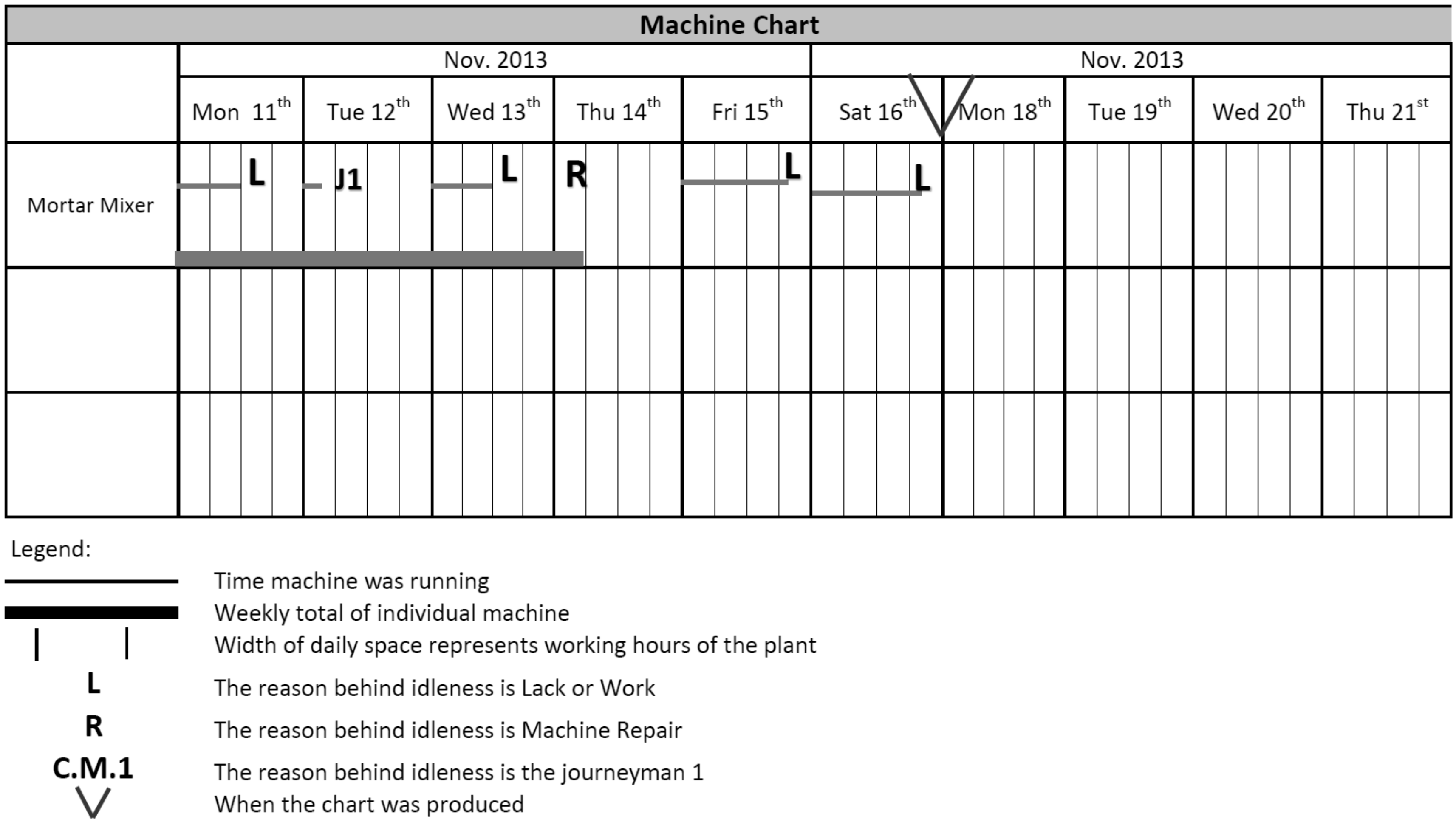
B-2 Machine Chart shwoing the second scenario ideness



B-3 Layout chart shwoing the second idleness on Thrursday the 14th



B-4 Man chart shwoing that the workmen worked an over time on Friday and worked on Saturday in order to make up for the delays



B-5 Machine Chart showing that the machine has worked on Saturday

to make up for the delay