Labor Management in Masonry Construction: A Sustainable Approach

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Abstract -

Work in masonry is divided in different tasks and performed by sub-contractors. Sub-contractors specialize in a given skill to accomplish a specific construction task and usually work with crews. Due to this specialization, multiple crews with different skills are present on the jobsite at any one time and the sub-contractor is responsible of configuring crews to produce good quality work by means of capitalizing skills. Even though crews work independently within the range of their own skills, they need to properly sequence and coordinate their work to complete tasks and eliminate disruptions. One of the problems masonry contractors face is the need to design crews, that is, determine the number of crews and the composition of each crew to be effectively used in the construction process to maximize workflow. This study proposes the framework for a decision support system to assist contractors in the allocation of crews in masonry projects. The proposed system can be a valuable tool to assist masonry contractors in the process of predicting the number of workers and allocating workers.

Keywords -

Labor Management; Masonry Construction; Social Sustainability, Simulation Optimization

1 Introduction

Project-oriented organizations such as construction companies use temporary organizations to perform work [1, 2]. Projects are limited in time and scope and every time a new project starts the configuration and allocation of workers changes [3]. This creates a dynamic and transient work environment frequently seen in masonry construction projects. In masonry, workers are transferred between different projects and even between different roles to accomplish a specific task. This temporary nature of the work influences the motivation of workers and creates pressure due to the uncertainty of future assignments, variability of work durations, and lack of opportunities for career growth [3, 4, 5]. Furthermore, the size and number of projects change constantly, making it difficult for contractors to predict future workers and for workers to achieve a work-life balance.

This paper proposes the framework of a decision support system (DSS) for sustainable labor management that is practical to implement in masonry construction projects. The DSS addresses both the challenges faced by contractors when predicting future labor and allocating workers and workers' needs of career development and labor stability. It is expected that the DSS will help contractors efficiently manage masonry workers in a more ethical and sustainable way.

2 Masonry Construction

Masonry activities such as scaffold installation, mixing mortar, laying block, cutting block, and grouting are labor dependent and require a large number of workers with diverse skills. Work is physically demanding (Spielholz et al, 2006) and masons as well as mason helpers (laborers) often lift heavy materials and stand for long periods of time (Boschman et al, 2011). A number of studies have identified masonry features that may impact masonry crew's performance. These include excessive block cutting, numerous corners (Sanders and Thomas, 1991), numerous openings (Hassanein and Melin, 1997), the use of non-adjustable scaffolds, and the size of masonry units (Mortlock and Whitehead, 1970). Additionally, masons work outdoors and are subject to poor weather conditions that reduce their work activity (BLS, 2014).

Masonry contractors divide work in different wall sections and usually work with crews (Ng and Tang, 2010) to accomplish a specific task. Tasks are dictated by what area of the building is accessible and available for crews to work in, and what pipes are already in place or what openings are marked and ready so that masons can work around. When a wall section is completed, often times, crews are re-assembled and the contractor is responsible of configuring and assigning crews with different skills (Ng and Tang, 2010) to produce good quality works. Due to this task division, multiple crews are present on the jobsite at any one time. Even though crews work independently within the range of their own skills, contractors need to properly staff crews to complete tasks and maximize workflow. Therefore, to optimally assign workers, contractors need to consider not only tasks and activities but also workers' skills.

By considering workers' needs and expectations, construction projects may not only benefit current workers but may also help attract new workers to fill these positions. Due to this task division, multiple crews are present on the jobsite at any one time and the contractor has to constantly assemble crews and properly sequence their work to maximize workflow.

2.1 Roles

Field observations indicated that masonry crews have a number of roles that need to be filled to build a wall. The masonry roles presented below were identified during extensive observations conducted in a masonry project and are complemented with the roles identified in Memarian and Mitropoulos [13]. The observations were conducted in a multi-storey building of mixed-use space with a parking structure and come from non-union crews. Labor rules on union jobs may change the job-sharing observed in this research. Typically in a block masonry crew there are seven major roles:

- The superintendent: responsible for staffing. Hires workers and allocates field personnel to the projects.
- Project superintendent (often-called foreman): monitors crews, layouts the walls, plans and distributes tasks, monitors workers, orders materials and equipment, performs quality control, and coordinates working areas with other foremen (electrical, plumbing, mechanical).
- Masons: lay block, install rebar and wire for reinforcement, and set up door frames. If needed they also perform support work, e.g., grouting and wall layout.
- Forklift operator: delivers materials from the storage areas to the work areas which include blocks, scaffold, mortar container, and grout container. In projects with small access areas, it often uses a warehouse lift in combination with the forklift. In big projects, the number of operators increases due to the number of workers and/or the number of floors.
- Saw operator: cuts block.
- Laborer on the mixer: makes grout and mortar.
- Laborers: perform support tasks including mixing mortar in the buckets and delivering mortar to the mortar boards, transporting and stacking the block, erecting and dismantling scaffold, grouting, and handling wire and rebar for reinforcement.

Some workers may have skills that will allow them to work in different roles that require those skills. For instance, some masons can be assigned to layout a wall (measuring and marking the walls) or to a wall to lay blocks. Additionally, laborers may have the skills to be assigned to look over a mason, operate the saw, operate the forklift, or work in the mixer. This role swapping is possible as long as the laborer possess the skills and knowledge to do so. For instance, the forklift operator needs a license to operate machines, the saw operator needs to know how to work on the saw and the one in the mixer needs to know the ratio of material to make mortar and/or grout. It is important to consider there are some basic operators that must be present in the jobsite at all times i.e. one laborer in the saw, one laborer mixing the mortar, and one laborer operating the forklift. This last one increases with the number of floors and/or the number of crews. The number of masons is determined by the workload, that is, what walls are ready for the masons to work in (in terms of space) and what walls have the ductwork, plumbing and conduits in place (in terms of availability). The number of laborers for support (to look over a mason) is often determined by the mason to laborer ratio the contractor wants to use.

2.2 Crew Makeup

Masonry contractors follow a process to design and configure crews. The process is applied by considering a set of rules that impact the whole crew design and ultimately helps contractors determine the number of workers per crew and the composition of each crew [10]. The rules presented in this study were determined from the observations conducted in the masonry project and are coupled with the rules identified in Hassanein and Melin [10].

- Rule 1- Crew composition: In general contractors don't have a typical crew, but they have some guidelines as to the worker's ratio in a crew that they use and try to maintain. This ratio dictates the typical number of laborers per number of masons that is used when forming crews [10].

- Rule 2- Crew operators: There are some basic operators that need to be present in the jobsite. There always has to be a laborer in the saw, a laborer making grout and/or mortar, and a laborer operating the fork lift. This last one increases with the number of crews present in the jobsite and/or the number of floors.

- Rule 3- Crew size: In regards to the crew size, there are a maximum number of workers that are assigned to a non-working foreman. Typically foremen determine the maximum number of workers they feel comfortable handling to guarantee an adequate control [10].

- Rule 4- Crew control: The foreman has a working assistant foreman (often times called labor foreman) that monitors crews, builds scaffold, and helps layout the job. The number of assistant foremen is dictated by the foreman and depends on the number of crews.

- Rule 5- Learning curve: When forming crews, the foreman (or assistant foreman) tends to keep the same masons in a crew due to the learning curve. Masons that have worked together know what they are doing and have identified ways to collaborate.

- Rule 6 -Compatibility of labor: The foreman (or assistant foreman) considers a compatibility factor, that is, how masons get along to keep production up. Masons have different ways to work and get things done. Some masons work well together, but some do not get along or the way they work is not compatible. The foreman tries to form crews with workers that are compatible because masons that work well together are more efficient and this can improve quality and increase throughput [14].

- Rule 7- Quality of work: When the quality of work is a factor, experienced masons (i.e., journeymen) are assigned to wall sections that require a high demand of craft work (e.g., openings, corners, details), whether non-experienced masons (i.e., apprentices) are assigned to non-craft work (e.g., straight walls). The foreman, or assistant foreman, knows which worker is good at what, based on the skills.

2.3 Management of labor

Masonry contractors usually manage a program of different project types that are unique, custom-made, and temporary. These features add uncertainty and novelty as no project is completed using the same approach. Consequently, contractors need to work in a cross-functional way and integrate resources (labor, equipment, and capital) in such a way so that they realize the maximum benefit for the operations. By integrating resources, contractors align resources to achieve the desired quality within the given time frame [15].

Management of labor is one of the key factors in masonry to balance production and quality. Forecasting human resource requirements and human allocation are the two approaches used for the management of labor. Determining the number of workers to complete the projects while balancing cost and production is the primary objective of predicting labor. On the other hand, human allocation deals with designing and configuring crews to assure workers have the skills required by the projects to complete tasks.

2.3.1 Forecasting labor

In construction, the resource demands for successive projects might be significantly different and that makes it difficult for contractors to plan for the required number of workers. Often times construction companies employ temporary workers for the periods of increased workload, but it takes time to find skilled and well-qualified workers. Consequently, predicting the labor power demand is essential to facilitate decision making and labor planning in construction [16]. Labor planning allows companies to have knowledge (in advance) of the possible consequences, which allows them to better deal with tight schedules and project demand. By predicting labor, a construction firm can assess long term staffing needs, ultimately increasing productivity and the quality of work.

There are several approaches that have been developed to predict labor in construction. Wong et al [16] used dynamic econometric modelling techniques to establish the relationship between the aggregate demand for manpower and a group of inter-related economic variables. They found that construction productivity and construction output are the most significant factors determining the demand of labor power. Wong et al [17] used multiple regression analysis to help establish labor demands in construction. Their regression models used variables such as project cost, project complexity attributes, project type and physical site conditions to predict labor. Cheng et al [18] developed a team human resource planning (THRP) method for deploying labor power in process reengineering using simulation. The method determined the maximum loading of projects the original labor power can carry and also identified the range of labor power required for the expected project loadings by combining process reengineering and a simulation approach.

2.3.2 Human allocation

Human resource allocation in construction is the process of assigning crews of workers to tasks [20]. Tasks may require several crews with diverse skills to be completed and crews need to be scheduled to ensure an efficient output and adequate control [10]. This allocation process in masonry construction is challenging. Often times, crews complete their work on a section, but then have to come back later to complete the other part of the work. Due to this characteristic, every time a wall section or part of a wall section is completed, the labor configuration is reorganized. This results in temporary crews that need to be constantly moving. One of the problems masonry contractors face is the need to allocate crews to maximize workflow while satisfying contractors' constraints and worker's needs.

There are several approaches that have been developed to allocate human resources in construction. Al-Bazi and Dawood [19] presented a strategy to allocate crews of workers in the precast concrete industry using genetic algorithms-based simulation modeling. Lin [20] proposed a decision-making model for human resource allocation in remote construction projects. El-Rayes and Moselhi [21] developed an optimization model that uses dynamic programming for repetitive construction projects. Maxwell et al [22] presented a stochastic simulation program to measure the elapsed time and activity cost of each candidate crew. Their proposal uses an optimization rule to determine the best crew configuration. A review of the aspects and modelling approaches in personnel allocation and scheduling can be found in Brucker et al. [1].

3 Workers' needs

Workers place a great value on requirements such as involvement, respect, and sense of personal growth (Lingard and Sublet, 2002). From the contractor's point of view, a project that offers continual employment allows the contractor to maintain an acceptable skill level and helps generate a sense of commitment to the job from the workers (MacKenzie et al, 2010). In addition, it decreases the possibility of schedule overruns and leads to less deviations from the normal workflow (Lee et al, 2004). From the worker's point of view, a job that gives stable work increases employment duration and provides opportunities for career growth (Loosemore et al, 2003). Furthermore, a change often implies not only a change in pay grade, but also the need to get familiar with new workers and practices. That is, workers prefer jobs that will keep them busy all the time. This situation increases labor skill level. Workers prefer to work with skilled peers because they are good at what they do. This decreases the possibility of rework and helps keep a normal workflow.

The proposed way to increase employment duration is based on the labor stability indicator developed in Florez et al. (2013). By considering labor stability, a construction project smoothes the allocation of workers to avoid drastic measures and minimize the variation of the number of workers. Therefore, a stable workforce provides benefits to the workers in terms of employment duration (Florez et al, 2013) and benefits to the contractor in terms of workflow (Lee et al, 2004).

This dynamic work environment is regularly seen in masonry construction: project demand is unpredictable, which forces managers to constantly adjust the number of workers and reconfigure crews to get the projects done. Workers are often transferred to different projects and even between different roles in a project according to the type of project and the necessary skills. This temporary organization and dynamic environment can influence the motivation and impose pressure and stress to workers. Workers cannot be sure what kinds of projects they will be assigned to, the location of the projects, or the co-workers they will work with [3]. Furthermore, given the peaks in workloads and the uncertainty of work, it is difficult for workers to achieve a work-life balance.

Given this temporary environment, there is a need for managers to assure an ethical treatment and the well-being of workers. However, project management has traditionally focused on planning operations with little attention being paid to the workers. The organizational perspective of project oriented organizations in sake of profit maximization and client demands usually prevails over the needs of workers [3].

People, unlike other resources, have their own needs and requirements beyond the financial compensation for their work. Workers place a great value on requirements such as involvement, respect, and sense of personal growth. Because of their needs and requirements, workers may represent the most difficult resource for organizations to manage, but when managed effectively can bring considerable benefits [4].

For instance, a project that links project assignments to career development allows contractors to not only develop staff for its future projects, but also helps workers develop skills and opportunities for career growth [5]. At the same time, contractors benefit through increased work control by better using education and competence development that increases job satisfaction and motivation [3]. Projects have better productivity rates where employee work experience is enhanced by assembling teams that consider managers and co-workers as well as tasks and roles [3, 4, 5]. By considering their needs and expectations, construction projects may not only benefit current workers but may also help attract other workers.

This study proposes a DSS to forecast labor needs and allocate crews of workers in masonry projects that considers simultaneously both contractor's requirements and workers' needs.

4 Proposed Tool

The proposed strategy for sustainable labor management in masonry considers two subsets. The first subset forecasts the number of workers such that the contractor can determine its labor needs. The second subset allocates those workers to projects such that the workflow is maximized while considering contractor's requirements and workers' needs.

The methodology for developing the decision support system (DSS) comprises three phases: data-analysis, simulation, and optimization. Figure 1 shows a high-level decision process diagram of the DSS for sustainable labor management in masonry. The data-analysis phase characterizes the projects in terms of duration and size. To represent the behavior of projects, the methodology adjusts probability distribution to the demand of projects in a contractor firm. The simulation phase aims to predict the number of workers that are needed to complete the projects within the given time constraints. The input to this phase includes the probability distributions of the activity durations (with the maximal labor power for an activity), which allow generating multiple scenarios using random numbers drawn from the probability distributions. The optimization phase aims to allocate workers to crews and crews to projects in order to maximize workflow. The input to this phase includes the labor prediction of the second phase, which allows generating multiple scenarios. The output is a detailed schedule of the times to start tasks, the number of workers and the skills of the workers needed as well as the crew configuration under the optimal schedule.

4.1 Data analysis phase

Because activity duration with maximal labor power is the input for the simulation phase and subsequently the optimization phase, the data analysis is the key phase of the methodology with two objectives. The first objective was to identify the types of activities required in the construction of masonry walls and the second is to characterize the duration of the activities. Generally, the duration of an activity is simplified as a linear function of the number of workers in an activity, that is, the duration will decrease as more labor power is assigned. In the masonry industry, the duration of an activity usually decreases with the number of workers in a crew, but there is a point of maximum labor power. After that point is reached, the productivity rate does not increase, that is, more workers cannot further reduce the duration [18].

The duration of any activity needed in the construction of masonry walls is defined as the shortest operation time with a given labor power for an activity. To examine the actual duration of all activities, this study characterized the activities and captured labor productivity as a function of crew size using self organizing maps [23] and time series analysis [24].

On the other hand, not only the identification of activities and their duration has a major effect on the methodology, but also the accuracy level is related to the duration's fit level. Therefore, the methodology captures the duration by fitting probability distributions. Fitting methods allow selecting the parameters that produce the best fit to the collected data. With this fitted distributions, it is possible to replicate the duration of activities in the next phases of the methodology.

4.1.1 Simulation model

The proposed discrete-event simulation model (shown in Figure 2) represents the construction of a masonry wall, where the workers are assigned to different activities to complete a wall. Figure 2 shows the workflow of the CMU process. The workflow starts with the layout process, which is the process of measuring and marking the walls. The project superintendent usually marks the walls but sometimes an experienced mason (that knows how to read the blueprints) does this process. The second process is to prepare the wall so when the masons get to the wall they can start laying block. The forklift operator delivers materials to the area while a laborer is in charge of placing the resources and accommodating the blocks and mortar boards.

The third process is the actual process of laying block and it is the mason's primary activity. The forklift operator is directly involved in this process since he has to deliver the mortar to the area in buckets. The laborer that is looking over the mason coordinates the delivery with the operator and is responsible of placing mortar in the boards on a timely basis to make sure the mason always has mortar to spread. The fourth process is grouting and this process involves completely filling the cells with grout to create a solid concrete wall. The fifth process is cleaning and finishing the wall. This process involves joining both the head joints and bed joints and brushing the wall to clean the mortar outside the joints.

Finally, the mason determines if the wall is at ‘scaffold height’ or if the maximum height has been reached. If it is scaffold high, the mason stops laying block and then the laborer proceeds to build the scaffold and prepare the wall so that the laborer can continue laying block in the next portion of the wall. Scaffolding involves erecting and dismantling the scaffold. The combination of laying block and scaffolding continues for as long as the maximum height of the wall is reached.

4.2 Optimization phase

This phase consists of running a series of optimization models capturing different labor requirements with the goal of maximizing workflow in a masonry program. To do so, a deterministic integer programming (IP) model which is fed with the predicted parameters from the simulation phase will be used. These parameters are random number generated using the output of the data analysis phase, the duration of activities and the number of workers probability distributions. Therefore, the optimization model input is the complete schedule and duration of all the activities. This detailed schedule represents a (random) labor requirement realization, drawn from the probability distributions derived in the data analysis phase.

The IP model obtains the optimal allocation of workers that maximizes the workflow for a particular realization of labor demand, taking into account contractor’s requirement’s and workers’ needs. In other words, the allocation of workers considers the rules that for crew design (Section 2.2) and also specific needs that workers have for developing skills and labor stability. Then, with a large number of randomly generated scenarios, the optimal allocation of workers sheds light into the right number of workers to have in payroll and the configuration of crews.

The data input module collects the information on the rules that contractors use to makeup crews. The reader is referred to the sub-section 2.2 for a detailed explanation of the rules. The data input module also includes for every time period, information on the availability of workers. Table 1 shows the skills for each worker. The binary parameter takes the value of 1 if a worker has that skill; it takes the value of 0, otherwise.

Table 1. Skills of labor

	Mason	Saw	Forklift	Mixer	Laborer
Worker1	1	1	1	0	0
Worker2	0	1	1	0	0
Worker3	0	1	1	0	1
Worker4	0	0	0	1	1

Note that some workers have different skills that will allow them to work in activities that require those skills. For instance, worker 1 is a mason that can operate the saw, and can be allocated to either a wall to lay blocks or to the saw to make cuts.

Once all the data input is entered, the optimization model allocates labor to the projects. The model’s objective is to allocate crews of workers so that the workflow, that is, production in terms of number of masonry units is maximized. The allocation process consists of assigning the time needed to be working in a specific task to each of the workers in the crew. Each task demands a certain number of crews and each crew demands a certain number of workers with different skills. To build the schedule, the model uses binary decision variables to define the times each worker is working in a specific task. The model determines which worker should be working in which crew and doing which task.

5 Discussion

The crew allocation process in masonry construction is challenging. Masonry is labor-intensive and often crews have to sequence their work to avoid disruptions and maximize production. Multiple crews with different skills are present on the jobsite at any one time and it is difficult to determine when each crew should be working and the workers that need to be assigned to a crew.

The proposed model aims to help contractors allocate crews of workers in masonry projects. The model integrates a simulation and a modeling approach in an attempt to help alleviate some of the issues faced by masonry decision-makers in their day-to-day practices. Typical contractors’ requirements are included to address realistic scenarios experienced by masonry contractors in the jobsite. These requirements dictate the rules contractors use to design and makeup crews based on experience. In addition, the model considers workers’ needs that helps workers stay longer on the project and increase continuity of job assignments. With the model, contractors are able not only to determine the optimal starting times for each of the crews, but also to quantify the number of crews and ultimately the number of workers needed to build a masonry project.

These new considerations should prove useful to masonry contractors and enable them to optimize the allocation of multiple workers in order to maximize workflow. An optimal schedule that considers the needs of workers and contractors contributes to formulate strategies to make project management more sustainable and increase the benefits achieved by both workers and contractors.

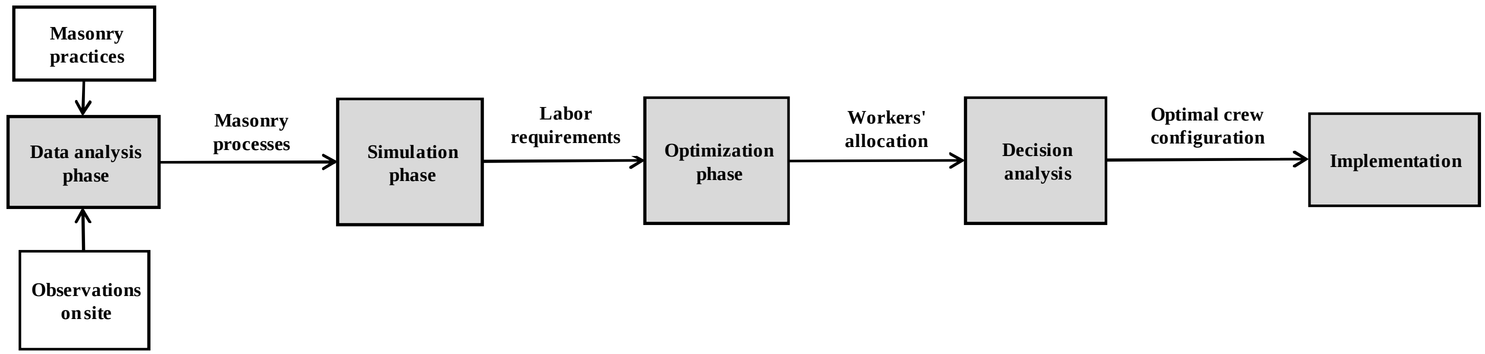

Figure 1. Decision support system (DSS) for labor management

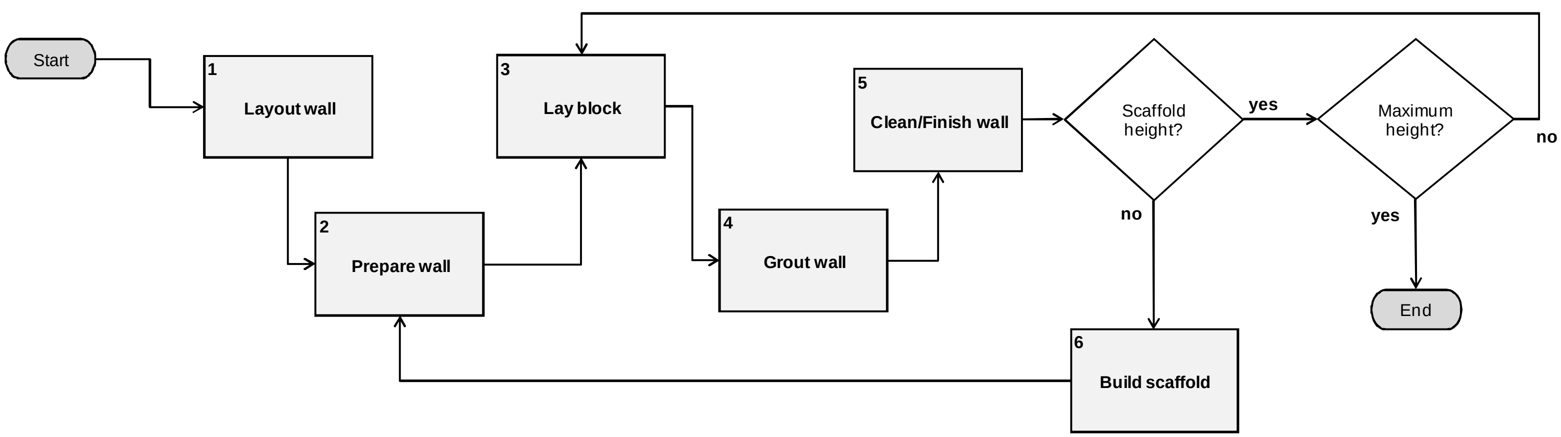

Figure 2. Workflow mapping diagram of the simulation process

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