# Data-Driven Industrial Engineering:

## Experimental Design, Workload Metrics, and Optimization Frameworks Across Sectors

Editor: Assist. Prof. Dr. Hatice ESEN

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# Experimental Design, Workload Metrics, and Optimization Frameworks Across Sectors

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# Chapter 1

# TAGUCHI EXPERIMENTAL DESIGN APPROACH AND ITS APPLICATIONS IN INDUSTRIAL ENGINEERING

**Ali İhsan BOYACI[1]***

## 1. Introduction

Quality, productivity and cost are ever present issues in the world of industrial engineering, they are real and evolving, and are not simply a question of volume; not everyone's approach is the same. Contemporary production scenarios generally have multiple inputs and changing operating conditions, and so a great number of the disturbances influencing performance cannot be fully managed. At this point, informal adjustments or trial after trial will rarely yield a valid result. What more often succeeds is to run experiments with some amount of statistical rigor and to measure whether process parameters are having an impact. Well, that's the idea behind Design of Experiments (DOE). But full DOE schemes typically entail the complexity and time and resource investments that often need to be taken into account, particularly at real facilities where a number of factors need to be tested or repeated times to validate the effectiveness of what happens.

This practical tension in practice has had some influence on Taguchi's practice. Where, for instance, it is more relevant to address a system that is suffering from the sensitivity to noise factors, it encourages this so that performance is not quick to fall out of action as a function of the noise factor. Quality in this instance is more than just about the measurement's value, it is also about how standard and consistent this measure is on the process at normal variation. As the complexity of manufacturing systems increased, so does the idea of this. More specifically with regards to machining research, studies that discuss factors including cutting conditions and their relationship with surface roughness have repeatedly found that Taguchi-type designs reduce variation and provide stable results (Antony et al., 2001). Evidence for this is found in the research of composite processing: it helps in establishing stabilizing conditions for the whole process, even if only a small amount of trials or small quantity of processing are available (Lesiuk et al., 2023).

Perhaps the biggest discrepancy between Taguchi's method and the other methods available is that Taguchi's approach intentionally adds noise conditions

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into the experimental design process. In the context of production problems, noise such as machine vibrations, ambient temperature, humidity, material batch micro-variations or operator induced variability is usually not controlled for in the classical DOE experiments. Nevertheless, Taguchi's inner-outer He argues that processes can be made more robust against external variations by systematically incorporating these variables when building up the model through array logic. This strategy has been advantageous, especially in processes where exact tolerances are desired for injection molding. Indeed, Abohashima et al. (2015) showed that in injection mold production the Taguchi parameter design was able to result in significantly smaller error rates. Critiques of the robust design features of the method are found not only in manufacturing, but in the field of quality engineering (Hisam et al., 2024).

One reason the Taguchi approach remains attractive to industrial engineering practitioners is that one has a relatively high efficiency by employing orthogonal arrays. Rather than completing a complete factorial program, which can easily become intractable when multiple factors are included, the arrays make it possible for the experimenter to probe the system with a much smaller number of experiments conducted systematically. For instance in metalworking research, L9 or L18 arrays are often used with low working times, and yet they are able to present reliable insights on how the factors work. This is different than the classic DOE systems, which tend to be more difficult to interpret and have a heavier mathematical complexity. For many corporations and in particular for smaller manufacturers, since none of the statistical support exists, the step process of Taguchi’s approach to implementation is more scalable to use and less burdensome.

The chapter provides both a conceptual, and practical approach to the method. It starts with a description of the essential building blocks of Taguchi’s thinking: the quality loss concept, its separation between controllable and noise factors, and the tendency to choose parameter levels that help ensure stable performance. From there, the reasoning behind orthogonal arrays is shown and the difference which to choose one array versus another is described. Signal-to-noise ratios are also covered as these calculations are one of the main ways in which we evaluate robustness in practice. After which a procedural guide is included to take the reader through the method step by step, intending to smooth the transition of theory to application. Collectively, the intention is to explain effectively why we still use the Taguchi method in industrial engineering and also the variety of problems it solves and with what limitations to be concerned.

## 2. Taguchi Philosophy and Basic Concepts

The Taguchi philosophy fundamentally changed the quality engineering tradition, and led to the development of the "goal-oriented" and "variation-minimizing" method in industrial processes. Typical DOE strategies emphasize testing statistically for factor effects, interaction modeling, and average performance. On the other hand, the Taguchi approach focuses on minimizing variation, which it considers more important than increasing average performance. Such process outputs, if not designed stably, are often the source of quality problems reflected at the customer's expense, and this fundamental principle of robust design is at the center of the Taguchi approach (Phadke, 1989). Quality, according to Taguchi, is not measured as the compliance with some specific quality metric but rather how achievable a target is, with little variability. Thus, process improvement endeavors should also be aimed at making the process predictable, not just increasing the average. Lowering variability, especially in automotive, electronics, composite materials, and plastic injection molding lines of business, looks more sensible than raising the average.

### 2.1 Quality Loss Function

Taguchi's approach of quality provides a novel analytical approach to quality and an ideal system to enable quality not only to be determined by tolerance-based evaluation, but also to be assessed by the target-value performance and the stability of the processes used for the product. Traditionally, products should be within a tolerance range, Taguchi claims, any product that deviates from the target value, even within the tolerance limits, creates a cost for the manufacturer, user, and society. This perspective is based on the fact that it relates quality not only to conformance but also to how close the functional performance is to the target. The quality loss function established by Taguchi can be described as follows:

- $L(y) = k(y - m)^2$

Here, y denotes the measured response value, m denotes the target value, and k represents the cost or importance coefficient. This function analytically states that every deviation from the target value introduces a loss and that the loss does not increase linearly, but exponentially as the deviation increases (Ross, 1988). Under this point, an operation becomes unreliable due to the "hidden cost", meaning that any production outcome which is in-range with the tolerance is contributing to the loss of process reliability for the enterprise. It has revolutionized quality planning and engineering choices in areas of tight tolerances, such as aircraft, medical device production, automobile parts, electronic components, and composite material manufacturing.

The quality loss function is also one of the few integrative tools which combines engineering economics and quality engineering. Most of the typical DOE methods concentrate only upon statistical optimisation, yet Taguchi's technique is to be more strategic by quantitatively reflecting the economic impact of performance deviations in the model. Given the cost-based nature, engineers can make more reasoned and quantifiable decisions in multiple domains, e.g., tolerance design, product development, process optimization and maintenance strategy (Phadke, 1989). Indeed, Rao et al. (2008) have shown in their study on the parameters of biotechnological production, that the Taguchi loss function is a significantly more suitable representation of the optimum point than traditional statistical methods. Thus, the quality loss function transforms quality from simply a one-dimensional compliance measure into a multi-faceted engineering indicator that merges economic, functional, and statistical performance.

### 2.2 Control and Noise Factors

Taguchi method is that it does not account for all variables affecting the performance of a production or service process at the same level of control. Standard in experimental design, engineers usually build variables into the model from a set of predictors rather than considering their controlled variable effect on the model, whereas the exogenous condition is presumed to hold constant. However, in practice production conditions, parameters such as weariness on a machine, micro variances among material batches, ambient temperature, humidity, vibration, operator-related variability or supply variability between batches introduce large variations to production output. Accordingly, Taguchi categorizes process variables as control factors which are controllable by the engineer and noise factors that cannot be controlled or kept constant. Taguchi's radical perspective posits that these noise factors must be integrated purposely into the design process by which the process is to be performed not only under lab controlled situations, but also with fluctuating real-world situations (Tsui, 1992).

This idea is Taguchi's inner – outer It underpins the array approach. Inner array shows how input control factors are organized systematically, and outer array shows a structure of noise factors changing at different levels. Using these two arrays also allows for modelling variations in the relevant real-time process environment under lab conditions. Engineers can directly examine which combinations of control factors provide more robust performance, even with noise changes. This model has the merit of an important benefit in industries where product usage conditions are more variable than production conditions. For instance, the dual-response method (Lin and Tu, 1995), which allows for parallel optimization of means and variance, cannot be used without capturing noise drivers. Excluding noise factors from the design process leads to statistically incomplete and engineeringly ill-formed results, which these findings show.

One key consideration when adding noise factors to the model is the systematic reduction of variation in process output. Process quality is not assured; optimizing a process average is not enough; high mean performance can exhibit significant deviations when noise conditions change. The Taguchi method is robust in itself, so it’s “noise-free,” which means that its average performance can survive not only well in the ideal world, but also in a real setting. Robust design thus becomes not only an optimization tool but, more importantly, a strategic tool for long-term quality assurance. This perspective enables modern manufacturing quality control to cross the boundary from end-of-process measurements to the design phase (Tsui, 1992; Phadke, 1989).

### 2.3 Parameter Design

Parameter design is one of the key elements of the Taguchi method and a systematic methodology for achieving process performance optimization. Out of the three design phases of Taguchi's model of system design, parameter design, and tolerance design, parameter design is crucial in particular because the factor-level combinations defined in this phase have a direct impact on the performance of the process. Although the main purpose of most conventional DOE applications is the enhancement of mean performance, the Taguchi method can be regarded as one that integrates mean and variation in an integrated approach considering variability as independent of noise influences as possible. In this light the parameter design is not only a statistical experimental optimization process, but also a decision-making process that includes engineering economics and quality assurance (Phadke, 1989; Ross, 1988).

The simple philosophy for parameter design is reducing the noise factor sensitivity of the process via an effective selection and leveling of control factors. Inner–outer the array method is important since control factors of different combinations can be employed to define the effects of noise factors on the array. The interaction of these two forms shows the important relation of control factors to the noise factors and shows where the process is weak and where it is robust (Tsui, 1992). Thus process optimization is not just the setting that "offers the best average" but also the best combination of settings used to retain variability at the lowest under various conditions. Taguchi This is the fundamental strength of robust design: the process must operate stably not only under perfect conditions but also changing real-world conditions.

The design of parameters has shown general usefulness in different machine design applications. In the machining process, control parameters like cutting speed, feed rate and depth of cut when subjected to noise can be optimized producing far more stable surface roughness and tool longevity and this is found; for example Antony et al. (2001) in metalworking, shows that this result gives a huge advantage to the quality and cost of both. Injection molding, the careful optimization of pressure, holding time, and mold temperature has rendered the process more resistant to such uncontrollable variables as ambient humidity or material moisture, resulting in the popularity of robust design among the plastics market. Equally, the recipe components and process parameters used in composite material manufacturing greatly influence the achievement of target mechanical performance; when parameter design is combined with a quality loss function, not only process consistency improves but recipe optimization reliability gets increased (Lesiuk et al., 2023).

## 3. Orthogonal Arrays

Orthogonal arrays are the mathematical structures of the Taguchi design of experiments method, where it is necessary to maximize knowledge in multifactorial processes by the least number of experiments. In traditional full factorial arrangements, the amount of combinations grows exponentially along proportionate to the factor and level set, so that it becomes impractical to test all combinations in industry. Orthogonal arrays help to solve this problem by organizing the experimental conditions in a statistically balanced fashion, however. As noted by Ross (1996), Taguchi arrays greatly reduce the amount of work required by producing their size through independent (and balanced) factor-level distributions, making it an ideal tool for researchers, with the most value-added in quality engineering projects. This concept also increases overall efficiency and leads to less experimental work and better understanding of factor size effects, thereby accelerating the detection of stability issues in production methods.

The main reason orthogonal arrays are so effective in industrial practice lies in the mathematical structure of the array based on “orthogonality”. The orthogonality of an array is such that each factor level is represented equally and the combinations of factors are distributed in a mathematical symmetric manner. This property means that one factor can be studied and other factors can be studied non-influently. Bolboacă and Jäntschi (2007) analyzed systematic aspects of factor level coverage and efficiency of different orthogonal arrays, with different sizes ranging from four to sixteen in experiment terms, in order to determine the optimal array structures. They state, the better the orthogonal array chosen not only decreases the amount of experiments, but also strengthens the statistical separation of factor effects. As a result, orthogonal arrays make an excellent foundation for an engineering design if there is a need for high accuracy combined with practical efficiency.

### 3.1 Logic of Orthogonal Arrays

On the basic level, orthogonal arrays can be assumed to use a specific matrix structure, in which experimental conditions are represented in rows and control factors are expressed as columns. Each row of the array describes a single combination of factor levels and that we would conduct our experiment according to the conditions of that row. In case of multi-level factors, the advantages over regular factorial designs are tremendous. Ross (1996) describes the common application of arrays like L8, L9, L12, L16, and L18 in engineering fields because their mathematical properties allow both factor and level balance to be maintained implicitly. For instance, the L9 array is one popular design alternative that has three-level factors and with its nine rows, all three-level factors are equally given representation.

The structuring of these arrays has also high fidelity in its reading. For instance, if the third row of the L9 array has a sequence of "1-2-3-1," in this case the first factor would be tested at level one, second factor at level two, third factor at level three, and fourth factor at level one in the experimental condition. If we check every row in the matrix, the level of the factor is repeated an equal number of times every column, which is the basic case for statistical balance. In their context of inspecting orthogonal arrays, Bolboacă and Jäntschi (2007) demonstrate that the distribution of a level(s) within columns ensures that the variables are mathematically orthogonal and allow the independent estimation of effects. For this reason, the orthogonal arrays can make a crucial contribution to the statistical reliability, both for processes with an above average factor concentration and in multilevel experiments.

### 3.2 Choosing the Right Index Based on Factor-Level Structure

The selection of the appropriate orthogonal array is one of the most crucial steps in Taguchi's methodology. A selected array is not only responsible for the number of experiments run but also for the model resolution of the experiment, the nature of interaction representation, as well as the statistical quality of the results. Roy (2001) asserts that the first step in choosing an array is to establish the factor and level structure; the second stage is to select the array that satisfies this structure using the minimum number of experiments. A high degree of interaction is expected between the elements; in a process where there are three-level elements, the L9 design generally is adequate, but if interactions to be involved become the major consideration, the broader one should use the L18 design. The L18 array that could handle both two- and three-level factors existing in the same table gives great advantages for mixed structures based industrial processes.

Bolboacă and Jäntschi (2007) stated the best array would depend not only on the number of factors, but also on the complexity of the process and expected density of interaction. So in the array selection, those decision questions are usually in three key areas to consider, (1) How many factors are there at each level, and at what number? (2) What interactions could be central to the process? (3) The purpose of the analysis is not to select the best setting, but to find a good statistical representation of the process. Kim (2013) pointed out that interactions have an important role in shaping process behavior, particularly in dynamic and multivariate systems, such that L9 arrays are unable to provide the desired resolution in such cases.

### 3.3 Managing Interactions

The Taguchi design of the experiments enables more limited interaction coverage than that of the classical DOE. This is because robust design's main concern is to ascertain main effects and render the process robust to noise factors. Nevertheless, this does not imply that interactions are ignored entirely. In orthogonal arrays, some column combinations are arranged to represent certain two-factor interactions. Ross (1996) argues that, when you use column assignment rules incorrectly, the main effect and the interaction will be confounded, making the results invalid. Hence, column assignment is an important deciding factor not just an infrequent mechanical approach.

Tang and Zhou (2009) greatly advanced the literature by detailing the mathematical circumstances by which both the main effects and selected interactions can be appropriately determined in the same array using the two-level orthogonal arrays. This study at least partially reduced the frequent criticism of the Taguchi approach as missing interactions and showed that it could be accurately included in the model if the correct column assignment is made. But, according to Kim (2013), in interaction-dominated cases, an orthogonal array would not be adequate and must be supplemented by response surface schemes or extended factorial designs.

From an engineering perspective, interactions might fall into one of three categories: (1) Weak interactions – arrays like L8 or L9 are adequate; (2) Moderate interactions – L18 is preferable; (3) Strong interactions – classical factorial or response surface designs are preferred. Interaction management, within this context, involves correctly tying process knowledge to statistical design. Taguchi with the right decision pays off for both cost and resolution.

## 4. Signal-to-Noise Ratios (S/N)

The Signal-to-Noise (S/N) is a fundamental concept that reflects the Taguchi approach's strong design approach, making process performance not only about average output but also variation assessment possible. Traditional statistical experimental designs tend to measure performance based on the mean value, but the Taguchi method states that a process is only effective when there is minimal variability. S/N, according to Ross (1996), is the most practicable aspect of the Taguchi methodology's aim "to reduce sensitivity to variation". So a factor level with a good mean value but a high degree of variation is weak from a robust design point of view; thus based on the S/N ratio the weakness of the factor level is also well defined.

The S/N ratio is the most powerful distinction between classical optimization and robust design. Classical experimental design may expect to try to make the average performance more or less; with one point of view, Taguchi method tries to reduce variability by increasing the average. In current quality engineering, of course, the S/N ratio is considered an essential part of the decision-making process addressing process stability and performance repeatability issues.

### 4.1 Three Basic S/N Types

S/N ratio performance variable classification in S/N ratios is arranged in three groups based on its attributes. This ranking has a central role in the computational approach and design direction.

***Smaller – the – Better:*** This approach is an effect reduction strategy; it is in the field of unwanted impact improvement. The obtained output values include the defect rate, surface roughness, wear rate, margin of error or energy consumption. Since we strive for value close to zero in this setting, the objective is to minimize variability. As Ross (1996) also points out, these types of methods are particularly capable of handling high-quality and cost-reduction applications. The formula for the mathematical calculation is:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

In this case, $y_i$ represents each measurement and n represents the number of repetitions.

***Larger – the – Better:*** This is when you need a bigger performance variable. Examples are tensile strength, productivity, production rate and yield, heat resistance, and material strength. Having a higher value is not enough; the machine is to be stable. According to Kim (2013), in high-performance line production production, variability plays a key role in which the larger - the - better formulations become the most common in practice. The formula of the mathematical calculation is:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

In this case, $y_i$ represents each measurement and n represents the number of repetitions.

***Nominal – the –best:*** Used when the output variable is as close as possible to a point set for the target value. These are measurements for which the deviation from an indicated target value is critical, such as optical lens diameter, shaft bearing tolerances, current intensity, engine speed or injection volume. This is a part of tolerance design as well. Roy (2001) states that in sectors and systems requiring assembly compatibility, dimensional accuracy etc, the standard of practice is the nominal -the - best approach. The three S/N structures represent a strong design philosophy easily tailored to a wide range of the process styles. So S/N ratio is not just an analytical measure, it also helps in classification of process objectives. The formula of the calculating mathematically is:

$$S/N = -10\log\left(\frac{s^2}{\bar{y}^2}\right)$$

Here$\bar{y}$ the average of the measurements, $s^2$ represents the variance.

### 4.2 Calculation Logic and Method of S/N Ratios

Methods for calculating S/N ratios are designed to systematically suppress the influence of variation. These methods are based on logarithmic scaling. The logarithmic transformation has two critical effects:

- It strengthens the effect of variation on the process, making stability more clearly visible.
- It balances the impact of extreme points on the analysis by normalizing large values.

As Ross (1996) states, the logarithmic structure provides reliability in engineering decisions, particularly in experiments involving repeated measurements, and high variation between measurements rapidly reduces the S/N ratio, guiding the decision maker to the correct level. The structure of S/N, centered on the variance rather than the mean, is the key element that elevates it beyond classical performance metrics.

The Taguchi method systematically integrates repeated measurements as variability from the process is only detectable through repetitions. The S/N ratio cannot be calculated in a single-measurement experiment, making robust design impractical. Designers frequently fail to account for the necessity for repeated measurements, and this is among the most frequent misapplications of S/N analysis (Roy 2001). Calculation process:

- Determination of measurement data
- Selecting the appropriate S/N type
- Applying the formula
- Tabulation of S/N values according to factor levels
- Determining the levels with the highest S/N value

Once these steps are completed, the process can be analyzed in terms of both average and variation.

### 4.3 Interpreting S/N Analysis and Mean Analysis Together

The Taguchi approach is that the S/N ratio alone is inadequate to answer, and needs to be analyzed in relation to average values. Taking a stand-alone average might be inaccurate since some levels produce high-mean performance yet present as highly variable. A high-variation process is not considered robust even if the average is good. Accordingly, when deciding upon which factor levels should be applied successfully, one is looking at a two-pronged assessment:

- Direction of typical performance.
- The size of the S/N ratio.

Process stability over average has previously been highlighted, especially in production lines and automated systems (Kim, 2013), and the S/N ratio reflects this. Accordingly, the S/N ratio should represent a critical parameter in the process of identifying the ideal solution with average performance as a secondary one. The reasons for employing both the types of analyses together can be described as follows:

- ***Stability Reflects in the Average:*** A stable procedure has a high S/N value no matter what the average is. This is important for robustness and stability-oriented design.
- ***Mean vs Variation:*** Some factor levels raise the mean but increase variation. While on the surface the mean appears to be improved, S/N analysis finds this to be misleading.
- ***Error Costs in Industrial Applications, as per quality loss function:*** The fact that a process might perform well on average is not going to allow for perfect assembly and may, as a direct consequence, result in rework costs due to high variation, such as economic losses. This risk is explicitly factored into S/N analysis during the decision process.
- ***Avoiding Wrong Level Selection:*** If an average level appears high but variance is high, we get an unstable process in the long term although it performs "well" in the short term. This is avoided by S/N analysis.
- ***Structural Process Stability:*** The environment for processes in applied industrial engineering works (CNC machining, plastic injection molding, assembly lines, heating-cooling), is inherently unstable. This variability can thus be used to inform design choices through the S/N analysis.

Therefore, the strength of S/N-mean pairwise analysis lies in the ability to choose factor levels that increase performance and also lead to a stably implemented, repeatable process. Thus, the Taguchi method's role in industrial applications is anchored in the importance of the S/N ratio for the pairwise analysis.

## 5. Taguchi Experimental Design Process

The Taguchi approach regards experimental design not simply “as a statistical computational procedure,” but as a methodical approach to problem-solving. The main objective of this method is to identify the necessary levels of controllable factors for the system to be robust to noise. The Taguchi method’s major strength, Ross (1996) stresses, is the "engineering logic that simplifies and systematizes complex processes." Thus, Taguchi's experimental design is not only an experimental project, but also an example of a quality-engineering philosophy in practice. The procedure includes five fundamental steps which are problem definition, factor and level selection, determination of the appropriate orthogonal array, experiment execution, and data analysis. All these processes contribute to the successful development of a robust design, and if any logical connection between the steps is lost, the results may be misleading. Accordingly, according to Roy (2001) the Taguchi method should be viewed as "a complete decision chain."

### 5.1 Problem Definition

The Taguchi design of experiments process starts with the right problem definition, which is first of all. Defining incorrect problem framing will result in wrong conclusions regarding the selected factors to be explored, the performance variable to optimize, and the S/N ratio to be applied. Defining problems in industrial applications often involves issues such as increased process variability, greater quality loss, inconsistent machine settings, or increasing costs. For analyzing process variation as well as improving, Kim (2013) says that the Taguchi process is a useful analytical tool.

The question of problem definition is not just “what is desired?” but also important questions like "why is it desired?", "where is the process deviating?", and "what structure does the performance characteristic have?" As an example, when performing a surface roughness process, the surface can be made less rough (smallest-best kind S/N), the target parameter is in this case, “smallest-best” S/N. In a tensile strength process the target is to increase tensile strength, so this problem will naturally be defined under the “largest-best” formula. In a dimensional measurement having a target value, a nominal-the-best is used, as the goal is to be near the target value. At this point, the most significant blunder is the misclassification of the performance characteristic. Misclassification makes the entire analytical chain false, and the results do not resemble process reality.

### 5.2 Factor and Level Selection

The Taguchi method: factor selection is one of the most important steps due to the adverse effect of factor selection on both experimental design and optimization. Ross (1996) argues that engineering knowledge, as much as statistical knowledge, plays an important role in determining factors. Factors range from machine settings and material properties to environmental conditions, process parameters, and control strategies. Appropriate level ranges must be established for each of these factors; if the selected levels are too narrow, the effect will be undetectable, and if they are too wide, the process will become unstable.

Roy (2001) bases factor-level selection on the triad of "engineering logic + process knowledge + measurability." Once factors are selected and their levels defined, the potential for interaction between these factors is assessed. Because the Taguchi method treats interactions in a limited way, only critical interactions need to be represented in the array; otherwise, unnecessary column consumption will occur.

### 5.3 Selecting the Appropriate Orthogonal Array (OD)

Selecting an orthogonal array is the mathematical foundation of the Taguchi experiment set up, but if this decision is made inappropriately the process will have been seriously faulty. OD is chosen according to factor number, factor levels and interaction density. As defined by Ross (1996), most of the applications are found in the L8, L9, L12, L16 and L18 arrays and it is the decision of who is to use each array that provides a clear separation in the engineering domain. Selecting an inadequate sequence may result in interactions being missed, confounding main effects or loss of resolution. Thus, OD selection goes beyond a mere formulary classification: it refers to the design of minimal yet sufficient experimental strategies to accurately visualize the process. According to Roy (2001), this stage is the "most critical engineering decision" of the Taguchi method.

### 5.4 Conducting the Experiment

Once the OD is chosen, the experiment is implemented. This experimental phase fills the gap between the theoretical design and the actual system. Mistakes during these stages can render the entire analysis invalid. The Taguchi methodology requires randomization of experiments and repeated measurements because randomization reduces the impact of systematic errors, and replication allows for the calculation of variation. At this time, the following principles are emphasized:

- ***Randomization:*** Experimental conditions are applied in a random order to prevent environmental effects from creating a systematic pattern.
- ***Repetitions:*** At least 2–3 repetitions under the same condition are required for S/N ratio calculation.
- ***Adding noise factors:*** Noise factors (heat, humidity, vibration, etc.) are included in controlled experiments to test the durability of the process. Ross (1996) describes this approach as "design under controlled stress."
- ***Consistency of data collection:*** Calibration of measurement tools, reduction of operator influence, and standardization of observation protocols are integral parts of robust design.

### 5.5 Data Analysis, S/N Interpretation, and Optimum Setting Determination

The data analysis is the part of the Taguchi process for which decision-making is concerned. At this stage, the S/N ratio is computed at every factor level, and the salient effects of the factors are visually represented with "factor-level effect graphs". The bigger the S/N is, the better the improvement of the process in both performance and variation. S/N analysis should be performed together with mean analysis because some levels with a high mean produce very low S/N due to high variation. Kim (2013) recommends the S/N ratio as the first criterion for choosing the optimal level and the mean as the second criterion. The appropriate levels are identified and the "estimated S/N value" and "estimated mean" of these are determined and a validation experiment conducted as well. The validation phase is crucial because it indicates that the design works not just in theory but also in practice. As Roy (2001) explains, studies lacking validation experiments exhibit limited robustness.

## 6. Taguchi Experimental Design Applications in Industrial Engineering

Eperimental design has been applied in various fields of Industrial Engineering from various fields in the industrial context especially through process optimization, quality and energy saving. Applications include conventional production (machining, welding, injection molding, etc.) (Boyacı et al., 2017), besides broader applications, such as food processing, reduction of energy consumption, and service processing (Figlali et al., 2009) . This section summarizes, in the light of the literature evidence, the kind of problems that have led to the use of the Taguchi approach, the performance metrics that have been devised, and the actual usage of S/N ratio and orthogonal arrays in practice. This systematically illustrates how theoretical models presented in the previous sections are operationalized in industrial engineering.

The application group in which Taguchi method is most widely practiced is works of machining. Nalbant, Gökkaya, & Sur (2007) utilized Taguchi method to find the cutting conditions to improve surface roughness during the turning of AISI 1030 steel and test the performance of L9 orthogonal array from the perspective of tip radius, feed rate, depth of cut on surface quality through S/N ratio & ANOVA (Nalbant et al., 2007). Under minimum lubrication (MQL) operation on a CNC lathe method a study conducted by Sarıkaya and Güllü analyzed the effect of cutting speed, feed rate, and depth of cut to surface roughness and tool wear in CNC lathe using the Taguchi design and the response surface method (Sarıkaya & Güllü, 2014). Utilizing the Taguchi method, Fratila and Caizar also specified the lubrication and cutting type selection in the face milling process of AlMg3 alloy and demonstrate cooling mechanism results can be verified in terms of an environment in parallel with other factors under L18 array (Fratila & Caizar, 2011). Finally, Zhang, Chen, and Kirby (2007) have also looked at the mold surface finishing. applied Taguchi design in the process of milling to reduce surface roughness, and analyzed this with finite element analysis (Zhang et al., 2007). Likewise, Singh et al. (2012) reported that under sustainable turning conditions, Taguchi method had been realized as an effective tool to control for multiple responses like surface quality, tool wear, and energy consumption.

Plastic injection molding applications have also been an area of significant interest in the field of industrial engineering, particularly Taguchi's method. Oktem, et al. (2007) for injection parameters use the Taguchi optimization technique for preventing the warping problem observed in thin-walled orthopedic parts and studied the influence of packing pressure, mold temperature and cooling time on shrinkage and warping as the product of L27 and L9 orthogonal arrays (Oktem et al., 2007). Since then, a range of experimental designs based on Taguchi and Moldflow simulations have been used to minimize warping errors in large-scale pieces (Ali et al., 2020) like injection-molded carrier trays, the most popular of these structures. This was addressed by Aslam et al. through their Taguchi method where the important effects of injection parameters on a part weight distribution, and part quality, especially filling time, holding pressure, and mold temperature, were analyzed throughout the part lifecycle (Aslam et al., 2023). The key takeaway from all these studies is their capacity to resolve nonlinear relationships between process parameters over a relatively short amount of experimenting.

On that welding process side, the experimental design is often employed in methods including MIG, TIG, and arc welding (Sabirli & Figlali, 2020). Adin (2022) analyzed the gouge angle, current, and voltage in MIG welding of AISI 1040 medium carbon steel rods using the L9 array and found that current is the more important factor for mechanical behavior (Adin, 2022). Kaulgud et al. was employed in Taguchi method to find the best parameters for both residual stresses, and the TIG strength in welding (Kaulgud et al., 2022). Nóbrega et al. examined by the Taguchi method the impact of heat input on the geometry of a bead for GMAW welding in an automotive context (Nóbrega et al., 2021).

The Taguchi method is generally regarded alongside machining in investigations to reduce energy use. Using Taguchi and gray relational analysis approaches, Yan (2012) performed simultaneous optimization of various responses as energy consumption and surface quality in turning operations (Yan, 2012). Using the Taguchi framework, Peng and coworkers assessed the impact of cutting conditions on energy consumption and carbon emissions, supporting a finding that optimal conditions have a direct effect on environmental performance (Peng et al., 2023). In a study developed by Şap et al. on Al-based hybrid composites, joint optimization of surface roughness, tool wear, cutting temperature, and energy consumption with the help of the L18 array was applied (Şap et al., 2023).

Taguchi has recently taken the lab stage in food processing. Sağır et al. employed Taguchi method to optimize the parameters influencing gel formation in pectin-containing gels and showed the texture-sensory quality relationship based on them (Sağır et al., 2019). Sarkisyan et al. adopted L9 design to optimize the flavor production process for meat in plant-based products (Sarkisyan et al., 2025). In the literature, even studies of peanut-based sauce production using Taguchi method for process control and quality performance optimization have been done (Alipın et al., 2023). Also, the Taguchi method has successfully modeled the influence of baking time and temperature on the defect rates of breads (Alipın et al., 2023).

To illustrate, the Taguchi method does not apply directly to physical quality parameters in the service process field but is applied to the configuration of service quality, logistics performance, or algorithm parameters. Taguchi-TOPSIS structure together with criteria weighting and performance ranking has been used in the studies assessing logistics service quality. Using the Taguchi method, Behmanesh et al. (2023) also improved the parameter settings of the memetic algorithms used in supply chain optimization (Behmanesh et al., 2023).

### 6.1. Taguchi Experimental Design Applications in Ergonomics

In the last several years, Taguchi experimental design approach in ergonomics has entered into use in the context of workstation design, manual operations, ergonomically important product design. In practice, as a result, these attributes of Taguchi that make it attractive for industrial process optimization – orthogonal arrays, systematic factor screening and signal-to-noise based robustness assessment – are used to adjust physical and atmosphere parameters, not only machine performance towards human operators. Recent research shows that Taguchi designs can be used to prioritize ergonomic design variables through importance rankings and connect them directly to established risk indices, including RULA, REBA and spinal compression forces, and to performance measures including typing speed, task time and quality outcomes.

The first contributions pertain to the utilization of Taguchi designs for the optimization of the environmental and layout parameters of the workplace, which affects comfort and basic performance. Using an orthogonal array, Mazda and

Setyaningsih (2024) performed ANOVA and signal-to-noise analysis on a shared workspace and treated lighting level, noise, temperature and ambient aroma as control factors. These factors show statistically significant but differentiated effects on typing speed and subjective comfort, and the Taguchi analysis provided a clear ranking allowing to prioritise environmental improvement in low-budget settings. Instead of evaluating all combinations of environmental settings, the orthogonal approach enabled authors to screen the design space effectively and suggest a reliable combination that maintained good performance under true variability of environmental conditions (Mazda & Setyaningsih, 2024).

A second, more detailed research uses Taguchi designs for physically demanding workstation redesign. Kumar et al. (2021) used a Taguchi experimental approach followed by digital human modelling to assess an automotive conveyor workstation. Control variables, including conveyor height and horizontal reach distance were organized in an orthogonal set and outcome variables included spinal compression and shear forces, RULA scores and work-related musculoskeletal disorder (MSD) risk. Conveyor height was identified a dominant factor responsible for spinal loads and postural risk; the optimal level combination based on Taguchi main effects significantly decreased estimated compression forces and risk for MSD in comparison to the baseline design (Kumar et al., 2021). In a similar vein, Das & Singh (2023) created and analysed a new gemstone polishing workstation utilizing an L27 orthogonal array. The factors involved levels of illumination, polishing height and tool position, while the responses included postural angles, electromyographic muscle activity and discomfort ratings. Such a workstation configuration reduced muscle activity and subjective discomfort without sacrificing productivity using the Taguchi analysis followed by confirmation experiments (Das & Singh, 2023).

Machine operation ergonomics applications demonstrate how Taguchi can be generalized to multi factor postural problems. Chourasia et al. (2022) used a Taguchi L27 concept and Grey relational analysis for analysing lathe machine operators. Control factors measured posture and operating conditions per summer heat, while responses included postural scores and performance measures. The Grey–Taguchi integration supported multiple-response optimisation, so these were factor levels selected to provide a compromise between ergonomic posture and operational performance rather than maximizing one over the other (Chourasia et al., 2022). This kind of hybrid approach is relevant in ergonomics, where designers generally combine physical load, task duration and product quality.

At the interface of ergonomic tool design and human biomechanical response, Taguchi designs have also been applied. Singh et al. (2019) used multiple-response optimisation techniques for the ergonomic assessment of a carpet weaving knife. Blade width and blade angle were systematically differed and evaluated with respect to wrist posture, muscle activity and performance metrics. While they use a Taguchi-type thinking and other multi-criteria methods for optimisation, their logic follows essentially the same path, that is, use a structured design to find combinations of anthropometrically relevant design parameters that reduce joint deviation and muscle load while maintaining acceptable productivity (Singh et al., 2019). At a more conceptual level, Veljković et al. (2018) presented how Taguchi's contribution ratio and Pareto diagrams can aid in determining influential factors influencing ergonomic experiments and contribute positively to overall transparency of design changes when considering their decisions. In particular, the

Taguchi method has been incorporated into several ergonomic design methodologies in a more recent industrial context that integrate parameter optimizations with digital human modelling and biomechanical analysis. Sharma et al. (2022) proposed an ergonomics-integrated design methodology for cleaning equipment incorporating parameter optimisation, computer aided design and digital human modelling as the approach to design with iterative parameters, iterative design approach. The approach, though not unique to Taguchi designs, adopts rigorous design principles and design rigorously designed experiments to control mechanical advantage enhancement, postural and joint forces adjustment, and results for successive versions of the equipment based on REBA scores and biomechanical feasibility indices (Sharma et al., 2022). Papetti et al. (2021) similarly described a human-centred methodology for designing ergonomic manufacturing equipment, in which experimental design and human factors evaluation are combined to standardise processes and improve both productivity and ergonomic indicators. From this point of view Taguchi is not an independently-included methodology but an embedded ergonomic engineering workflow.

At the interface of ergonomics and operations management several works integrating Taguchi logic and multi-objective optimisation and decision making frameworks are developed to deal with explicit trade-offs between ergonomic risk and performance. Pascual et al. (2019) present an application of multi-objective optimisation on ergonomics in production, where ergonomic risk indices and production performance are jointly optimised. While their optimisation engine is more extensive than solely Taguchi designs, the primary basis of factor screening and shaping the design space are based on experimental design principles which align with Taguchi's orthogonal array philosophy. Crnjac et al. (2019) proposed a two-stage product design selection procedure, using PROMETHEE with

Taguchi procedures. In the study presented, multi-criteria decision-making is employed to minimize competition for design choices and Taguchi experiments are then performed to optimize key parameters in a limited number of physical prototypes, minimizing the development time and maintaining ergonomic performance (Crnjac et al., 2019). Almansoori et al. (2020) takes a further step in a manual spray painting with Taguchi robust design with regression and multi-response optimisation. Their study included fatigue, hand stability and speed as human-centred variables, alongside paint quality, time and cost result outputs. These findings demonstrate how Taguchi can be integrated into noise management approaches that improve quality at the same time as alleviating operator fatigue (Almansoori et al., 2020).

The use of digital human modelling and virtual environments in ergonomics research also had an impact on how Taguchi experiments are designed and interpreted. Digital tools such as JACK, CATIA and virtual manufacturing platforms are highly utilised to produce postural information, joint forces, and reach envelopes that act as responses or constraints of Taguchi-driven optimising. For example, Iqbal et al. (2020), using virtual manufacturing tools, investigated ergonomic performance with respect to the workstation scope distance, the height and the chair height, which is significantly influenced by design parameters of the cycle time, posture and allowable load. Although their optimisation was based on response surface methodology rather than a pure Taguchi array, their factor–response exploration structure is largely in line with the Taguchi method of good experimental planning (Iqbal et al., 2020). Taguchi experiments are conducted on physical prototypes with workstations developed or pre-validated in a virtual environment to ultimately enhance workstations, with studies that integrate virtual prototyping with Quick Exposure Check and user feedback for redesign workstations (Sahu et al., 2022).

From the perspective of ergonomics, these applications collectively suggest that Taguchi experimental design shows great potential for three design problems. First, it is suitable for screening and ranking physical and environmental factors in complex workstations where there are many factors that plausibly affect ergonomic risk, but only a very small subgroup of them could feasibly be modified in fact. Second, Taguchi offers a signal-to-noise methodology for identifying parameter settings, especially in tasks that involve human performance and are demanding (e.g. polishing, manual painting, assembly) that provide stable human performance under inevitable posture, fatigue, and environmental variability. Third, in a context of human-centred design methodologies extending beyond digital human models, Taguchi designs offer effective and inexpensive way of validating and refining design extensions without necessarily needing to expand design adoption at scale. Meanwhile, ergonomic literature indicates the limitations also common with Taguchi and the general critiques. To date, most studies referenced use relatively small samples and focus on short-term exposure, limiting the generality of their findings and leaving long-term health outcomes uncertain (Mazda & Setyaningsih, 2024; Das & Singh, 2023). Additionally, the majority of Taguchi-based ergonomic applications focus on the physical aspects of the individual and fail to include the psychosocial and cognitive factors that have been shown to contribute to MSD risk and productivity (Kulaç & Kiraz, 2024). In highly interaction-driven environments, such as complex human–robot collaborative processes or multi-device control rooms, the limited interaction resolution of classical orthogonal arrays can be limiting, too. For these reasons, a number of authors state that Taguchi should be viewed as part of multiple toolbox in addition to multi-objective optimisation, fuzzy logic, genetic algorithms and digital twins when more complex ergonomic design difficulties are tackled (Harari et al., 2019; Lind et al., 2024).

Taguchi experimental design has a strong and direct practical market niche in ergonomics. It provides an organized, efficient mechanism for identifying and prioritising ergonomic design factors, quantitatively linking them to risk indices and performance metrics, and establishing strong parameter setting for workstations and products. In conjunction with human-centred assessment instruments and innovative digital ergonomics solutions, it opens a pragmatic direction from fundamental ergonomic principles to tangible design interventions to mitigate risk of MSD and promote steady human performance in industrial and service settings.

## 7. Conclusion and Recommendations

The Taguchi Design of Experiments approach is still a tool that can be used with increasing industry pressures along this factor of cost, but also to achieve quality and sustainability requirements. Strength of the method is its systematic method for analyzing a sizable number of parameters with limited number of experiments and for targeting process variations directly. A practical advantage arises from this property, especially where process parameters of production lines change frequently and optimization must be done quickly. Moreover, its robust design philosophy mitigates the introduction of noise factors with a robust engineering strategy and improves stability of process performance. Literature review results clearly indicate that Taguchi process is quite effective in enhancing product quality and resource utilisation not only in manufacturing but also in processing processes such as food processing, welding, polymer processing, and energy-optimized processes.

But the approach is not appropriate in every kind of problem. In cases where interactions are strong, the model structure is nonlinear or response variable is associated with complex functions, the Taguchi design needs further refinement. The limited resolution of orthogonal arrays can result in the loss or misinterpretation of interaction effects, especially in high-dimensional parameter space. In such cases, the more flexible response surface methods such as RSM, full factorial-based models, evolutionary techniques or Bayesian optimisation should take precedence. Moreover, when the task involves multiple responses optimization, Taguchi is just not enough, as it is used together with grey relational analysis, TOPSIS and MOORA.

For practitioners, there should be some principles in order to apply the Taguchi method. First, factor and level selection on the basis of engineering knowledge, in addition to variables that are easily measurable, which makes up the design, should define aspects that influence the actual process. Second, the selected orthogonal array can only be fit for factor-level structure, choosing the incorrect array invalidates all analyses. Third negligence when randomization is not involved and this makes systematic errors and unreliability of the S/N analysis. To conclude, a verification experiment has to be performed once the optimal parameters are determined, otherwise, the validity of the optimum combination in the real process will not be guaranteed.

Overall, Taguchi method fits well in the environment as appropriate to process variation reduction, quick experimental design, and optimized design for low-budget conditions (low resource conditions under conditions of rapidly developing designs with small number of experimental space in environments). However, for complicated multivariables with interactions and multivariable problems, the approach is not enough and it needs to combine with better developed experimental-based designs or optimization methods in a more complex solution as well. With the appropriate use in the industrial engineering industry, Taguchi Approach still shows good potential to provide stable and cost effective design decisions at the production and service level that are available to analyze.

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# Chapter 2

# MENTAL WORKLOAD ANALYSIS

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## 1. INTRODUCTION

Mental workload is a fundamental concept that describes the relationship between a person's limited cognitive resources and the amount of processing required by a task. This concept is essential for understanding human performance, error rates, decision quality, and safety, particularly in complex socio-technical systems. In today's working life, while physical labor has been delegated to automation in many areas, cognitive demands have increased; information processing, decision-making, monitoring, and coordination-focused jobs have become widespread. Therefore, mental workload plays a central role not only in specific "high-tech" areas but also in many contexts, from call centers to educational institutions, hospitals to software development teams.

Traditionally, the mental workload model has rooted in psychological theories explaining such aspects of cognitive function as attention and memory. Kahneman's attention and effort theory assumes that people have a bounded volume of mental energy and require the ability to allocate this resource among tasks. This pool becomes limited when a person is multitasking or when a task becomes too large or involved with a single task. Mental workload represents the extent to which this resource is depleted. When task demands surpass a person's capacity, performance drops, the risk of errors rises, decision-making slows down, and the individual begins to experience a sense of being "overloaded." (Bruya & Tang, 2018)

The importance of the concept of mental workload extends beyond performance outcomes to include employee health and well-being. Working under high cognitive demands for long periods can lead to chronic stress, burnout syndrome, job dissatisfaction, and intention to leave the job (Karasek, 1979; Maslach & Jackson, 1981). Conversely, very low mental load (underload) is associated with monotony, distraction, loss of attention, and decreased situational

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awareness; this creates serious risks, especially in tasks involving constant monitoring and surveillance (e.g., monitoring security cameras, control rooms).

Employees' mental workload is not only about output but also includes mental health and overall wellness of the workforce. Working under high cognitive load for prolonged working durations may result in chronic stress and burnout syndrome, job dissatisfaction, and intention to leave the job (Karasek, 1979; Maslach & Jackson, 1981). On the other hand, under- or extremely low mental load (underload) contributes to monotony, distraction, loss of attention, and decreased situational awareness, and is dangerous to those involved in tasks in which there is constant monitoring and surveillance (e.g., monitoring security cameras, control rooms).

## 2. CONCEPTUAL FOUNDATIONS OF MENTAL WORKLOAD

In order to understand mental workload, it is necessary to look at basic models of human cognitive architecture. Three main components of this study are referred to as capacity models, multi-resource theories, and cognitive load theory. Kahneman's capacity model assumes that attention and mental effort are extracted from one type of general pool. In this model, the level of arousal affects available capacity; in stress and sleep deprivation, this capacity is lowered. The model lays out a framework for explaining resource allocation -- people allocate their resources consciously or unconsciously, so it is a matter of prioritization, in a logical way. However, it does not differentiate between different sensory modalities or sorts of responses (Bruya & Tang, 2018). The Multiple Resources Theory introduced by Wickens (2002, 2008) provides a more nuanced view of the topic of mental workload. In this theoretical interpretation, humans have multiple (or some) independent or partly independent resource pools. For instance, processing of visual-spatial information requires different resources from processing auditory-verbal information; but it also differentiates between manual and vocal response forms. In the context of this theory, the task efficiency of conducting two tasks at once is thus also based on the demand placed on the system. It is important to note this important point for the dual task design: the workload can grow quite rapidly when two visual tasks are performed simultaneously, while the combination of a visual task with an auditory task may be more sustainable. Sweller's (1994) cognitive load theory has an especially important application in the context of learning and education, but the concepts built on it also play a quite practical role in intricate activities and in interface designs in the commercial realm. This theory talks about 3 types of load: intrinsic load (the natural problem-solving complexity of the task), extrinsic load (unneeded cognitive load that comes from the task or the interface design), and productive load (useful effort that supports learning and schema formation). A good system reduces extrinsic load; modifies intrinsic load based on the user level; and induces productive load. This distinction, for instance, has utility in simplifying more complex production processes, training materials and software interfaces. The general property of such theoretical frameworks is the understanding of mental workload being considered an element of human-system collaboration. That is, workload is not just a "personal characteristic" or merely a "task-related attribute"; as a result work is a "malleable" product of the interplay of the two. Thus, mental workload analyses need to be holistic in nature that is able to accommodate individual"s differences in their work burden along with task and system attributes (Büchli & Troche, 2025).

## 3. MENTAL WORKLOAD MEASUREMENT METHODS

Mental workload is difficult to measure because it is very abstract. There is no right or perfect measure; different methods have their limitations. Accordingly, contemporary works have suggested combining subjective, performance-based, and psychophysiological measurements in a multi-method approach (Wickens, 2008; Gevins & Smith, 2003; Bartolomei et al., 2026).

Subjective measurements are based upon the person's own perception. NASA-TLX is the most widely used subjective measurement tool (Hart & Staveland, 1988). The form is given to the participant after the task is completed; the person scores six different dimensions on a scale of 0–100 and, if desired, weighs the dimensions based on pairwise comparisons. The beauty of the scale is that it is relatively easy to administer, it has been adapted to various languages and cultures, and it is a "common language" that makes comparison across sectors possible. But its subjective nature renders the measurements context-sensitive: the emotions of the person who measures it, social pressures in their social networks, and the desire to "look good" could all affect whether the results are valid. Moreover, people do not always perceive their own mental load accurately — like perceiving an automated but also extremely risky task as "easy." (Babaei et al., 2025).

Performance based measurements represent behavioural outputs in terms of reflecting the amount of mental effort involved. Performance on a primary task — in terms of error count, reaction time, completion time, quality criteria, etc. — may also say something about workload for us. But performance doesn't have to be low-impact; a person can perform well with significant exertion. The secondary task paradigm was developed to account for this behaviour. Within these paradigms you also perform a simple secondary task while you perform a primary task (e.g., pressing a button when hearing a certain sound) and as mental workload increases, their reaction time in the secondary task lengthens and, consequently, their error rate increases (Wickens, 2008). The secondary task paradox has an advantageous role of indirectly, but sensitively measuring workload; however, this has the downside of modifying workload by adding some extra work to the system. This is why careful design is important.

Psychophysiological measurements track the body’s automatic responses when mental load rises. Pupillometry is one of the classic methods in this domain. Pupil width is sensitive to both light level and cognitive load; when light is held constant, pupils dilate as load increases (Beatty, 1982). This approach offers high temporal resolution and is particularly applicable to monitoring short-term load changes ( Lee et al., 2024).

Eye movements also offer rich data for insight behind pursuit of information and visual load: the duration of fixation, the saccade length, and the number of regressions represent both interface complexity and the strain imposed on the user. Neurophysiological techniques like EEG and fNIRS are able to measure brain activity directly (Sharma & Gupta, 2025).

Increased frontal midline theta band in EEG is linked to sustained attention and cognitive effort. Beta activity may reflect alertness and information processing speed (Gevins & Smith, 2003). fNIRS is used to indicate decision-making and problem-solving load, particularly by measuring oxygenation changes in the prefrontal cortex. Heart rate and heart rate variability (HRV) are sensitive to changes in mental stress and load via the autonomic nervous system: decreased HRV is generally associated with increased stress and load (Mehler et al., 2009). Skin conductance (EDA), on the other hand, reflects increased sympathetic activity; it increases when cognitive demand and emotional arousal rise

Each of these techniques has its individual advantages and limitations. For instance, NASA-TLX is a very quick, practical tool which does not have setup costs but lacks temporal resolution; it only gives a general assessment at the conclusion of the task. EEG and fNIRS provide high scientific precision but are expensive, time-consuming, and involve experts. The secondary task paradigm is sensitive, but difficult to design without disrupting the system. As a result, the recommended approach, especially for safety-critical systems, is the combined use of subjective, performance-based, and psychophysiological indicators. By combining measures that address their respective biases or limitations, this multi-method strategy gives a more reliable and valid workload profile than a single one (Babaei et al., 2025).

## 4. FACTORS AFFECTING MENTAL WORKLOAD

The factors affecting mental workload are multi-dimensional and often interdependent. We may classify these causes as task-related, individual-related, environmental and system-related, and temporal/organizational. Yet, this categorization is an artificial distinction, and in actual settings, these dimensions are interrelated. Task-related factors are the most prominent determinants of workload. The complexity of the task, information density, level of uncertainty, cost of error, time pressure, and the focus needed (sustained, selective, divided) can directly influence the amount of cognitive effort required. For instance, performing a surgical procedure involves simultaneous monitoring of dynamic visual information, the interpretation of data from various devices, and managing the communication between the team members; these tasks account for the multidimensional mental load. The conceptual levels of more trivial and high pace tasks (e.g., rapidly sorting products on a conveyor belt) are relatively simpler, but may carry high mental load because people must make those steps under time pressure. Task uncertainty (e.g., frequent exceptions, unclear rules, unexpected events) also raises cognitive demand as the individual is in constant form of predictions, categorizing new situations, and problem solving.

There are other individual factors, creating distinct workload experiences for different people for each task. One of the foremost among these is expertise level. For someone who has done a job for many years and has cultivated rich mental schemas in that area, there is less load in the task as most steps have become automatic (Sweller, 1994). For beginners, conversely, the same task demands a lot of cognitive effort. Working memory capacity, attention control, multitasking ability, cognitive flexibility, and personality traits (neuroticism, conscientiousness) can all impact perceived workload.

Moreover, an individual's emotional state, stress level, sleep quality, physical fatigue, and motivation can impact their momentary workload experience (Esen et al., 2017). For example, a nurse working shifts may perform the same task with greater mental effort during the night shift due to sleep deprivation. Many factors external to us, such as environmental and system-related ones often perceived as "background," have a direct impact on how much mental load we can endure. The physical environment, including noise, excessive or insufficient lighting, temperature, and non-ergonomic work arrangements, may influence attention and comfort. Excess auditory or visual distractions involuntarily consume mental resources. System design, including the information architecture of interfaces, symbols used, menu structures, error messages, feedback times, and interface terminology (Norman, 2013), all have a direct impact on workload. A poorly designed interface can unnecessarily complicate a simple task, leaving users constantly wondering, "What do I need to do?"

Time and the work organisation should not be forgotten. Busy periods, shift lengths, the frequency and duration of breaks, task rotation, staff shortages, leadership style, and organisational culture all indirectly but significantly affect mental load. Karasek's (1979) job demands–control model has demonstrated that the combination of high demands and low control is particularly risky in terms of stress and mental load. When employees have no say in their tasks, cannot play a role in designing tasks, and remain only in the role of “implementer”, the same level of demand can be perceived as a higher mental and emotional load. Internal-organizational communication, uncertainty management, role conflicts, performance pressure, and reward systems all influence the perception of workload.

These factors interact with one another in non-linear ways. For example, high expertise may diminish the actual burden of a task in and of itself, but allocating additional responsibilities to the same individual (such as team leadership or training) may increase the overall burden. Or, a well-designed interface might be enough to allow for high information density. Thus, when analyzing mental workload, no single factor should be seen as "the sole explanatory factor"; a contextual analysis must be performed.

## 5. **CONSEQUENCES OF MENTAL WORKLOAD**

The impacts of mental workload are felt through many layers on both an individual and organizational level, as a result of mental load. It is also useful to view these effects in terms of both the immediate (immediate/periodic) and long-term consequences.

In the short term, the overuse of mental workload sharply undermines cognitive performance. Attention narrows and environmental cues are missed causing a reduction in awareness surrounding what is happening, making oneself forgetful (Endsley & Bolstad, 1994). Decision processes become either so slow as to be sluggish or on the other hand, "hasty", as the individual either gathers more information without deciding or picks the first thing to go with the information so as not have a cognitive load. Poor attention resources consumption can make a mistake, especially in the case of multi-step applications such as skipping steps, applying them in an inappropriate order, or omitting the essential checks. In domains such as aviation, medicine and nuclear energy, the consequences of these types of mistakes can be dire.

One immediate impact of mental workload is changes in behaviour. Those who are under stress are more likely to use simplifying heuristics; e.g., the tendency to depend too much on past experience in evaluating risk, to rely on stereotypes, to accept “default” measures with no skepticism, for example. These can often be adaptations, but in uncertain, highly dynamic scenarios, such as those in systems where rare but critical events present themselves, they translate into dangerous results.

At the psychological level, excessive workload produces irritability, impatience, anxiety, a loss of sense of control and frustration. Hart and Staveland (1988) propose that NASA-TLX should account for this emotional element through their disappointment dimension. People who repeatedly feel “inadequate,” “inability,” or “failure” when executing the task, may have their self-efficacy perception weakened and suffer from a lack of motivation. Long-lasting elevated stress hormones (such as cortisol) can have adverse long-term effects on physical health as well.

Mental workloads that are chronically high are associated over time with burnout syndrome, depression, anxiety disorders, and psychosomatic complaints (Maslach & Jackson, 1981). Burnout involves emotional exhaustion, depersonalization, and low personal accomplishment. Individuals who work under constantly high cognitive demands and at the same time experience low control, low social support, and low rewards are vulnerable. On the organizational level, high workload can lead to, for instance: increased absenteeism, staff turnover, low commitment, and low organizational citizenship behavior (Chireh et al., 2025).

And the effects of mental workload are harmful not only at "very high" levels but also at "very low" levels. Workload is insufficient so that you are bored and forgetful, which causes 'microsleeps', distraction and the inability to pay attention. This has been common to experience in control rooms, radar monitoring, and long highway drives. The Yerkes–Dodson law describes performance and arousal/level as an inverted U—when it is low arousal, motivation and attention are low while on high arousal, level of stress and cognitive disorganisation are too high. Mental workload management is managed to maintain performance to within this optimal range, to try and ensure that performance remains in place and stays there.

From the organizational level, workload imbalance can appear as quality failures, customer complaints, lost times, delay in process, loss of process innovation, the ability to innovate and security compromise. Using too much load to assign too many others to too little can undermine fairness within a team. Thus mental work is not just a question of "individual resilience" but an issue of strategic management.

## 6. MENTAL WORKLOAD MANAGEMENT AND REDUCTION STRATEGIES

This should come at the same time as managing mental workload is all about rationalizing the load of a task, strengthening human resources, and organization structures. Good management of workload is not just "reducing a load": Often it is redistributing the load and making it more purposeful or sustainable is a more suitable aim.

The initial task design and process design steps are to simplify the task and eliminate unnecessary cognitive loads. The internal–external–productive load distinction from the cognitive load theory is a useful framework (Sweller, 1994) now at this stage. Internal load (complexity related to the work to be performed) can be inescapable until a point, but external load (unnecessary complexity associated with a suboptimal design) can be reduced. Effective strategies for doing this may include reviewing procedures or eliminating unnecessary approval steps, automating data entry tasks, and helping the user to take the most repetitive manual tasks (templates, macros, auto-fill, etc.). Streamlining screens, reports and forms (e.g., for information systems), spreading information density across time and visually marking key-pieces of information to help reduce workload (Norman, 2013) and reducing the amount of time for important things like information, is also a key.

And finally. Principles of design must be user-centered in interface and system design. Watching users in use, doing task analysis, modeling information flows, and testing prototypes with users early on can anticipate the cognitive costs of a completed system. Lining, proximity grouping, visual consistency of icon images, and colour palettes contribute to lesser cognitive search costs. In order to avoid alarm fatigue in warning mechanisms, there is need for prioritization of alarms settings, the proper thresholds and minimization of unnecessary alarms, if users are to differentiate the more critical alarms and more alarm frequency which will increase workload and error rate.

Workload management at the organizational level involves aspects like job design, task distribution, shift planning, break arrangements or the need to select the right number of employees. Karasek's (1979) model of high demands only makes it clear that it is very hard to tolerate high demands with inadequate control and support. Thus, by empowering employees to be involved in their own task, with their involvement in process improvement programs, providing open feedback, and maintaining an open feedback channel contribute towards a fair load perspective. When planning shifts, circadian rhythms should be included with a focus toward minimizing or rotating the most cognitively demanding tasks in the night shift. And they should also be frequent in duration and form; the shorter of those breaks, the better. These pauses must ensure a true “disengagement” (e.g., moving one’s body away from a screen or quiet areas) required for mental restoration.

It was also recommended that individual mental workload coping strategies are provided, but it is important not to take responsibility solely on the individual level. Mindfulness-oriented attention training, breathing strategies, time management strategies, prioritization techniques, multitasking prevention, cognitive flexibility and sleep hygiene are a few of the topics that can help the individual to be able to cope. When offered as "just get better yourself" and without affecting the system they function as a barrier through which inequitable workloads are concealed. Hence, individual strategies should be viewed in the context of, not in terms of, organizational and design interventions.

Artificial Intelligence and Automation And artificial intelligence and automation as powerful tools, “adaptive” methods are the new paradigm for mental workload management! Chen and Barnes (2014) highlight that such systems should adjust task distribution dynamically to distribute the load across human-agent teams. For example, it has been proposed that driving assistance systems should trigger more alerts upon low attention levels of drivers, and in some cases prototypes have been created for predicting workload depending on the EEG, HRV or pupil data of the operator and modifying the interface as appropriate. Yet, while these systems start to bring new problems concerning ethics, privacy and control, they will eventually be among the most critical tools for workload management.

## 7. APPLICATION AREAS

Mental workload analysis may take many forms across industries and professional classes but one principle is core: humans use their cognitive capacity while performing a specific task within a specific system, and risks increase when approaching the limits of that capacity. By comparing applications across disciplines, it decreases the abstraction of the concept and emphasizes the practical value.

Mental workload is one of the key variables associated with clinical error risk and employee burnout in the health domain. In intensive care units, nurses watch several patients at once, evaluate monitor alerts, calculate medication doses, communicate with physicians and respond to emergency calls. This is a mental heavy lift, and all that time demanding. Studies show that when alarm volume is high, nurses become desensitized to alarms and miss the most critical alarms — a phenomenon that is known as alarm fatigue. Mental workload analysis can be applied towards designing alarm systems, to enhance the assignment of work. In the same way, in surgical teams, for example, one may use variation in workload over time to better plan breaks, team changes and support protocols, especially when performing lengthy and complicated surgeries.

In that regard aviation is the field with the most rigorous historical research on mental workload. Pilots work extremely different types of hard demands. However, in the different phases of flight, workloads can vary significantly: takeoff and landing will be very high, cruise relatively low. These are related to both the engagement and disengagement with automation and environmental demands. For example, you will have very heavy workload in the field; an error in time and distance required to respond can lead to a loss of situational awareness with dangerous consequences (Endsley & Bolstad, 1994). In contrast to high workload and prolonged monotony under autopilot, very low workload increases chances of inattention and delay in responding to emergencies. Workload profiles are explored in detailed ways in cockpit design; indicators, warning systems, automation levels, and task distribution are calculated via these analyses.

Driver mental workload is a critical predictor of safe driving in road transport. Long stretches of driving on flat highways might result in low arousal and boredom, whereas driving in urban areas generates high mental workload due to high information density and time pressure. As navigation systems, driver assistance systems and in-vehicle infotainment systems can exceed cognitive capacity of the driver, workload analyses should be implemented in the design of these systems. As Mehler and associates (2009) demonstrated: even speech-based secondary tasks can substantially increase workload on the driver as well as physiological arousal.

Workload is an important factor in industrial production and process control for not only the worker(s) on the production line, but it also needs to be taken into account by the engineers of the system in the control rooms. Repetitive tasks on the line under time pressure lead to high level of mental load, which may cause error. In the control room, the observation of rare events is characterized by a combination of low arousal and high potential risk. Mental workload analysis is used here in the development of screen layouts, alarm systems, reporting tools, and shift structure design.

A shift of student/teacher workload has taken place in educational staff and instruction, especially with the increasing popularity of a digital learning environment in places such as education and training, as students (as well as their teacher) has been redefined. High information density and difficult user interface in online platforms can contribute to increasing cognitive load that does not need to be there and thus decreases the learning efficiency from the students. For the teachers, multi-tasking, using two online and face-to-face channels, constant notifications and messages results in a high workload. Cognitive Load Theory has been an indispensable reference in developing course designs and digital content generation (Sweller, 1994).

Mental workload and emotional labor are linked in the service sector, and that is particularly true in call centers and services requiring an excessive amount of customer interaction. Call center workers have to deal with hundreds or thousands of customers in a small period of time, manage complex systems in a fast-paced environment, follow many scripts and control their tone to others emotionally. This adds cognitive and emotional load. Workload analyses are useful here to ensure the realistic adjustment to the task duration targets, performance metrics, or screen designs (Bachman et al., 2026).

## 8. RESEARCH DESIGN IN MENTAL WORKLOAD ANALYSIS

Various methodological choices need to be made by mental workload researchers: what will be measured, in what context will it be measured, what methods will be used to measure it, and how will the results be interpreted? Questions like these determine the validity and how widely the study can be extended.

In the first instance, a researcher needs to define mental workload conceptually. An example of such a concept is “perceived workload,” “effect of workload on performance,” or “workload as a physiological response.” This definition directly informs the measurement strategies that are chosen. Subjective scales like NASA-TLX focus on perceived load, while secondary task paradigms stress behavioral reflections; and devices like EEG, fNIRS, and HRV emphasize the physiological side.

In experimental design, independent variables are task demands: manipulations, such as information density levels, time pressure present/absent, and low/medium/high task complexity, are widely applied. Dependent variables are workload indicators (NASA-TLX scores, secondary task performance, physiological measurements) and primary task performance. The researcher must balance between internal validity (reliability of the cause-effect relationship) and external validity (the generalizability of results to the real world). Very rigorously controlled laboratory studies isolate variables nicely enough but can be disconnected from the actual context; and field studies produce contextual richness but are more challenging to control for confounders.

Selection of the sample is also crucial. Using expert vs. novice users in the same study can give better insights into the contribution of expertise to workload. But in most fields it is hard to obtain experts: the researcher has to find practical limitations while at the same time keep an idealistic view. The ethical aspect is also crucial: high workload manipulations, in particular, must not put participants under unnecessary stress; the risks of the study should be clearly explained, and the voluntary consent of the subjects must be obtained.

For determining measurement methods, both the suitability for the research question and resources (budget, time, level of expertise) need to be taken into account. For example, high-resolution EEG or fNIRS systems may not be present in all institutions, whereas the NASA-TLX scale and simple secondary task setups are much more accessible. Synchronization is crucial for data collection, especially when multiple physiological measurements are used, and hence the timestamps of the measurements must be consistent with the workload manipulation.

When data were analyzed it commonly used analysis of variance (ANOVA), mixed models, regression analyses, and correlation analyses (Boyacı et al., 2025; Boyacı & Baynal, 2019). In multi-method settings, cross-type relationship analysis can look into such relationships or relationships between various sorts of measure: e.g., are NASA-TLX scores and changes in HRV closely related? These kinds of analyses add more weight to the validity of the measurements. Moreover, time series analysis is also a useful means to see the change in the workload dynamics over time, particularly in long tasks.

Finally, when interpreting their findings, researchers must not only look for statistical significance but also at the effect sizes, practical relevance, and context. Mental workload is a multidimensional concept that cannot be simplified to just a number; it is therefore crucial for reporting rich descriptive information and contextual explanations.

## 9. FUTURE DIRECTIONS

As well as technological and social changes, mental workload analysis is posed with fresh questions and possibilities. Workload is being transformed by artificial intelligence, learning systems, smart wearables, immersive reality/augmented reality environments, telework, and flexible organizational structures. That includes technologies like real-time, continual workload monitoring systems. Wearable sensors (smartwatches, chest straps, glasses) can capture HRV, skin conductance, movement patterns, and even EEG-like signals in the course of daily workflows. Machine learning algorithms can process this information and transform it into "workload prediction models." For instance, such a system may sound alarms when the workload of an operator in a control room approaches dangerous levels or suggest that task redistribution be temporarily expedited; these tools serve to support automation. These applications also bring up ethical issues like privacy, data security, surveillance pressure, and the sensation of "constant monitoring," though.

Adaptive interfaces and automation systems are the second trend which could stem from the above mentioned. Here the objective is that the system will shift from a framework that imposes a one-way demand on humans, and become a two-way interaction object that is sensitive to the cognitive state of human (Chen & Barnes, 2014). For example, a complex dashboard will go into a “simplified mode” that emphasizes only the important information when the operator's workload increases. For example, educational software can adjust speed of content based on student cognitive load, and provide additional explanations by identifying points where they struggle. Since such programs mean that part of the design and control is taken from humans to machines, there will be new controversies surrounding human autonomy and responsibility.

The development of remote and hybrid working models can also mean there is greater potential for research on mental workload. The blurring of boundaries between home and work spaces, the expectation of constant online availability, notification overload, and the blurring of time boundaries make it increasingly difficult to track workload and develop the right approach to managing it. Here, the concept of mental workload has to be rethought, and we would need to understand that, instead of something experienced "during a task," it is a continuous flow throughout the day.

Future themes also revolve around cultural diversity and inclusivity. Perceptions about workload, authority relationships, tolerance for error, and help-seeking behaviors may differ across cultures. Thus, the cross-cultural validity of seemingly universal scales and methods must be reevaluated. Likewise, neurodiversity (e.g., individuals with ADHD or on the autism spectrum) will become more visible in workload analysis; traditional workload profiles often fit everyone into the same cognitive template; more flexible and customizable models are needed to avoid this.

Finally, it is envisaged that mental workload analysis will develop from the previous "risk and error prevention" orientation and take into account positive aspects such as creativity, learning, flow, and meaningful work experience. Sometimes a certain level of difficulty and cognitive demand is necessary for deep learning and satisfaction. Therefore, future research will aim to propose "ideal workload profiles" not only towards a safety view but also toward a sustainable and satisfying working life.

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# Chapter 3

# ASSESSMENT OF MUSCULOSKELETAL DISORDERS CAUSED BY POOR WORKING POSTURES

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## 1. Introduction

Work-related musculoskeletal disorders (WMSDs) are common health issues affecting workers across various industries. These disorders include conditions like back pain, neck strain, shoulder problems, and repetitive strain injuries. (Alhashim et al (2025). When human workers are involved in repetitive tasks, awkward postures, heavy lifting, prolonged static postures, and/or climbing (trees, ladders, walls, etc.) that strain their musculoskeletal system, they are susceptible to frequent work-related injuries (Arachchige, 2024).

Investigations of the reasons of absence and sick reports in the working environment show that musculoskeletal disorders (MSDs) are the most common reason. These conditions can be triggered by both the work environment and the type of work performed, factors that, in some cases, can also exacerbate pre-existing conditions (Greggi et.al., 2024).

The design and adjustment of the workplace should be determined by considering both the production requirements of the companies and the employee needs within the scope of Occupational Ergonomics. Besides competitive market structure, high performance expectancy, harder working arrangements and longer working hours cause significant pressure on workers. Related to this fact, work-related disabilities and injuries become greater in most industries.

In the modern world, the most important reason of work-oriented disabilities and injuries is musculoskeletal disorders (MSDs) (Öztürk and Esin, 2011). If the main cause of an MSD is the work environment, then it is called as a work-related musculoskeletal disorder (WMSD) (Ekpenyong and Inyang, 2014). MSDs affect the muscles, nerves, joints, cartilage, and spinal discs muscles, bones, tendons and ligaments (Mosaly, 2016). The most prevalent WMSD is the back-related ones such as lower back pain, ischiadics, disc degeneration and herniation. These are followed

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by neck and upper extremities, and finally, knee and hip (Ghasemkhani et. al; 2008; Pınar et al., 2013). Around 26% of the world population has experienced the low back pain on 2010 (Panush, 2017). This disability needs a median of 7 days to recover regardless of the occupation type. Although the shoulder disabilities constitute 13.2 percent of all disorders in 2010, they require a median of 21 days to recover, being the most serious one among all disorders (Bhattacharya, 2014).

WMSDs result in pain, difficulty performing work-related tasks, long periods of absence from work,  disability in the workforce, reduced productivity, rising costs of wage compensation, high use of health care services, increasing insurances claims, disability pensions and low health-related quality of life (Kee and Karwowski, 2007; Ekpenyong and Inyang ,2014; Arezes and Serranheira, 2016**;** Roquelaure, 2016).

WMSDs were the cause of 29-35% of all work-related illnesses and injuries including the work-away days between 1992 and 2010 ( Bhattacharya, 2014). Similarly, they constituted 34% of all work-related injuries and illnesses in 2012 (Mora et al 2016**).** For example, a British worker with a WMSD lost average 15 work days in 2013-2014 (Sarkar et al.,2016).

The risk factors related to WMSDs, which have such an important effect both on economy and life quality, are usually grouped into four classes:

**(1)** Personal: age, education, gender, smoking, Body Mass Index (BMI), chronic diseases, work experience, hobbies.

**(2)** Physical: work organization, highly repetitive tasks, daily working hours, heavy lifting, mechanical stress, high-force exertions, whole-body or hand-arm vibration, static muscle load, poor working postures such as working with arms overhead.

**(3)** Psychosocial:  work organization, monotonous work task, job status.

**(4)** Environmental: cold temperature and other climatic conditions (Kee and Karwowski, 2007; Ghasemkhani et al., 2008; Pınar et al., 2013; Tribble et al., 2016; Gallagher and Schall, 2016; Jain et al., 2017).

The risk factors except personal one, can be avoided by applying some interventions. To prevent these factors, companies usually focused on the work environment such as machines, and processes, the job organization (schedules, human resources, job rotation, pauses, etc.), the psychology of employee (information, training, etc.) (Arezes and Serranheira, 2016) and finally, poor working postures such as bending, twisting, overreaching and repetitive tasks lead to musculoskeletal disorder.

Working posture is the orientation of body parts when worker does the job. The aspects of the workers, the plan of the work place and the task itself define a work posture (Zein et al., 2015). Some observational methods are greater in numbers to analyze poor working postures that lead to MSDs and their risk levels. Moreover some improvements and developments should be made on these issues according to these methods.These methods are divided into three groups: Load lifting-related methods (Snook's Table, Revised NIOSH Lifting Equation, Putting Down, Pushing, Pulling and the Carrying model and so forth), observation or survey-based methods (OWAS – Ovako Working Posture Analyzing System, RULA – Rapid Upper Limb Assessment, REBA – Rapid Entire Body Assessment, Job Strain Index, Quick Exposure Check, etc.) and ergonomic checklists (ACGIH-Hand/Arm Vibration Threshold Limit Value, Risk Factor Checklist, etc.) (Fığlalı et al., 2015).

This study, that adopts multilevel approach, was conducted in an automotive supply company producing seats that has high absence and day-off rates due to WMSDs. After all the stations in the assembly line are tested with the QEC and Ergonomic Checklist the risky stations with priorities are identified. QEC, one of the methods used to identify high-risk work stations, is preferred because it allows a quick assessment of the work both by analysts and workers. QEC risk score helps determine the level of exposure to risk and provides guidance for further improvements (Ansyar Bora et al., 2025). Ergonomic checklist is used to understand the excuses of day-offs and absence by identifying the pain degree, frequency and the body parts in which they feel pain. The result of analysis showed that 8 of 21 work stations contain a high risk for the musculoskeletal system. Inappropriate working postures are determined by applying an OWAS analysis on these 8 stations. Analysis results have been presented separately for each station. Then, we suggest improvements for these stations based on the analysis results according to the working conditions.

## 2.Methodology

To offer some improvements by analyzing the poor working postures that cause WMSDs on the workers at the assembly line that has a high rate of absence and sick reports, we followed the study plan shown below:

### 2.1 The identification of the assembly line with high rates of absence and sick reports as the pilot study area

The factory in which the study is conducted produces driver, dual and back seats. The assembly line that has highest day-off and absence rates is selected as the pilot study area. The job definitions in selected assembly line are described in detail below.

The job in station 1 is to assembly back and seat carcasses, the job in station 2 is to torch the assembly bolts and to place airbag on carcass, the job in station 3 is to assembly seat belt and airbag, , the job in station 4 is to assembly retractor and low flor, the job in station 5 is to assembly the back heating and to clad the back cover, the job in station 6 is to hold the screws that assembly the edge, the job in station 7 is to assembly EPP and clad the cover, the job in station 8 is to assembly heating buton,  the job in station 9 is to assembly foldout table and bezel , the job in station 10 is to hide V strip , the job in station 11 is to assembly topcap, the job in station 12 is to assembly side panel and cable ,the job in station 13 is to torch the side cover screws, the job in station 14 is to assembly Cushion Pan, the job in station 15 is to torch buckle, the job in station 16 is to iron the seat cover, the job in station 20 is to control  the safety belts, head restraints and seat, the job in station Offline 1 is to assembly the carcass and finally, the job in station Offline 2 and Offline 4 is to clad the seat cover.

### 2.2 To determine WMSD prevalence at assembly line workers and high risk work stations by QEC and Ergonomic Checklist

The risk factors related to musculoskeletal disorders can be assessed with several observational methods. QEC, as one of these methods, was proposed to examine the musculoskeletal risk factors in workers (Bulduk et al., 2014). QEC can be employed to examine a working posture as well as the related musculor effort and exerting forces (Abareshi et al., 2015).

QEC can assess the risks in four body parts: the back, shoulder/ arm, wrist and neck (David et al 2008). The score of each part depends on the degree of flexion, the amount of rotation, and the frequency of movement encountered during the work task. In addition to these, the worker’s perception of weight handled, time spent on task, force, visual demand, driving, vibration, and stress are also included in the analysis.  During the analysis, an exposure level is attached to each response, then, these exposure levels are combined to calculate the score of each body part (Stankevitz et al., 2016). A larger score represents a greater WMSD risk (Rwamamara & Simonsson, 2012).

QEC has fair interobserver and intraobserver reliabilities in assessing the physical exposure to musculoskeletal risks in the work environment (Choobineh et al., 2009). The benefit of this method is that the perspectives are used in the assessment of worker’s condition: observers and workers. By that, the bias from observer’s assessment can be decreased. This method is also helpful on preventing WMSDs (Bidiawati J.R and Suryani 2015). Besides, it can be applied to many tasks such as such as manual handling, repetitive tasks, and static or dynamic work  (Rwamamara & Simonsson, 2012).

The main advantages of QEC can be stated as;

- is a user friendly assessment tool with a fair validity,
- can be used to convince the organisations for ergonomic changes,
- is adaptable to Health, Safety and Environment risk assessment methods (David et al., 2005).

Chiasson et al. (2012) compared eight different risk factors' assessment methods. They considered 12 work characteristics: Posture, Weight/effort force applied, Frequency, Duration, Movements, Execution speed, Rest, Environmental factors, Psychosocial factors, Anthropometric data/gender, Worker's perception/Opinion and Other (Visual accuracy, quality of the hand coupling, height of lifting, tissue compression, vibration). The comparison showed that QEC answered highest number of the work characteristics among the studied methods (Chiasson et al 2012).

Thus, in this study, we used QEC method to identify the health problems experienced by the workers. And high risk work stations are determined applying the same approach. The analytical results of disturbance in the back, shoulder, wrist, and neck by QEC are presented in Table 1. The means are calculated for each body parts in whole stations. The decision was made according to total of these means in order to whether the station is risky or not. The lower limit of the transition to high-risk regions is defined as 130. The stations that are selected for the working posture analysing are, 1, 6, 16, 20, Offline 1, Offline 2 and Offline 4 in the order.

Then, to validate these results, an ergonomic checklist was provided to the workers asking which part of their body has the pain because of their job and which severity level this pain has. The ergonomic checklist results are presented in Table 2.

**Table 1.** Analysis results of QEC

| Station Number | QEC Score | B | S/A | W/H | N | Total | Station Number | QEC Score | B | S/A | W/H | N | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **Mean Score** | 51,2 | 44,4 | 32,4 | 41,4 | 169 | **2** | **Mean Score** | 28,5 | 22 | 24 | 35,75 | 110 |
| | **%** | 0,30 | 0,26 | 0,19 | 0,24 | 1,00 | | **%** | 0,26 | 0,20 | 0,22 | 0,32 | |
| **3** | **Mean Score** | 15,6 | 19,6 | 15,2 | 21 | 71 | **4** | **Mean Score** | 16,67 | 16 | 20 | 26,67 | 79 |
| | **%** | 0,22 | 0,27 | 0,21 | 0,29 | | | **%** | 0,21 | 0,20 | 0,25 | 0,34 | |
| **5** | **Mean Score** | 28 | 19 | 24 | 36 | 107 | **6** | **Mean Score** | 35 | 28 | 25 | 41,5 | 130 |
| | **%** | 0,26 | 0,18 | 0,22 | 0,34 | | | **%** | 0,27 | 0,22 | 0,19 | 0,32 | |
| **7** | **Mean Score** | 20 | 22 | 22 | 41 | 105 | **8** | **Mean Score** | 32 | 26 | 26 | 41 | 125 |
| | **%** | 0,19 | 0,21 | 0,21 | 0,39 | | | **%** | 0,26 | 0,21 | 0,21 | 0,33 | |
| **9** | **Mean Score** | 32 | 24 | 32 | 39 | 127 | **10** | **Mean Score** | 28 | 24 | 30 | 41 | 123 |
| | **%** | 0,25 | 0,19 | 0,25 | 0,31 | | | **%** | 0,23 | 0,20 | 0,24 | 0,33 | |
| **11** | **Mean Score** | 16 | 14 | 20 | 21 | 71 | **12** | **Mean Score** | 16 | 14 | 20 | 23 | 73 |
| | **%** | 0,23 | 0,20 | 0,28 | 0,30 | | | **%** | 0,22 | 0,19 | 0,27 | 0,32 | |
| **13** | **Mean Score** | 24 | 28 | 29 | 32,5 | 114 | **14** | **Mean Score** | 24 | 20 | 26 | 27 | 97 |
| | **%** | 0,21 | 0,25 | 0,26 | 0,29 | | | **%** | 0,25 | 0,21 | 0,27 | 0,28 | |
| **15** | **Mean Score** | 24 | 24 | 26 | 27 | 101 | **16** | **Mean Score** | 32 | 38 | 36 | 43 | 149 |
| | **%** | 0,24 | 0,24 | 0,26 | 0,27 | | | **%** | 0,21 | 0,26 | 0,24 | 0,29 | |
| **20** | **Mean Score** | 36 | 34 | 34 | 45 | 149 | **Off line1** | **Mean Score** | 36 | 30 | 34 | 43 | 143 |
| | **%** | 0,24 | 0,23 | 0,23 | 0,30 | | | **%** | 0,25 | 0,21 | 0,24 | 0,30 | |
| **Off line2** | **Mean Score** | 36 | 26 | 34 | 43 | 139 | **Off line3** | **Mean Score** | 28 | 23 | 22 | 39 | 112 |
| | **%** | 0,26 | 0,19 | 0,24 | 0,31 | | | **%** | 0,25 | 0,21 | 0,20 | 0,35 | |
| **Off line4** | **Mean Score** | 36 | 30 | 34 | 43 | 143 | | | | | | | |
| | **%** | 0,25 | 0,21 | 0,24 | 0,30 | | | | | | | | |

B:Back, S/A: Shoulder/Arm, W/H: Wrists/Hands, Neck: N

**Table 2.** Analysis results of Ergonomic Checklist

| | Station 1 | | | | Station 2 | | | | Station 3 | | | | Station 4 | | | | Station 5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV |
| Neck | 5 | 4 | 3 | 60 | 3 | 3 | 3 | 27 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 9 | 5 | 3 | 1 | 15 |
| Shoulder | 5 | 4 | 3 | 60 | 3 | 3 | 3 | 27 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 9 | 1 | 1 | 1 | 1 |
| Back | 4 | 3 | 3 | 36 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 |
| Upper arm | 5 | 4 | 3 | 60 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 |
| Waist | 5 | 4 | 3 | 60 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 |
| Fore arm | 5 | 4 | 3 | 60 | 3 | 3 | 3 | 27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Wrist | 5 | 4 | 3 | 60 | 3 | 3 | 3 | 27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 3 | 1 | 12 |
| Total | | | | 396 | | | | 111 | | | | 7 | | | | 25 | | | | 60 |
| | Station 6 | | | | Station 7 | | | | Station 8 | | | | Station 9 | | | | Station 10 | | | |
| | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV |
| Neck | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 | 5 | 3 | 1 | 15 | 5 | 3 | 1 | 15 | 5 | 3 | 1 | 15 |
| Shoulder | 3 | 3 | 3 | 27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 5 | 1 | 15 | 3 | 5 | 1 | 15 |
| Back | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 9 | 3 | 3 | 3 | 27 |
| Upper arm | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 | 5 | 3 | 1 | 15 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Waist | 5 | 3 | 3 | 45 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fore arm | 5 | 3 | 3 | 45 | 5 | 3 | 1 | 15 | 5 | 3 | 1 | 15 | 3 | 3 | 1 | 9 | 3 | 3 | 1 | 9 |
| Wrist | 5 | 5 | 1 | 25 | 5 | 3 | 1 | 15 | 5 | 3 | 1 | 15 | 3 | 3 | 3 | 27 | 3 | 3 | 1 | 9 |
| Total | | | | 145 | | | | 63 | | | | 63 | | | | 77 | | | | 77 |
| | Station 12 | | | | Station 13 | | | | Station 14 | | | | Station 15 | | | | Station 16 | | | |
| | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV |
| Neck | 1 | 1 | 1 | 1 | 5 | 5 | 3 | 75 | 5 | 3 | 1 | 15 | 2 | 1 | 1 | 2 | 3 | 3 | 1 | 9 |
| Shoulder | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Back | 5 | 3 | 1 | 15 | 5 | 5 | 3 | 75 | 5 | 3 | 1 | 15 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 |
| Upper arm | 1 | 1 | 1 | 1 | 5 | 5 | 3 | 75 | 3 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Waist | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fore arm | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 |
| Wrist | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 1 | 15 |
| Total | | | | 21 | | | | 229 | | | | 51 | | | | 8 | | | | 57 |
| | Station 20 | | | | Off-line 1 | | | | Off-line 2 | | | | Off-line 3 | | | | Off-line 4 | | | |
| | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV | F | S | NE | PV |
| Neck | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 4 | 1 | 1 | 1 | 1 |
| Shoulder | 3 | 3 | 3 | 27 | 3 | 3 | 4 | 36 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 4 | 5 | 5 | 5 | 125 |
| Back | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 27 | 4 | 3 | 1 | 12 | 1 | 1 | 1 | 1 |
| Upper arm | 3 | 3 | 3 | 27 | 2 | 3 | 3 | 18 | 1 | 1 | 1 | 1 | 4 | 4 | 1 | 16 | 5 | 5 | 5 | 125 |
| Waist | 5 | 3 | 3 | 45 | 5 | 3 | 3 | 45 | 5 | 3 | 5 | 45 | 4 | 3 | 3 | 36 | 2 | 3 | 3 | 18 |
| Fore arm | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 18 | 1 | 1 | 1 | 1 | 4 | 4 | 1 | 16 | 5 | 5 | 5 | 75 |
| Wrist | 2 | 3 | 3 | 18 | 4 | 4 | 3 | 48 | 5 | 5 | 5 | 75 | 4 | 4 | 3 | 48 | 5 | 5 | 5 | 125 |
| Total | | | | 120 | | | | 167 | | | | 231 | | | | 136 | | | | 520 |

F:Frequency, S:Severity, NE: Negative Effect, PV: Priority Value

First, it was found that 7 stations have a high risk of WMSDs by applying QEC. Checklist results also support these 7 same stations. As a result of this ergonomic checklist application, station 13 was also included in the analysis.

The results of analysis showed that 8 of 21 work stations contain a high risk for the musculoskeletal system.

### 2.3 To analyze the working postures by using OWAS

The working environment can be improved by the removal of poor working postures. Although QEC method can identify the area that results in health problems, it is not enough to analyze the working postures leading to WMSDs.

One of the several methods aiming to analyze the working postures in the literature, OWAS, is a successful methodology that considers the postures at all parts of a body in particular physical work and widely accepted due to ease of use and results validity.

At this point, some improvements have been suggested by identifying the working postures leading to the health problems according to OWAS.

OWAS is a technique to determine and evaluate the working postures to guarantee a safe and comfortable job environment. This tool can be used to identify the safety level of the working postures, any possible preventions and to evaluate the associated risk levels (Wahyudi et al 2015). It is a qualitative method to investigate the moves of the worker within a series of actions. During the analysis, the working postures are grouped according to the force that s/he uses (Santos et al, 2007). Each possible posture and force is combined and assigned with a four-digit code. There are four trunk postures, three arm postures, seven leg postures and three kinds of force. Considering all these factors, there are 252 ($4 \times 3 \times 7 \times 3$) code combination in OWAS (Lee and Han,2013). The observed positions of body parts and exerted force in each process are put into one of the four Risk Categories (RC) of work environment evaluation and improvement suggestions.

- RC 1: no need for any change in the task.
- RC 2: can be dangerous for the musculoskeletal system of the worker in the long term, thus, should be changed soon.
- RC 3: is dangerous for the musculoskeletal system of the worker, thus, should be changed as quick as possible.
- RC 4: is very dangerous for the musculoskeletal system, thus, should be changed now (Brandl et al 2016).

This categorization based on risk assessment was originally constructed by physicians, work analysts and workers. Then revised and validated by an international group of experts (Karwowski and Marras, 1999).

In the literature, there are many successful examples of OWAS application in very different sectors. These applications range from construction sector to automotive sector, from maintenance works to household works, from health services to livestock sector. The studies below show the poor working postures that lead to musculoskeletal problems in variety of sectors:

Kee and Karwowski (2007) use three observational methods, RULA, OWAS, and REBA, to examine postural load in iron and steel, electronics, automotive, and chemical industries, and a general hospital. Then, they compare the results obtained with these three methods. Kayis and Kothiyal (1996) rate Manual Material Handling tasks, leading to dangerous postures, in a subjective and objective manner. They use a multilevel approach and combined OWAS, Chaffin's biomechanical model and Borg's scale. Gangopadhyay et al., (2010) examine the incidence of MSDs in male stonecutters at West Bengal, India. Besides, they study the postural strain related to the working postures in stonecutting and setting. Groborz et al. (2011) study the working postures in cow milking at two different farms. Their results indicate that the amount of work in a mechanized farm may be more than that on a nonmechanized farm. Lee and Han (2013) determine the most dangerous working postures in building the foundations of a log cabin by using OWAS. Based on the analysis, they also provide some suggestions to improve the conditions. Brandl et al (2016) use OWAS to analyze the working postures in semi-trailer assembly and find that the current conditions are dangerous for the musculoskeletal system of workers.

Das and Sengupta (2000) focus on the dangerous effects of working postures, especially related to back pain or injury, on the high stand kill floor workers in beef skinning. Sarkar et al. (2016) identify the incidence rate of MSDs in Manual material handling workers in Calcutta, India. They specifically focus on the postures in heavy load handling. Spinelli et al. (2016) examine the risk of working postures in firewood processing by using currently available firewood processing machines. Gilkey et al. (2007) conduct a cross-sectional analysis of the risk factors and incidence of lower back pain at residential carpenters. Kumar et al. (2005) investigate how a low cost enhancement would affect the postures of cleaners in an office. Lu et al. (2016) consider the MSD risks in the workers of a Taiwanese thin film transistor liquid crystal display manufacturing company. They use a subjective questionnaire and some other methods such as OSHA MSDs checklist, the Baseline Risk Identification of Ergonomic Factors (BRIEF) checklist, OWAS, the Michigan 3D Static Strength Prediction Program (3D SSPP) and NIOSH lifting equation. Keester et al (2017) examine possible working postures that could result in MSDs in tattoo artists.

OWAS is a method with high success that can be applied to various field and assesses working postures as explained above. By applying OWAS, we identify the working postures that lead to the high risk in these 8 stations and suggest improvements.

Every station is recorded for 15-20 minutes with a camera. The beginning and end of cycles of each station are considered during this process. Station 1, Station 6, Station 13, Station 16, Station 20, Station Offline 1, Station Offline 2, Station Offline 4 are recorded for sixteen cycles, ten cycles, eleven cycles, eleven cycles, ten cycles, thirteen cycles, thirteen cycles and eleven cycles respectively.

The records are decomposed, which one second intervals are applied, as photographs to investigate all movements of the respective station in the identified period. These photographs are coded according to the four digit code structure defined in the OWAS methodology. The resulting codes are put into a macro Excel table that is prepared according to the OWAS job procedure and they are divided into four risk categories by running the macros. The risk levels of the categories are identified for all stations based on the resulting coding process. Thus, we identified the importance levels of third and fourth categories that are important for OWAS and can require some improvements.

Detailed analysis results of OWAS for station 1 is given in Table 3 as an example. For all stations' results are given in Table 4 briefly. In the study, several improvements are made to eliminate the postures in third and fourth risk categories.

**Table 3.** Analysis results of OWAS for station 1

| **Category 1** | | | **Category 2** | | | **Category 3** | | | **Category 4** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **P** | **F** | **%** | **P** | **F** | **%** | **P** | **F** | **%** | **P** | **F** | **%** |
| 1121 | 396 | 38,9 | 2132 | 3 | 0,3 | 2141 | 40 | 3,9 | 4141 | 7 | 0,7 |
| 1172 | 26 | 2,6 | 4132 | 3 | 0,3 | 2151 | 2 | 0,2 | 4151 | 15 | 1,5 |
| 3121 | 80 | 7,9 | 2121 | 76 | 7,5 | 2142 | 13 | 1,3 | 3251 | 1 | 0,1 |
| 1231 | 2 | 0,2 | 4131 | 87 | 8,5 | 2172 | 1 | 0,1 | 3152 | 2 | 0,2 |
| 1131 | 12 | 1,2 | 2131 | 19 | 1,9 | 2152 | 3 | 0,3 | 4152 | 3 | 0,3 |
| 3231 | 6 | 0,6 | 4121 | 46 | 4,5 | 4222 | 1 | 0,1 | 3151 | 1 | 0,1 |
| 1221 | 52 | 5,1 | 2322 | 2 | 0,2 | 4231 | 11 | 1,1 | 4242 | 3 | 0,3 |
| 3131 | 55 | 5,4 | 4122 | 3 | 0,3 | 4232 | 1 | 0,1 | | | |
| 1372 | 1 | 0,1 | 2122 | 6 | 0,6 | 3141 | 1 | 0,1 | | | |
| 1171 | 18 | 1,8 | 1351 | 1 | 0,1 | | | | | | |
| 1321 | 11 | 1,1 | 1151 | 1 | 0,1 | | | | | | |
| 3221 | 4 | 0,4 | 1252 | 1 | 0,1 | | | | | | |
| 3132 | 1 | 0,1 | | | | | | | | | |
| 3122 | 1 | 0,1 | | | | | | | | | |
| 1122 | 1 | 0,1 | | | | | | | | | |
| TOTAL | | **66** | | | **24** | | | **7** | | | **3** |
| P:OWAS Posture Code F:Frequency | | | | | | | | | | | |

**Table 4.** Risk categories of OWAS analysis results

| **Station No** | **Category 1 (%)** | **Category 2 (%)** | **Category 3 (%)** | **Category 4 (%)** |
|---|---|---|---|---|
| 1 | 66 | 24 | 7 | 3 |
| 6 | 34 | 33 | 15 | 18 |
| 13 | 86 | 14 | 0 | 0 |
| 16 | 70 | 29 | 1 | 0 |
| 20 | 60 | 38 | 2 | 0 |
| Offline-1 | 56 | 40 | 1 | 3 |
| Offline-2 | 57 | 43 | 0 | 0 |
| Offline-4 | 66 | 31 | 0 | 3 |

The improvement suggestions for Station 6 that has the highest working risk as shown in Table 4 should be implemented as soon as possible. The other stations that require an immediate change are Station 1, station 20, Offline 1 and Offline 4. As the table also shows, there are improvement suggestions for the stations with low 3th and 4th level risk categories as well. By these suggestions, the repetitions of the postures with low risk level, belonging to category 1 and 2, that have been habits or continuing for a very long time, can be prevented.

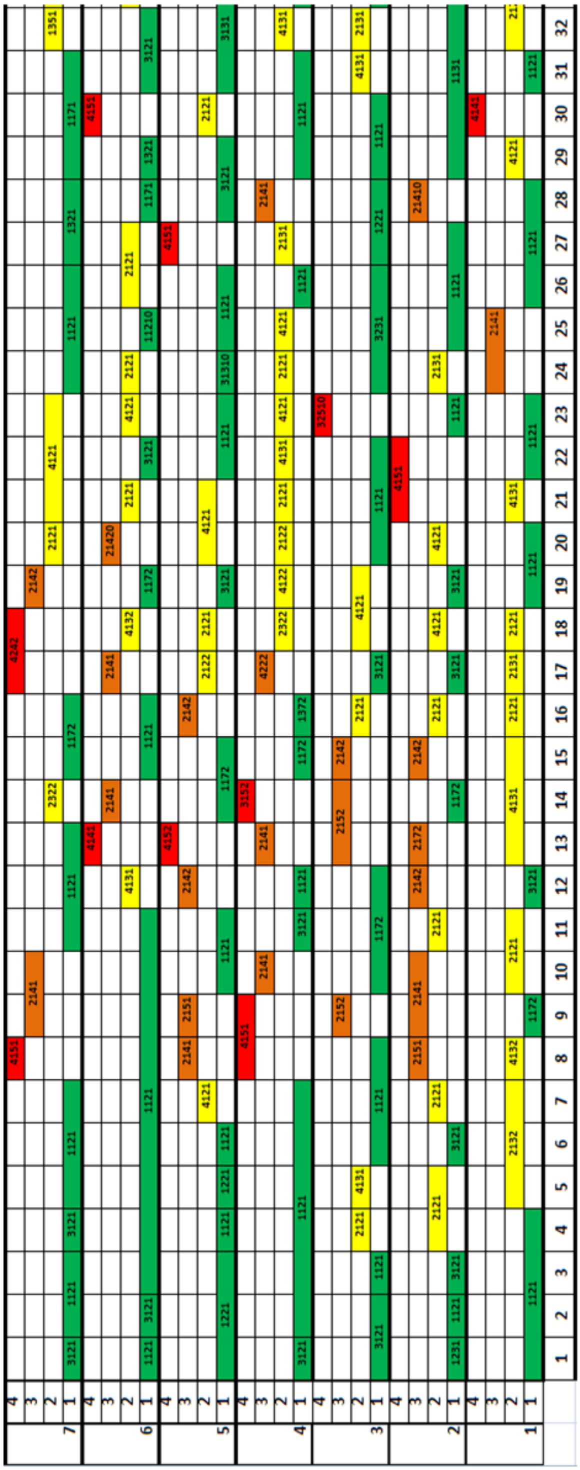
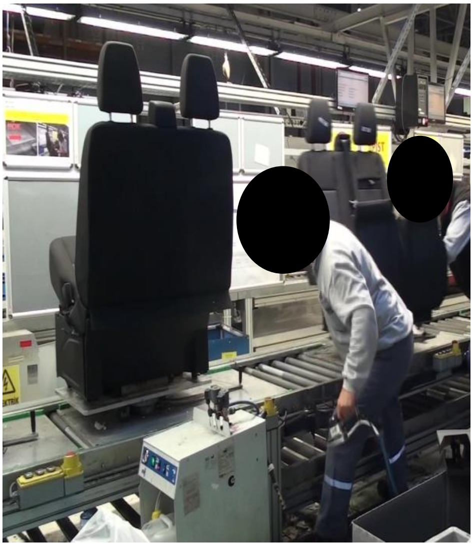


**Figure 1.** Gant schema for station 1

The OWAS analysis shows the distribution of the working postures according to the risk categories. However, it is not possible to identify the durations of the postures from these categories. To show that, we present a sample section of gant schemas for Station 1 in Figure 1 and similar gant schemas are prepared for all other stations. The Gant schema shows how many seconds the movements last in terms of the cycles. The horizontal axis shows the duration in seconds while the vertical axis shows the cycles and the posture codes in each cycle are shown in different colors. Different colours indicate the risk category type; green, yellow, orange and red represents the first, second, third and forth categories respectively.

Figure 2 shows several working postures belong to Category 2 and Category 4. The photographs show the workers with different characteristics and antropometrical measures performing different jobs in other work stations. Considering all these differences, different suggestions have been made for each work station. The first working posture's OWAS code is 4141. The second working posture's code is 3331. The third working posture's code is 4141.



***a)*** OWAS code:4141

***b)*** OWAS code:3331

***c)*** OWAS code:4141

**Figure 2.** Poor working postures

***Figure 3.*** Poor adopted working posture without work flow

OWAS analysis allows to identify whether a working posture is really required for the corresponding work flow. Sometimes, the postures adopted by workers are not actually required for the job and cause negative effects on their musculoskeletal system. Figure 3 shows an example of such situation. In this case, the worker adopts a poor working posture while he was waiting for the material in the line. Although having this posture just for a moment does not harm the musculoskeletal system, the repetition of this posture during the day results in health problems. The best solution for this case is to train the worker about the situation and the results.

### 2.4 To give recommendations about eliminating or decreasing the poor working postures

By conducting an OWAS analysis, we proposed several suggestions to improve the work flow and environment for the stations with category 3 and 4 risk levels. Recommendations for the selected stations as a result of OWAS analysis are listed as follows:

**Station 1:** Carcasses should be ordered and put in the place that has the smallest distance to the operator. The operator should not carry the carcass weight.

The unnecessary waiting in the first station affects all the following stations in a bad manner. The reasons of this waiting should be investigated and the necessary actions should be taken to prevent it.

Escalating the assembly line in all stations would prevent the operators from stooping.

**Station 6:** Shortening the distance between the worker and the seat would decrease the number of risky postures. For this purpose, one step can be placed into the ground. If the costs are in an acceptable level, in addition to the line that the seats move on, another mechanism that allows the worker to pull the seat can be built.

**Station 13:** There is a long waiting time after the worker completes the job in station 13. There are two reasons of this waiting:

1. The seat does not come forward from the previous station.
2. The worker waits for the next station to complete the job.

Shortening this waiting would decrease overall work duration in this station.

Even though the movements in Station 16 and 20, in which the seat cover is ironed and generall control is conducted respectively, do not have high risk level, since they are repeated for a long time, can cause problems for workers in the long run. The main issue is that the used parts and the button, that is used to carry the product from one station to the other, are in a low position.

The movements that are repeated for a long time in these stations should be shortened. Besides, the operator works while only one of his/her legs carries all his/her body weight. This weight should be balanced between both legs. Another problem in this station is the locations of button, scissors, etc. The operator has to stoop to take these items. This causes negative effects on the back of the worker. To eliminate these poor working postures, the location of these materials should be raised up.

Even though the posture codes that belong to third and fourth risk categories in the stations Ofline 1,2 and 4, these stations are rated as high-risky by the workers in QEC and ergonomic checklists. For this reason, even though they are in a low-risk working posture group, some movements that are repeated for a long time or implemented improperly by the workers can cause problems and fatigue in the long run. To train the workers is as important as the dimensions of the work place.

## 3. Discussion and Conclusion

30% of the work absences that have significant effects on the workers' motivation, quality of product and productivity are due to WMSDs. WMSDs that are at the top of the list showing the expenditures for all disorders, and affecting the job efficiency, life quality and physical and social functions of a worker in a negative way, is generally due to the poor, extreme and repetitive working postures. This study was conducted in an automotive supply company producing seats assembly line with 21 work stations.

The main motivator of this study is to reduce high absence and insurance rate due to WMSDs by making improvements to prevent WMSDs caused by working posture.

In the ergonomic improvement and development studies, several methodologies should be used in order to suggest improvements and eliminate the poor working postures. As the first step of the study, we determined the assembly line with the highest rate of absence and injury. We identified 7 stations that the workers experience difficulties by applying QEC in the selected assembly line with 21 work stations. The ergonomic checklist applied into the same line and one more station was identified in addition to these 7 stations. The QEC analysis showed that 24%, 21%, 24%, and 31% of workers in 8 stations suffer from back pain, shoulder and arm pain, hand and wrist pain, and neck pain respectively as seen in Figure 4. We applied OWAS analysis for these 8 stations that were evaluated as the riskiest stations by the workers.

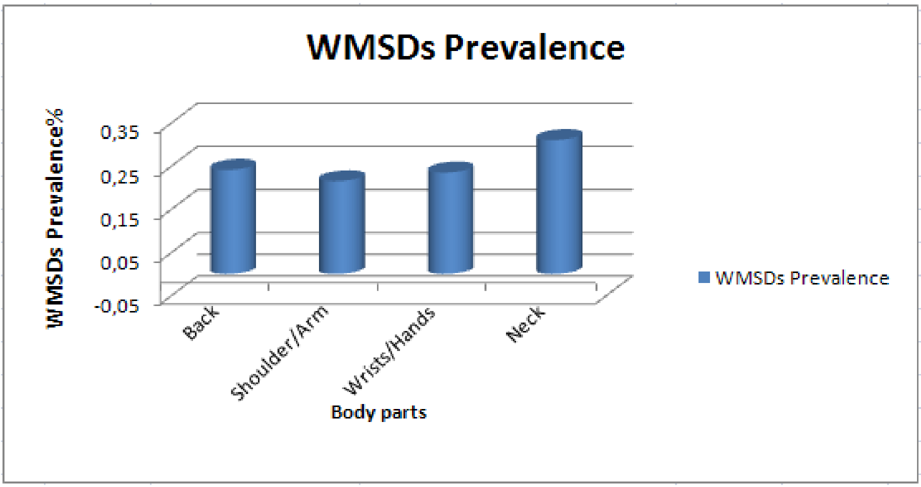



**Figure 4.** WMSDs prevalence schema in high risk stations

Considering the biomechanical, physiological and anthropometrical design principles would decrease the incidence of WMSDs. A working place with a well designed layout and appropriate equipment avoid the workers from the poor movements of neck, shoulder or upper-body parts. The workers had poor positions mainly because there were no anthropometric measurements for the station plan and environment. To prevent these poor positions, the anthropometric measurements should be conducted and the dimensions of the tools and equipment should be calculated again. The suggestions based on this analysis are provided below:

- ✓ Based on the principle that requires the job to be conducted as close as possible to the body; we suggest to decrease the distance between the operator and the seat, and escalating the assembly line in all stations. For this purpose, one step can be placed into the ground. If the costs are in an acceptable level, in addition to the line that the seats move on, another mechanism that allows the worker to pull the seat can be built.

- ✓ The carrying operations in the workplace result in the wear in spine disks, and problems in back and wrist. Lifting and carrying the load in inappropriate positions lead to unrepairable damages on the spine and muscles. Hence, carcasses should be put in the place that has the smallest distance to the operator. The operator should not carry the carcass weight.
- ✓ The postures and movements of the body should fit the natural shape of the body. This is due to the fact that the overload and stress is at the minimum when the body is in its natural shape. Besides, the operator works while only one of his/her legs carries all his/her body weight. This weight should be balanced between both legs.
- ✓ The twisting and bending of the body should be avoided. To prevent these kinds of working postures, we reconsidered the locations of the button, scissors, etc. and suggested to relocate these items to higher places such that the worker can reach them more easily.
- ✓ The postures or moves should not be maintained for a long time. The static muscle works or static holding for a long time result in a quicker fatique in the muscles and a decrease in muscle performance. The movements that are repeated for a long time in all stations should be shortened.
- ✓ Ergonomic training and awareness are effective in reducing musculoskeletal risk factors. OWAS analysis showed that some moves that are not required for the job are actually adopted by the workers. These moves that have become habits may have negative effects on the musculoskeletal system of the workers in the long term. Some training and awakening sessions should be made to make the workers quit these moves and decrease the stress in their musculoskeletal systems. The workers have to know how to adjust the work stations according to their personal and job-related needs. The trainings for the workers should inform them about the importance and advantages of the small breaks and relaxing times for the relief of the muscles. The trainings should also emphasize the importance of being aware of their postures and step orientation to prevent the twisting the trunk, to relax for enough time during the day, and to decrese the duration spent in each posture.

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# Chapter 4

## THE ROLE AND IMPACT OF SHIFT WORK IN WORKING LIFE

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### 1. INTRODUCTION

Globalisation, technology and expansion of competition have made 24/7 continuity of production and services a widespread reality in the business industry. So, companies have shifted away from the day shift to shift work mode. More specifically, companies in industries (which include healthcare, transportation, security, manufacturing, logistics), schedule time for every member of the workforce to be available to execute business.

Although the shift system brings great benefits to employers as it increases production efficiency and customer satisfaction and enables them to remain competitive, it also raises quite a number of physical, psychological, social and legal issues for their employees. Such issues have a direct impact on employees' health, job satisfaction, quality of life, and family relationships (Costa, 2010; Haus & Smolensky, 2013).

Using a scientific and multi-faceted approach, the goal of this study is to provide insights on the status of shift work systems in the working life, the field of application, the impact of these systems on employees and businesses, the problems faced and proposed solutions. Simultaneously, considerations about the sustainability of shift work will also be explored in the light of existing literature and theoretical framework.

Shift work is an employment model that allows employees to work at different times of the day within a specific work organization. It is mainly done in three general shifts; morning (day), evening (afternoon), and night. But the nature of how jobs are arranged in different organizations can differ on certain types of businesses and level of performance (Knauth, 2013).

It is not only a question of time management--it is an interdisciplinary problem related in large part to occupational safety and health, organizational behavior, human resources management, labor law, and social norms.

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Under circumstances of shift work as an organisational necessity, the question of how this system can be made sustainable and more people directed arises. Scientific evidence indicates that work accidents are far more prevalent in shift systems and that sleep problems and psychological stress are higher for workers (Åkerstedt, 2003; Folkard & Tucker, 2003). Thus, this study addresses the following issues:

- How do shift systems impact employee health and productivity?
- How can shift systems be developed as strategic tools for businesses?
- What are the social effects of shift work and how can these be reduced?
- How to support employees' adjustment to the shift systems?

The qualitative approach to this part of the book brings together conceptual explanations with theoretical approaches and empirical findings that form from literature review. In-depth studies from various departments, articles, reports and industry cases in national and international research context have all been reviewed under pertinent headings.

## 2. DEFINITION AND TYPES OF SHIFT WORK

Shift work is a term that explains work and practices based on the principle of keeping workers at different times of day (Knauth, 2013). This system involves working in a series of different shifts, or rotation, of different types, and is not the same as the average "08:00–17:00" hours of working.

The International Labor Organization (ILO) states that shift work is “a work system that is not limited to a specific time period, is spread across different hours of the day, includes night work, and is used in a regular form or an irregular form” (ILO, 2017). Across various sectors, this system is vital for flexibility, productivity and service continuity.

Shifts are prevalent and are especially common in the fields of industrial production, healthcare, transport, energy, communications, security, hospitality, and tourism. Statistics of 2022 from TÜİK suggest that about 17% of total employment in Turkey is based on a shift system. This rate can be up to 30% in some sectors in European Union countries in certain industries.

Shift work has its origins in the Industrial Revolution. The process of production mechanization required constant production of goods, therefore, a 24/7 work system was required (Moore-Ede, 2010). Shift systems were invented in sectors like energy, textile and heavy industries due to the necessity for continuous work.

In this digital era — marked by globalization and the availability of global markets — work has shifted yet more widely from the four walls of a warehouse/shift shop to call centers, e-commerce and remote service sectors.

### 2.1. Types of Shift Systems

Formal types of shift work are developed in relation with the objectives of the business, the dynamics of the industry and the demographic composition of the people employed by the organisation. But the focus in all systems is to work towards a synergy that will drive productivity while safeguarding humankind's health and quality of life. The shift system must be designed at this point as an ethical and social responsibility.

Shift work systems are classified into categories based upon implementation. These categories are defined by types of organization of the work force, working hour allocation, shift number, and shift transitioning:

#### 2.1.1. Fixed Shift System

Under this system, employees will tend to work a specific shift, such as exclusively in the morning shift. This can be especially convenient when a scheduling arrangement fits with a person's biological clock, allowing work schedules to correspond to their natural circadian rhythms. A big bonus for employees involved in this approach is that they can readily adapt to their circadian rhythm — potentially increasing alertness and functioning, as well as mental health. More to the point, it brings some aspect of a routine to a longitude, giving us greater predictability when it comes to activities.

However, fixed shifts can have quite a few drawbacks. Those who work night shifts are at greater risk of being ill because of altered sleep patterns and mismatching of the work hours with the natural circadian rhythms. In addition, working night shifts could impose greater social isolation and limited exposure than employees on other shifts, which could have adverse effects on psychological well-being and social connectedness (Åkerstedt, 2003).

#### 2.1.2. Rotational Shift System (Rotation-Based)

In this configuration, the employee rotates from one shift to the next and rotation of their time period in between, for example two weeks on morning shift and two weeks on night shift. This method is usually used to ensure a fair work is evenly spread and an even workload is maintained. There are different modes of rotation of that system such as rotations on a weekly basis, rotations on a monthly basis, and sequences in which a shift progresses to another — for example, morning to afternoon to night. Studies show clockwise rotation -- moving from morning to afternoon to night in the same direction is better tolerated than counterclockwise rotation in general and does not result in fatigue and also the more effective response to changes in the daily work programme (Tucker, 2003).

### 2.1.3. Continuous Shift Work

An hour's continuous shift may be necessary for workers, but one that the clock is a good example of what actually does to the worker's mental schedule and morale. The solution runs continuous (24 hours a day, 7 days a week) – uninterrupted (out of public service) in weekends, public holidays and on other day. It is widely applied in industries and services where a constant operation is required like power plants, hospitals, and security units for example. Despite this system providing 24-hour service, it poses multiple challenges for workers. Constant rotation and night work can interfere with how sleep-wake cycles work, leading to fatigue, less alertness, and even long-term health problems. Organizations that use such a schedule also have high employee turnover since the work is demanding and that's what makes turnover a challenge (Costa, 2010).

### 2.1.4. Split Shift

This system organizes the workday into two or more distinct blocks of time. For instance, someone might work from 7 a.m. to 11 a.m. in the morning and return for a second shift from 5 p.m. to 9:00 p.m. Schedules like those found in restaurants, transportation and education industries are industries which often observe such scheduling. Even though the aggregate working day may seem fairly modest in the aggregate hours, there are no shortage of workers who may seem moderate to the eye on average, but the fragmentation of the work day may make for a time of deep weariness on the whole. In addition, long pauses between shift gaps mean that employees may not be able to handle their social and their family schedule or life with as well, since the change in schedules between shifts may result in disruptions in a life-time at a more or less regular pattern in their home or family life and so forth.

### 2.1.5. Night Shift

The term night shift specifies hours of work between 10:00 p.m. to 6:00 a.m. It has been defined under legislation as "night work" in a number of countries and is in the law regulated with stipulated stipulations for payment, rest periods, and compulsory health checks (ILO, 2017). It is working at these times that the employees are at risk. Night staff are more likely to suffer from sleep disturbances, poorer attentiveness, and greater accidents in occupational settings (Folkard & Tucker, 2003). Night work over long periods of time can disturb hormonal regulation and may lead to metabolic diseases, and is linked with higher odds of developing long-term health problems, for example, diabetes (Haus & Smolensky, 2013).

### 2.2. Shift Duration and Rest Periods

While a shift length tends to be 8 hours, a 12-hour shift is also used in certain industries. According to the European Union standards, no more than 40 hours can be devoted weekly working hours for night workers, while 15 minutes should be offered every 6 hours (European Working Time Directive, 2003).

### 2.3. Application Examples: From Turkey and Around the World

From Turkey and Around the World. The first instance of this is of the shift work in Turkey. In health systems more than 70% of nurses and emergency workers work under rotating shift systems to compensate for the requirements of constant patient care (Sağlık-Sen, 2021). Worldwide, this practice varies greatly between countries and industries. In some countries, such as Japan, as in the automotive industry, a 3+1 system with 3 work shifts followed by 1 day off is widely followed. In contrast, those in Norway and Sweden, for instance, limit shift lengths to only six hours long, and pay more for night shift duty in the service of the well-being of their workers, designed to safeguard (Sallinen & Kecklund, 2010).

## 2. THE IMPORTANCE OF SHIFT WORK FOR BUSINESSES

The primary objective of all business in the global competitive landscape is to improve productivity, lower costs, respond promptly to customer needs, and remain competitive (Akman & Boyacı, 2024; Boyacı et al., 2025). By this end, production and service continuity is key. For example, the shift work system is an organizational model that in this context grants time and resource benefits to the companies.

The shift systems allow companies to speed up the return on investment period by being proactive in utilising their physical infrastructure (machines, facilities, etc.) throughout the day. They can also meet flexible production goals by facilitating better workforce planning.

### 3.1. Strategic Functions of Shift Work

The shift work system keeps production on site 24 hours a day, cutting down on production wait times. The expense of the business in the forms of "idle time" of machines is much higher in the area of capital-intensive manufacturing. This is why shift work is essential in the automotive, petrochemical, and iron and steel industries.

"The shift arrangement is not mandatory but rather a cost cutting mechanism in industries that are capital-intensive." (Costa, 2010)

Shift systems improve customer satisfaction due to quicker order delivery times. They are advantageous in the sense of delivery flexibility and inventory saving, particularly worldwide supply chains. In addition, shift work raises the applicability of Just in Time (JIT) production systems (Womack et al., 2007).

For example, Amazon runs the call center and logistics distribution operations 24 hours a day through a shift system which ensures same-day delivery.

When machines with high investment costs are operated in three shifts and the production costs of these machines become relatively low, the "unit production cost" declines. In addition, fixed costs (such as rent, energy, and maintenance) are spread over more products/services (Özkan & Çelik, 2017).

Demand is higher at certain times of the day or week for certain sectors. For example: retail, transportation, fast food chains. Dynamic shift planning is key in these industries, to meet consumers where they're at in the industry. Folkard and Tucker (2003), the shift system has an inherent role to play for flexibility in meeting shifts based on time-based demand.

In a number of industries shift work is no longer what we would prefer, but it is increasingly necessary. For example, the healthcare sector is obliged, and the fire service, firefighting, police service, energy, public services, and public sector sectors - all require 24-hour service (ILO, 2017). In these types of industries, the shift provision becomes a compulsory entity for the preservation of public safety as well as the functioning of the daily routine.

### 3.2. Shift Management from a Human Resources Perspective

It is shift systems that maintain a balanced distribution of the workforce. In order for this to work, it needs fair, predictable, and employee-friendly shift schedules. Without it, workforce turnover increases (Sallinen & Kecklund, 2010).

Unfair shift distribution is detrimental to employee morale and employees' performance. Effective shift management can result in increased employee morale, productivity, and retention. In this respect it is very important to note that even though additional payments (shift premiums), work days off, and health supplements are also important.

Shift systems may provide businesses with myriad benefits, but are also highly potentially dangerous if they are mismanaged. Excessive overtime; the resulting burnout syndrome; increased risks of workplace accidents and injuries; union tensions; employee turnover; loyalty issues; are the adverse consequences of shift work systems. This has serious implications for employee well-being, as well as business success, threatening the sustainability of sustainable industries and the occupational safety of the workforce. And these shift work networks are indispensable, it is therefore critical that shift work systems should be well managed, fair, ethical and scientifically based.

As shift work is beneficial to the business it can only make a difference not only with production planning or management of production planning but also managing ergonomics, human resources, occupational health, and communication systems.

But for these experiences to materialize into enduring benefits, concerns for employees' wellbeing need to also be taken into account. “People-focused shift management” becomes an essential element for success in today’s businesses.

## 3. EMPLOYEE HEALTH AND PSYCHOSOCIAL IMPACTS

But, at the individual level shift work has serious effects on health and psychosocial well-being for those who work it, although there are many advantages to working in shift mode from a work organization perspective. The human body is designed naturally to work during the day and sleep at night. Thus, night work or rotating work becomes a mismatch with the biological rhythm (circadian rhythm) which contributes to myriad health disorders (Åkerstedt, 2003; Haus & Smolensky, 2013).

In this section the physiological, psychological and social effects of shift work, based on scientific evidence, will be explored; the reasons for (and implications, and the suggestions for mitigating this), will be discussed.

### 4.1. Physiological Effects

Among shift workers sleep disorders are one of the most common health issues. Sleeping during the day, especially after a night shift, leads to a decrease in sleep duration and quality. Such an event can lead to a particular clinical condition known as "Shift Work Sleep Disorder" (SWSD) (Sack et al., 2007). Symptoms of a sleep disorder may include the following: excessive daytime sleepiness, persistent fatigue after waking up, difficulty falling asleep or frequent awakenings, and chronic fatigue. Insufficient amount of sleep is not only adverse to health and well-being of the individual but also a significant hazard or the most prominent risk factor for accidents and performance losses.

Night-time individuals and irregular shift workers have been found to be more likely to get cardiovascular disease as per studies (Knutsson, 2003). These include chronic stress, poor food habits, lack of rest, and physical inactivity. In addition, disrupted circadian rhythm can cause metabolic diseases that include insulin resistance, obesity, diabetes and thyroid disorders (Scheer et al., 2009). In people who work night shifts, hormones like cortisol and melatonin are reduced in production, which weakens the immune system and increases vulnerability to disease.

### 4.2. Psychological Effects

Shift work induces a lot of stress in employees due to shifting hours as well as social isolation. Chronic stress promotes the development of mental diseases like anxiety and depression (Nielsen et al., 2019). Workers are disconnected from social life, unable to adjust to constantly shifting sleep-wake rhythm, and physically fatigued. In other words the workload of work is always way too demanding, leading to a serious emotional toll. Burnout syndrome — which is driven by the fast pace of shift work, the heavy workload and mental exhaustion — may affect those in fields that require emotional labor especially, healthcare and call centre staff ( ). Job satisfaction would decrease with long-term shift work, adversely influencing the physical and psychological health of employees (Maslach et al., 2001). Thus, it is really important to address the issues of stress and fatigue of workers working in shift systems and to foster ways of psychological care.

### 4.3. Effects on Social and Family Life

Shift work presents great challenges where employees are unable to lead a good life together with family and colleagues and their companions. This predicament becomes particularly acute for those having to work weekends or in the evenings. As a result, spouse communication problems may crop up, child-sustaining activities become difficult, and people's feelings of loneliness increase. More importantly, making plans or attending social events can be hard. In this way, people find it increasingly difficult to try to balance their daily lives with their work lives. Therefore, it is critical that flexibilities in both the work schedules developed by staff and policies are conducive to shift-working families' overall social and family lives.

Shift work affects female workers more. The result is the double duty of maintaining both work and housework, which is the dual-burden of women working shift work or double obligation (ILO, 2017). Childcare, mothering and other family responsibilities mean extra measures are needed for women who work while sleeping at night.

### 4.4. Workplace Accidents and Safety

Lack of attention and fatigue cause a high number of fall-out in the workplace for shift workers. While reflexes and cognitive capacities become weak during night shifts, the prospect for the mistakes associated with machine work increase

(Folkard & Lombardi, 2006). For instance, in the US, nurses working night shifts made 27% more errors than they did when working during the day (Rogers et al., 2004). These results underscore the impact of shift work on occupational safety and how planning works against work site accidents.

### 4.5. Health Screenings and Preventive Measures

Many countries have laws establishing a periodic health condition for night workers according to the law (Turkish Labor Law, Art. 69). What's more, institutions can protect employee health and minimize the adverse impacts of shift work, including providing rest areas in the early shift hours, psychological counseling services, training staff about sleep hygiene, regulating exposure to light and healthy eating practices, and promoting physical activity and healthy exercise. Some of the benefits of such practices include employee physical and psychological health, which contributes to the general productivity of the workforce and decreases the likelihood of accidents and burnout.

## 4. SOCIAL AND ECONOMIC IMPACTS

Shift work systems form the basis of a socio-economic structure not only affecting individuals and organizations, but also families, social relationships, and the local economy. Especially in the age of the global 24-hour work model a "night-working society" became increasingly appealing (Rajaratnam & Arendt, 2001).

This chapter then will consider the impact of shift work in relation to social organization, in the economic framework and in relation to social inequities, gender expectations and public policy.

### 5.1. Effects on Social Life

The most obvious social impact of shift work is the conflict between worker's roles in family (Esen et al.,2019). One person who works night shifts, as well as night or weekend shifts, misses out on family meals, going to children's activities, vacations or special occasions. Eventually, this results in deteriorating marital relationships, a loss of communications with children and an affective fragility of the family structure.

Social engagement of shift workers declines. A huge part of society, "working during the day and resting at night," works at the counterpoint, a shift worker lives exactly the opposite life. This restricts their interaction with their social environment. Night shift workers, in particular, are alienated from their social world due to the time they need to rest during the day (Costa, 2010).

### 5.2. Gender Roles and Inequalities

Female workers suffer from dual burden like working in force and for others in the household. Women's nighttime work increases their psychosocial stress levels because they face challenges for childcare and domestic chores. Furthermore social customs may cast moral doubt on women night workers which might result discrimination in work setting for women (ILO, 2017). Shift work is most often used in low-wage and physically demanding industries. Health and social rights are not as readily available to the poor. The majority of night workers work in areas such as transportation, cleaning, manufacturing, and security (Nielsen et al., 2019).

### 5.3. Night Economy and Urban Life

The nighttime economy is a system of economies in which the night-time business sector operations include restaurants, railroads, and retail, leisure, and services. Not only in major cities, opening up these 24-hour operations drives the development of the night business (Moore-Ede, 2010).

Shift workers provide both the labor force and the consumers for this economy. For instance, someone who is working a night shift needs the services needed like bakeries, grocery stores or public transportation upon leaving work at 7 a.m. This gives rise to "secondary shift sectors."

As the night economy develops and shift work proliferates, cities must modernize their public transportation, lighting, security and social service systems to serve those hours of the night. Otherwise, workers have to bear greater risks, such as difficulties getting to work on the road, street safety problems as well as social isolation.

### 5.4. Effects on Education and Childcare

Shift working parents, particularly female workers, are more likely to become disengaged to be part of their children's education. Processes such as going to school meetings, checking on homework and helping at home may be missing. Thus, this situation may result in developmental and educational failure of the children.

In some countries, night nurseries and flexible education programs designed for shift workers have been devised as a solution to this problem.

### 5.5. Economic Benefits and Costs

Shift systems play a strong role in fulfilling countries' objectives for creating more jobs, continuing economic growth and enhancing productivity. This increases the utilization and the turnover of operating capital in production when a three-shift system is used especially in industrial sector. For instance, the rotation of the shift system in approximately 75% of workplaces in Germany leads to an increase in the annual production level of 30% (Statista, 2023). But shift systems have their hidden costs, as well as economic benefits. This is in addition to higher health costs, material losses from work accidents, high turnover rates among staff, and less productivity, especially at the end of the night shift. Hence, this short-term resource advantage could not be equal long-term depending on an equilibrium with "health, productivity, and production loss" (Tucker, 2003).

### 5.6. Public Policies and Social Responsibility

Public policy must be well established to constrain the societal effects of shift work. Within this framework open public transport services free or at a discounted rate for night workers, psychological support centers established for shift workers and childcare and care centers for women working in the evening can be offered. Also, the availability of choice regarding health checks and social security rights could be a key policy tool to promote the physical health as well as society's well being of the workers. Organising at an institutional level, creating policies that safeguard and enhance employee welfare under the auspices of CSR is not only a legal requirement but an ethical one. Hence such measures aid in mitigating the harmful effects of shift work systems while also enhancing employee loyalty and productivity.

Shift work systems represent the backbone of the economic continuity of modern societies. But that system has the capacity to endanger the overall social welfare of individuals and the social order. Hence, the establishment of a satisfactory equilibrium between social stability and economy is a joint responsibility of policy maker and employer.

## 6. MANAGEMENT ISSUES AND IMPROVEMENT RECOMMENDATIONS

Shift work systems provide businesses with the opportunity to enhance and provide significant benefits, whilst managing them at the organizational level is an exceptionally complex and multidimensional undertaking. Some other aspects of management (e.g., human resources, communication, leadership, occupational health and safety, employee satisfaction and corporate culture) are also influenced by the success of these systems beyond making a schedule. Shift management errors caused by poor shift performance can result in the reduction of quality of output, higher employee turnover, as well as an increase in accidents at work.

This Section will consider the major issues faced in managing shift systems and then provide science based solution and recommendation for improvements.

### 6.1. Fundamental Management Issues

The inappropriate shift planning is one of the most basic errors of management in shift systems. Unforeseen planning can result in:

- Staff shortages,
- Overwork due to overtime load,
- Uneven work distribution,
- Frequent shift changes in shift rotation.

This phenomenon manifests in the form of burnout, demotivation and absenteeism, and withdrawal out of the employees (Tucker, 2003).

Weak information transfer between shifts raises the error rate particularly in industries such as healthcare and manufacturing. The quality of the process is lowered if daily reports are not passed along, shift logs are not kept regularly, and proper coordination does not occur.

When such employees are consistently given heavier or often night shifts, a sense of internal justice in effect disappears. This decreases employees' commitment and organizational citizenship activities (Greenberg, 1990).

The design of shifts not using ergonomics in design is harmful both for physical health and productivity. Bad break hours, lighting, noise and poor indoor temperature are some of the various negative factors that contribute to the deterioration of physical quality of work (Sallinen & Kecklund, 2010).

### 6.2. Improvement Recommendations

Human physiology and ergonomic principles should be the foundation of shift systems development. Within this framework concepts like clockwise rotation of the shifts (morning to afternoon, afternoon to night), at least 11 hours' rest per shift, 8-hour limits to the number of shifts and two free days per week will be important standards proposed by the European Sleep Research Society (ESRS) and International Labor Organization (ILO). Shift schedules should account for employees' individual preference, living conditions, and family life to build employee loyalty and job satisfaction. It would be useful to obtain repeated feedback through surveys, so the success of the shift system could be periodically measured.

Regular training on the health, social and psychological impacts of shift work raises the awareness of employees. Training should include sleep hygiene, stress and nutrition, physical activity and policies on occupational health and safety, and should be integrated into the orientation process, especially for new employees. Shift workers must be periodically cared for, monitored for, such as biological rhythm disorders during work, and the potential health risks for night shift workers. Psychological counseling services should also be provided to employees at risk for anxiety, stress, and burnout (Haus & Smolensky, 2013).

Artificial intelligence-enabled software is now being used to great effect in shift scheduling. These systems can form optimal shift schedules based on employee productivity, leave requests, regulations, and production timelines. For any time period based on customer data, they're the one to be used to determine an optimal shift timetable. Dynamic, transparent, scientifically driven, and scientifically based shift management that aligns with human resources information systems (HRIS) allows employees to protect their health and work to business productivity.

### 6.3. Organizational Culture and Leadership Approach

The culture of the organization and the way a leader is perceived. Stability of shift systems must be discussed not simply as a technical issue but also a cultural one. Making night-shift workers a key part of the company culture, getting them engaged, and protecting their rights is important. This work should be supported by effective leadership – in the sense that the process can be more empowered for people as one with equality and respect across teams, while the achievements of shift workers should be visible and one on one meetings of night-shift personnel should be conducted, it can increase employees' motivation and commitment. Thus shift work ceases to be simply a productivity oriented organisation and becomes a part of a people-friendly and fair work culture that is based on everyone's well-being.

### 6.4. Case Studies

Toyota Japan uses dynamic systems that cater to individuals whose preferences work in shift rotation to increase satisfaction with shifts to 85%. And Finland also has the Finnish Ministry of Health to provide healthcare workers working night shifts free of charge with physical therapy and sleep therapies. Furthermore, a few cities run projects to provide night workers free transport and 24-hour daycare. This is because the extent to which shift work systems succeed is directly linked to their management. Inefficient planning has a detrimental effect on employee wellbeing – and decreases business productivity too. This means that sustainable shift management (both at the organizational level as well as at the societal level) should be based on a human-centered, equity and scientific basis.

## 7. CONCLUSION AND EVALUATION

The shift work system is a condition of modern industrial and service economy. Shift work is a strategic necessity to businesses, particularly in industries that require continuous working 24/7. That being said, this system does have a physical, psychological, social and even family impact on employees, it should be noted, that this shift work is the social and human issue that the shift system does not stop at being a schedule preference. This book chapter gives an overview with respect to the definition, history and types of shift work, further discusses its contribution to firms, employee health, social implications and management difficulties. It states that shift systems lead not only to productivity but provide the quality of life and social welfare of individuals.

From the corporate side, shift systems provide multiple advantages in areas including, but not limited to, production continuity, capacity utilization, delivery speed and cost. But they present complex risks to workers in terms of problems like sleep problems, stress, social withdrawal, work-family conflict, and chronic health issues. For society as a whole, shift work has the potential to deepen socioeconomic inequalities; women and low-income groups are particularly negatively affected by this system. Management deficiencies exacerbate the negative effects of shift work, and unfair shift distribution, communication gaps, and ergonomic violations reduce employee satisfaction.

Various measures can be taken to mitigate the negative effects of shift work and ensure the sustainability of the system. Ergonomic planning requires the preparation of shift schedules based on biological rhythms, taking into account rest periods and following a cyclical logic. With an employee-focused management approach, individuals' living conditions, health status, and social roles should be taken into account in shift planning, and a transparent and fair system should be established. Corporate support mechanisms should be strengthened with practices such as psychological counseling, health screenings, transportation, and care services. In addition, policy-level regulations should guarantee additional social rights, occupational health checks, and public support systems for night workers.

Shift work is not only a technical production organization but also a life organizer. Therefore, the system should be managed with a human-centered approach that is sensitive to ethical values and anticipates long-term effects. Employers, unions, public authorities, and academic circles should take joint responsibility to reduce the risks of shift work and share its opportunities more fairly. In this context, more scientific research on shift work, policies centered on employee experiences, and innovative practices will ensure that the system functions in a more livable way for both individuals and society.

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