

Work Factors Affecting Task Demands of Masonry Work

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This study investigates the factors that shape the task demands of masonry activities and affect the production and safety performance of masonry work. The study explores two sets of factors: (1) the project attributes that shape the difficulty of masonry activities, and (2) the foremen's work practices that can mitigate the workers' task demands. The paper discusses how the task demands influence construction workers' performance. The study analyzes two projects—it describes the project characteristics, reviews the work practices of the masonry crews, and analyzes the level of task demands. The NASA-TLX questionnaire was used for the subjective self-assessment of the workers' task demands. Follow up interviews investigated the sources of task demands from the workers' perspective. The findings identify the work practices that affect task demands, which result in fewer errors and enhance workers' performance.

Keywords: Task demand, Construction foreman, Masonry, NASA-TLX.

Introduction

Workers in construction face physical, mental, and temporal task demands. This is the result of performing physical and/or cognitive tasks under time pressure (DiDomenico & Nussbaum 2008). Task demand is defined as the knowledge, skills, and effort required for successful task performance (Wood 1986). Physical demands refer to energetic, biomechanical and environmental demands (Sluiter 2006). In construction, heavy load lifting, and awkward posture generate significant physical demands that often result in injuries and musculoskeletal disorders. Mental demands require cognitive inputs including concentration, memory, decision making and attention (Sluiter 2006). Mental workload can be influenced by characteristics of the task, equipment, environment, and organization, and can result in mental fatigue, monotony, and reduced vigilance (Nachreiner 1995). Increased mental workload can increase task errors (Morris & Leung 2006). Temporal demands refer to the time pressure that an operator experiences due to the pace of work (Hart & Staveland 1988). In construction, the temporal demand is usually caused by schedule and production pressures. When task demands exceed the individual's capacity, the likelihood of errors increases and performance decreases (Stassen et al. 1990, Wood 1986).

From a human factors perspective, occupational injuries and incidents are the result of poor task and work place design which lead to errors, accidents and lower productivity (Jung & Jung 2001). This study investigates the factors that shape the task demands in masonry crews and explores the effect of such task demands on the production, safety, and quality performance of the crew. The study explores two sets of factors: 1) the project attributes that increase the difficulty of masonry work; and 2) the foremen's work practices that affect the level of workers' task demands, including work planning, material management, equipment management, and task distribution practices. Then, we discuss how the task demands influence construction workers' safety and productivity performance.

Background: CMU Masonry Production

On projects using Concrete Masonry Units (CMU), masonry work consists of six major tasks: 1) layout work, 2) material handling, 3) block laying, 4) rebar installation, 5) scaffold erection and dismantling, and 6) grouting.

- *Layout:* In this task the lines and location of the walls, joints, doors, windows, and other work elements are measured and marked for the crew to follow based on the plans.
- *Material handling*: This task involves preparation and distribution of material (block, mortar, etc.) and is typically performed by laborers and (on larger projects, a forklift operator.
- *Block laying*: This is the masons' major task. This activity involves measuring and cutting block, spreading mortar, laying block, and leveling.

- *Rebar* is used to reinforce masonry walls. The masons measure and cut rebar to length according to the plan. Horizontal rebar is placed along the blocks and vertical rebar is placed in specified distance. Other steel components include steel embeds and window lintels.
- *Scaffold*: There are three major categories of scaffold: 1) supported scaffolds, 2) suspended scaffolds, and 3) other scaffolds including man-lifts, personnel hoists, etc. Scaffold work involves placing base plates, assembling cross braces, plumb vertical, access ladders, planks, guard rails, and access gates.
- *Grouting*: This task involves filling the blocks with grout to create a solid concrete wall. This activity is done usually every six courses of blocks or four feet height. Grouting consists of pouring grout, vibrating, and cleaning. Grouting must be done within the allowable timeframe to pour the grout, which is usually 90 minutes from the time the mixer-truck leaves the plant.

There are four major roles in a masonry crew: 1) foreman, 2) masons, 3) laborers, and 4) forklift operators.

- *The foreman* usually performs two groups of task: 1) management tasks including work planning, distributing tasks, ordering materials and equipment, coordination, safety and quality control and 2) physical work like layout and block/brick laying.
- *The masons* perform the installation tasks including block/brick laying, rebar work, installing door frames, and grouting. If needed masons may participate in support work, i.e., material handling and housekeeping.
- *The laborers* perform the support tasks including mixing and delivering mortar, transporting and stacking the block, sometimes cutting block, erecting and dismantling scaffold, and housekeeping.
- *The forklift operator* is responsible for delivering materials from material storage zone to work areas. In small project the forklift operator may help in manual material handling as well.

With regards to productivity, Sanders and Thomas (1991) identify the following design attributes that reduce the masonry crews' productivity: excessive block cutting due to design details, corners not 90°, numerous corners, numerous openings, and double- and triple-wythe walls. Thomas & Zarvski (1999) identify additional features including multiple block sizes, numerous walls and corners not at 90°, and minimal consistent scope of work.

According to Bureau of Labor Statistics (BLS 2008), masonry workers have low risk of fatality compared to other trades, with a rate of 0.61 fatalities per 100,000 workers. The major cause of fatalities (39 % of fatalities) is fall from elevation (BLS 2008). Janicak (1998) found that erecting and dismantling of scaffold were the major causes of the deadly falls in masonry. Masonry work is physically demanding. Low Back Pain (LBP) is the most prevalent musculoskeletal disorder among masons (Goldsheyder et al. 2002). 87 % of bricklayers experience LBP over their life span (Schneider et al. 1994).

Methodology

In order to investigate the effect of project attributes and crew foremen's work practices on the workers' task demands, two masonry projects from two major local companies were studied. Project A was a public safety facility that consisted of detention cells, shooting range, and court room. The masonry crew consisted of 14 members and worked four months to finish the work. Project B was a multi-story office building including offices and parking structure. The crew worked six months with eight members to finish the work.

Data collection was carried out in three phases: 1) survey, 2) interviews, and 3) observations. The NASA Task Load Index (TLX) was used to survey each worker's perception of task demands (Hart & Staveland 1988). The NASA-TLX uses six questions to assess mental demand, physical demand, temporal demand, performance, effort, and frustration as shown in Table 1. Each question has a rating from 1 to 10, where 1 represents the lowest task demand, and 10 represents the highest, with the exception of the performance question, where 1 indicates the highest, and 10 indicates the lowest. The overall TLX score is calculated as the sum of the six scores. The NASA-TLX is one of the most widely used subjective measures (Rubio et al 2004). In this study, the NASA-TLX was used to assess each worker's overall work difficulty, not only to assess the demands for a single task.

After the survey, the foremen and workers were interviewed to investigate the sources of task demands from their perspective. The foremen were interviewed further to identify the strategies and work practices they use to manage the task demands and to meet the safety, productivity, and quality goals. Finally, the operations of two crews were observed closely. The foremen's work practices including planning, instructing workers, material management, and task distribution were observed to investigate the potential effect of these practices on the task demands, and consequently the likelihood of errors the crew performance.

Table 1

NASA-TLX questionnaire.

Item	Endpoints	Description
Mental demand	1 - 10 Low / High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	1 - 10 Low / High	How much physical activity was required (e.g.. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	1 - 10 Low / High	How much time pressure did you feel due to the rate or pace at which the tasks occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	1 – 10 Good / Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	1 - 10 Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	1 - 10 Low / High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Project A

Project A was a public safety facility that included detention cells, a court room and a shooting range. According to the foreman, the design involved significant complexity and high quality requirements because of the following attributes: (1) There were four colors and five different sizes of block and three different colors of mortar. (2) There were some two-wyth (double layer) and curved walls. (3) Most of the walls were exposed block, which required high level of work quality. (4) The project was seismically designed, which required significant amount of rebar. (5) There was considerable number of wall openings for the door and window frames. (6) The schedule pressures (for masonry) were considered average. The schedule pressures (for masonry) were considered average.

The size of the crew was for most of the project was 14-19 members, with 22 at the most. The survey was conducted in the middle of the masonry work, when the crew size was 15 members—one foreman, nine masons, four laborers, and one forklift operator. The ratio of one laborer for two masons is typical for masonry crews. Because of the poor market conditions, there was high availability of high-skilled masons, and the crew was very experienced. The contractor wanted to keep as many experienced workers employed on the project as possible.

Work Practices

Foreman A spent most of his time (70 %) on management tasks like giving instruction to workers, coordination, inspection, etc. The foreman also performed layout work and some work that required higher quality, such as the curved wall and leads. The foreman had also assigned two experienced masons to build the leads. He considered the openings as the critical points that masons make mistakes like missing the openings or mistakes in the opening dimensions. To avoid such mistakes, the foreman wrote down the dimensions of the openings on pieces of duct tape and also marked the center point of the openings. To make sure that the material handlers deliver the correct color and type of block at every wall, the foreman marked on the concrete slab the color of the wall at every area. Rebar installation was assigned to an experienced mason.

Because most of the walls were exposed block, the work required high level of quality. To help his workers visualize the quality expectations, the foreman made a mockup wall. The foreman's goal was to "make things right the first time" and he did not rush the work to avoid quality problems and rework. Another concern was to keep the exposed walls clean. During grouting, the foreman was often handling the concrete pump hose himself, as he wanted to minimize grout spilled on the exposed wall that would require clean up.

The foreman had assigned groups of masons to several work areas. The number of work areas was influenced by several factors including (1) delays of the concrete contractor to complete work areas as planned, (2) material delays (window lintels for some walls) prevented further work on walls already started and had to start at new areas, and (3) pressures to keep as many masons as possible working.

Task Demands

Table 2 summarizes the TLX scores for the different crew roles, and Table 3 presents the sources of task demands. The foreman had the highest mental demand due to performing more managerial and decision making tasks, as well as physical tasks that require more calculations and accuracy, such as layout, leads and curved walls. The masons indicated the highest physical demand mainly attributed to the repetitive work with heavy blocks and laying blocks through rebar. Among all, the forklift operator experienced the highest temporal demand which was mainly attributed to traveling and taking care of several work areas at the same time.

Table 2

Average NASA-TLX scores for crew A.

	Mental demand	Physical demand	Temporal demand	Effort	Frustration	Performance	TLX score
Foreman (n=1)	9	3	8	9	4	5	38
Masons (n=9)	7.3	8.3	6.3	8.1	6.6	2.4	39
Laborers (n=4)	6.75	7	6	6.25	2.75	2	30.75
Operator (n=1)	7	6	9	9	9	2	42

Table 3

Sources of task demands and frustration for crew A

Role	Mental demand	Physical demand	Temporal demand	Frustration
Foreman	• Different colors of block & mortar • # of wall openings • # of work areas	• Some lead and layout work • Doing rework	• Other crews waiting for the masonry crew to release the work	• Waiting for material • Repetitive mistakes by workers
Masons	• Working on the scaffold • Exposed walls & high level of work quality	• Heavy block • Laying blocks through rebar		• Lack of instruction • Plans errors • Waiting for material • Defective materials • Rework
Laborers	• Different colors of block & mortar • Safety while working on the scaffold	• Carrying heavy blocks for long run on the scaffold • Lifting planks	• Changes in work plan causes rushing to erect scaffold & deliver material	• Multiple demands at the same time
Forklift Operator	• Coordination with work crews • Delivering the right materials	• Helping w/ manual handling • Moving mortar container	• Delivering material on-time to several work areas	• Taking care of several work areas at the same time

Performance Outcomes

Based on the foreman's estimate, crew A had three percent rework. This included the following items: (1) A layout error resulted in a "busted" building perimeter—this did not cause rework, but increased the amount of measuring and block cutting. (2) Significant amount of chipped block had to be repaired (because of the exposed walls). The rework involved cutting and removing the face of the damaged blocks and replacing them with new block. (3) Errors in installation and alignment of door frames. In one instance, the rework was caused by a twisted door frame, which was discovered after the wall around it had been grouted. After this incident, the foreman instructed the crew to check all the frames. (4) Rework around windows. The window lintels for one of the buildings were delayed for several weeks. At first, the crew moved to other work areas, but when there was no other work available, the foreman continued building the wall, knowing that they would have to rework part of it later. (5) Another mistake was "wet striking" the mortar, which leaves the effect of tool on the mortar. Because of the exposed walls, the marks had to be cleaned up. The above problems did not only create rework—they also increased exposure to hazards, such as amount of cutting, waste and housekeeping conditions, and more time spent on the scaffold.

Project B

Project B was a multi-story office building including offices and parking structure. The jobsite was congested and different crews were working tightly in each other's proximity. The layout of the building was complex with a large number of corners. There was a single color (gray) of block and mortar. Walls were not exposed, and there was less amount of rebar used in the walls compared to the project A. The schedule pressures were considered relatively low. Crew B had eight members including one foreman, three masons, three laborers, and a forklift operator. The observations were made and the survey was conducted in the middle of the life of the project.

Work Practices

Foreman B allocated about 50% of his time to management tasks and another 50% for physical work. Because of the excessive number of corners and layout complexity, to avoid mistakes by other workers, the foreman did most of the leads and layout works. The foreman was marking the material stacking points and writing instructions on the concrete slab for his workers. The foreman did not put pressure for speed on the crew in order to avoid mistakes and consequently rework. In this crew, everybody allowed to use power tools. In order to avoid interruptions in the work process due to forklift operator's absenteeism, the foreman had two certified operators in his crew.

Task Demands

Table 4 presents the result of the NASA-TLX survey conducted for crew B, and Table 5 summarizes the sources of task demands from the workers perspective. The crew foreman and the forklift operator perceived the highest mental demand. For the foreman, the high mental demand was attributed to work layout complexity and the lack of manpower (driven by the congested work space). The small crew size increased the foreman thinking about how to effectively distribute his workforce to meet project goals. The work area congestion increased the mental demand for the operator. The masons and laborers had similar score of physical demand, 8 and 8.3 respectively. Masons and laborers also pointed out similar sources of physical demand as working with heavy blocks and excessive use of power saw, as the layout required extensive measuring and cutting block. The forklift operator had the highest temporal demand due to delivering material to different work areas on-time to avoid interruption in work process.

Table 4

Average NASA-TLX scores for crew B

	Mental demand	Physical demand	Temporal demand	Effort	Frustration	Performance	**TLX score**
Foreman (n=1)	10	5	7	9	8	4	**43**
Masons (n=3)	7.3	8	3.7	8	7.3	2.3	**36.6**
Laborers (n=3)	5.7	8.3	3.7	7	2.3	1	**28**
Operator (n=1)	10	4	10	6	3	1	**34**

Table 5

Sources of task demands and frustration for crew B

	Mental demand	**Physical demand**	**Temporal demand**	**Frustration**
Foreman	• Layout complexity • Lack of manpower	• Working with heavy blocks		• Changing plans • Congested site • Rework
Masons	• Excessive measuring & cutting blocks • Plan changes	• Heavy blocks • Excessive cutting	• No rush due to change of schedule	• Plan changes • Rework
Laborers	• Excessive measuring & cutting blocks	• Carrying heavy blocks for long run • Excessive cutting	• Handling materials to masons on-time	
Forklift Operator	• Congested site • Power cords around the site	• Sometimes helping in manual handling	• Rushing to deliver materials on-time	• Everybody calling for materials

Performance Outcomes

According to the project manager of the masonry contractor, crew B had almost eight percent rework. The rework was mostly attributed to an error in the layout of a CMU wall. Because of the layout error, the wall was slightly out of position. The wall was also designed to receive a "brick veneer." To compensate for the wrong layout, the masons were trimming the brick veneer to reduce its thickness. Although the layout work was done mostly by the foreman, there were mistakes in layout. In one instance, a wrong lead stopped the whole crew for 45 minutes to fix the problem. Frequent mistakes in measuring and cutting blocks created too much block waste. The congested site created difficulties for the forklift operator to maneuver and deliver materials. In one instance, due to lack of enough space to move, the operator hit the surrounding fence. Frequent changes in architectural plans were another source of rework, but not due to the crew's mistakes.

Findings: Project Attributes and Work Practices Affecting Task Demands

The findings focus on the project attributes and foremen's work practices that shape the workers task demands.

Layout complexity. On the projects observed, layout complexity was due to two main reasons: (1) the multiple colors and sizes of block and mortar, and (2) The shape of the wall, such as curved walls or walls with many corners. These findings are consistent with Thomas and Zarvski (1999). Layout complexity requires more measurement steps (which has high potential for error), and more measuring and cutting block. With regards to safety, use of power tools increases the workers' exposure to hazards. With regards to productivity, excessive block cutting would affect crew performance due to mistakes in cutting which increases waste of material and rework as well. Because of the increased mental demands, both foremen performed the layout work themselves—this however, did not prevent some layout mistakes. To make sure that the laborers place the correct block at the proper locations, the foreman would mark the wall color on the slab.

The **wall openings** are another area of concern for errors. To reduce the likelihood of error (such as missing the openings or wrong dimensions) foreman A wrote the opening information on pieces of duct tape and indicated the center point of the openings. This does not eliminate the mental demand on the masons, as they still have to calculate and measure dimensions. But it reduces the mental demand compared to reading the drawings.

In project A, **extensive use of rebar** (due to the seismic design of the buildings) was the major source of the physical demand for the masons in the block laying task. In order for the masons to lay blocks through rebar, they needed to hold the block for a longer time and lift it above their shoulder height, which increases the risk of musculoskeletal disorders. In order to overcome this difficulty, different approaches may be helpful; for instance, some engineering interventions like use of the light-weighted blocks (Hess et al. 2010) or cutting blocks from the side to lay them through rebar instead of lifting.

Exposed walls create increased task demands for both laborers and masons. (1) Exposed walls require careful handling of the block to avoid chipping it. This increases the physical demand on the laborers because they may have to transport the block by hand more (instead of using the dolly). (2) It increases the mental demands for the masons because it requires more accurate placement, and more attention to keeping the wall clean of mortar. This increases the attention and time needed to handle and lay blocks. To help the masons understand the quality expectations and avoid errors and rework, the foreman in project A built a "mock up" wall section.

On projects with high quality requirements (exposed walls), the **quality of the block** is critical. The defects of chipped block are not covered with paint and the block has to be replaced. Lower quality block has high dimensional variation; this causes the mortar line to vary in thickness or to be crooked, with a poor aesthetic result. Poor control of materials on the site can also result in such problems and rework. Foreman practices that can prevent such problems and rework (as it occurred on project A) include: (1) procurement of higher quality block, (2) checking the block when delivered at the site, and (3) careful handling of the block.

The **number of work areas** appeared to be another important factor affecting the workload, task demands and frustration. For the foreman, more work areas means that he has to form and supervise several sub-crews which increases his load and may reduce the quality of his supervision, as he may oversee some mistakes. The forklift operator needs to communicate with different sub-crews over the radio and travel to different work areas to provide them with right materials on-time. This issue not only increases his mental load due to increase in number of work steps, but also takes more time to travel to different points frequently, as seen in project A.

Finally, **changes in the work plan** often create high temporal demands and rushing for the support group (laborers and operator) to provide the material, scaffold and housekeeping to the masons. It can also increase the work areas to more than what the foreman can supervise effectively.

Discussion and Recommendations

In order to increase the masonry crews' productivity and safety performance, the management must (1) recognize, (2) manage effectively, and (3) reduce task demands. The task demands for the different crew members are influenced by two main factors: design features and foreman practices. The design complexity is recognized as a factor that affects the difficulty. However, the effect of the foreman practices on the task demands is less obvious. Foremen's practices influence both the overall task demands, as well as the allocation of task demands among the foreman, masons, laborers and operator. Thus, the work design affects the distribution of task demands. Common strategies that foremen use to manage the task demands include:

- **Matching task demands with capabilities**. Foremen assign workers with higher capability and experience to perform the tasks that are more complex and require more accuracy.
- **Reducing the temporal demands** is a common strategy for managing mental and physical demands to prevent errors. Both foremen's primary strategy was "go slower and do the work right the first time." The significant amount of rework however, especially in case B shows that this strategy was not sufficient to prevent errors.

This study however, did not find many examples where the foremen reduced the overall task demands. Reducing task demands can increase speed (thus productivity), and prevent errors & rework and avoid tasks with even higher demands and safety exposures. To reduce task demands, the study proposes the following strategies.

- **Prevent rework**. Rework tasks are often more demanding and often involve more hazards than normal tasks. For example, removing a grouted wall or removing the face of chipped block, require more cutting, in more awkward positions, more time on the scaffold and more frustration.
- Need **better techniques and methods to perform horizontal and vertical (wall openings) layout** that minimize the likelihood of errors.
- **Material selection**. Provide material of appropriate quality. The choice of materials can strongly affect the task difficulty and the amount of effort required.
- **Material management**. Checking material when received on site (e.g., door frames, quality of block for exposed walls) would reduce the task difficulty and could prevent errors and rework.
- The **number of work areas** should not be more than what can be effectively supported and supervised.
- Need to **reduce manual handling** while protecting the block from damage.

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