Production practices affecting worker task demands in concrete operations: A case study

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Received 13 March 2014
Accepted 19 January 2015

Abstract.

BACKGROUND: Construction work involves significant physical, mental, and temporal task demands. Excessive task demands can have negative consequences for safety, errors and production.

OBJECTIVE: This exploratory study investigates the magnitude and sources of task demands on a concrete operation, and examines the effect of the production practices on the workers’ task demands.

METHODS: The NASA Task Load Index was used to measure the perceived task demands of two work crews. The operation involved the construction of a cast-in-place concrete building under high schedule pressures. Interviews with each crew member were used to identify the main sources of the perceived demands. Extensive field observations and interviews with the supervisors and crews identified the production practices.

RESULTS: The workers perceived different level of task demands depending on their role. The production practices influenced the task demands in two ways: (1) practices related to work organization, task design, resource management, and crew management mitigated the task demands; and (2) other practices related to work planning and crew management increased the crew’s ability to cope with and adapt to high task demands.

CONCLUSIONS: The findings identify production practices that regulate the workers’ task demands. The effect of task demands on performance is mitigated by the ability to cope with high demands.

Keywords: Production system design, construction, concrete, NASA-TLX, worker, task demands

1. Introduction

In construction operations, workers experience significant physical, mental, and temporal task demands. Physical demands are primarily due to heavy load lifting, awkward postures and repetitive forces. The physical conditions—temperature, light, noise, vibration, etc., can exacerbate the difficulties of the work. Mental demands are generated due to extensive planning, deciding, measuring, calculating, aligning, checking, and searching. Work coordination and communications also generate cognitive demands. Construction work is subject to significant temporal demands due to production pressures to meet project schedule. In addition, the social conditions of the work group can generate psychological stress.

Task demands affect task performance and workers’ safety. In general, when demands exceed the worker’s capacity, the time to perform the task and the likelihood of errors increase [1, 2]. Excessive production pressures can also conflict with safety...
requirements [3, 4] and may result in shortcuts, omissions and safety violations, which in turn can increase the likelihood of incidents [5, 6]. Sectors such as aviation, transportation, and health care have long been concerned with the effects of task demands on performance and errors. In construction, however, the role and management of task demands has not been addressed. To address this gap, this exploratory study investigates the task demands on construction crews.

The study is based on two premises: First, to ensure the safety and efficiency of workers, it is important to effectively manage the task demands so that they neither under load nor overload the individual. Second, the organization and management of the production (such as method selection, crew size, work preparation, task allocation, sequencing, workload, pace, coordination, etc.) shape the task demands on the workers. This exploratory case study investigates the following research questions:

- What is the magnitude of the perceived task demands (mental, physical, temporal, etc.) for the different crew roles (foreman, laborers, carpenters)?
- What factors contribute to the task demands from the workers’ perspective?
- How do the production practices influence the task demands?
- How do the task demands affect task performance?

The operation studied was the construction of a cast-in-place concrete frame of a 10-story commercial building under very high schedule pressures. The study investigated the task demands on two concrete crews—the “deck crew” who performed the horizontal concrete, and the “vertical crew” who build the walls and columns.

2. Background

2.1. Definition of terms

Task demand is defined as the effort, skills, and knowledge required for successful task performance [1]. It is the result of performing physical and cognitive tasks under time pressure [7]. Physical demands refer to energetic, biomechanical and environmental demands of the task [8]. Mental demands require cognitive inputs such as concentration, memory, decision making and attention while performing a task [8]. Temporal demands refer to the time pressure that an operator experiences while performing the given task [9]. The combination of the various demands that influence performance and responses from a human operator is called “workload.” Workload describes the overall effort invested by the human to accomplish the task requirements. This may be reflected in the depletion of attention, cognitive or response resources, emotional stress, fatigue, or errors [10, 11]. Task difficulty is another term used to describe the effort required for successful completion of a task [12]. The subjective task demands indicate the perceived difficulty of the task by the operator.

2.2. Effect of task demands on performance

The effect of task demands on performance has been examined in different sectors such as aviation, driving, etc. The relationship between task demands and performance is considered to be an inverted U [13, 14]—performance decreases when the workload is too low or too high. Sustained low workload (under-loading) can lead to mental fatigue, monotony, boredom, and reduced vigilance [13], which can result in a deterioration of performance. On the other hand, high levels of task demand can reduce the time available for information processing, degrade the operator’s concentration and decision making and increase stress, and may lead to increased errors [15]. The operator’s strategies play important role in the relationship between workload and performance, as they dynamically adapt their behaviors to the workload [16]. Operators manage their attention and effort, rescheduling, deferring or shedding less important tasks to achieve acceptable performance and maintain acceptable level of workload. However, if the task demands exceed the operator’s capacities, performance degrades; response time and errors increase, and fewer tasks are completed within a specific time [1, 2].

Research in driving has found that more complex tasks create higher mental workload and result in higher response time [17]. It was also found that when the driver’s mental workload is very low, vigilance decreases and consequently response time increases [18]. In aviation, Hancock and colleagues [11] reported more successful performance in low task demand conditions while the rate of errors increased in high demand conditions. Morris and Leung [19] found that as the mental workload increased, the pilots’ flight control performance significantly decreased. Research in nuclear power plant control teams found that higher task com-
plexity and workload result in longer response time and more errors [20]. On the other hand, when the load imposed by the task becomes very low, the probability of human error also increases [21]. In healthcare, studies have found that increased task demands such as interruptions, divided attention, and rushing increased errors in medication dispensing tasks [22]. In manufacturing, research has shown that concurrent physical and cognitive demands decrease operator’s physical endurance, increase perceived stress, and affect performance [58, 59].

In occupational safety research, work overload is considered an important factor linked to accidents [23]. This is reflected in the increased incident rates in periods of economic growth, as the need for greater production presumably increases workload [24]. On the other hand, work underload is also important for occupational safety as it leads to job boredom, which has been associated with workplace injuries [25] as well as transportation incidents [26]. The above discussion highlights that many sectors have recognized the importance of task demands for errors and performance. In construction, however, the workers’ task demands their role in performance, and the strategies to manage them have not been investigated. The background suggests that construction researchers and practitioners could benefit from a systematic investigation of task demands as a way to understand and prevent performance problems.

2.3. Factors affecting task demands in the construction context

Construction tasks involve significant physical demands, due to heavy load lifting, awkward or static body postures, repetitive motion, contact stress, vibration, and extreme temperatures [27–29, 60]. These demands often lead to musculoskeletal disorders (MSD) [30, 31]. Physical conditions such as temperature, visibility, noise, housekeeping, and surrounding hazards (trenches, moving equipment of other activities, power lines, etc.) can increase the difficulty and complexity of a task. To reduce construction workers’ physical work demand and consequently the risk of MSD, research has emphasized the importance of work system design and use of mechanical transport to reduce manual handling [61–63].

In construction, mental demands are generated by extensive planning, deciding, measuring, calculating, aligning, checking, and searching. Task complexity and uncertainty [32] increase the cognitive demands. Monitoring and controlling tasks, communicating and coordinating, also require attention and mental resources. Significant attention requirements are due to safety hazards, tool use, accuracy requirements, etc. Construction operations also have significant temporal demands, as the workers are often under time pressures. Safety research has recognized that high production pressures create work overload [33, 34] and increase the likelihood of accidents. Hinze & Parker [5] found that production pressures and crew competition are related to more injuries, and suggested that job practices are more important than safety policies in preventing accidents.

The organization of production influences the task demands by affecting the characteristics of the task and the work environment [35]. For example, the selection of the work method, tools and equipment and the difficulty involved in their use strongly affects the workers’ physical task demands [36–38]. Interruptions increase workload [39] and stress [40, 41] and have been found to increase omissions and errors [42–46]. The social environment—such as the support from coworkers and supervisor also affects worker’s stress [33, 47]. In construction, the organization of the production is typically decided by a crew supervisor, within the constraints of the organization. As a result, the supervisors’ production practices play a critical role in managing and regulating the workers’ task demands. A study of task demands in masonry operations [48] identified product features and production practices that influence the workers’ task demands, including design complexity, quality of material, the number of work areas, and rework.

The perceived task demands also depend on the worker’s capability—that is, the worker’s skill, human factors (such as fatigue, etc.) and the level of activation. Workers also influence the task difficulty by dynamically adapting their task behavior. For example, workers can increase the task demands by performing multiple tasks at the same time, or by increasing the pace of work. If the demands become too high, the workers can adjust their speed or level of effort to mitigate the task demands.

2.4. Task demands in concrete operations

Concrete work involves significant demands, which are partly reflected in the safety statistics. According to the U.S. Bureau of Labor Statistics (BLS), concrete construction involves significant safety risk. The recordable incident rate for “poured concrete foundation and structure con-
tractors” (NAISC 23811) is 6.5 per 100 equivalent full-time workers—that is, more than double of the recordable incident rate for all non-residential building construction, which is 3.1 incidents per 100 full-time workers [49]. Design attributes can increase the complexity of operations, and consequently the workers’ task demands. Thomas & Zarvski [50] reported several features that increase the complexity of formwork operation: sloped walls, irregular height, panel modifications, numerous shapes and sizes of forms, curved walls, finish work requirements, penetrations, restricted access, integral columns, and alignment tolerance. From an ergonomics perspective, Abdelhamid and Everett [51] investigated the physical demands of concrete workers using three major physiological indicators—oxygen consumption, heart rate, and energy expenditure. They reported that when the worker exceeds the accepted physiological threshold, it can lead to physical fatigue that consequently results in decreased productivity and increased risk of accidents and injuries.

3. Method

The background review recognizes the importance of task demands on workers’ performance and safety. This study explores the factors that contribute to the task demands of concrete operations, and particularly the role of production practices on task demands. The exploratory nature of this study, led to using the case study method. The case study methodology was employed because it enables an in-depth examination of the production practices in the real-life context. To address the research questions the study investigated the task demands of two crews from the same company on a concrete operation. A large local contractor agreed to participate in the study and provide access to projects and data. At the time, the company had just started the construction of a cast-in-place concrete frame for a 10-story office building, which was performed under high schedule pressures and under challenging weather conditions.

Due to challenging nature of the project, the company assigned one of their most experienced supervisors to design and supervise the operation. According to the company’s operations manager, the supervisor had managed some of the contractor’s most complex projects with excellent production and safety performance. During the previous three years, he had supervised over 94,000 labor hours with zero recordable incidents, and one first aid incident.

3.1. Data collection

Data collection focused on three main issues: (1) The production practices, (2) The workers’ task demands; and (3) Performance outcomes. With regards to production practices, data were collected on: (1) Work organization; (2) Task design; (3) Resource management; (4) Crew management; and (5) Safety management. The workers’ task demands were measured using the NASA-Task Load Index (TLX) [52]. Project performance data were collected primarily on quality problems, safety incidents, and delays.

The investigation focused on the two primary concrete crews; the deck crew and the vertical concrete crew. The authors conducted the data collection over a three-month period. To enhance the reliability and validity of findings the authors used triangulation of methods employing three methods to collect data including multiple personal interviews, direct observations and worker surveys. The supervisors were interviewed multiple times regarding the practices they used on the current as well as previous projects. Site observations were conducted two to three times a week for 10 weeks and totaled over 80 hours. The production practices of the crews were observed closely in order to understand the details of the operation and to cross-examine and validate the findings from interviews. All the crew members were surveyed during week 5, using the NASA TLX questionnaire.

3.2. Task demands assessment instrument

To assess the workers’ task demands the study used the NASA-TLX instrument. The NASA-TLX is a subjective assessment method [52] originally developed by the National Aeronautics and Space Administration (NASA) to measure the task demand on flight crews [9]. Since then, it has been used to evaluate task demands in many different domains, activities and settings [53]. Subjective workload is defined as the subject’s judgment of the workload experienced during task performance [54]. Subjective methods used to measure task demands include the subjective workload assessment technique (SWAT), work profile (WP), and NASA-TLX) [9, 55].
NASA-TLX uses six questions to assess (1) mental demand, (2) physical demand, (3) temporal demand, (4) effort, (5) performance, and (6) frustration, as shown in Table 1 [9]. 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 NASA TLX was used because of the following advantages: (1) it uses a multi-dimensional scale to measure different types of task demands (mental, physical, temporal, etc.) which are present in construction operations. Other methods focus primarily on one type of demand; (2) the NASA TLX has high face validity; and (3) it is easy for participants to assign ratings, and requires little effort and time from the participants. This was an important concern in the context of the construction operation.

### 4. Production system design

#### 4.1. Project description

The project was a 10-story office building, with a cast-in-place (CIP) concrete frame with a post-tensioned concrete slab. Each floor was 2,500 square meters (27,000 Square Feet) with identical layout. There were 28 columns and an elevator shaft on each floor. According to the supervisor, the design complexity was low, and the main challenge was the tight schedule, as the concrete frame had to be completed in 13 weeks. In addition, construction was performed during the summer with the temperature constantly over 43 degrees Celsius (110° F). This was a major concern in terms of safety and productivity risk.

In depth data were collected on the following production practices: (1) work organization practices, including the work process design, work sequence, and work division, (2) task design practices, including the work methods, preparation and execution of the activities, (3) resource management practices (material, equipment), and especially the limited ones, (4) crew management practices—including crew selection, orientation, task assignment, production control, and (5) safety management practices.

#### 4.2. Work organization

The senior supervisor organized the overall concrete work in three major operations: (1) the horizontal concrete (the deck), (2) the vertical concrete (walls and columns), and (3) the reinforcing steel (rebar), and assigned a specialized crew to each operation. In addition, a night crew supported the work of the deck and vertical crews. The senior supervisor was in charge of the entire operation, and he was also managing the deck crew. A second supervisor, less experienced with building work, was managing the vertical concrete crew under the supervision of the senior supervisor.

#### 4.2.1. Concrete deck operation

The concrete deck crew consisted of 19 members including one carpenter foreman, two carpenters leadmen, 12 carpenters, one grader, and three laborers. The concrete deck crew performed the following activities: (1) Set up deck forms. Elevated aluminum tables were used for the deck formwork, which would be lifted and placed by the crane on the next floor,
where three carpenters set the tables, and the grader leveled them. (2) Set edge forms. The edge form of the slab was built using plywood. The sides of the deep concrete beams were formed using Z-shaped metal plates. (3) Set shoring. The laborers installed aluminum shores every six feet. (4) Install steel embeds. The carpenters installed about 500 embeds on each floor. (5) Clean the deck and oil the forms. This was a very tedious task as the laborers had to walk for hours on the deck rebar under the sun. (6) Place concrete. The concrete for the deck was placed by a separate crew. (7) Strip the forms & “fly” the tables. After the concrete was adequately cured and tensioned, the crew removed the edge forms and the shoring. Then, the tables were stripped, lowered, and rigged to the next floor. (8) Set reshores. After the tables were removed, the shores were repositioned.

4.2.2. Vertical concrete operation

The vertical concrete crew consisted of nine members including one field supervisor, one carpenter foreman, five carpenters, and two laborers. After the rebar was installed, the crew performed the following activities: (1) Install embeds and spreaders. Embeds were installed in the walls before pouring concrete. Spreaders (rebar chairs) are accessories installed on the rebar cage to maintain the clearance between form and rebar. (2) Prepare the forms & ties. The crew cleaned and oiled the forms and checked and repaired the form ties. (3) Set the wall and column forms. Wall and column forms were lifted by the crane and set by four carpenters. This task was identified as the most critical part of the work, for both safety and productivity. (4) Place concrete. The vertical crew performed this activity. (5) Remove the forms. After the concrete was cured enough, the crew removed the forms and patched the walls.

A night crew that consisted of eight members was supporting the vertical and deck crews. They were working six days a week, from 9 pm to 6 am. A subcontractor performed the rebar work, which included the slab rebar, the post-tension cables, assembling the wall and column cages on the ground, and setting them in place with the crane.

4.3. Work sequence

Using the normal approach the contractor would have built one floor at a time. The cycle time for each floor would have been about 2.5–3 weeks, and the duration of the concrete operation would be about 25–30 weeks for the whole project. To reduce the duration to 12 weeks the supervisor used two main strategies: overtime and overlapping. The work schedule was six days a week, 10 hours a day. To enable overlapping of the deck and vertical operations the supervisor divided each floor into two equal sections of A and B (Fig. 1). This way, the deck crew was working on section A, and at the same time, the vertical crew was following, working on section B of the lower floor.

To minimize interference between the crews the supervisor assigned each work area to one primary crew every day. Some coordination problems occurred between the day crews and the night shift. The main difficulty was communicating to the night shift how exactly the day crew wanted the activities performed. For example, the night shift stripped and stacked the wall forms in a sequence that was not what the vertical crew needed. This affected the vertical crew’s speed of finding and setting the forms on the next floor. Such issues were addressed and resolved by the crew supervisors.

4.4. Task design practices

To complete the work in the short duration, there was a systematic effort to reduce the difficulty, complexity and time demands of the activities. This effort included (1) the selection of the work methods; (2) actions to simplify, standardize and error-proof the
activities; and (3) systematic preparation of the activities using dedicated personnel.

4.4.1. Method selection

The selected methods utilized modular systems that required less onsite assembly effort: aluminum tables for the deck formwork, Z metals for the beam side forms, aluminum shoring, and industrialized metal panels for the vertical elements. These methods reduced the need for measurement, cutting and assembling wood material on site. As a result, they reduced the operation time and the potential for errors and delays.

4.4.2. Task simplification, standardization and error-proofing

The supervisors looked for opportunities to simplify and decouple activities, with a primary focus on reducing the installation time, preventing mistakes, and reducing the physical burden on the workers:

- The supervisor designed the configuration of the aluminum tables to reduce the difficulty of moving them—for example, he would use two smaller tables instead of a large one, if that would make the work overall easier.
- The tables were designed with folding extensions to cover the columns from four sides and reduce the filling activity.
- The tables were numbered and the crew members and crane operator had a map with the table locations.
- The table legs were pre-marked at the appropriate heights to speed up installation and minimize potential grading mistakes.
- The workers setting the tables used rubber mallets that deliver a softer blow to reduce the workers’ discomfort.
- To reduce the complexity of wall/column pours, the number of concrete mix designs was reduced from four to two (with the engineer’s approval).
- The activity sequence was standardized. Both crews established a specific sequence for moving and installing the forms.

4.4.3. Extensive preparations

Thorough activity preparation was essential to ensure that all the needed resources were available when needed. In the deck crew, a leadman was responsible to gather and organize embeds needed for the next day. Because of the limited access to the crane, it was important to have all the needed material bundled and ready to lift when they had access to the crane. Two crew members were dedicated to preparing all the material needed. In the vertical crew, one worker was assigned to check all forms, tools, and materials and repair them before their “heavy” days. Another one would clean and oil the forms. Materials including 2” × 4” timber (standard size), form oil, and curing compounds would be ordered one month in advance. The materials needed for each floor was checked one week ahead of time to make sure it was available. In addition, a buffer of 100 pieces of 2” × 4” timber was stored on site.

4.5. Resource management practices

With the overlapping of the work activities, all three day crews—deck, rebar and vertical, required access to the crane. However, there was one tower-cranes on the job, and all three crews were dependent on that crane. This made the crane the bottleneck resource. In order to provide sufficient access to the crane and avoid conflicts, the supervisor used three strategies: First, he developed a detailed crane schedule. Each crew was the primary user of the crane during their “heavy” days. For instance, Mondays and Thursdays the deck crew had full access to crane, and the other crews had limited access. Second, the limited resource was exploited—the crews tried to make the best use of the crane’s time by minimize their lifts. This required thorough preparation for the lifts, to make sure that they had all the material and tools needed. Third, the night crew had a crane operator, to perform some lifts that the day shift did not have time to do.

During the early stages of the operation, some other material also turned out to be bottlenecks. Some simple materials like 2 × 4 and straps to bundle materials for lifts were shared by all crews and sometimes they were taking each other’s material, which created some delays. To solve this problem, the supervisor simply provided more resources.

4.6. Crew management practices

4.6.1. Crew size and selection

The supervisor sized the crew to reliably meet the schedule goals. To determine the crew sizes the supervisor prepared a detailed work plan to ensure that all tasks were taken into account including the support tasks (preparation, logistics, cleanup, etc.), and then he adjusted the manpower to account for
reduced productivity due to the heat. Different levels of manpower were needed on different days. This allowed some resting period for the crew members who performed the heavier activities.

4.6.2. Absenteeism prevention

Preventing absenteeism was a major concern as it could affect the schedule. The supervisor had a zero tolerance policy on absenteeism, which he explained to each worker at the time of hiring. He considered unjustified absenteeism as “stealing other workers’ time, which is not fair.”

4.6.3. Work assignment

Specialized workers were used for the tasks that required high accuracy: (1) the most skilled carpenters were assigned to the areas where higher accuracy of the edge form was required. (2) A carpenter leadman with strong construction engineering background was assigned to perform the layout task. (3) A dedicated grader was used to set the table forms at the correct elevations. (4) In the vertical concrete crew, four carpenters would perform wall forms setting task. To prevent errors and omissions in important activities (layout, embeds, etc.) the supervisor established additional inspections.

Task rotation was used for the heavier tasks (such as moving the tables). In addition, the crew members who performed the heavy tasks on Monday or Thursday had resting days on Wednesday/Saturday.

4.6.4. Crew engagement

Keeping the crew informed and focused was essential. Every morning, the supervisors reviewed the timetable with the crews, specifying what time each task had to be finished. The crew had a clear work plan which specified when, where, and how to do the work.

4.6.5. Performance monitoring and response to problems

The detailed daily plan provided the basis for close monitoring of progress. To prevent performance problems at one task affecting other tasks the crew members had clear instructions not to stop their work to help someone with a production problem (with some exceptions to this rule), but to bring these problems immediately to the foreman. The deck foreman was responsible to handle the problem and redistribute the workload to workers as needed. The foreman knew the status of all tasks, and he could assign resources so that other tasks would not be delayed.

4.6.6. Mutual performance monitoring

The supervisor emphasized cross-checking primarily for early identification of the safety problems. The crew members were encouraged to check each other for signs of dehydration and heat stroke—the symptoms were reviewed daily basis during the crew briefings. Systematic cross checking was also done to double check layout, as it was critical to avoid such errors.

4.7. Safety practices

The safety program included safety planning, training, and inspections. The project had a full time safety professional on site. At the morning crew meeting, the supervisor discussed the safety hazards of the upcoming tasks. During critical activities, the supervisor repeated the safety hazards during the lunch break. The four most important safety concerns were: falls, struck by falling objects, crane operations and heat sickness/dehydration.

To prevent falls the contractor installed a perimeter railing around the tables, which remained in place during the rigging operation. The contractor enforced a 100% tie-off policy and had zero tolerance on fall protection. The greatest risk from falling objects was when the aluminum tables were removed, and the “Z metal” was often falling. To minimize exposures, only the necessary personnel was allowed under the tables, and the operation was monitored by the foreman. The most critical time was when the crane was pulling the aluminum tables off one floor and hoisting them to the next floor. The crew supervisor monitored the rigging operation and controlled the ground traffic. Measures to prevent dehydration included: (1) providing extra water, (2) rotating workers to task in the shade, and (3) teaching the symptoms of dehydration to his crew and asking the crew to cross monitor each other.

4.8. Operation outcomes

The concrete operation was successfully completed in 12 weeks, using the planned manpower and with zero injuries. One first aid incident occurred that involved debris in a worker’s eye. With regards to quality, the most significant mistakes were the following: (1) both the deck and vertical crew missed one embed. However, the structural engineer devel-
oped a solution that did not require rework. (2) In one area on the fourth floor, the concrete deck was poured about 1.5 inch thicker than it should be. This was a mistake by the concrete placing crew that created extra work for the vertical crew as they had to adjust the wall formwork.

5. Findings

5.1. Magnitude and sources of task demands for deck crew

Tables 2 and 3 provide the NASA-TLX survey results for the deck crew. Table 4 summarizes the major sources of task demands based on the interviews.

The mean physical demand of the deck crew was moderate-high (7.7). The major sources were the heat and working with heavy aluminum tables. The carpenters identified stripping and setting up the tables as the main causes of their physical demand (7.8). For the grader, the physical demand was moderate (5). The laborers considered excessive manual handling of heavy items, lifting and installing shoring, and climbing ladders with their tools as the major sources of physical demand (8.3).

The mean mental demand of the deck crew was moderate-high (8.0). The carpenters reported several activities that required accurate measuring and careful sequencing (such as layout of edge form and embeds, stripping and flying tables) as the major source of their mental demand (7.9). The deck crew members each performed several different tasks, which also required utilizing mental resources to learn new tasks. For the laborers, the major source of mental demands (7.8) was the attention needed to avoid incidents while working on rebar. The grader reported a mental demand of 10 due to the extensive need for remembering, measuring, setting and checking the table elevations. Earlier on the project, there were some mistakes made in the elevation of the tables. The errors were identified and corrected during additional checks. To prevent more errors, the supervisor had the crew pre-mark the table legs. This practice, along with the standard floor heights, prevented more errors.
The mean temporal demand was relatively high (8.3) and was attributed to performing several tasks and meeting several milestones within the limited allocated time. The deck crew reported moderate level of frustration (5.4). For the carpenters, the major sources of frustration were rushing to complete last minute requests, delay in delivery of material, and not receiving the expected output from the night crew. The grader reported the defective table legs as the main source of his frustration (7.0). For the laborers, frustration was low (2.7) and mainly due to other crews’ or crew members’ performance, heat, and running out of water.

5.2. Magnitude and sources of task demands for vertical concrete crew

Tables 5 and 6 summarize the TLX scores for the vertical crew, and Table 7 summarizes the major sources of task demands.

The crew indicated a relatively high physical demand (8.0), which was attributed primarily to the heat, lifting loads, climbing the wall forms, and pouring concrete. The forms used for the walls were not designed to climb up, which created difficulty for the workers while setting up the wall forms. The mean mental demand was moderate-high (7.3). The carpenters reported mental demands (7.4) due to planning for the next step, the accuracy requirements of the vertical forms, awareness of the hazards in the environment (flying forms, etc.) and some problem solving (protecting the embeds during pouring). The tight schedule was reported as the main source of temporal demand, but the mean temporal demand was moderate-high (7.3). The carpenters reported that some out-of-sequence work increased the temporal demand, and apprentices identified working at multiple locations as another source of temporal demand.
Table 6
Mean TLX scores for different worker categories in vertical concrete crew

<table>
<thead>
<tr>
<th>Role</th>
<th>Mental</th>
<th>Physical</th>
<th>Temporal</th>
<th>Performance</th>
<th>Effort</th>
<th>Frustration</th>
<th>TLX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpenters (n = 7)</td>
<td>7.4</td>
<td>8.1</td>
<td>7.3</td>
<td>3.4</td>
<td>7.7</td>
<td>5.9</td>
<td>39.8</td>
</tr>
<tr>
<td>Apprentices (n = 2)</td>
<td>7.0</td>
<td>7.5</td>
<td>7.5</td>
<td>2.5</td>
<td>8.0</td>
<td>4.5</td>
<td>37.0</td>
</tr>
<tr>
<td>Crew mean</td>
<td>7.3</td>
<td>8.0</td>
<td>7.3</td>
<td>3.2</td>
<td>7.8</td>
<td>5.6</td>
<td>39.2</td>
</tr>
<tr>
<td>Crew Std deviation</td>
<td>1.5</td>
<td>1.2</td>
<td>0.5</td>
<td>0.9</td>
<td>1.1</td>
<td>2.9</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Table 7
Sources of task demands for vertical concrete crew

<table>
<thead>
<tr>
<th>Role</th>
<th>Mental Demand</th>
<th>Physical Demand</th>
<th>Temporal Demand</th>
<th>Frustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpenters</td>
<td>Looking &amp; planning ahead (3)</td>
<td>Heat- from sun &amp; fresh concrete (4)</td>
<td>Tight schedule (7)</td>
<td>Lack of instruction to do the task (4)</td>
</tr>
<tr>
<td></td>
<td>Measurement &amp; Plumb ups (2)</td>
<td>Lifting heavy items manually- no mechanical equipment (2)</td>
<td>Out of sequence work (1)</td>
<td>Night crew is always behind (2)</td>
</tr>
<tr>
<td></td>
<td>How make things easier (2)</td>
<td>Climbing over wall forms while carrying tools (2)</td>
<td></td>
<td>Changing plans -superintendent doesn’t know exactly what and how to do (2)</td>
</tr>
<tr>
<td></td>
<td>How do the work not covering embeds while pouring (1)</td>
<td>Flying &amp; pushing wall forms (1)</td>
<td></td>
<td>Schedule pressure (2)</td>
</tr>
<tr>
<td></td>
<td>Situation awareness (1)</td>
<td>Pouring concrete with bucket- when no pump forms (1)</td>
<td></td>
<td>Waiting for crane (1)</td>
</tr>
<tr>
<td>Apprentices</td>
<td>Safety (1)</td>
<td>Lifting heavy items manually- no mechanical equipment (power lift) (2)</td>
<td>Tight schedule (2)</td>
<td>Working at multiple locations (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Working at different locations (2)</td>
<td>Changing plans</td>
</tr>
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<td>Rework (1)</td>
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<td>Mistakes are due to superintendent’s fault - he doesn’t tell us exactly what and how to do (1)</td>
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<td>Heat (2)</td>
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<td></td>
<td></td>
<td>Not enough work to do (1)</td>
</tr>
</tbody>
</table>

The vertical crew reported moderate levels of frustration (5.6). For the carpenters, frustration (5.9) was attributed to lack of instruction, changing plans by the supervisor, and delays by the night crew. For the laborers, the main sources of frustration were working at multiple locations, frequent changes of work plans, rework, and mistakes due to superintendent’s lack of experience with the type of work. Overall, the sources of frustration were related to interferences and disruptions of the production process, and included factors that added to the normal task difficulty. Both crews reported relatively low level of frustration, which indicates that overall, such problems were limited.

The crews identified project conditions (such as schedule, weather) and specific task requirements (order of stripping tables, checking material, climbing ladders, handling heavy material, etc.) as the sources of their task demands. However, the production practices mitigated the effect of project factors and shaped the task requirements. For example, the high schedule pressures do not necessarily translate into high temporal pressures for the workers—the production practices related to crew sizing and work organization determined the distribution of the overall workload to the crew members, in a similar way that the loads of a structure are distributed to the structural members. In a similar way, the supervisor’s practices mitigated the physical demands due to the high temperature—the day shift started at 3:00 A.M. when the temperature was lower, and the supervisor increased the originally estimated crew size in order to account for the increased fatigue. The following section discusses the effect of production practices on task demands.

6. Discussion: Effect of production practices on task demands

Figure 2 illustrates the effect of production practices on task demands. The analysis identifies two categories of production practices that had an influence on task demands: (1) practices that mitigated
the task demands and (2) practices that increased the crew’s ability to adapt to and cope with high task demands.

6.1. Practices that mitigated the task demands

The use of modular methods (aluminum tables, column and wall panels, Z metal, and aluminum shores) reduced the fabrication and assembly tasks on site. These methods reduced the overall workload and task durations. In addition, they reduced the complexity of the work process (by reducing measuring and cutting), which reduced the likelihood of errors and rework. The use of dedicated crews for the deck and vertical concrete operations reduced the task complexity and consequently the mental demands for the crews. The assignment of different work areas to the three main crews (deck, rebar and vertical concrete) minimized interference and coordination demands. The resource management practices reduced dependency on shared resources. These practices reduced the task complexity. However, the use of a night shift created another interface that had to be managed. Coordination difficulties with the night shift, especially during the early stages of the work, created some frustration for the day crews.

Actions to simplify and standardize tasks reduced the cognitive demands and potential for errors. The standard production cycle increased the predictability of the work process. The configuration of the tables was designed to facilitate easy removal, lifting, and placement. Numbering of the tables reduced the likelihood of error in figuring out the work sequence. Pre-marking the table legs reduced the time needed to set up the tables and the opportunities for measurement errors. Reducing the number of concrete mix designs reduced the complexity and possible mistakes of the concrete pouring operation.

The size of the crews provided adequate capacity to keep up with the schedule and workload. The supervisor’s emphasis on absenteeism prevention stabilized the crew capacity and prevented excessive workload and time pressure due to lack of workforce. The extensive task preparations prevented task disruptions that would increase frustration and temporal demands.

The rotational on heavy tasks distributed the physical demands to several workers. In addition, the provisions for resting days for those who worked on the heavier tasks facilitated the workers’ recovery. The task specialization for tasks that required accuracy (i.e., the grader and layout) created learning efficiencies in order to minimize mistakes on these important tasks.

The selection of tools and equipment influenced the physical demands. For example, the selection of rubberized mallets reduced the ergonomic loads. On the other hand, the choice of some equipment increased the ergonomic demands. For example, access to the work area was provided via ladders, while a personnel lift would have reduced the physical demands.

6.2. Practices that increased the ability to cope with high task demands

Another set of practices enabled the crew to successfully cope with high task demands—these practices included the selection of highly skilled crews, close monitoring and fast response to problems, and additional resources to respond to demands peak.

Close monitoring of the operations enabled the supervisor and crew to identify problems, errors, and excessive task demands. As discussed earlier, in order to meet the schedule goals, it was important to complete all tasks everyday as planned. To achieve this, the supervisor: (1) established several daily milestones and developed checklists with specific timeline to finish each step, (2) increased the crew’s awareness of the schedule goals through frequently communicating the work plan and status of the work, and (3) established close monitoring of progress and quality by the deck foreman. Additional checks on layout tasks helped identify errors such as the wrong table grade. This, however, did not prevent two omitted embeds. In addition, the crew had clear guidelines regarding how to respond to problems—the goal was to address the problems immediately with minimum disruption to other activities.

Teamwork behaviors increase the crew’s ability to support each other under high task demands. Effective teamwork interactions and behaviors can develop through the interpersonal relations of the team members, as well as through systematic use of team processes such as team briefings, mutual performance monitoring and feedback, assertiveness, backing up behaviors, and learning processes [56]. The team tenure among the concrete crews in this study was relatively short, as the longest tenure was eight months and the shortest was two weeks. Despite the short tenure, the supervisor’s practices promoted teamwork behaviors. The mutual performance monitoring supported early identification of safety problems. With
regards to assertiveness, the workers were encouraged to speak up and stop the work whenever they noticed errors or safety hazards.

The availability of additional resource capacity (such as the foreman) was an important factor of the ability to respond quickly to unexpected problems and variability. The night shift also provided the resources needed to absorb some variability and perform work that was not completed during the day shift. In addition, the supervisor had the flexibility to shift manpower between the deck and vertical crews if needed.

6.3. Task demands and performance

Although the mean task demands of the two crews were moderate-high (ranging from 7.3 to 8.3), several workers indicated very high demand levels. On the deck crew, five workers indicated 10 on mental demands, four workers indicated 10 on physical demands, and four workers indicated 10 on temporal demands (Table 2). On the vertical concrete crew, one worker indicated 10 on mental demands, two workers indicated 10 on physical demands, and no workers indicated 10 on temporal demands (Table 5). The expectation was that very high task demands would result in a large number of performance problems. However, despite the high task demands, performance problems in terms of delays, rework, and safety incidents were minimal. Some potential explanations for this are the following:

- A TLX rating of “10” does not necessarily mean that the demand exceeded their worker’s capabilities. It may indicate a high level of difficulty, but not enough to create a significant increase in errors or failures. Thus, the relationship between the level of task demands and performance problems (such as the frequency of errors) is unclear.
- Practices that increased the crews’ ability to cope with the high task demands mitigated the impact of task demands on performance. For example, the ability to identify address problems fast, minimized the consequences of such problems.
- It is possible that the high demands also increased the level of workers’ activation and task engagement, which prevented performance problems.
- The reported task demands were higher than the experienced task demands.

7. Conclusions

This exploratory study investigated the factors that generated the workers’ task demands in a concrete operation, and the effect of production practices on workers’ task demands. The findings indicate that although the project features and requirements may create high demands, the design of the production system determines how these demands are managed and distributed to the crews and the workers. The case identified specific practices that the supervisor
used to mitigate the task demands and prevent performance problems. However, the analysis cannot quantify to what extent the above practices actually reduced the task demands, compared to a production system where these practices were not used.

The study also examined the relationship between task demands and performance. Although the case provided important insights, the relationship between the perceived task demands and performance was inconclusive, and more cases are required for a comparative analysis. The findings suggest the following areas for further research:

- Comparisons of operations of similar nature will improve understanding of the effect of different production practices on the workers’ task demands.
- Comparison of task demands and task performance across a larger sample of operations is needed to understand at what level of demands the performance deteriorates and to what extent. Conducting the NASA-TLX survey at different timeframes during the project lifecycle would help better understand the prolonged effect of working under high task demands.
- Comparison of crews using different coping strategies will increase understanding of the effect of such strategies on performance. This ability can create “resilience” where a system is able to cope successfully with high demands and failures [57].

Further research into the above issues will increase the ability to design effective production systems for concrete operations that support high task performance as well as the workers’ safety and well-being.

References


550  B. Memarian and P. Mitropoulos / Production practices affecting worker task demands in concrete operations


