CONSTRUCTION CREW DESIGN GUIDELINES: A LEAN APPROACH

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ABSTRACT

Construction work is executed by a variety of specialty trades, using group of workers commonly known as crews. Performance of these crews is very crucial to the work being executed and consequently for the overall project performance. Yet decisions regarding how to design a crew (makeup and how work itself will flow) and improve their performance are addressed in an ad hoc fashion, if at all. Also, despite the clear significance of crew design, only a modest scholarly interest in this area has been seen in the last two decades. Developing lean-based guidelines for crew design will allow us to answer questions such as: Can we choreographically design construction work crews, and how? The aim of this research is to address this question by developing lean-based crew design guidelines for construction operations by conducting an extensive literature review focused on "work design/team design" that have well developed theoretical and empirical foundations in Lean Production, Lean Construction, Socio-Technical System theory, and Organizational Psychology. These theories provide important soft and hard factors which affect crew interactions. Synthesizing these existing production theories into a new unified model to develop a set of lean-based crew design guidelines is expected to lead to better overall performance of crews achieving *lean construction* ideals of minimizing waste and maximizing value for construction operations and projects at large.

KEYWORDS

Work structuring, production system design, lean construction, training

INTRODUCTION

The construction process may be considered the most complex undertaking in any industry (Bennett 1991). Construction can be characterized as a "Localized Production" system with high levels of customization required. It consists of multitude of interdependent, uncertain and variable flow of resources. These flows of resources may produce varied outcomes in terms of cost, time and other performance outcomes, with no clear understanding yet of underlying causal relations.

In the early stages of a construction project, a crew design process is very crucial to both the scheduling and estimating functions in terms of its direct relation with activity durations & activity labour costs and consequently with project cost and duration (Hassanein and Melin 1997). How to form or design a crew to carry out an operation in a dynamically changing construction environment is a complex task. Any change in the crew size, composition, or other important crew parameters might

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result in irreversible spiralling consequences to the cost, duration, and other performance outcomes.

Crew design is often confused with construction process design (method or operation design). However, in this paper we use crew design as an integral part of any production process that involves the analysis and redesign of crew make-up. As stated by Medsker and Campion (2007), work design or "job design is one of those aspects of managing organizations that is so commonplace that it often goes unnoticed".

Different scientific disciplines such as industrial engineering, organizational psychology, social psychology and socio-technical system theory have developed approaches for crew or work design (Gladstein 1984; Hackman 1980 1987; Hackman and Oldham 1980; Guzzo and Shea 1992; Niepcel and Molleman 1998; Campion et al. 1993 2005; Morgeson and Humphrey 2008; Morgeson et al. 2006). These studies have been relatively independent of each other resulting in identifying distinct work/team characteristics or indicators, possibly leading to conflicting recommendations.

In this research, we adopted several approaches to satisfy the following: (1) focus and specify the desired performance outcomes of the design process; (2) synthesize the inter-disciplinary approaches; (3) develop a framework for the crew design process to pursue joint optimization of the outcomes desired.

The interdisciplinary approach suggested by Campion et al. (1993) was adopted to synthesize the existing crew or work design approaches. Further, meta-analytic findings from theoretical literature were also identified to determine significant soft and hard factors having direct or indirect causal effect on the performance of crews. This research contributes by providing a set of flow and work design characteristics to ensure joint optimization of both the *crew* and the *work* performed, resulting in better overall *crew performance*. Further, a Lean-based crew design model is proposed where the flow and work design characteristics are analysed to refine the initial crew design and maximize the crew performance based on lean crew design guidelines to achieve the *Lean Construction* ideals of minimizing waste and maximizing value for construction operations.

HYPOTHESIS

It is hypothesized that lean-based crew design guidelines will give rise to better overall crew performance, measured based on system throughput. Hence, using the developed guidelines for crew design, the following will be achieved, or at least approached:

- Executing the construction operations in the most efficient way.
- Minimizing waste in the construction operations.
- Maximizing value generation in the construction operations.

CREW AND WORK DESIGN CONCEPT

Designing "a team for work" or "work for a team" are different but complimentary aspects, and involve the design of "*group of workers/people*" and the "*work/job*" that needs to be executed by them (NB: design of work for a team is what we call in this community lean work structuring). Design of only one aspect would not lead to a joint optimization of both *work* and *team/crew*. When work is executed by a "*group* *of workers/people*” known as a “team”, “group” or “crew”, then the performance of this entity affects the performance of the overall work or the operation. In addition there are numerous decisions to be made regarding how the work is to be executed, how many workers need to be in a crew/team, what should be the composition of workers in a crew, sequencing of tasks, how the work should flow among the workers in a crew, and so on. In related literature, “Job Design”, “Work Design” or “Team Design” has been known by different names, but all of them generally mean the same.

Sundstrom et al. (1990) suggested that *work teams* have been extensively used to generate products or services, such as in manufacturing, maintenance, construction, mining, commercial, airlines, etc, and they “usually consist of first-line employees working together full-time, sometimes over protracted periods, with freedom to decide their division of labor”. Optimizing the performance of crews (production work teams) is a very essential element as “work teams are considered to be an integral tool aiding continuous improvement in work operations” (Cutcher-Gershenfeld and Associates 1994). For this research, Cohen and Bailey (1997) and Sundstrom (1990 1999) define *work teams* as “continuing work units responsible for producing goods and providing service.” We use this definition for a construction crew. Performance of work teams has been assessed based on different approaches such as productivity, efficiency, satisfaction, motivation, errors, stress, overburden/overload, reduced cost and time, quality of work performed, and customer satisfaction.

CREW DESIGN CHARACTERISTICS AND PERFORMANCE OUTCOMES

Through an extensive literature review of research studies on “work design/team design”, several design indicators/characteristics and their relation to different performance outcomes was determined (Gladstein 1984; Hackman 1980 1987; Hackman and Oldham 1980; Guzzo and Shea 1992; Niepcel and Molleman 1998; Steiner 1972; Davis and Wacker 1987; Campion et al. 1993 2005; Morgeson and Campion 2003; Morgeson et al. 2005 2006 2008; Medsker and Campion 2007; Cohen and Bailey 1997; Leach et al. 2005; Kozlowski and Bell 2003). In this paper, it is not possible to give the supporting literature and meta-analytic findings for all the characteristics; for that the reader is directed to Nerwal (2012).

Figure 1 show what we call “lean crew design” characteristics and summarizes the design characteristics into four main groups and provides the performance outcomes. Lean crew design characteristics are comprised of “primary crew design characteristics”, “intermediate crew design characteristics and outcomes” and “final crew performance outcomes”. The primary crew design characteristics are divided into two groups: (1) Work Characteristics and (2) Flow Characteristics. These are described in the following sections.

In general, performance is the ability to meet preset targets. In this research, crew performance is defined in terms of: (1) worker satisfaction; (2) worker motivation; (3) learning; (4) pride in work performed; (5) cost of work performed; (6) duration of work performed; (7) quality for work performed; (8) productivity.

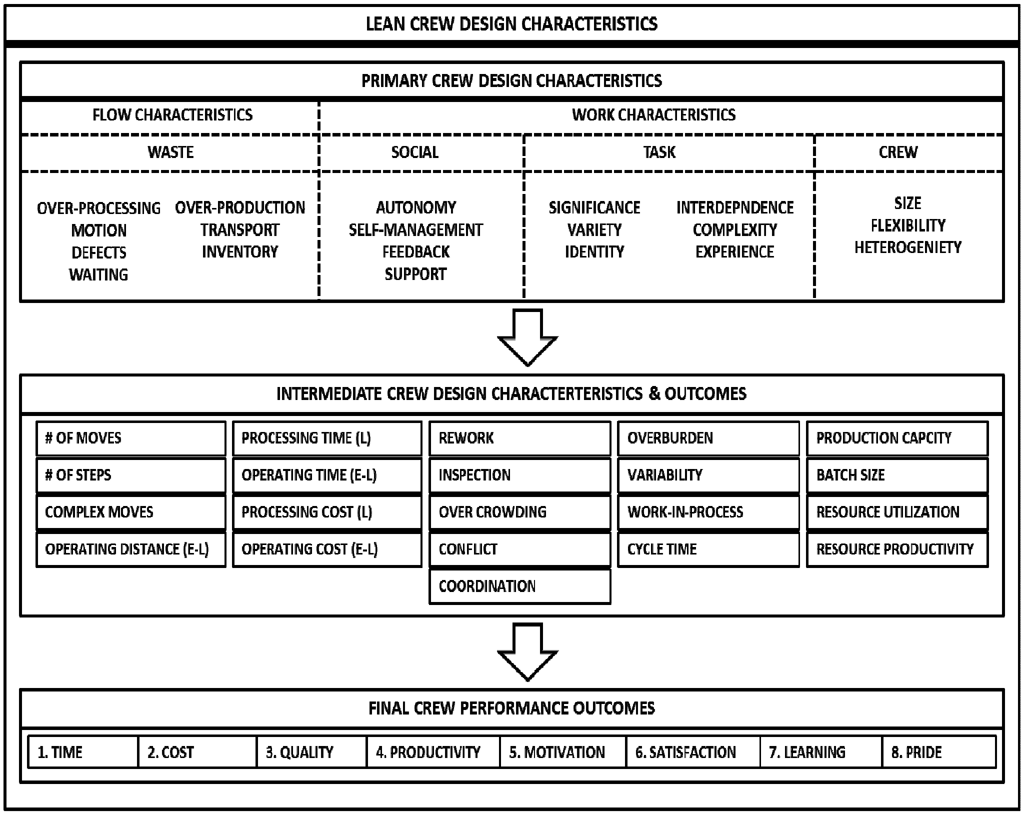

Figure 1: Lean Crew Design Characteristics

As shown in Figure 1, Crew, Task, and Social, are the further division of "Work Characteristics". For 'Crew', the factors are size, flexibility and heterogeneity. *Size* is the number of individuals in a team/crew/group and has shown to be related to performance. Crew size is positively related to productivity; negatively to work space available; and leads to increased coordination needs. Further, *flexibility* can be defined as the ability of crew members to perform each other's work/tasks; logically it is seen to be related to time, cost, satisfaction and learning. Lastly, *heterogeneity* relates to how a crew is composed in terms of its member's experience, skills etc and is positively related to support, learning, and motivation.

The 'work characteristic' *Task* is influenced by the factors: *significance, variety, identity, interdependence, complexity, and experience. Task significance* means the extent to which the group's work has significant consequences inside and outside the organization and the impact it has on the lives of others. *Task variety* means the extent to which workers (same skill level) are involved in a variety of tasks; it relates to the concept of job-enlargement from socio-technical theory allowing both interesting and dull tasks to be shared among members. *Task identity* is the degree to which the group/individual completes an entire or separate piece of work from start to finish and it may increase worker motivation by instilling a feeling of pride.

Further, t*ask complexity* is the extent to which a given task is difficult to perform or the "extent to which a task/job is multifaceted" (Humphrey et al. 2007). This was also called "Task Demand" by Mitropoulos and Namboodiri (2009). It is argued that reducing the complexity or simplifying work should generally lead to productivity gains. *Task experience* is the amount of time spent by a team/individual in performing a task; the number of times a similar type of task has been performed; or the prior amount of knowledge an individual has in performing that task. *Task interdependence* exists when a group of individuals get together and depend on one another to perform a certain work consisting of several tasks; and either start or finish of one task is dependent on the other tasks; and is related to cycle time, work-in-process or in process inventory, overburden, and work flow disruptions.

Under the “social” work characteristic, *Autonomy* means the “amount of freedom and independence an individual has in terms of carrying out his or her work assignment. Increased autonomy in execution of work leads to increased work satisfaction and motivation among the workers. *Self-management* is the group level analogy to Autonomy and is presumed to enhance performance or effectiveness by increasing the workers sense of responsibility and ownership of work (Campion et al. 1993; Manz & Sims 1980; Morgeson and Humphrey 2008; Medsker and Campion 2007).

Feedback is considered to be another significant characteristic. Feedback from others is the “extent to which members of the organization provide information about job performance whereas feedback from the job is the extent to which a job imparts information about an individuals’ performance” (Humphrey et al. 2007; Morgeson & Humphrey 2006). *Support* is another characteristic recognized in research studies, defined as the “extent to which there are opportunities for getting assistance and advice from supervisors and coworkers” (Morgeson & Humphrey 2006, 2008) Campion et al. (1993) suggested that “effectiveness may be enhanced when members help each other and have positive social interactions”.

The relationship between the different work characteristics (social, task, and crew) and job satisfaction is well documented in meta-analytic findings by Humphrey et al. (2007), and detailed in Nerwal (2012). An example of this data is as follows: *task significance* has impacts job satisfaction ($\rho = .41$) and work motivation ($\rho = .45$).

The relationship between primary crew design characteristics and the intermediate crew design characteristics and final performance outcomes depicted in Figure 1 is expanded in Figure 2. The graphical representation provides the effect each design characteristic would have on the intermediate and final performance outcomes of the crew design framework. Knowledge of these cause and effect relationships is of value in determining the optimal crew design. In this graphical representation, the plus sign denotes an increase (positive effect) and a minus sign denotes a decrease (negative effect) on the characteristic or outcome.

For example, reducing overproduction reduces the work-in-process which would mean less overburden among the workers. This would lead to decreased cycle time by the reduction in variability. And decreasing the cycle time would mean reducing the duration of the work performed. Hence careful consideration and evaluation of each of the work (crew, task and social) design characteristics must be made in order have a crew design which would lead to maximizing the performance outcomes.

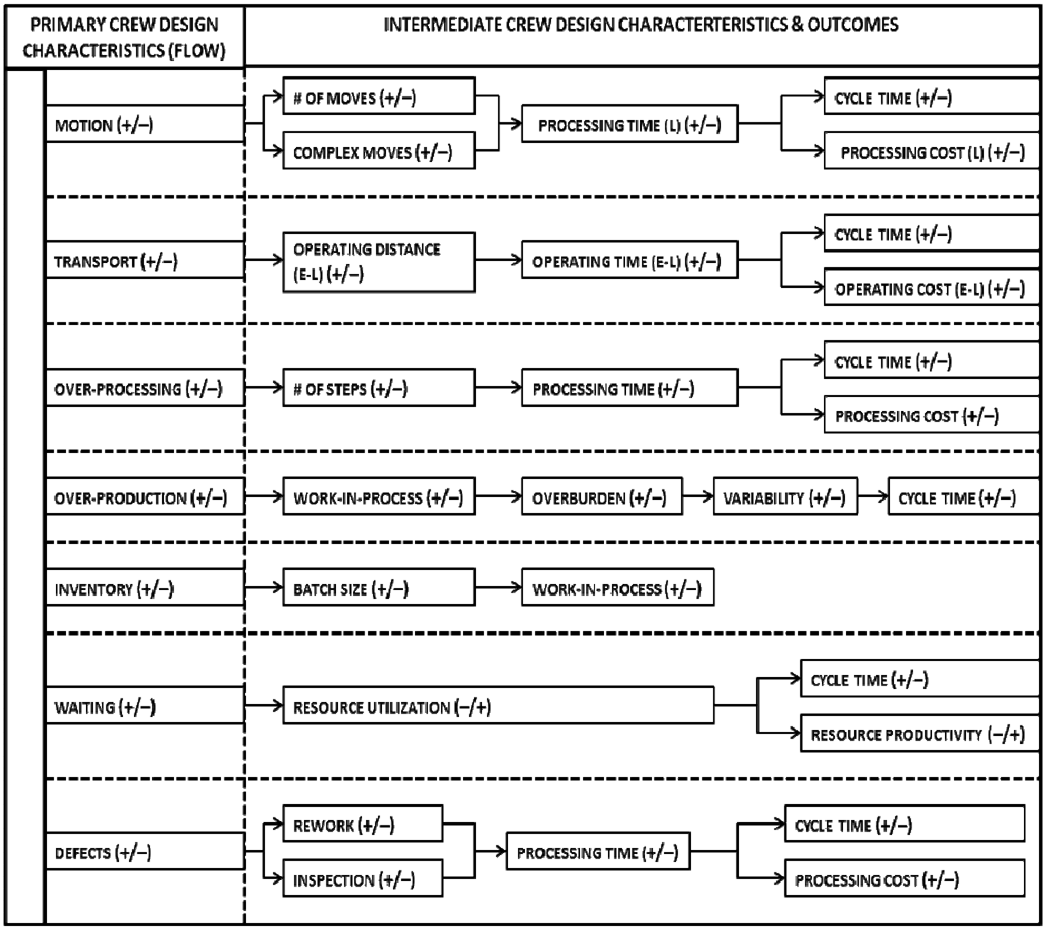

Figure 2: Graphical representation of the relationships between design (waste) characteristics and the performance outcomes.

LEAN CREW DESIGN GUIDELINES

The crew performance is optimized by (1) "Minimizing Waste" in the construction operations and (2) "Maximizing Value" generation in the construction operations. Minimizing "Waste" in the work performed by the crew is achieved by eliminating or reducing the types of wastes affecting flow characteristics. Maximizing Value" in the design of crews is delivered by optimizing all the eight performance outcomes: (1) duration of work performed; (2) cost of work performed; (3) productivity; (4) quality of work performed; (5) worker satisfaction; (6) worker learning; (7) worker motivation; (8) pride in work performed. The proposed guidelines follow.

(1) The ***"Duration of Work"*** can be optimized by improving and keeping the cycle time of the operation to a minimum. Steps involved in reducing the cycle-time of operations are as follows:

- Simplification of process and reduction of processing time
  a. Reduce the number of unnecessary steps in a process
  b. Reduce the number of moves required to execute each step in a process
  c. Reduce the task complexity/number of complex moves in each step in a process

   d. Reduce the operating distance to execute each step in a process
   e. Increase the movement speed for the operating distances

- Reduction of non-processing time
   a. Reduce transportation/motion time
   b. Reduce wait time
   c. Reduce set-up time
   d. Reduce inspection time
   e. Reduce rework

- Reduction of Variation
   a. Level the work load among each step of the process
   b. Reduce overburden
   c. Reduce work-in-process (WIP)
   d. Reduce the batch size
   e. Apply pull system

(2) The ***"Cost of Work"*** can be optimized by the following steps:

- Keep the crew size to minimum; Increase crew flexibility; Reduce processing cost; Reduce non-processing cost; Reduce defective products

(3) The ***"Overall Crew Productivity"*** can be optimized by the following steps:

- Increase task experience of crew; Reduce overburden; Apply advanced technology to labor and equipment; Increase resource utilization; Increase crew flexibility; Increase crew heterogeneity; Reduce task complexity; Reduce task interdependence

(4) The ***"Quality of Work"*** can be optimized by the following steps:

- Reduce defective products; Increase task experience; Reduce task complexity; Reduce overburden; Reduce task interdependence

(5) The **"Worker satisfaction"** can be optimized by the following steps:

- Reduce conflict; Increase coordination; Increase crew flexibility; Increase crew heterogeneity; Increase support; Increase task significance; Increase task variety; Increase task identity; Increase self-management; Provide reasonable autonomy; Increase feedback

(6) The **"Worker Learning"** can be optimized by the following steps:

- Increase coordination; Increase crew flexibility; Increase crew heterogeneity; Increase task experience; Increase task variety; Increase feedback

(7) The **"Worker Motivation"** can be optimized by the following steps:

- Increase coordination; Reduce conflict; Increase crew heterogeneity; Increase task significance; Increase task identity; Provide reasonable autonomy

(8) The **" Work Pride"** can be optimized by the following steps:

- Increase task identity; Increase self-management

LEAN BASED CREW DESIGN MODEL

In this research, the structure of the Lean-based Crew Design (LbCD) model was patterned after a transformation process structure where in inputs are converted to outputs by means of a conversion process. The proposed LbCD model is shown in the Figure 3 below.

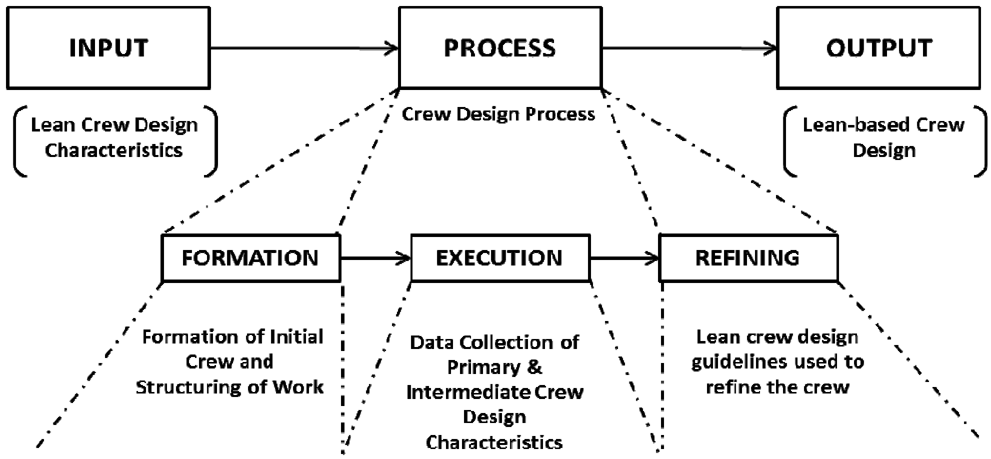

Figure 3: Lean-based Crew Design (LbCD) Model

As shown in Figure 3, the model input consists of the lean crew design characteristics, developed based on existing crew and work design approaches (outlined in Figure 1). The characteristics include both soft and hard factors from several scientific disciplines. The characteristics are used in the design process to develop the final crew design that will achieve the joint optimization of both the crew and work performed. The crew design process itself consists of three main phases, namely, formation, execution, and refining.

LEAN CREW DESIGN PROCESS

The three phases, namely: (1) formation, (2) execution, and (3) refining, are proposed to guide the crew design process in a production setting. It consists of the initial formation of the crew and structuring of work involved, followed by execution and refining of the crew.

In the *formation* phase, the initial crew formation is completed along with structuring of the work. In *formation of crew,* the pull plan teams (as in Last Planner® System) determine the standard crew, number of activities required to perform the particular work, list of tasks in a activity and activity/task durations. The initial size and composition of the crew is determined based on the amount of work/quantity that needs to be done generally by using standard construction industry data (example RS Means) or the contractors' own data and other work/job specific data. From these data, standard crew productivity is determined, which is used to calculate the activity/task durations or the standard unit crew days/time required to execute the work.

After the initial standard crew size and makeup, list of activity and tasks, and activity/task durations are determined, the structuring of work should be done by determining the sequence of tasks involved in an activity (This is at the level of the Make Ready and Weekly Work Planning in LPS®). Once the task sequence is determined, amount of work that needs to be executed by each crew member needs to be determined (including the amount assigned and released from each crew member).

In the second phase, *execution,* work is completed, in a simulated environment or a First Runs study fashion, by the initial crew determined in the formation phase. In addition, data collection of primary and intermediate crew design indicators takes place. Then these design indicators are analyzed in the third phase to refine the initial crew design and maximize the crew performance based on the lean crew design guidelines proposed in the previous section to a achieve a Lean-based crew design.

SUMMARY

In a dynamically changing construction environment, performance of crews is very crucial to the work being executed and consequently for the overall project performance. Also in early stages of a project, crew design in terms of crew composition and crew make-up is very important for scheduling and estimating functions. Despite its significance, only a modest research work has been seen such as work sampling conducted to improve labour utilization and production. Further, there are only a few research studies that take in account all the characteristics that affect the crew design.

In this research paper, an interdisciplinary approach was adopted to provide crew flow and work design characteristics and develop lean-based crew design guidelines. This framework is derived from well-developed theoretical and empirical studies in lean production, lean construction, and socio-technical system theory, social and organizational psychology. It provides important crew, task, social and waste characteristics along with several performance outcomes that should be considered in the design of crews. Further, the causal relationships between the primary design characteristics, intermediate performance outcomes and final performance outcomes provided in this paper guide the crew design process leading to the joint optimization of both the crew and the work performed, resulting in better overall crew performance.

Future research would include developing system dynamics and discrete event simulation models for a construction crew executing construction operations and testing the lean crew design characteristics for all the flow and work design soft and hard factors based on the lean crew design guidelines proposed in this research.

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