Influence of Ergonomic Risk Factors on Hazard Mitigation in SMEs—A Case Study on the Use of the Network Thinking Methodology

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ABSTRACT

In order to function effectively, enterprises need to define various fields of their activity [1], [2]. This includes safety criteria and the satisfaction of safety-related needs of their workers [3]. Occupational safety should be seen as a set of working conditions that enable workers to operate safely. Such conditions are defined with reference to hazards and strains associated with ergonomic risk factors. Their identification is vital for meeting employee needs and expectations [4]. An effort to ensure them should be viewed as critical for competitiveness, leading to advantageous contracts. Many benefits are a direct consequence of the trust earned by enterprises that successfully shield themselves and their partners from losses precipitated by safety deficiencies.

The article attempts to find ways to employ the network thinking methodology to identify ergonomic risk factors and thus essentially contribute to improving occupational safety by mitigating ergonomic hazards.

ENSURING SAFE WORKING CONDITIONS BY MITIGATING HAZARDS IN SMALL AND MEDIUM-SIZED ENTERPRISES

Risk mitigation efforts need to be combined with the knowledge on how to improve the work environment. Every employer, manufacturing process designer and rank-and-file employee should be keenly aware of workplace risks and the need to mitigate their impacts [5], [6], [7], [8]. Some of the key responsibilities of employers associated with the improvement of working conditions are to:

− Ensure that the workplace fits the individual characteristics of workers and their jobs while protecting worker health,
− Provide workers with working conditions that adequately satisfy their needs,
− Consult and collaborate with their workers.

To establish safety standards, it is essential to define and document actions taken to reduce the impacts of risks, including the impacts of ergonomic risk factors. To that

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end, enterprises should identify competent individuals, assign them to specific tasks, set task completion deadlines, find the resources needed to support their effort and adopt indicators for assessing actual improvements [9]. To successfully implement improvement measures, enterprises should [9], [10]:

- Secure any resources (funding, materials and technical items) that are necessary to identify risks and implement and oversee measures designed to improve safety,
- Monitor irregularities to identify improvement needs and assess whether improvement measures have been adequately implemented,
- Oversee the measures taken to reduce safety risk factors.

Such an approach will help improve work design and generate savings in company operations [3], [11], [12], [13], [14]. Any improvement efforts need to account for the unique operating characteristics of SMEs. To this end, emphasis should be placed on the commitment of enterprise owners to the improvement effort as well as on preparing informal improvement plans and ensuring intuitive task performance [7].

The operation of SMEs is a function of their characteristics, which include the dominant position of owners, close interpersonal relationships across the company, the predominance of informal relations among workers, high operational dynamics and proximity to markets. These features affect the choice of priority considerations for improvement projects [15] and fall into the categories of:

- Economic characteristics, manifested in small market shares and ultimately in limitations in SMEs’ ability to undertake any improvement measures that require substantial financial outlays,
- Management-practice-related characteristics, manifested in the proprietor running most of the company’s affairs and therefore requiring knowledge on how to eliminate ergonomic risk factors,
- Ownership-related characteristics, which define companies’ capabilities and determine their ability to demonstrate and justify the need for improvement measures.

APPLICATION OF ERGONOMIC RISK FACTORS FOR HAZARD MITIGATION

Any organization setting out to make improvements needs to keep in mind the critical importance of workers for its business. Workers are the biggest efficiency drivers. They should be recognized as a key source of competitive advantage and be provided with a safe work environment. Systems that recognize the essential role of workers in facilitating improvements tend to excel in achieving their goals [15], [16]. When selecting improvement measures, it is critical to consider worker needs [2] and thus to appreciate the importance of ergonomic risk factors [5], [15].

To identify ergonomic factors, one should identify their root causes. These include [4], [11], [17], [18], [19], [20]:

- The forced assumption of awkward body postures during work performance,
- Highly repetitive motions,
- The stress associated with the manual handling of objects,
- The difficulty of moving heavy objects with awkwardly placed centers of gravity,
- Work that puts stress on joints that are forced into extreme angles,
- Workstations poorly suited to worker anthropometrics.
ASSessment of the impact of ergonomic risk factors on hazard mitigation

The network thinking methodology

The network thinking methodology facilitates the assessment of the role and significance of issues that are central for analysis. The conclusions it enables result from a comprehensive approach to problems [21], [22]. The method frequently requires an analysis of complex relationships. These should be seen as forming a dynamic whole whose individual components interact in a variety of ways. The assessment helps identify system components and their impact on issues at hand.

The practical application of the network analysis method requires actions that can be classified into six steps. These are [21]:

• STEP 1: Goal setting and problem modeling. This step requires the identification of the system components that undergo changes.
• STEP 2: The determination of the type, timing and severity of impacts among system components.
• STEP 3: The identification of future expectations that define guidelines for building event scenarios. The key is to identify factors that affect the extent and timing of changes.
• STEP 4: Identification of factors that are essential for the control process. These include:
  − Controllable factors: factors affected by change,
  − Uncontrollable factors: factors that remain unaffected or are minimally affected by change,
  − Indicators: early warnings of imminent problems,
  − Feedback: factors that facilitate the choice of the proposed course of action,
  − Preemptive feedback: factors that facilitate the choice of preventive measures.
• STEP 5: Selection of strategies and decisions by either continuing or modifying previously adopted strategies. The choice of strategy relies on the identified interactions among individual factors.
• STEP 6: Deployment of the solution of choice to ensure efficient system operation. To make certain that a system operates efficiently, organizations should properly account for both existing and potential irregularities.

Scope of assessment

The assessment was aimed at gauging the impact of ergonomic risk factors on safety seen as the absence of threats that exert an unacceptable impact on workers. Ergonomic risk factors have been identified on the basis of a literature review and enterprise observations by supervisors. The characteristics of the companies covered by the study are provided in Table 1.

Table 1. Characteristics of companies assessed for ergonomic risk factors.

| Enterprise number | Scope of enterprise business                  |
|-------------------|----------------------------------------------|
| 1                 | - Manufacturing of steel structures,          |
|                   | - Mechanical working of metal items and welding. |
| 2                 | - Procurement of parts and components for assembly. |
| 3                 | - Services involving the mechanical working of metal items. |
| 4                 | - Manufacturing of steel structures,          |
|                   | - Assembly and welding.                      |
The limited range of tasks performed by workers has significantly affected the risk profile. A more in-depth characterization is provided in Table 2.

Table 2. Ergonomic risk factors covered by analysis.

| Ergonomic risk factor                                                                 | Causes of ergonomic risk factors                                                                 |
|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| ① Performance of work in unnatural (forced) body posture                              | - Forced neck bending during work,                                                               |
|                                                                                       | - Forced torso bending or twisting,                                                               |
|                                                                                       | - Forced arm raising above shoulders.                                                              |
| ② Highly repetitive motions                                                           | - Multiple repetitive motions putting stress on specific muscle groups,                            |
|                                                                                       | - Intervals between activities to short to allow muscles to recover.                              |
| ③ Strain resulting from manual handling of objects                                      | - Carrying and pushing of unacceptably heavy loads,                                               |
|                                                                                       | - Pushing of loads uncomfortably positioned on transport devices.                                 |
| ④ Difficulties moving heavy objects with awkawardly placed centers of gravity          | - Inability to securely grip loads making them difficult to carry,                                |
|                                                                                       | - Difficulty moving loads due to awkawardly positioned centers of gravity (e.g. where centers of |
|                                                                                       | gravity do not correspond to geometric centers of item).                                         |
| ⑤ Work that places stress on joints positioned at extreme angles                      | - Work with overly outstretched arms,                                                             |
|                                                                                       | - Work in cramped spaces that confine free movement and work performance.                         |
| ⑥ Workstations poorly adapted to worker anthropometrics                                | - Workstations failing to ensure freedom of work performance,                                    |
|                                                                                       | - Absence of ergonomically-compliant seats or places of rest,                                   |
|                                                                                       | - Work area placed too high or too low to allow neutral posture,                                 |
|                                                                                       | - Work tables without height adjustment.                                                          |

Assessment of ergonomic risk factors and related relationships

Based on the identified factors and their impacts, it was possible to build a relationships network. Its structure is shown in Figure 1.

The relationship network was then used to analyze the impacts of ergonomic risk factors. The resulting detailed assessment is provided in Table 3.

The impact was gauged on the basis of:
- The severity of impacts of factors measured on a 4-point scale of impact (0—no impact, 1—slight impact, 2—medium impact, 3—strong impact),
- The temporal impact horizon, i.e. the duration of impact. In view of SME
characteristics, including the speed of SME responses to change, impacts were classified into:

- **S**—short-term, lasting up to 3 months,
- **M**—medium-term, lasting 3 to 6 months,
- **L**—long-term, lasting longer than 6 months.

Table 3. Analysis of the impact of ergonomic risk factors on occupational safety.

| depends on | impact severity | impact duration | RELATIONSHIP FACTOR | impact on | impact severity | impact duration |
|------------|-----------------|-----------------|---------------------|-----------|-----------------|-----------------|
| ① 1        | S               | S               | ① Performance of work in unnatural body posture | ⑤ 2       | S               | S               |
| ⑥ 2        | M               |                  |                      |           |                 |                 |
| ⑥ 2        | S               | S               |                      | ⑤ 1       | L               | L               |
| ⑤ 3        | S               | S               | ④ Strain resulting from manual handling of objects | ① 1       | S               |                 |
| ⑥ 1        | S               | S               |                      | ⑤ 2       | M               | S               |
| ⑥ 3        | M               |                  |                      | ⑤ 3       | S               | S               |
| ⑤ 2        | S               |                  | ② Difficulties moving heavy objects with awkwardly placed centers of gravity | ① 1       | S               | S               |
| ⑥ 2        | S               |                  |                      | ② 1       | L               | S               |
| ⑤ 2        | S               |                  | ③ Work that places stress on joints positioned at extreme angles | ① 2       | S               | S               |
| ⑥ 2        | S               |                  |                      | ③ 3       | M               | S               |
| ⑤ 2        | S               |                  | ⑥ Workstations poorly adapted to worker anthropometrics | ① 2       | S               | S               |
| ⑥ 2        | S               |                  |                      | ⑥ 2       | S               | S               |

For the purposes of the analysis, it is crucial to determine the values and directions of impact forces. The fact that positive influences occurred for all factors largely simplified the evaluation method. The values of forces operating among the factors are shown in Table 4.

Table 4. Overview of impact characteristics.

|       | ① | ② | ③ | ④ | ⑤ | ⑥ | total A |
|-------|----|----|----|----|----|----|---------|
| ①    | ×  | 0  | 0  | 0  | 2  | 0  | 2       |
| ②    | 0  | ×  | 0  | 0  | 1  | 0  | 2       |
| ③    | 1  | 0  | ×  | 0  | 0  | 1  | 1       |
| ④    | 2  | 0  | 3  | ×  | 2  | 0  | 7       |
| ⑤    | 0  | 0  | 1  | 2  | ×  | 0  | 3       |
| ⑥    | 2  | 1  | 3  | 2  | 2  | ×  | 10      |
| total P| 5  | 1  | 7  | 4  | 7  | 0  | 24      |

Once the impact forces and their averages were identified, it became possible to group factors according to A and P indicators. Final factor allocations were based on the severity map presented in Figure 2. The dividing line was placed at 50% of the
maximum values of $A$ and $P$. Whether improvements can be made to reduce or fully eliminate the impacts of ergonomic risk factors depends on critical and active factors.

Critical factors include factor $\circ$, which describes the difficulties experienced moving heavy loads with awkwardly placed centers of gravity. It should be regarded as a major ergonomic problem, affecting the convenience of performing the transport works. Analyzing the problem in ergonomic terms should be drows, among others, the impact of hazards to effective and lacking risks functioning of workers. This factor exerts a strong influence on other factors while itself remaining susceptible to strong impacts.

In the circumstances at hand, factor $\odot$ has been classified as active. This factor describes the risk of a failure to adapt a workstation to fit worker anthrometrics, significantly affecting the limitation of the job opportunities of employees at the workplace. The existing hazards generates a number of negative effects to the employee health, including generating overmuch musculoskeletal load. The factor strongly influences other factors while itself remaining unaffected.

**Guidelines for improving hazard mitigation**

The ability to make improvements depends on the factors identified in the analysis. As described by [4], [21], [22], these are:

- Controllable factors with a potential to affect system operation,
- Factors that are either poorly controlled or fully uncontrollable,
- Early warning factors: the indicators,
- Feedback—which informs the system of the effects of the measures taken and therefore enables further improvements,
- Preemptive feedback—feedback that prepares the system for imminent changes.

In view of the operating and management characteristics of SMEs, improvements were assumed to depend most critically on the controllable factors and indicators. Referring to the subject of incompatibility occurrence, attention should be paid to their assignment to ergonomic criteria or to the relationship with ergonomic criteria. The indicators are used to assess the effectiveness of improvement measures.

Their placement in the change creation algorithm is shown in Figure 3.

**CHANGE PROSPECTS AFFECTING RISK MITIGATION**

Based on the analysis and a review of factors affecting the feasibility of improvements, the authors developed relevant scenarios accounting for the role of ergonomic risk factors in the mitigation of workstation hazards.

- Pessimistic scenario (describing failures to achieve desired effects):
  1. Improvement measures are only seen as necessary owing to their potential to reduce the cost of failures to ensure occupational safety.
  2. The company does not view ergonomic risk factors as essential for improving safety at work. Improvement measures are adopted solely on the basis of the ergonomic factors to which a response is required by law.
**Controllable factors**

- Advisability of improvement measures, including improvement the friendliness of work environment for employees,
- Availability of funds for the improvement measures undertaken in ergonomic improvement plans,
- Timing of improvement measures,
- Worker preparation to deploy improvement measures,
- Inclusion the issues of ergonomics and improving the comfort of work in the implemented improvement measures.

**Indicators**

- Accident rates, morbidities and burdens of ergonomic nature,
- Number of identified diseases, including diseases related to burdens occurring in the work environment,
- Number of absences, including absence at work caused by an excessive burden from the work environment and the scope of tasks performed,
- Variability of employment,
- Job satisfaction and guaranteed work comfort,
- Workloads, which are output the lack of compatibility with ergonomic recommendations,
- Number of identified risks and irregularities, with indication of their relationship with ergonomic risk factors,
- Ergonomics problems reporting by workers.

### Figure 3. Change generating algorithm.

**Optimistic scenario** (describing an unlikely course of events):

1. Growing emphasis is placed on mitigating the impacts of ergonomic risk factors on safety at work. The scope of improvement measures, including process mechanization and automation, will largely ensure the elimination of hazards classified as ergonomic risk factors.
2. To become a responsible enterprise, the ergonomic factors that effect work efficiency and task completion will be seen as significantly more critical. In addition, managerial personnel of various levels will improve their competencies.
3. Ergonomic risk factors will be seen as an essential component of working conditions that vitally contributes to safety. One should nevertheless bear in mind that the perception of their significance will depend on the assignment of roles to workers in the organization.

**Realistic scenario** (presenting a likely course of events):

1. Risk mitigation is seen as critical for reducing the enterprise’s operating expenses. The factors that define the required scope of improvement include ergonomic risk factors. The process may be hindered by budget constraints.
2. The owner views ergonomic risk mitigation as a way to improve work efficiency and effectiveness.
3. Hazard reduction with proper account taken of ergonomic risk factors requires the raising of worker awareness of the problems faced and the need to resolve them.
SUMMARY

To ensure friendly working conditions, it is essential to recognize the impacts of ergonomic risk factors. Such factors affect workers’ ability to function, their safety and performance quality and efficiency [1]. Improvement measures require a detailed identification of safety concerns. This includes identifying the causes of problems, the nature of impacts and improvement opportunities. An analysis of SME characteristics reveals high variability of the circumstances that affect working conditions. This is of particular importance where improvements of an enterprise’s processes require the elimination of risk factors associated with failures to comply with ergonomic requirements.

The above scenarios, which follow the guidelines for SME operation and recognize the opportunities to mitigate ergonomic risks, define the scope of implementation of improvement measures. Given that the key source of competitive advantages of SMEs are people (employees) and, specifically, their qualifications, aspirations, motivations and behaviors, it is critical to afford them with an environment in which they will be able to perform their work safely. The intended economic results are achieved in systems which recognize human factors as critical for successful improvements.

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