

The Multiple Activity Chart: A Multifaceted Tool for Project Planning and Control

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Project scheduling and control are among the main skills a professional construction manager, or one aspiring to be, must possess in their skill set. Different types of schedules are developed for the project in its different development phases including master schedules, milestone schedules, phase schedules, reverse phase schedules, and very short term schedules. Among the techniques that have been used successfully in other parts of the world, and seldom in the US is the Multiple Activity Chart (MAC), which can be an effective tool for scheduling daily activities, particularly the interaction between crews of labor and other resources including materials and equipment. This paper addresses an educational approach utilizing the MAC as a tool for delivering project management education and training not only linked to scheduling and control, but including other skills such as estimating, equipment management, productivity improvement, and most importantly creative thinking and problem solving.

Key words: Scheduling, lean construction, process improvement, productivity, project management.

Introduction

Time is an essential project resource that needs to be carefully managed in any type of projects, particularly in construction. Errors in effective time management result in project delays leading to liquidated damages, claims that could escalate into disputes, or contractor initiated project acceleration resulting in an increase in cost, thus reducing the contractor's profitability and long term survival in the construction industry. Time is usually listed as one of the original triple constraints in project management, with the other two being cost and scope, or cost and quality, or cost and client satisfaction. (PMIBOK, 2017)

Project managers have long recognized the importance of carefully managing time, and different tools and techniques have been devised to facilitate this important and continuous task. These tools have evolved from textual checklists, to graphic representation such as the Gantt charts. Further development resulted in a newer school of network techniques utilizing the critical path method CPM [ADM, PDM, PERT, CCM and GERT] (PMI 2011). These networks led to the development of linear and repetitive scheduling tools [Line of Balance LoB, computer simulations], (Halpin, 1992) and ending full circle with the Gantt chart as the communication tool among different project stakeholders (Mubarak, 2005).
These different schedules range in their time span between several years for master schedules, to a few months for phase schedules, to a few weeks for look-ahead and reverse phase schedules, to a few days or fractions of a day for simulations.(AACE 1,2, 2010)

One of the tools in the larger arsenal of work measurement and productivity improvement techniques is the Multiple Activity Chart (MAC) that has consistently been used to a great success overseas, particularly in the United Kingdom and Australia (Harris et al. 2013, Usher et al. 2011), but not quite often in the US. Building on the strengths of the CPM in sequencing and scheduling long and medium term activities and operations, the MAC focuses on very short term schedules, especially when the schedule is resource driven.

Blackwell Encyclopedia of Management defines MAC as *"are diagrams used to show the interrelationships of individuals in teams of workers, or the relationships between workers and equipment, usually during the record stage of method study. "* (Blackwell, 2017)

While the Critical Path Method (CPM) algorithm has been successfully used in construction projects to develop different types of schedules, it does not lend the same flexibility to very short term schedules, particularly activity resource interactions for one day or less. MAC on the other hand manifests its usefulness only for such types of very short term schedules, especially if they are repetitive in nature, with effective savings achieved through reduction in cycle times. Ideally, combining MAC with other scheduling techniques such as the Line of Balance (LoB) can magnify the achieved time optimization, as the time savings from each cycle accumulate over the repetition of these cycles.

Most scheduling references, especially the most commonly used in the US, do not address the MAC as an available tool, therefore not exposing students and trainees to its uses and benefits. This paper aims at shedding light on MAC and providing a case study for its utilization in the classroom and for professional training.

Where to start

The starting point for the utilization of the MAC builds on the finest detail in a construction schedule, and looking at the modular unit in such a schedule: the activity. In order to reach this granular level within a construction schedule, a scheduler must go through the process of breaking down the project along logical lines, and decomposing its scope through the technique known as the Work Breakdown Structure (WBS).
A simple rule of thumb for developing the WBS is 1-5-5-5, where each level of the project is broken down into approximately five subsequent sublevels (five is a good starting point but is not carved in stone), until a reasonable level of definition is reached in what is known as a work package. The work packages (which are the lowest level on the WBS) are further broken down into operational units representing the activities. Each activity is represented by a verb and a noun, a finite amount of work, and quantifiable resources assigned to it. The duration of the activity in deterministic scheduling is calculated as the quotient of the Quantity (Q) divided by the lowest production rate (P) of the resources involved in the activity (Q/P).

Optimizing the usage of these interrelated resources can have a direct impact on the activity production rate, therefore its own duration and the duration of the whole project. This utilization improvement is a main objective of lean construction, which aims at reducing all types of waste in operations, particularly idle time for different resources. (Plenert, 2007)

Building the MAC

There are several available models of MACs where time is represented either on the horizontal axis (Columns) and activities on the vertical axis (Rows), or in the transposed version where the two axes are interchanged. The model that this paper will follow is the latter, where the activities and their resources are displayed as columns, and the time frame for performing these activities and the utilization of the resources appears in rows.

One of the first steps in building the MAC consists of a detailed breakdown of the short-term activity or operation, identifying the sequence of steps involved therein, the required resources, and their production rates. The sequence of steps can be presented in the form of a fragment of a network or a Gantt chart. Commonly, these activities or operations are repetitive, as the MAC reflects different iterations of the interaction among the different resources utilized within the activity.

The scheduler then estimates the duration of the different operations or steps involved in the activity through the simple equation: Duration = Quantity / Production Rate (Q/P), or using the Program Evaluation and Review Technique (PERT) equation for probabilistic scheduling. In the case of PERT, three durations (optimistic, most likely, and pessimistic) are identified for the activity based on historical information, and a weighted average is calculated based on the equation: Duration = (Optimistic + 4*Most Likely + Pessimistic) / 6. As mentioned above, when a series of resources are utilized within the activity, the driving resource is that which has the lowest production rate, thus yielding the longest duration for the same quantity. The main goal of using the MAC is optimizing the duration while improving the productivity of the different resources, especially those deemed as critical, driving, or most costly. Adjustments to the balance among resources offers different iterations of the MAC resulting in a version that can produce the shortest duration, another version that produces the least total cost, or a third one that can maximize the utilization of a certain resource.

The best use of the MAC is achieved in case of repetitive activities, therefore making it suitable for use in scheduling techniques for repetitive work such as the Line of Balance (LoB). Activities representing the start and finish of the operation are identified, and the first cycle of the repetitive work is charted. As might be expected, the first and last cycles are going to differ from the other repetitive cycles, as the start-up and the winding-down are usually slower, and the learning curve with repetitive cycles helps achieve fluency thus reducing the cycle time.

Case Study

To illustrate the concepts of building and utilizing the MAC, a case study was presented in a scheduling class, aiming at introducing lean and productivity improvement concepts through the study of a repetitive cycle for placing concrete in a multi-floor building. The schedule representing these repetitive activities is built into a Line of Balance chart (LoB)

In the case study, concrete was centrally mixed in a remotely-located batch plant and transported to the site via transit mixers. Students had the option to choose between two different placement methods: a tower crane and buckets, or a concrete pump. Once placed at the required level, concrete crews spread, vibrated and finished the concrete surface to the required specifications.

The case study integrated several concepts including:

- Equipment selection and productivity in the determination of cycle times, travel time, equipment efficiency, and equipment economics.
- The use of reference manuals and other estimating databases to calculate the production rates and the estimated cost for the different resources was emphasized as well.

These elements were considered a reaffirmation and further emphasis on information obtained through other courses including construction techniques, construction equipment, and construction cost estimating.

Option 1: Crane and buckets

Under the first option, students were given the specifications for the batch plant, its maximum hourly production, and its distance from the site. 8 Cubic yard transit mixers were available to transport the mixed concrete to the site. The cycle time for the transit mixers was calculated, based on the distance to the construction site, to be 30 minutes broken down as follows:

- Maneuver and load: 6 minutes
- Travel full: 9 minutes
- Unload and clean: 6 minutes
- Return empty: 9 minutes
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The selected batch plant has a capacity up to 100 CY/Hr.; however, the actual production rate is only 32 CY/Hr. limited by the number of trucks. If the number of trucks is increased, the utilization factor of the batch plant can increase as well. It is assumed that the batch plant can be used for other projects at the same time, thus increasing its utilization factor above the 32%. On the other hand, since the transit mixers and the crane are dedicated to this project, it would be desirable to get as much production from these assets as possible. To maximize the use of the transit mixers, 4 buckets are used, allowing for a total cycle time for the crane and bucket of 12 minutes, thus also maximizing the utilization factor for the tower crane. The Gantt chart representing the cycle for the crane and bucket is shown in Figure 1 below.

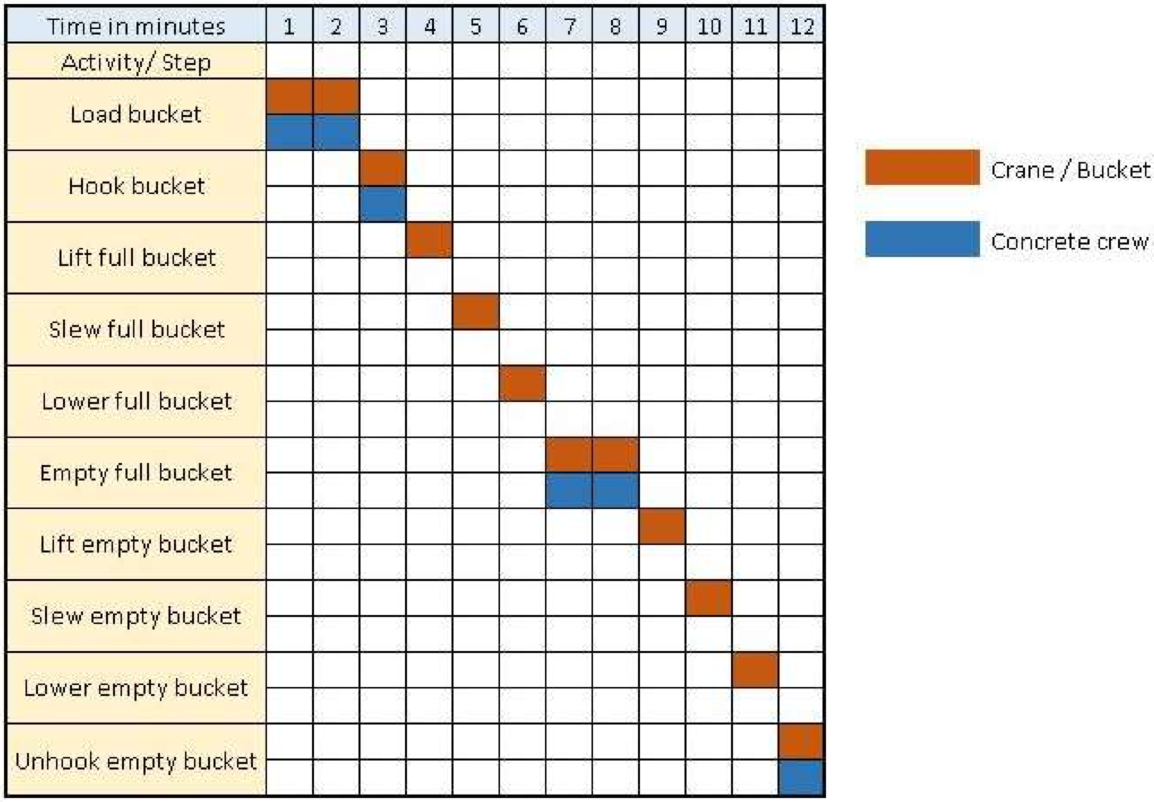

Figure 1. Crane/Bucket/Crew cycle

As it appears in Figure 2, the utilization factor for the tower crane and the transit mixers is 100%, with two crews of labor being used to place up to 32 CY/Hr. This solution shows that the utilization factor for the crews is 100%, with the possibility of adding a third crew to allow for some redundancy and to cater for breaks and rest periods. Since the tower crane is fully utilized, adding additional transit mixers would be a waste, leading to unnecessary queues without any increase in production. Had the site been farther from the batch plant, leading to an increase in the travel time for the transit mixers, adding additional mixers would be justified. By the same token, Figure 2 shows that the optimum number of buckets is 4, as a smaller number results in idle time for the crane and mixers, and a larger number does not contribute to increased production. Learning about the proper balance among the different assets was one of the main learning objectives of this exercise. As expected, the startup of the operation does not allow for the full production to be reached. However, once the first cycle is completed, production takes a regular rhythm, which contributes to an improvement in the learning curve that can be translated into a stabilization of the production rates.

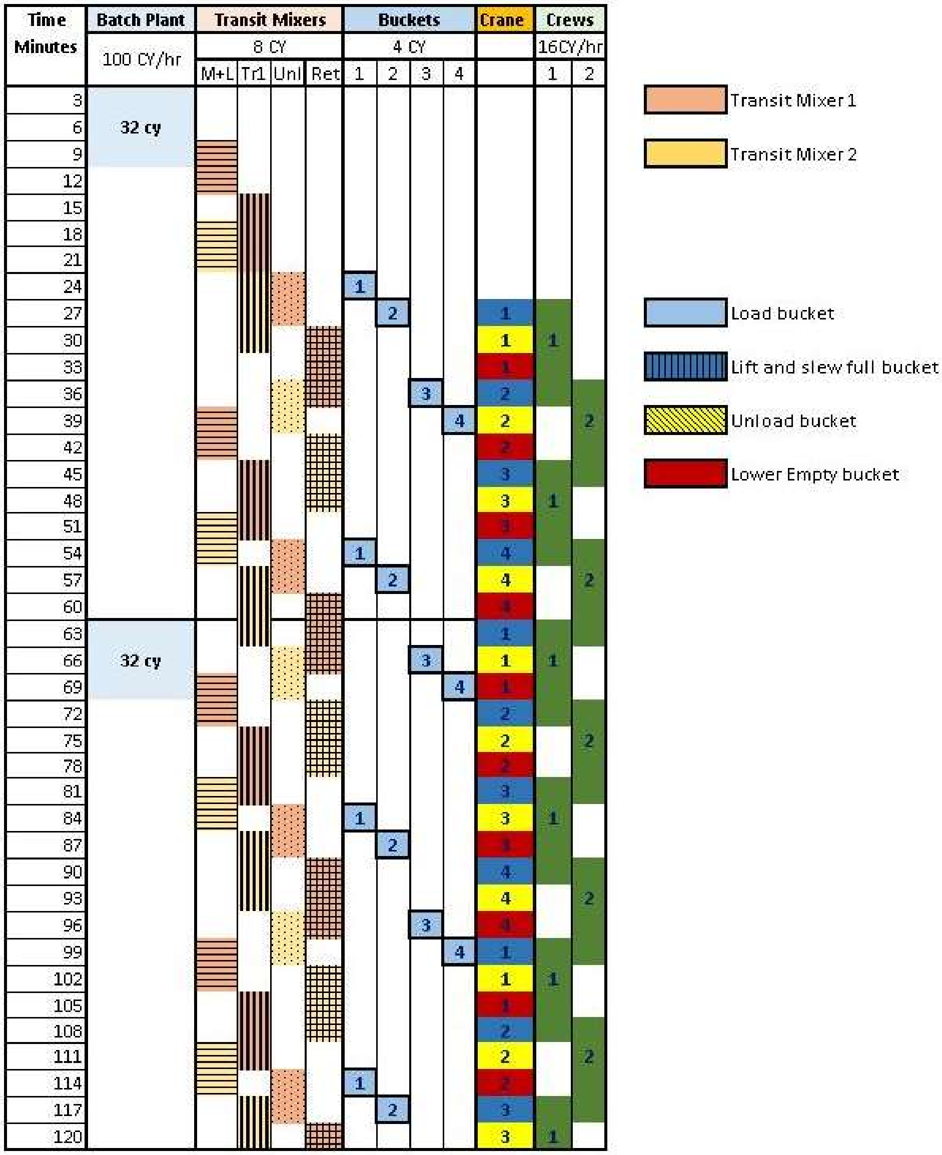

Figure 2. MAC showing Crane / Bucket option

Option 2: Concrete Pump

The second available option for placing concrete on the same project was a mobile concrete pump. Following the same logic and logistics used in the first example, and using the same mode of transport for the concrete mixed remotely at the batch plant, this solution was tested with two different scenarios:

- 2 transit mixers
- 3 transit mixers.

The difference between the two solutions is displayed in Figures 3 and 4 respectively. Figure 3 shows a full utilization of the two transit mixers, at the expense of a reduced utilization factor for the concrete pump. The concrete pump has a maximum production of up to 200 CY/Hr., however, its actual production is limited by the transit mixers to only 32 CY/Hr., or only 16%.

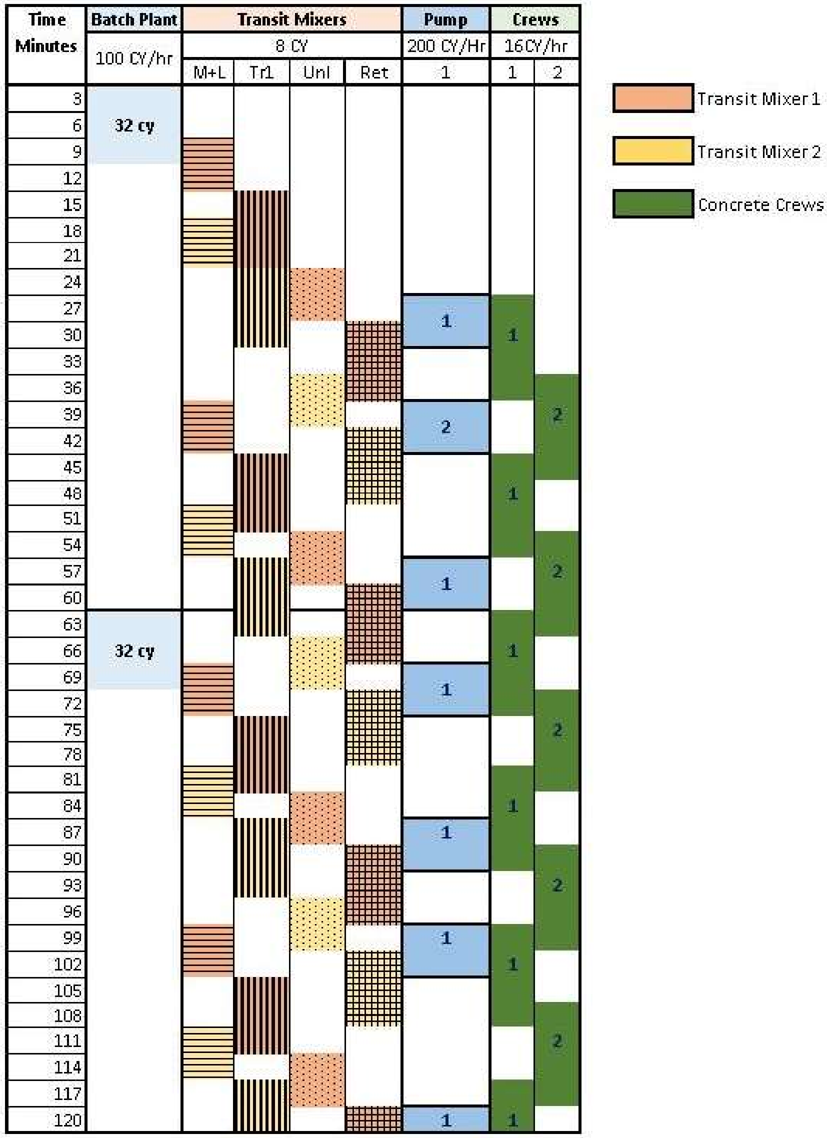

Figure 3. MAC showing two transit mixers and a pump option

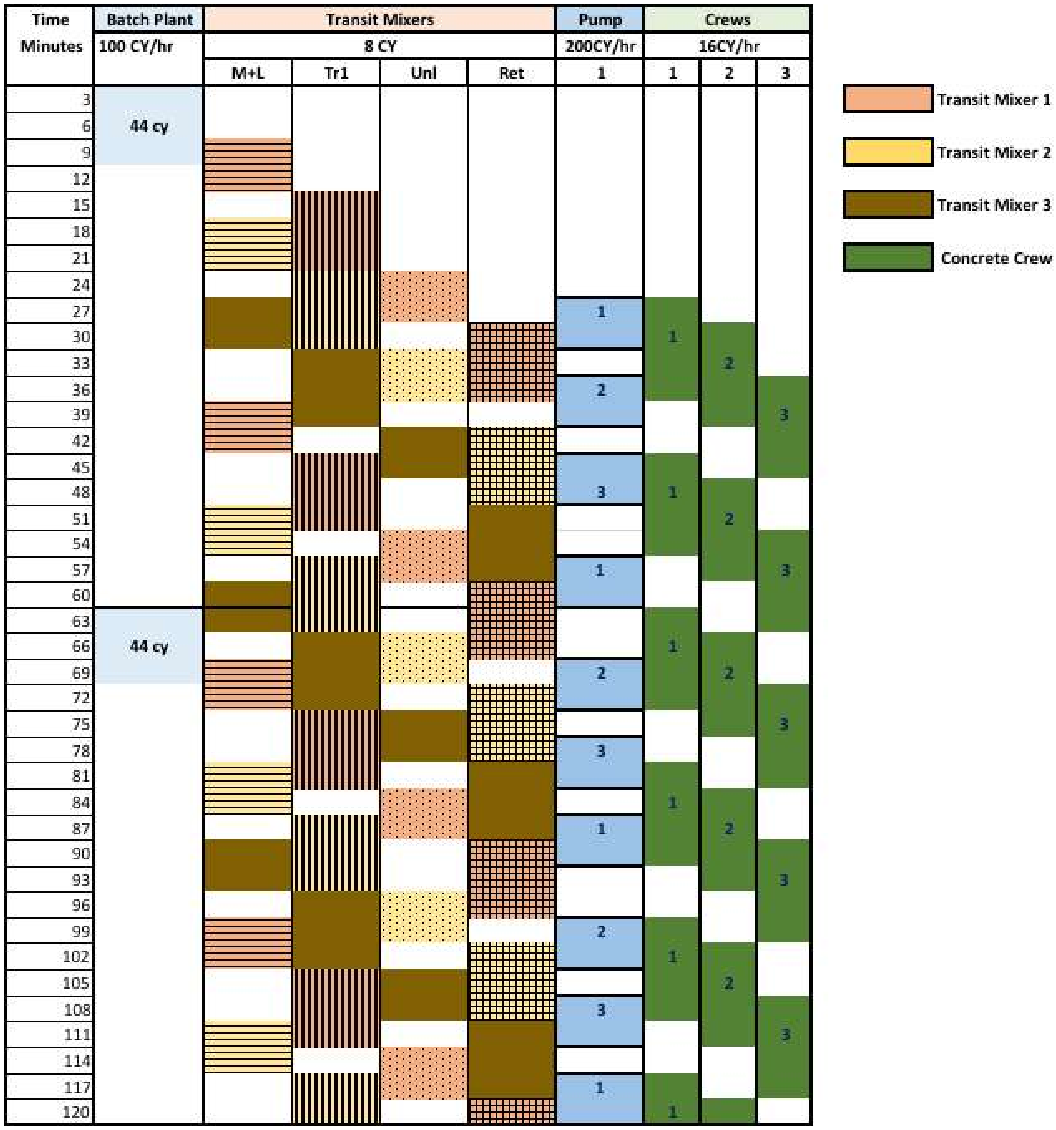

Figure 4. MAC showing three transit mixers and a pump option

Adding a third transit mixer, which is displayed in Figure 4, allows for a full utilization of all three mixers, and increasing the production rate of the batch plant to 44 CY/Hr., which in turn increases the utilization factor for the pump to 22%. Though still not properly balanced with the other resources, this solution shows that replacing this pump with a smaller one could result in a higher utilization rate. This increase in concrete delivery capacity necessitates an increase in the number of finishing crews to 3 crews with a maximum productivity of up to 48 CY/H/. This solution shows that the utilization factor for the crews is less than 100%, taking into consideration issues of efficiency and adding some needed redundancy.

Students must evaluate the available fleet, and balance production with availability and both vertical and horizontal reach of the selected pump.

Conclusion

A multiple activity chart (MAC) is a simple, yet efficient tool in scheduling short term project activities. It is best used for repetitive operations involving the interaction among different types of resources. Using the MAC in an academic or professional environment emphasizes the integration of several branches of knowledge including but not limited to scheduling, estimating, equipment management, and productivity improvement. MACs are most effective to use in conjunction with other repetitive scheduling techniques such as the Line of Balance (LoB) to reach the length or duration of the repetitive cycle, showing different iterations until a balance is reached. Productivity improvement and reduction in cycle times leads to a reduction in waste, which is one of the main objectives of lean construction.

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