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Macroergonomics as an organizing process for systems safety

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ABSTRACT

Hendrick is attributed with the formalization of organizational design and management (ODAM) in ergonomics [Hendrick, H.W., Kleiner, B.M., 2001. Macroergonomics: An Introduction to Work System Design. Human Factors and Ergonomics Society, Santa Monica, CA.]. Specifically, the method called "Macroergonomic Analysis of Structure" or MAS provides a framework and analysis of these factors and provides the context for an analysis of organizational design and management process through the MacroErgonomic Analysis and Design method (MEAD). Together, MAS and MEAD represent the formalization of staple methods in macroergonomics and can be used to organize existing tools and methods such as those that exist in systems safety and help to differentiate macroergonomics from other approaches. This article illustrates such an integrative role for macroergonomics with respect to systems safety using the example of the construction sector, a domain in which accidents, injuries and fatalities are all too common.

1. Introduction

Macroergonomics is a top-down sociotechnical system approach to the design of work systems and the application of the overall work-system design of the human–job, human–machine, and human–software interfaces (Hendrick and Kleiner, 2001). It is the formalization of attention to organizational design and management factors in ergonomics (Hendrick, 1991). Macroergonomics is based on the sociotechnical systems framework which dates back to English coal mine studies performed by Trist and Bamforth of the London Travistock Institute (Trist and Bamforth, 1951).

Macroergonomics adopts a "systems ergonomics" perspective. Nigel Corlett of the United Kingdom is attributed with a perspective that a larger systems perspective is beneficial in the study and application of ergonomics (Hendrick, 1991). This perspective is operationally coined, "systems ergonomics". Essentially, the human factors model of human–machine performance is based on a systems approach that attends to the complex interaction of major subsystems including task, operator, machine and environment (Czaja et al., 1983) and presumes a high level of cooperation and involvement of operators.

If systems ergonomics adopts a multiple subsystem philosophy (Hendrick, 1991), is participatory and has been defined in terms of several subsystems (e.g. Czaja et al., 1983), then how can macroergonomics be differentiated? It is suggested that macroergonomics' uniqueness centers on its special attention to organizational design and management factors within the multiple subsystem, sociotechnical perspective. Specifically, it is Hendrick's articulation of the Macroergonomic Analysis of Structure (MAS) and methods derived from this structural, analytical framework, that characterize macroergonomics as a sub-discipline of ergonomics (Hendrick, 2005).

It is proposed a macroergonomics approach can be applied to the construction industry, where organizational design and management factors can vary from project to project, specifically in safety solutions. The ability of an occupational safety and health solution, including safety regulatory requirements and performance, to fit with the needs and constraints of an overall construction company is not the same as its ability to fit with the contractors and sub-contractors of the company. In order to create and evaluate the fit of safety solutions, a system perspective is recommended as an alternative to the traditional piecemeal or components approach. It is further suggested that a Macroergonomic approach will provide a comprehensive process to select and implement a system safety analysis that will include an understanding of technology, personnel, external environment, internal environment, organizational and management structure and the interactions between these.

2. MAS method

The MAS method combines empirically developed analytical models of the effects of three major sociotechnical system elements, the technological subsystem, personnel subsystem

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and relevant external environment, on the fourth major element, the structure of the organization's work system (Hendrick, 2005). The MAS analysis results can help identify discrepancies when compared to the work system of an existing organization or can be applied to the design of a new organization.

The three major sociotechnical system elements include the (1) technological subsystem, (2) personnel subsystem and (3) relevant external environment that permeate the organization (DeGreene, 1973). Empirical models have been developed that study each of the sociotechnical system elements in relation to the effects upon the three organizational design dimensions of complexity, formalization and centralization (Hendrick, 2005). Hendrick (2005) defined the core dimensions that provide a platform for MAS as follows:

- Complexity—degree of differentiation and integration that exist within a work system's structure.
- Formalization—degree to which jobs within the work system are standardized.
- Centralization—where formal decision-making occurs within the work system.

The MAS utilizes analytical empirical models for the sociotechnical components analysis as described in Fig. 1. Combined with a rating system of 1 = low, 3 = intermediate and 5 = high, the components identified by the models are evaluated and a table is created. The empirical models utilized include the following (Hendrick, 2005):

- Technological Subsystem Analysis—model by Charles Perrow (1967) for the technology–work-system structure relationship using a knowledge-based classification scheme. Two dimensions: (1) task variability—the number of exceptions in one's work and (2) task analyzability—type of search procedures available for responding to task exceptions. A matrix yields four knowledge-based technologies: routine, nonroutine, engineering and craft.
- Personnel Subsystem Analysis—includes three major characteristics: (1) professionalism, (2) cultural factors, and (3) psychosocial factors, which includes cognitive complexity.
- Relevant External Environment—five types of external environments were identified by Negandhi (1973) that impact organizations: (1) socioeconomic, (2) educational, (3) political, (4) cultural, and (5) legal. Furthermore, environmental uncertainly is considered using the dimensions of change, the extent to which a given specific task environment is dynamic or remains stable and predictable over time, and complexity, the number of components that constitutes an organization's specific task environment.

Using MAS as a tool includes the subjective assessment of organizations, related to the rating scales used. The outcome will provide a numeric value that can be compared to the current exiting work-system data. Both the analysis of each key sociotechnical variable and work-system structure require knowledge of organizations and their assessment due combination of subjective and objective process. The analysis of structural components through MAS is the context for an analysis of process through MacroErgonomic Analysis and Design (MEAD).

3. MacroErgonomic Analysis and Design (MEAD) method

Based on MAS, Macroergonomic Analysis and Design is a 10-step framework used for conducting work-system assessments and improvements (Hendrick and Kleiner, 2001). The 10 phases

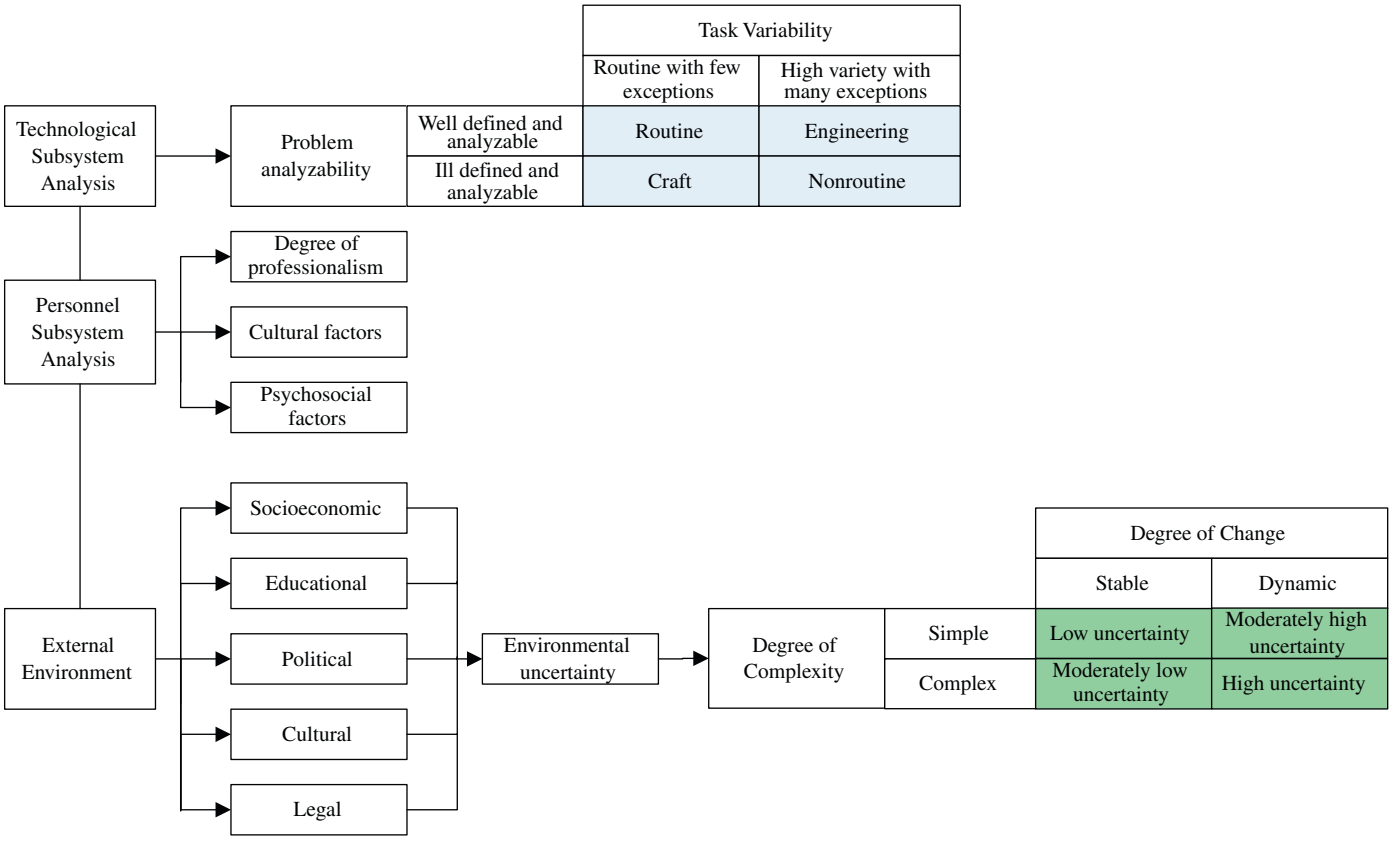

Fig. 1. Models used in MAS for the three key organization sociotechnical variables.

include: (1) Scanning Analysis, (2) System Type and Performance Analysis, (3) Technical Work Process Analysis, (4) Variance Data Collection, (5) Variance Matrix Analysis, (6) Variance Control and Role Analysis, (7) Organizational, Joint and Function Design, (8) Responsibility Perception Analysis, (9) Support System and Interface Design, and (10) Implement, Iterate and Improve.

The MEAD method is beneficial in that it can integrate existing tools from multiple disciplines to provide a comprehensive evaluation of the system. Using the macroergonomic approach allows for the flexibility of using classical methods such as laboratory experiments, field studies, field experiments, organizational questionnaires and surveys, interview surveys and focus groups (Hendrick and Kleiner, 2001). Imada (2002) suggests the use of participatory approaches which includes involving workers in the process.

Phase 1, initial scanning, identifies the main elements of the system including inputs, outputs, boundaries, environment interaction, stakeholders and objectives. The gaps between the stated goals of the system and the actual behavior are identified. The main elements of the safety system will be identified, including the theoretical and actual states. The perceived and actual ownership of the system will emerge. Proposed methods include interviews and organizational questionnaire surveys. Next, the system type and performance analysis will identify performance expectations and performance criteria for the system. This phase will highlight the expectation of the system and the metrics used to measure the performance. The reporting system, external (regulatory) versus internal (performance metrics) will be identified. Proposed methods include interviews, questionnaires and quantitative regulatory analysis.

Beginning with phase 3, the suggested approach includes a participatory team including experts and end-users. The technical work process analysis involves flowcharting the system processes and identifying unit operations. Unit operations are groupings of conversion steps from inputs to outputs that together form a complete or whole set of tasks and are separated from other steps by territorial, technological or temporal boundaries (Robertson et al., 2002). Phases 4–6 include variance analyses and control. Variances are deviations from standard operating procedures. The variances are identified, classified and a variance matrix is created. The variance matrix is analyzed and a control table and role analysis is completed. The control table will highlight how the existing variances are controlled and by whom. The role matrix identifies the roles (external and internal) and relationships. Organizational, joint and function design, phase 7, includes the control of variances through the introduction of interventions or solutions. The human–machine function allocation is performed and technological, personnel and organizational subsystem recommendations are designed. Since at this stage, "micro" elements of the system are also designed or redesigned, participatory approaches should be employed.

The roles and responsibilities are evaluated in phase 8 through the use of participatory methods. Next, support subsystems are evaluated and redesigned, if necessary. The last phase includes implementation, iteration and any improvement changes. Due to the analysis being research based, the last stage will be in form of a proposal which includes the recommendations.

Macroergonomic analyses have led to a variety of ergonomic interventions that have resulted in improved productivity, reduced costs, and improved health and safety. For example, a macroergonomic analysis was completed in a petroleum company with the goal of improving safety and health. A participatory approach was used to introduce employee recommended ergonomic modifications, safety training and structures and work improvements which resulted in a 54% reduction in industrial injuries, 51% reduction in motor vehicle accidents and a reduction of lost work days of 94% (Nagamachi and Imada, 1992).

4. Safety in the construction industry

The construction industry is a good example of an industry in need of systemic change. It ranks high in the hazards of the occupation due to the nature of the work, including the integration of materials, tools, environment, and the various human factors. According to the United States Department of Labor, Bureau of Labor Statistics, the private construction industry sector recorded 1226 fatal work injuries in 2006 (10.8 rate per 100,000 employed), the most of any industry sector as shown in Fig. 2; an increase of 3% over the 2005 total (BLS, 2007a). The total recordable case (TRC) rate in construction declined from 6.3 to 5.9 cases per 100 full-time workers in 2006; the number of cases of all types remained statistically unchanged while there was a 6% increase in hours worked (BLS, 2007b). In Great Britain, construction and agriculture have the highest rates of fatal injury, accounting for 46% of fatal injuries to workers. In 2006, there were 77 fatalities with a rate of fatal injury of 3.7 per 100,000 workers (HSE, 2007). These alarming statistics continue to highlight the health and safety concerns of the industry.

There is a multitude of government regulations in the United States that apply to construction worksites to address unsafe work habits and practices. The interpretation and implementation of these standards is often the responsibility of the employer, usually the general contractor. The OSH Act General Duty Clause states that each employer "shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employee" (OSHA, 2006).

The construction industry presents challenges unique to each individual project such as size, location, labor composition, organizational structures, and logistics management. Construction worksites are dynamic due to sequential work processes, levels of technology, tool iterations, workforce factors, and the various levels of safety awareness and training of personnel. Isolating health and safety accountability in the industry to one party provides limited success since it does not distribute the responsibility of safety among all involved stakeholders. Perrow (1999, p. 343), when referring to high-risk systems (having combined complexity and tight coupling with the potential for catastrophic failure), concluded that potential for a system accident can increase in a poorly-run organization; if there is poor regulation, poor quality control, or poor training, there is an increased chance of failure in the DEPOSE (Design, Equipment, Procedures, Operators, Supplies, Materials and Environment) components and these can make the unexpected interaction of failures more likely, because there are more failures to interact.

The Healthy People 2010 (2000) agenda, a US-based health promotion and disease prevention initiative which includes national objectives for high-risk sectors, targeted a 30% reduction goal for work-related injuries and deaths among construction workers by 2010. Additionally, the increasing awareness of construction workplace hazards has resulted in special interest in the US and international organizations, such as The Center for Innovation in Construction Safety and Health (CICSH), The Center for Construction Research and Training (CPWR), The Centre for Innovative and Collaborative Engineering (CICE), Finnish Institute of Occupational Health, The Australian Centre for Construction Innovation (ACCI), and The Dutch Arbouw Institute, which conduct research and provide information and services on occupational safety and health and many others.

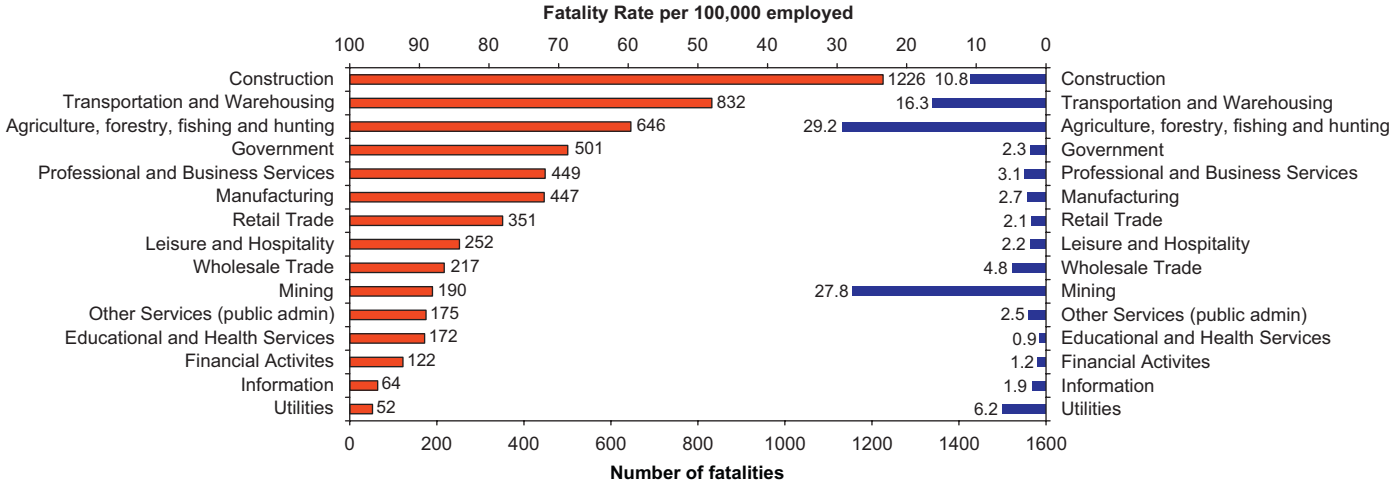

Fig. 2. Number of fatal occupational injuries in the US private sector.

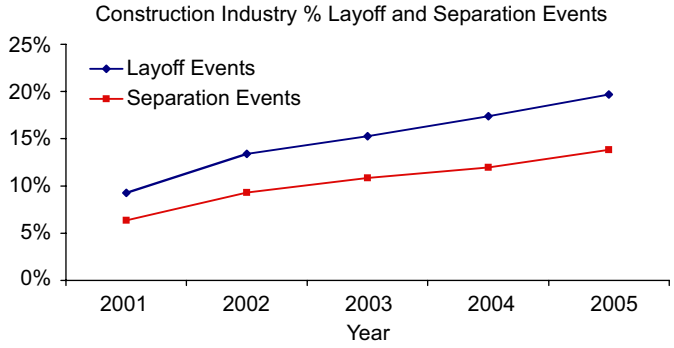

Fig. 3. Layoff and separation percentages in the US construction industry.

The variability in interpretation and application of Occupational Safety and Health Regulations, safety efforts and indicators, and their evaluation as independent variables have provided solutions that do not address the overall safety system. The use of safety coordinators, an increase of safety inspections, safety programs and "back to work" programs are some examples of solutions construction companies have implemented to reduce fines and accident potentials (Jaselskis et al., 1996). Still, construction continues to be at the forefront of safety concerns.

There are additional confounding factors that may impact the accident occurrence in the construction industry: temporary employment, seasonal employment, layoffs and changing population trends. For example, the Bureau of Labor Statistics reported the US construction industry accounted for 20% of private nonfarm mass layoff events and 14% of separations with 86% of all layoffs due to ending of seasonal work and completion of contracts (BLS, 2007b). Fig. 3 shows the layoff and separation trends in the industry. Additionally, in 2005, the Latino population was documented as 23% of the US construction industry population (BLS, 2007b).

5. Using macroergonomics as an organizing and integrative process for systems safety

It is proposed that the MEAD framework can be used as an organizing and integrative process to select and implement system safety tool(s) analysis to facilitate improvements in an industry such as construction. A criterion for selecting a specific system safety analysis tool for a construction industry example will be suggested based on assumptions from the systems theory accident causation model and the MEAD phases.

Chapanis defines a system as an interacting combination, at any level of complexity, of people, materials, tools, machines, software, facilities and procedures designed to work together for some common purpose (Chapanis, 1996, p. 22). Additionally a system can be a combination of smaller systems. Changes in one part of the system can possibly affect other parts and the system as a whole. System safety analysis and hazards are defined by Stephans (2004, pp. 360–365) as:

- *Hazard*—a source of danger (i.e. material, energy source or operation) with the potential to cause illness, injury, or death to a person or damage to a facility or to the environment (without regard to the likelihood or credibility of accident scenarios or consequence mitigation).
- *System safety analysis*—the formal analysis of a system and the interrelationships among its various parts (including plant and hardware, policies and procedures and personnel) to determine the real and potential hazards within the system and suggest ways to reduce and control those hazards.

The engineering process for the control of hazards includes: (1) Evaluate process or operation and identify its harmful agents, (2) Eliminate the harmful agents by redesign or substitute a less harmful material, arrangement, and so on, (3) Shield, enclose, (guard) the hazard, (4) Isolate the hazard, (5) Dilute the harmful effect, and (6) If steps 2–5 do not give the appropriate level of control, provide personal protective equipment (Grimaldi, 1975, p. 136). The approach to the control of hazards, through a system safety approach is a proactive way to identify the ways to eliminate or mitigate hazards. According to Stephans (2004), there is a difference between traditional compliance safety and system safety; compliance safety focuses 100% compliance with codes, standards and regulations while system safety approach focuses on optimum safety. The system safety philosophy uses a set of analytical tools compatible with the engineering hazard control process.

It is important to understand the causes of accidents. There are several theories of accident causation that attempt to explain why accidents occur. One such example is the Systems Theory of Accident Causation which views a situation in which an accident might occur as a system comprised of the following

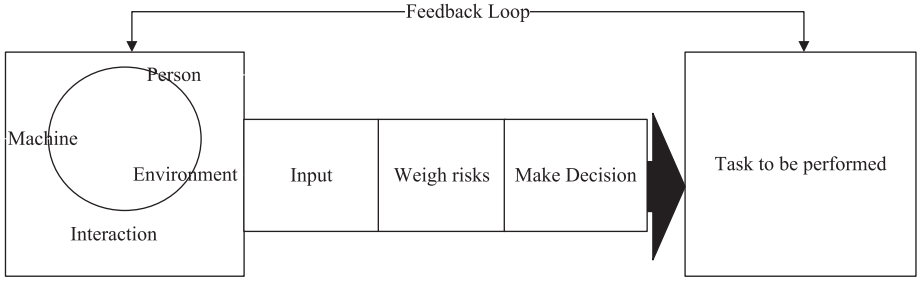

Fig. 4. Systems theory accident causation model.

components: person (host), machine (agency), and environment; the likelihood of an accident occurring is determined by how these components interact (Goetsch, 1999, p. 43). Fig. 4 shows the R.J. Firenze systems (as cited by Goetsch, 1999) theory model of accident causation which shows that each component has a bearing on the probability that an accident will occur (Goetsch, 1999, p. 44).

A limitation of this and other like accident causation models can be the lack of social and organizational factors. According to Leveson (2004), event-based models are poor at representing systemic accident factors such as structural deficiencies in the organization, management deficiencies, and flaws in the safety culture of the company or industry since they do not understand the social and organizational criteria used to construct and operate systems.

Rasmussen (1997) has argued that court reports from several accidents such as Bhopal, Flixborough, Zeebrugge, and Chernobyl demonstrated that they were not caused by a coincidence of independent failures and human errors, but by a systematic migration of organizational behavior toward accident under the influence of pressure toward cost-effectiveness in an aggressive, competitive environment. It is therefore important to understand not just the elements of accident causation and system integration but also the sociotechnical system as a whole.

5.1. System safety analysis methods

System safety focuses on the complex combinations of subcomponents acting together. The tasks required to establish, conduct and maintain an ongoing safety effort can be categorized as: planning tasks needed to initiate the program, primary system safety tasks that identify, analyze and control hazards to conduct the program and support tasks to maintain the program (Stephans, 2004). These tasks are completed throughout the life cycle of a project.

There are many system safety analysis methods, mostly industry based. Following are some of the systems that are unique to the system safety human system integration: Preliminary Analysis, Event Tree Analysis, Fault Tree Analysis (FTA), Failure Modes and Effects Analysis (FMEA), Fault Hazard Analysis, Subsystem Hazard Analysis, System Hazard Analysis, Cause–Consequence Analysis (Swallom et al., 2004). Selecting the appropriate system safety tool can be a comprehensive process. Some of the system safety analysis tools descriptions according to Swallom et al. (2004) and Stephans (2004) include:

- Preliminary Hazard Analysis (PHA)—performed to identify the system hazards and their preliminary causal factors during system development. Hazards are formally documented to include the description of the hazard, causal factors, the effects of the hazard, and preliminary design considerations for hazard control by mitigating each cause.
- Event Tree Analysis (ETA)—used to organize, characterize and quantify potential accidents in a systematic manner. It models the sequence of events resulting from a single initiating event (inductive).
- Fault tree analysis (FTA)—assess a system by identifying a postulated undesirable end event and evaluating the potential event leading to that condition. It flows from general to specific (deductive).
- Failure modes and effects analysis (FMEA)—evaluates how the failure modes of each system component can result in system performance problems to define appropriate solution.
- Fault Hazard Analysis—inductive method of analysis that is used to perform an evaluation that starts with the specific elements and integrates individual examinations into the total system evaluation.
- Subsystem Hazard Analysis (SSHA)—subsystem-level hazards analysis.
- System Hazard Analysis (SHA)—safety analysis of the subsystem interfaces and system functional, physical and zonal requirements.
- Cause–Consequence Analysis—a technique using six steps that relates specific accident consequences to their many possible causes.
  1. Select event or type of accident situation to be evaluated.
  2. Construct various accident paths based on the chronological successes and failures of the appropriate safety.
  3. Develop the accident paths resulting from the event through an ETA.
  4. Develop an initiating event through FTA.
  5. Compose accident sequence.
  6. Document.
- Project Evaluation Tree (PET)—graphic checklist that allows the identification of each procedure, individual and/or organization, facility and piece of equipment to be analyzed and then systematically use the appropriate branch of the PET tree to evaluate each part of the system or project.

The system safety approach can be expanded to include sociotechnical components by coupling it with MEAD. System safety tools can provide additional methodologies to evaluate the work-system processes, including a detailed analysis of the safety components in the construction industry.

6. Macroergonomics and system safety compatibility

In order to design a criterion to select a system safety analysis tool, considering the sociotechnical structure, a very simple and preliminary application of MEAD will be assumed. MEAD provides a comprehensive framework for evaluating a system and encourages the use of analysis systems. Table 1 lists the suggested

description and required data for the applicable phases suggested relation to the system safety process.

Phase 1, initial scanning, identifies the main elements of the system including inputs, outputs, boundaries, environment interaction, stakeholders and objectives. The gaps between the stated goals of the system and the actual behavior are identified. The main element of the regulatory compliance and reporting system, including the theoretical and actual states, is evaluated. Next, the system type and performance analysis will identify performance expectations and performance criteria for the system. This phase will highlight the expectation of the system and the metrics used to measure the performance. The reporting system, external (regulatory) versus internal (performance metrics) will be identified. During this step, the degree of spatial dispersion, activities are performed in more than one location, is important, especially if global locations are included.

Currently, there are differences in regulatory metrics across countries for the construction industry. In order to review compatible metrics, Wokutch and McLaughlin (1988, p. 115) identified eight nation-specific factors to consider when comparing metrics across countries: (1) injury definitions, (2) incentives and disincentives for having an incident counted as a work injury, (3) methods by which injury statistics are collected that rely on "reported" versus "compensated" injuries and that exclude certain employers on the basis of size or industrial sectors, (4) political influences at national levels regarding the compiling and reporting of injury statistics, (5) national traditions regarding injury reporting, (6) basis upon which injury rates are calculated, (7) distributions of the industrial composition on the national work forces and (8) degrees of ethnic homogeneity of the national work forces.

Fig. 5 includes a simple input/output diagram for a construction safety system with specific performance criteria, to provide a general point for the safety system support discussion. This is based on the standardized checkpoints or critical points in the system (Hendrick and Kleiner, 2001, p. 73). The unit operations and flow charts will be created next. This step will highlight the specifics of the construction project, including the sub-products that are very common in the construction industry due to the use of sub-contractors. Flow charts will be created which will, in parallel with the system safety analysis, provide a breakdown of the processes, sub-processes and their interactions. This step is followed by the collection of variances, the construction of a variance matrix and the variance control table. This is complimentary to a system safety plan, which includes detailed information about the system safety personnel (responsibilities, qualifications and level of effort), procedures (tasks to be performed and techniques to be used) and products (formats and scheduled); the type of tool selected depends on operational constraints of effectiveness, time and money (Stephans, 2004).

According to Hendrick and Kleiner (2001), the checkpoints, identified in Fig. 5, as the circle connectors, pertain to different measures throughout the system. Some of these measures might exist while others might be derived. Table 2 lists the measurements and the necessary information for the analysis of the safety system.

Phases 4–6 include the safety variance identification, classification and ownership allocation. The determination for variances

Table 1
Description of MEAD as input to the system safety analysis tools

MEAD phase	Required data—construction based
1. Scanning analysis	1.1 Company documented safety information and employee perceptions (climate, culture) 1.2 Suppliers, contractors, sub-contractors, inputs, processes, outputs, customers users, feedback, internal controls, outcomes (specific to construction project) 1.3 Environmental expectation of the system (regulations) and system expectation of the environment (regulatory support). Account for differences in metrics based on geography 1.4 Levels of organizational complexity, centralization, and formalization (specific to construction project) with respect to company, contractors and sub-contractors
2. System type and performance analysis	2.1 Tasks descriptions and types 2.2 Checkpoints 2.3 Levels of organizational complexity, centralization and formalization 2.4 Human–machine information
3. Technical work process and unit operations	3.1 Trade schedule, shift work, unions 3.2 Breakdown by functions and tasks
4. Variance data	4.1 Identify safety variances at the process and task level 4.2 Differentiate between input and throughput variances
5. Construct variance matrix	5.1 Establish relationship between variances 5.2 Identify key variances
6. Variance control table and role network	6.1 Construct key variance control table to include hazards, risks 6.2 Construct role network to include owner, contractors, sub-contractors, etc. 6.3 Evaluate effectiveness 6.4 Specify organizational design dimensions
7. Function allocation and joint design	7.1 Perform function with results from system safety analysis tool 7.2 Design technological, personnel an organizational change to manage with system safety tool recommendation/gap checklist
8. Roles and responsibilities	8.1 Evaluate role and responsibility perception of safety from identified stakeholders 8.2 Provide safety training support
9. Design/redesign	Based on joint analysis
10. Implement, iterate and improve	Based on follow up analysis; may generate a reevaluation of the system

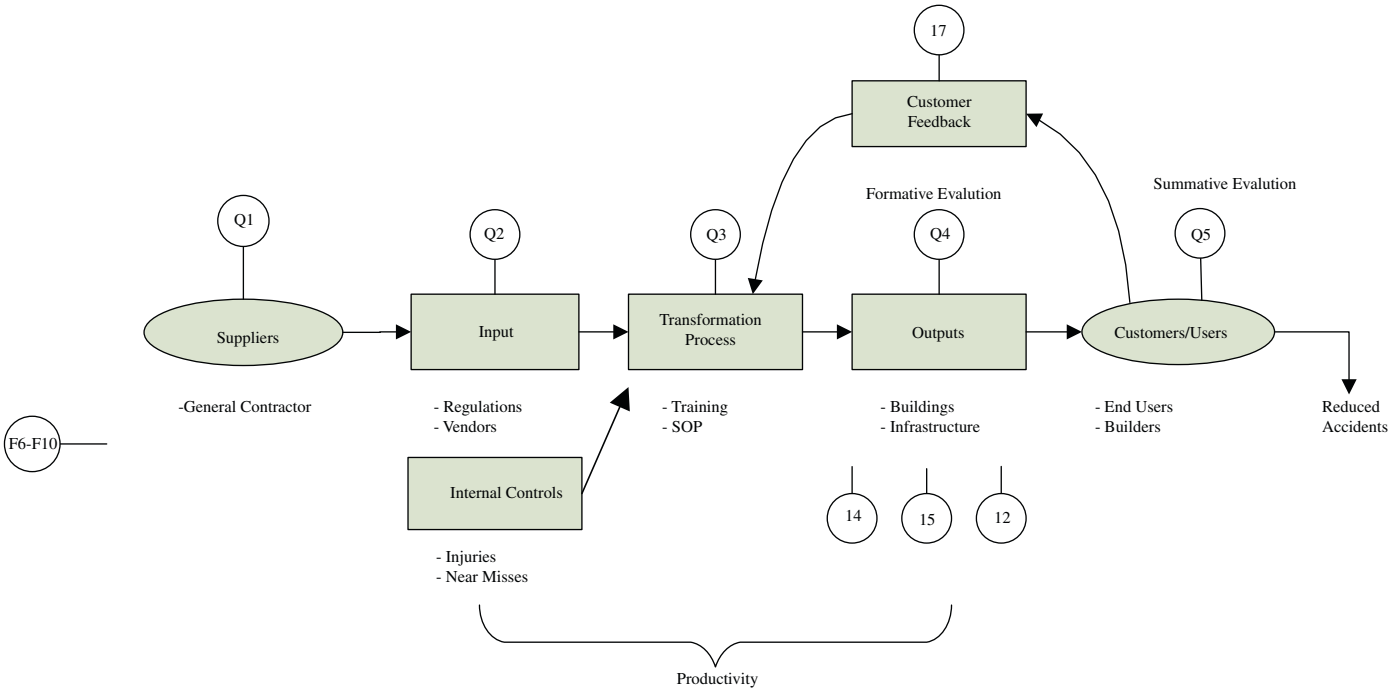

Fig. 5. Input/output diagram with standard checkpoints to construction safety system.

Table 2
Measurements for system safety analysis

Checkpoints	Description	Information
Q2, Q4	Measures of quality control through inspections of inputs and outputs	In process (safety) SOP, hazards
Q1, Q3, Q5	Q1- Supplier certification Q3- In process control to monitor and control processes Q5- Customer satisfaction	Errors (not resulting in accidents), non reportable occurrences, grievances
F6–F0	Flexibility; iteration of the system	Changes to system
12	Production output	Zero incident jobs
14	System capacity	Safety tools
15	Creative changes to process or products that results in performance gains	In and out of scope of safety SOP
17	Management system to manage criteria	Culture (absenteeism, tardiness), climate
Productivity	Ratio of output/input	Safety metrics

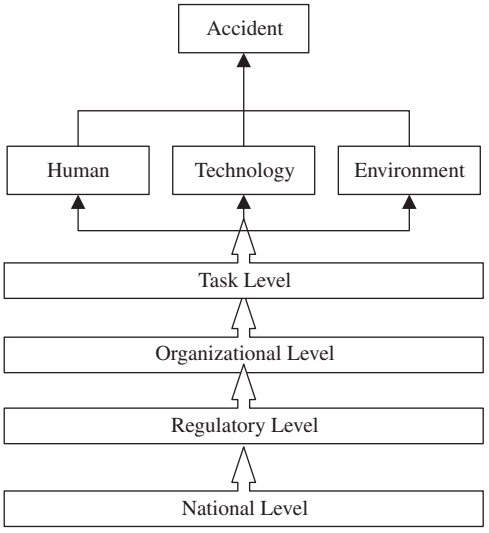

Fig. 6. Proposed general criteria for system safety analysis tool selection.

will be completed using the system safety analysis flow charts. Based on these results, function allocation can be performed. Phases 8 and 9 will include the recommendations for changes in the system through roles and responsibilities and any design/redesign interventions. Construction processes change frequently, sometimes varying from job to job. The suggested following criteria can provide a supporting tool for organizing the safety evaluations from a sociotechnical work process perspective.

7. Macroergonomics and system safety selection criteria

Based on the MEAD process and MAS, a systems accident causation model, and the existing system safety analysis tools, general criteria for selecting a systems analysis tool has been created to include: human, technology and environment at the task, organizational, regulatory and national level. It is assumed that the systems to be reviewed are in the operations phase (there is an established safety program). Refer to Fig. 6 for the diagram.

The tools are evaluated against the pre-established criteria to identify the best fit for the MEAD phases. When evaluating the safety system, several questions were considered at the O, R, N level (O = organization, R = regulatory, N = national). Refer to Table 3 for the evaluation criteria.

(1) The system safety analysis tool can work at the element, subsystem, and system level.
(2) Life cycle phases of the project are known (concept, design, production, operations, and disposal).
(3) The system safety analysis tool considers interactions.
(4) The system safety analysis tool can evaluate tasks.

Table 3
Evaluation criteria for system safety analysis tool selection

	Human				Technology				Environment			
	T	O	R	N	T	O	R	N	T	O	R	N
Preliminary Analysis	X	X	X	X	X	X	X	X	X	X	X	X
Event Tree Analysis	X		X		X		X		X		X	
Fault Tree Analysis		X	X			X	X			X	X	
Failure Mode and Effects Analysis	X		X		X		X		X		X	
Fault Hazard Analysis	X		X		X		X		X		X	
Subsystem Hazard Analysis	X		X		X		X		X		X	
System Hazard Analysis	X	X	X	X	X	X	X	X	X	X	X	X
Cause–Consequence Analysis	X	X	X	X	X	X	X	X	X	X	X	X

(5) Due to operational phase assumption, system is compatible with:
   A. Job safety analysis results.
   B. Project evaluation analysis.

An important assumption is that the system safety analysis tools can be utilized to evaluate any system. The information collected through the MEAD process will provide inputs, evaluations and measurements throughout the process. Phases 1–5 of the MEAD process will provide inputs for the system safety tool selected and phases 6–10 will provide tools for designing, implementing and measuring solutions within a sociotechnical content.

For example, after evaluating a specific project, it was determined a Hazard Analysis combined with a Subsystem Hazard Analysis would be a good fit. The tools selected will analyze those hazards introduced to the system by the interfaces between subsystems, man–machine, and hardware–software. It assesses the entire system as a unit and the hazards and failure modes that could be introduced through system physical integration and system functional integration (Swallom et al., 2004).

The System Hazard Analysis should be completed for the processes identified in the input/output diagram during phase 1 of the MEAD process. A subsystem and system hazard analysis will be completed to compliment the performance expectations (checkpoints), organizational design dimensions and system function allocation requirement. In order to perform the System Hazard Analysis, it is proposed that a Project Evaluation Tree (PET) be created. The PET analysis is a relatively new technique, an adaptation of the oversight and risk tree (MORT) tool (Stephans, 2004). PET is a graphic checklist that allows to identify each procedure, individual and/or organization, facility and piece of equipment to be analyzed and then systematically use the appropriate branch of the PET tree to evaluate each part of the system or project (Stephans, 2004). Since PET has an organization component, results from the MEAD analysis phase 1 (proposed survey for culture and/or climate results) can be modeled. These can be utilized for any spatial considerations.

Since phase 2 the MEAD process includes metrics that can be part of the internal controls, the PET analysis will use the metrics as inputs. The PET analysis results will then be utilized to complete System Hazard Analysis and Subsystem Hazard Analysis. The PET analysis is the detailed, subsystem review, followed by the sub system hazard analysis and the high level hazard analysis. These can be completed using the flow chart information from phase 3 of the mead process. Discrepancies in risk and hazards will be recognized and documented as variances. Next, the MEAD process will be continued to classify, evaluate and define safety interventions.

Currently, some accident prevention models take a systems approach to understanding accident causation further. Embrey (1992) distinguished two categories of latent errors: (1) operational include error which may leave critical systems unavailable and (2) organizational which include design, management or policy errors and use these to create a model. Embrey (1992) created a generic model called MACHINE (Model of Accident Causation using Hierarchical Influence Network) to use an audit tool to manage organizational and management factors that create risks. An additional sociotechnical modeling approach to risk management that uses a functional abstraction instead of a structural decomposition (Rasmussen, 1997; Rasmussen and Svedung, 2000).

Based on MAS, Kleiner and Smith-Jackson (2005) completed an evaluation of construction as a sociotechnical system and identified the following components for the industry:

- Technical subsystem—manner in which work is performed:
  - Heavy machinery, equipment, power tools, hand tools, methods and procedures;
- Personnel subsystem—sociocultural and socioeconomic characteristics of the construction workers, including selection and training;
- External environment—political, economic, technological, educational, and cultural forces;
- Internal environment—physical and cultural job site;
- Organizational and management structure—formal or informal.

8. Conclusion

Macroergonomics and its MAS framework, provide an excellent foundation for methods such as MEAD and the incorporation and integration of existing tools and techniques like those in the systems safety arena. Through additional application, additional refinements can be made and knowledge contributed in terms of what works and why.

A partial validation of the general approach, a Rapid Universal Safety and Health (RUSH) system was designed, developed and deployed to incorporate a safety process for rapid build construction projects (Kleiner et al., 2006). The RUSH system was created using sociotechnical and system safety concepts. The system was applied to a 106 h residential construction project that resulted in zero recordables. A complete validation of the proposed approach is recommended as the next step.

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