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Making Sense of Highway Construction: A Taxonomic Framework for Ergonomic Exposure Assessment and Intervention Research

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Construction is one of the most hazardous industries in the United States. Occupational health research to characterize the hazards in construction work has been hampered by the lack of a systematic approach to classification of construction work and its associated hazards. A taxonomy of construction work, a nested system of classification, has been developed to systematize the collection and reporting of exposure assessment data for the characterization and reduction of hazards and the prevention of musculoskeletal injury. This taxonomy subdivides construction work into the categories of stage, operation, task, and activity. It is based on a bidding specification system already in use within the industry and thus provides a terminology common among workers, supervisors, and managers. The identification of tasks and activities that are present in multiple stages and/or trades contributes to the efficiency of exposure data collection and facilitates the generalizabilty to other settings for both exposure data and intervention evaluations. The taxonomy provides a framework and vocabulary that facilitates field work and participatory research activities. It can also potentially be linked to personnel and economic data for estimation of costs of safety and health problems, as well as benefits of interventions. Although developed for construction ergonomics, the taxonomic approach has application to non-routine work in other industry sectors and possibly in occupational health research other than ergonomics.

Keywords Construction, Ergonomics, Exposure Assessment, Intervention Research, Participatory Research

Until the early 1990s, the construction industry had the highest incidence of injuries and illnesses of all industrial sectors in the United States. While reported injury and illness rates for construction steadily declined through the 1990s, the total injury rates in construction are still the highest of all industrial sectors (8.4 per 100 full-time workers). The severity of the injuries and illnesses experienced in construction is also an issue. In 1998 and 1999, the construction industry had the highest reported rate per lost workday (LWD) injury rate (3.3) among industrial sectors. Within the construction sector, injuries and illnesses in highway and street construction were above average, with an incidence rate of 8.9 per 100 full-time workers.[1]

Physical loading of the musculoskeletal system has repeatedly been shown to be associated with risk of musculoskeletal disorders (MSD).[2,3] Commonly cited risk factors for MSDs include strenuous manual material handling; repetitive and/or forceful exertions; awkward postures of the trunk, neck, shoulders, arms and legs; temperature extremes; and segmental vibration. Considering the strenuous work that they perform, construction workers have elevated risks for developing work-related musculoskeletal disorders of the back and the extremities.[4–10] However, the ergonomic hazards specific to most construction job tasks have been poorly characterized, and the generalizability of exposure data to construction projects in other places and time periods is usually unknown.[11]

The lack of exposure information on construction work is due, at least in part, to the nature of the work itself. In most modern manufacturing settings, production employees generally perform a job comprised of only one or a few tasks. Unless a new line or cell is introduced, the environmental characteristics of the plant remain fairly constant. The cyclic and non-variable nature of manufacturing environments is conducive to obtaining representative data on an employee's job demands and work environment fairly quickly using either observation or direct measurement methods.

Unlike most manufacturing plants, construction work sites are highly dynamic; the nature and magnitude of ergonomic hazards change daily because of the physical changes made to the construction site during the construction process (e.g., built

structures, scaffolding, trenches, etc.), the technology employed by the contractor (e.g., heavy machinery, manual labor), and environmental conditions (e.g., climatic conditions). Because construction trades generally have different responsibilities, the ergonomic hazards may also vary considerably among trades. Additionally, the work performed by an individual worker is generally constantly changing (non-cyclical) or has long and irregular cycles (i.e., cycle times may vary or cycles may have different elements). This dynamic nature of construction work makes characterizing the ergonomic hazards more challenging than repetitive jobs such as assembly line work or data entry at a video display terminal.

Researchers interested in characterizing ergonomic hazards in construction have addressed the logistical difficulties through the development of exposure assessment methodologies that employ work sampling techniques.[12–15] These methods provide estimates of the frequency of exposures to certain ergonomic stressors for individual tasks and the frequency of each of the tasks over the period of observation. However, in order to generalize these results to the entire workforce for geographical and temporal extrapolation, it is necessary to know when and who performs similar activities in other stages of the construction process. To estimate ergonomic exposures over etiologically relevant time periods for epidemiologic studies or to identify the most frequently performed tasks with the highest exposure levels for intervention research, these ergonomic assessments must be made within the context of the entire construction process. This need led us to develop a broad model or taxonomic framework to provide more complete and accurate exposure assessment. Providing a model applicable to the entire construction project permits improved identification of potential high impact ergonomic controls, that is, those that would benefit the most workers and/or impact the greatest amount of person-time.

This article describes:

1. an existing framework for characterizing highway construction work;
2. how this model has been adapted to the evaluation of ergonomic hazards and interventions;
3. the application of the construction taxonomy, or nested system of classification, to both systematic exposure assessment and participatory intervention research activities.

METHODS

The Massachusetts Standard Specifications for Highways and Bridges (SSHB) is a system developed by the Massachusetts Highway Department (MHD) to classify construction work hierarchically and systematically.[16] The SSHB includes descriptions of the major highway construction stages and a sequence of specifications for construction tools, methods, and materials for all sections (subtypes) of each stage. This system is a distillation of construction engineering practice and has been developed mainly to provide specifications on work methods, the types and quantity of materials used, and quality of the structures built for bidding, quality control, and billing purposes. Contractors usually use the SSHB's standardized terminology when developing construction schedules that are communicated to supervisors and construction workers. Therefore, contractors, supervisors, and construction workers are familiar with the classification system. Because contractors and workers understand this system and because personnel data (person-hours devoted to a particular process) can be linked to it, it serves as a useful foundation upon which to base both ergonomic hazard evaluation and communication of research results to the construction industry and unions.

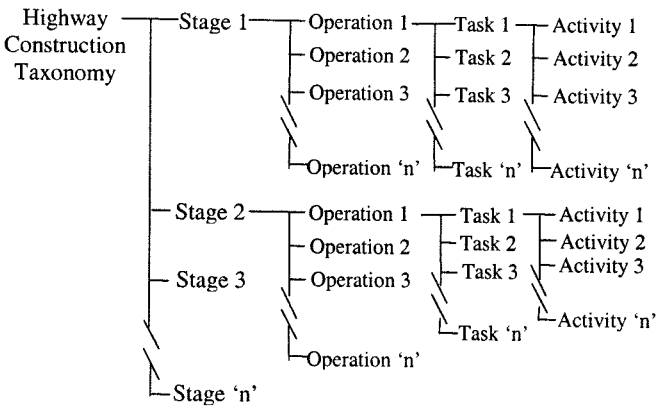


FIGURE 1
Taxonomy of construction work.

This hierarchical system was used to develop a taxonomy for assessing and characterizing musculoskeletal exposures associated with specific construction tasks (Figure 1). The taxonomy described here uses the same basic SSHB hierarchical framework of stages, but it differs in several ways:

- It is much more detailed with regard to the actual work content; several levels of subdivisions (operations, tasks and activities) were added and defined;
- Work is classified in ways that more closely resemble how it is scheduled and performed on the construction site;
- The classification system provides a vehicle for organizing information in what often appears to be a disorganized setting to the outside observer; and
- The classification system provides a vehicle for comparing task-specific ergonomic exposures when the same or similar tasks are performed in more than one stage or operation of a construction project and for comparing exposure data (quantitative or qualitative) from one construction project to another.

The taxonomy has four levels: construction *stages*, which are divided into *operations*; the tasks performed during each operation; and *activities* performed within each task. These levels of classification are defined as follows:

Stages are taken directly from the SSHB's list of construction details. These are large engineering processes that are overseen by engineers and other off-site management personnel. The beginning and end of a construction stage is marked by at least one important change in the construction process (e.g., changes in goals, technologies, or personnel). The construction stages described in the SSHB are modified as necessary to reflect the unique characteristics of the construction site and project. For example, the SSHB does not describe a tunnel explicitly, although the relevant specifications can be found under stages such as Excavation and Structures.

Stages are generally ordered sequentially, but for large construction projects, different stages can occur simultaneously at different locations on the site. The location and sequence of the stages does not appear to be important with regard to ergonomic exposures, although this has not been evaluated directly. The sequence of the stages does matter for industrial hygiene exposures, because abutting stages and operations may greatly influence bystander exposures.

We defined an *operation* as a component step of a stage. It is a construction process overseen by a foreman and other on-site supervisors and is performed by at least one crew of workers. On any given project, only some operations in a stage may be performed. For example, whether a structure is built of concrete, wood, or steel determines whether operations such as pouring concrete or structural steel erection are necessary. A drainage installation operation may also require a utility relocation operation if utilities are in the path of the new drainage system. Information such as this is obtained through interviews with designers, contractor personnel, and supervisors. Contractors also have a schedule of operations for each stage. Such a schedule is particularly valuable to the researcher for operations that are not specified per se in the SSHB.

We defined *task* in the standard manner as a sequence of steps or activities performed by an individual worker or a group of workers to accomplish a specific purpose or "functional objective."[17] Stammers and Shepherd have noted that, although the concept of "task" is central to most job analysis systems, there is no widely agreed-upon definition that is independent of the setting in which it is used.[18] For any given highway construction operation, a trade is usually responsible for between one and five tasks. Tasks are not specified in the SSHB. They are generally identified by interviewing workers and by direct observation. Other common methods, such as use of job descriptions or historical data, are not generally a useful option for analysis of construction work.

To date, we have found that tasks within an operation do not depend on the stage in which it is performed. For example, Concrete Masonry operations are found in the stages of Structures, Drainage, Paving, Utilities, and Incidental Work, and the tasks of pouring concrete, spreading concrete, and smoothing concrete have been observed consistently in the Concrete Masonry operation in each of the stages. However, the *exposures* associated with a specific task may be affected by the stage in which it is performed because that affects the physical conditions of the work (e.g., whether a vertical wall or horizontal surface is being built).

Finally we define *activities* as the physical actions performed by an individual worker to achieve a simple work goal. Activities are comprised of cycles of work elements (as defined by industrial engineers in time study methodologies, i.e., lift, lower, reach, wipe, etc.) and are transferable from one worker to another.[19] For example, the activity of "hammering" would include the work elements of grasp hammer, position hammer, strike nail, and set hammer aside. Determining the activities in which the most severe exposures occur also guides prioritizing activities for intervention.

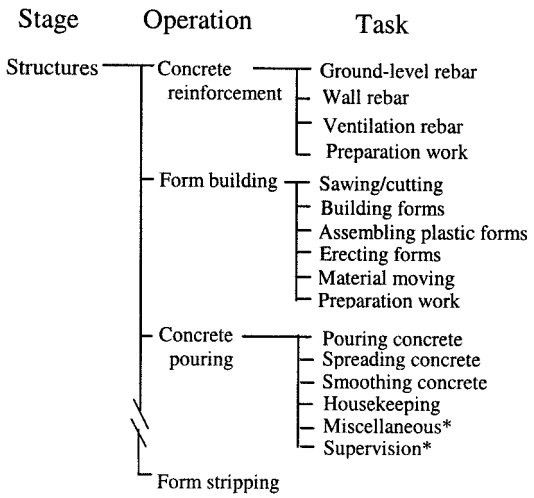
These elements of our taxonomy need to be understood in the context of the construction trades. A trade is a group of workers defined by their training and specialization. One or more trades is involved in each operation. For construction sites that employ union construction workers, the job tasks performed by trades are defined by jurisdiction and by collective bargaining agreements. Therefore, there is generally little overlap of job tasks between trades. It is useful to identify the trades performing each task, because this may have important consequences for problem solving, communication, and strategizing. However, specific trades assigned to perform the various tasks within an operation can often not be generalized from one geographical location to another. Therefore studies that attempt to link work-related exposures of a construction trade to personnel data (e.g., OSHA recordable injury data, pay rates, absenteeism) should evaluate the specific tasks performed by the trade and not assume that trade alone is sufficiently specific.

RESULTS

The value of the taxonomy can be demonstrated in its application to the study of ergonomic hazards on a single, very large highway construction project. The Central Artery/Third Harbor Tunnel (CA/T) is a 15-year, multi-billion–dollar project involving the construction of a new underwater tunnel, underground highway, a cable-span bridge, and multiple highway interchanges in Boston, Massachusetts. Between 1990 and the project's completion 15 years later, dozens of contractors and over 5000 construction workers will have been involved with its construction. Large construction projects such as this consist of multiple stages, each having multiple operations that require a variety of tasks to be performed by different skilled tradespersons. It would have been nearly impossible to characterize the ergonomic hazards associated with this construction project without first systematically breaking down the construction process into smaller units of work.

Example 1: An Overview—the Tunnel Structures Stage

A major proportion of the CA/T has been tunnel building. Broadly this encompasses three stages: Excavation, Concrete Structures (formwork), and Finishing. These stages represent the way in which the Massachusetts Highway Department



* Miscellaneous and Supervision tasks consist of activities that do not apply to the core tasks (e.g., communication between workers about the overall progress of the project). In large operations such as the one illustrated above, there will usually be at least one supervisor.

FIGURE 2

Taxonomy of highway construction applied to the Structures stage involving reinforced concrete masonry for a large tunnel construction project. Tasks associated with the form stripping operation, heavy equipment operation, and materials transportation are not shown.

used the SSHB to award the construction contracts and represent generalizable types of work recognized by construction engineers. The operations that comprise the stage of Tunnel Construction (one type of Structure) have been studied extensively by our group, in part because this project represented an important opportunity to collect data on construction work not performed in many projects. The operations within the construction stage are used here (Figure 2) to illustrate the taxonomy of highway construction work in more detail, along with the tasks that have been observed in the parts of these operations studied.

On the CA/T construction project, ergonomic exposure information has been collected through a variety of exposure assessment methods, including worker interviews and focus groups, evaluation of videotapes and photographs, systematic job analysis, a standardized checklist, and PATH, a work sampling-based observational approach used to quantify the percent of time during which workers assumed awkward postures, used tools, and handled heavy loads.[12] Worker interviews allowed us to collect information on aspects of the tasks that are unobservable such as workers' perceptions of the physical and environmental characteristics of the work and whether the tasks were similar to those performed on other sites. The PATH method, a work sampling method, incorporates elements of OWAS and structured ergonomic job analysis to characterize specific exposures such as repetitive motions, forceful exertions, awkward body postures, localized contact stresses, temperature extremes, and vibration that exist in each task.[12,20,21]

The taxonomy has provided a framework within which diverse types of data can be organized to give a composite overview of the operations observed (e.g., Figure 2), with the level of detail available depending on the data collection method. Once ergonomic hazard assessments are completed for each task, tasks and operations can be prioritized for intervention based on the severity of each ergonomic hazard separately or based on the total amount of person-time spent in those and similar tasks.

Example 2: Systematic Exposure Assessment and the Use of Ergonomic Controls in Highway Tunnel Finishing Stage

On the CA/T construction project Tunnel Finishing involved the finishing of a four-lane, two-mile tunnel consisting of tiled walls and a paneled ceiling. This stage consisted of many discrete construction operations, including plastering the unfinished walls, wall tiling and grouting, ceiling panel assembly, panel installation, ventilation duct installation, light trough installation, and utility room installation, among others. Trades employed included laborers, plasterers, tile mechanics and finishers, ironworkers, carpenters, cement masons, and electricians.

The taxonomy provided the framework for a study of the ergonomic hazards and the development of potential solutions for the tunnel finishing operations. The tunnel finishing site was visited two or three times per week for one year. Descriptions of the finishing operations were obtained from documentation provided by the contractors. Information about the trades, person-time, and job tasks of each operation were obtained primarily through employee interviews and direct observation. Using the taxonomy, the results of the ergonomic analyses were organized to identify the job tasks with the most severe hazards performed most often by the largest number of people. The taxonomy for the stage of Tunnel Finishing is illustrated in Figure 3, and application of the taxonomy to exposure assessment is provided in Table I.

The operations of wall plastering, wall tiling, and ceiling module assembly involved the greatest amount of person-time and also were in the greatest need of ergonomic improvement. Researchers worked with the contractors and workers on interventions designed to reduce the ergonomic exposures associated with tasks required during wall tiling and ceiling panel assembly. Successful changes included manual materials handling (MMH) aides such as pulleys and dollies to reduce heavy MMH and awkward body postures for the tasks of "Install tile" and "Prepare/mix/deliver thinset" during wall tiling, and improved work heights and use of gravity assisted rollers to improve MMH activities for the ceiling module assembly tasks. Some tasks were re-evaluated after the interventions were put in place, and many of the ergonomic exposures associated with the tasks were shown to have been eliminated or reduced. (See Buchholz et al. for a detailed description of the evaluation.[22])

While the ergonomic evaluations could have been carried out without knowing how these operations fit into the entire

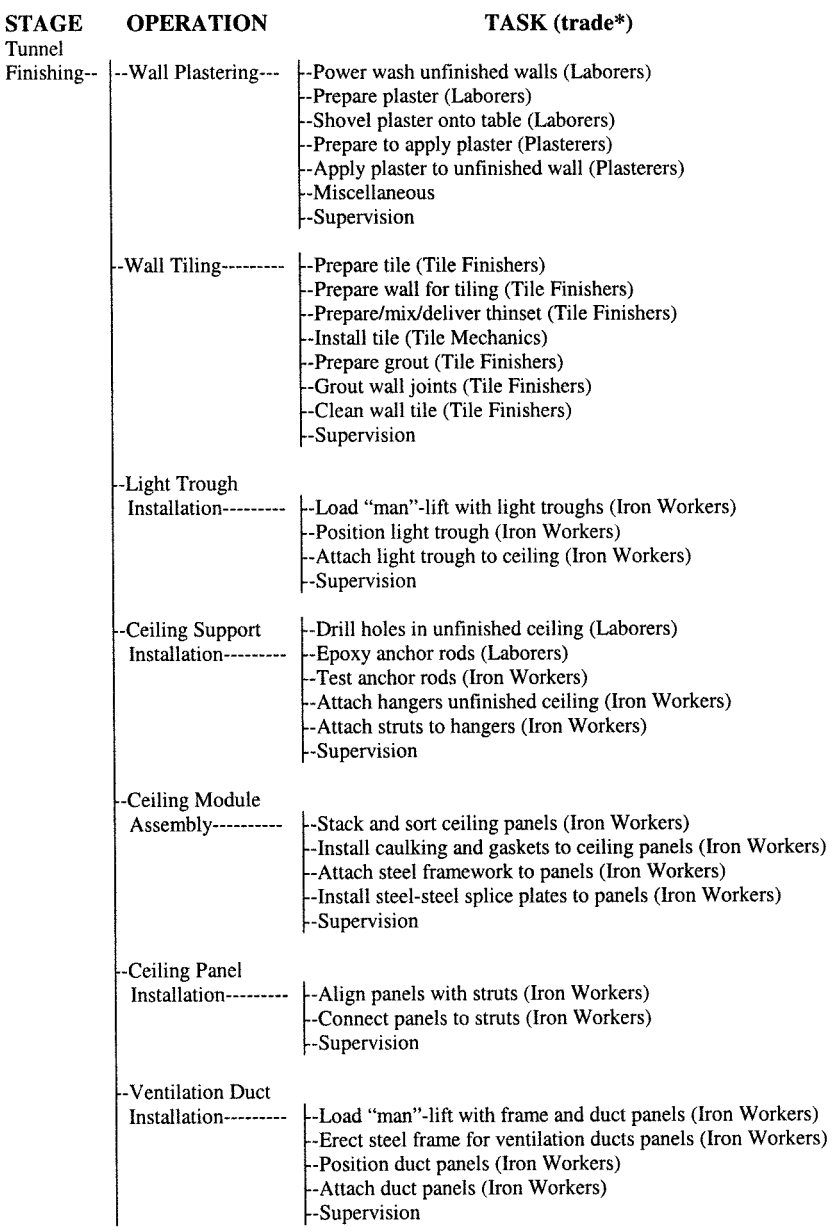


FIGURE 3

Taxonomy of the tunnel finishing stage of a large highway construction project. Wall and ceiling finishing operations shown. Floor finishing operations and mechanical installations are not shown.

scope of the CA/T, reporting the results in the context of the taxonomy permitted us to identify more easily where else on the CA/T the same problems might occur, and allowed ergonomists and construction managers in other locales to recognize more easily whether these results were relevant to their sites. Thus, understanding when and where these activities occur facilitates using data already collected to identify future opportunities for hazard prevention.

Example 3: Application of the Taxonomy to Participatory Intervention Research

Another particularly useful application of the taxonomy is in providing a common language for use by researchers and members of the construction industry to describe construction processes, their hazards, and possible interventions. Researchers applied the taxonomy in a participatory research project called "Health Trak." Prior to a time-limited participatory intervention

TABLE I

Application of the construction taxonomy in the ergonomic job analysis of three Tunnel Finishing operations

		Ergonomic evaluation methods						
Operation	Job tasks	Video analysis	Observation	Interviews	Photographs	Erg. job analysis	Work sampling	Ergonomic exposures identified
Wall plastering	Power wash walls		√					Frequent awkward trunk postures, repetitive motion of arms
	Prepare plaster	√	√					Heavy repetitive lifting, twisting, and bending while lifting
	Shovel plaster onto table	√	√					Frequent awkward trunk postures, repetitive motion of arms
	Prepare to apply plaster	√	√	√	√	√	√	Frequent hand tool use and non-neutral trunk postures
	Apply plaster to unfinished wall	√	√	√	√	√	√	Static loading on shoulders, repetitive/forceful hand exertions, frequent awkward postures, and hand tool use
Wall tiling	Prepare mix	√	√	√	√		√	Heavy manual material handling (MMH)
	Prepare tile	√	√	√	√		√	Heavy MMH, frequent awkward trunk postures
	Prepare wall for tiling	√	√	√	√		√	Heavy MMH
	Tile installation	√	√	√	√		√	Frequent awkward trunk, arm, and knee postures
	Prepare grout	√	√	√	√		√	Heavy MMH, frequent awkward trunk and knee postures
	Grout wall joints	√	√	√	√		√	Static loading on shoulders, frequent wrist motions, frequent awkward trunk and knee postures
	Clean wall tile	√	√	√	√		√	Static loading on shoulders, frequent wrist motions, frequent awkward trunk and knee postures
Ceiling module assembly	Panel Sorting	√	√	√	√	√		No major hazards identified
	Panel preparation	√	√	√	√	√		Heavy MMH, static awkward postures of the trunk and knees
	Submodule assembly	√	√	√	√	√		Heavy MMH, static awkward postures of the trunk and knees, repetitive and awkward wrist postures
	Module assembly	√	√	√	√	√		Heavy MMH, static awkward postures of the trunk and knees, repetitive and awkward wrist postures

activity, researchers and research participants identified a single high-hazard operation. The taxonomy of this operation's tasks and activities then provided the framework for participatory ergonomic job analysis as workers and supervisors involved in the operation identified hazards and potential design solutions.

Health Trak is an intervention program involving labor and management representatives in identifying solutions to health problems on construction sites and attempting to implement and evaluate those solutions.[23,24] The operational unit that carries out this plan is a joint labor/management committee that meets on-site for an hour each week for eight weeks (Health Trak Committee). The goal for this committee is to complete a process of identifying hazards, designing risk-reducing interventions, and implementing and evaluating at least one intervention during that time period.

Early Health Trak cycles had limited success and evaluation showed that this resulted from trying to address too broad a realm of hazards. Researchers decided to focus on a particular construction operation and to limit hazard analysis to musculoskeletal hazards and ergonomic job analysis. Researchers and the participating contractor's representatives identified Concrete Formwork Assembly as the operation of interest. For this effort, the Health Trak Committee was composed of carpenters' and laborers' stewards, a carpenters' foreman, an engineer, and the contractor's site safety manager.

The method used to facilitate the committee's hazard identification activity was risk mapping.[25–27] This method allows full participation by all members of the group and results in a very complete graphic representation of the hazards of a particular workplace. In this instance, however, the Health Trak Committee mapped not a particular workplace but a generic operation, concrete formwork assembly.

The researchers provided the committee with a long sheet of butcher paper covering a conference room table and an assortment of colored markers. Committee members were asked to draw the steps needed to complete Concrete Formwork Assembly operations. Researchers facilitated the activity by asking probing questions such as, "What happens first?," "What comes next?," and "Who does that?," and by noting details of activities on the drawings. In two one-hour meetings, the committee completed drawings of the seven tasks that comprise the operation of Concrete Formwork Assembly and identified the constituent activities for each task (Figure 4).

Over subsequent weeks, the Health Trak Committee used their taxonomy as a framework to conduct an ergonomic job analysis on Concrete Formwork Assembly (Table II) and to identify over two dozen potential interventions to reduce MSDs (Figure 5).

The taxonomic approach allowed researchers and the Health Trak Committee to communicate with common vocabulary across conceptual barriers and led to the efficient production of a detailed ergonomic job analysis and an extensive list of potential interventions. Enhanced communication improved the participatory research process. A complete and detailed taxonomy

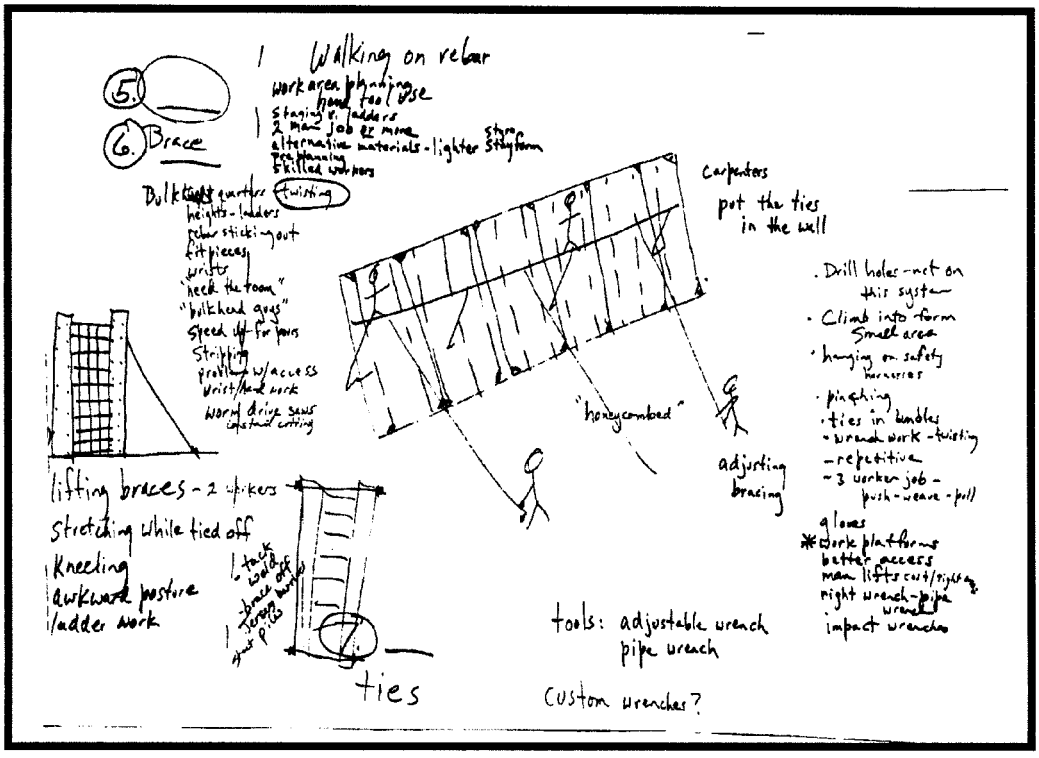


FIGURE 4
A portion of the Health Track Committee's risk map of tasks in the operation: Concrete Formwork Assembly.

TABLE II
Summary of Health Trak Committee ergonomic job analysis of Concrete Formwork Assembly

Task	Activity	Hazard	Body area
Unloading truck to laydown area	Moving forms and hardware	Awkward postures	Back and shoulders
	Breaking down hardware	Forceful exertions	Back and shoulders
		Awkward postures	Back and shoulders
Assembling gang forms	Adjusting/prying forms	Forceful exertions	Back and shoulders
		Awkward postures	Back and shoulders
	Bolting with speed bolts	Awkward postures	Back, shoulders, forearms, wrists, and hands
		Repetition	Forearms and wrists
		Contact stresses	Knees and hands
Placing gang forms	Adjusting/prying forms	Forceful exertions	Back and shoulders
		Awkward postures	Back and shoulders
Bracing gang forms	Lifting and positioning braces	Forceful exertions	Back and shoulders
		Awkward postures	Back and shoulders
Inserting ties	Bolting ties to panels	Awkward postures	Back, shoulders, forearms, wrists, and hands
		Repetition	Forearms and wrists
		Contact stresses	Knees and hands
Building bulkheads	Weaving and tying metal between rebar	Awkward postures	Back, shoulders, forearms, wrists, and hands
		Repetition	Forearms and wrists
		Contact stresses	Hands

was constructed in less than two hours, leaving time for the completion of the other goals set for a time-limited intervention research activity. In addition, use of the taxonomy in the Health Trak process resulted in the identification of hazards that researchers may have missed. Two examples were transferring small hardware, which is very hand intensive but essential to the operation, and using a prybar to set form precisely, which requires great force but occurs rarely.

DISCUSSION

Construction work typically involves many persons performing different, specialized tasks, usually with no visible work cycles or patterns. This makes it challenging for an outside observer to determine how to extrapolate from the work period observed to the larger population of workers on site. We have described a system for characterizing units of construction work that facilitates such extrapolation.

In highway construction, most operations are specific to a single stage, whereas many tasks are common to multiple operations. The taxonomy is useful for exposure assessment purposes because it provides a structure within which we can identify those tasks that occur in multiple stages and/or operations and group together tasks with similar exposure profiles. This means greater efficiency in data collection because we can avoid spending time analyzing tasks that have already been observed unless the environmental characteristics are markedly different. One example of a task that is repeated in nearly every operation is Supervision. It was evaluated for the operation of Wall Finishing, and minimal exposure to ergonomic stressors was found compared to the other tasks. Subsequent observation of ironworkers and tile mechanics also showed that they experienced few exposures during Supervision, supporting the conclusion that it would not be necessary to evaluate Supervision in the future for physical stressors.

To date, experience indicates that task-specific exposures can be generalized from one operation to another, provided that the scale of the construction work remains in the same category of residential, commercial building, or heavy/highway. For example, ironworkers tying vertical rebar have similar exposures wherever this task has been observed on the CA/T. However, on a smaller project, the rebar itself would be smaller and lighter, and mechanical lift assist devices may not be provided. Carpenters building forms would similarly be affected by the scale of the project because this would determine whether forms were made of wood or plastic composite, whether they were pre-fabricated, whether a temporary construction shop was set up onsite, and so on.

This taxonomy is based on the bidding specification system already in use within the industry and thus provides a common terminology with workers, supervisors, and managers. The identification of tasks and activities that are common to multiple stages and/or trades increases the efficiency of exposure data collection and facilitates the generalizability to other settings of both exposure data and intervention evaluations.

1. Truck unloading
- Unbinding and moving loads:
  - Awareness of safe strapping release and band cutting methods
  - Watch for bystanders
  - Don't stand on loads when unbinding
  - Let vendor know of unsafe loads
  - Have vendor pre-rig loads
  - Watch for pinch/crushing hazards when moving loads
- Moving/handling hardware: most are in cartons on pallets and can be picked with crane

2. Laydown area
- Provide designated laydown area with enough room for panels and hardware: difficult for current formwork but will future work be different?
- Moving/handling hardware
  - Look at weights of cartons and how they are handled
  - Transfer hardware into skip pans or containers that can be picked by crane and lowered in pit
  - Provide wheels/casters on containers so they can be pushed
- Stacking forms: offset or stagger to allow easier/quicker stacking, reduce pinch points, and provide room to remove/install lifting eyes

3. Gang form assembly
- Provide designated area for panel assembly: difficult for current formwork—will future formwork be different?
- Tools: Use electric or pneumatic impact wrenches for speed bolting panels; evaluate tools for ergonomic benefits/costs and purchase best tools
- Switch off workers doing repetitive, forceful, awkward posture jobs

4. Placing gang form (Depends on crane location, use of taglines, size of form, and wind)
- Look into longer, lighter pry bars
- Use forms with pry groove/easy access to pry point

5. Installing bracing
- Move braces to placement area with crane
- Attach braces to gang form before placing (requires adjustment of brace after placement and adjustment is high up)
- Hold up braces with rope looped through form when securing to panel

6. Building bulkheads
- Preplan to improve access (improve by excavating enough around forming area and use staging instead of ladders)
- Make two or more person job
- Use alternative, lighter materials (i.e., styrofoam) or Stayform materials (doesn't need to be removed)

7. Putting ties in
- Preplan to improve access to bolting area (improve by excavating enough around forming area and use personnel lift or staging)
- Use the right tool for the job (long enough wrench or electric or pneumatic impact wrench)

FIGURE 5
Solutions for reducing hazards in formwork assembly (Health Trak Committee).

Information about the total person-time allocated to each construction operation may be available from contractor production schedules, although the contractors sometimes consider this information to be proprietary. Information about the person-time allocated to specific job tasks can be obtained through on-site observational methods (e.g., work sampling) or worker and supervisor interviews. It can also potentially be linked to personnel and economic data for estimation of direct costs of safety and health hazards.

Another application of the taxonomy concerns the collection of exposure information for epidemiologic research. Two continuing challenges in exposure assessment are how to reconstruct an exposure history when work tasks are no longer being performed at the present time, and the level of detail in work histories and exposure characterization that can accurately be obtained from individuals' self-reports. With the structure provided by the taxonomy, work history questionnaire items can be worded in terms of units (operations and tasks) that are known to the workers and can be grouped together to the extent that their exposures have been observed and found to be similar. This can help to reduce the burden of recall and judgment placed on the respondent and to maximize the utility of the information collected. As the database of observed ergonomic hazards in specific operations and job tasks becomes more complete, more accurate ergonomic exposure histories for construction workers can be developed for epidemiologic research.

In the sparse literature to date, most studies have compared rates of acute injuries or musculoskeletal disorders among construction occupations.[28–30] While occupation-specific risks are important to identify, this approach does not identify specific, preventable exposures and also does not provide the information with which to determine whether similarly named jobs in other localities would entail the same risks. A few studies have collected detailed data on specific activities or exposures.[31–33] While permitting identification of causally relevant exposures, without identification of the tasks or operations in which those activities occur, more information is needed in order to target prevention efforts in a feasible manner and it may be difficult for other researchers to determine whether similar exposures would be found in similarly named jobs. The rare combination of task and exposure information permits both generalizability and insight into the role of specific exposures in etiology.[34]

Although developed for construction ergonomics, the taxonomic approach has potential application in ergonomics activities conducted in other non-cyclical work ranging from maintenance work to healthcare and possibly in occupational health research other than ergonomics.[35–39]

CONCLUSIONS

More effective exposure assessment and intervention research requires improved data collection and greater collaboration with subject populations. The development of a taxonomy of construction work aids researchers in making sense of the dynamic and often confusing construction workplace. It can also provide the basis for a jointly constructed framework for collaborative research on hazard identification and implementation and evaluation of interventions. This article has described the use of a taxonomy of construction work in exposure assessment and participatory intervention studies.

There are a number of advantages to using the construction taxonomy to better describe and characterize the construction work environment:

- It provides a systematic classification system of large construction processes that nests tasks within operations and stages;
- Workers and contractor personnel are familiar with the classification scheme and therefore hazards can be efficiently communicated to the parties involved;
- It is compatible with exposure assessment methods whether they link exposures to activities, tasks, or operations;
- It can be used with construction contract specifications or production schedules to anticipate future ergonomic hazards; and
- It facilitates efficiency and accuracy in the collection of ergonomic exposure data for epidemiologic and intervention studies.

We hypothesize that the taxonomic approach can be useful in researching dynamic work environments other than construction and in characterizing workplace hazards other than ergonomics.

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