

Ergonomic Work Allowance for Cyclical Industrial Work

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Abstract. This paper will produce a guide to industrial engineers for the application of ergonomic work allowances as a means to determine the correct quantity of cyclical work assigned to a worker in a manufacturing plant, in order to meet the definition of a fair day's work. A fair day's work is that length of working day and that intensity of actual work, which expends one day's full working power of the worker, without encroaching upon his capacity for the same amount of work for the next and following days. In the old-fashioned production systems (piecework based) the fair day's work concept was used in connection with the fair day's wage. In this report, and in our view, the studies about the definition of the fair day's work become fundamental to connect work-study with the most recent knowledge about biomechanical load (occupational health and safety), with a special focus on the product-process design phase.

Keywords: work, biomechanics, industrial, measurement, allowance, standard

1. Taxonomy

The definitions below refer to Figure 1.

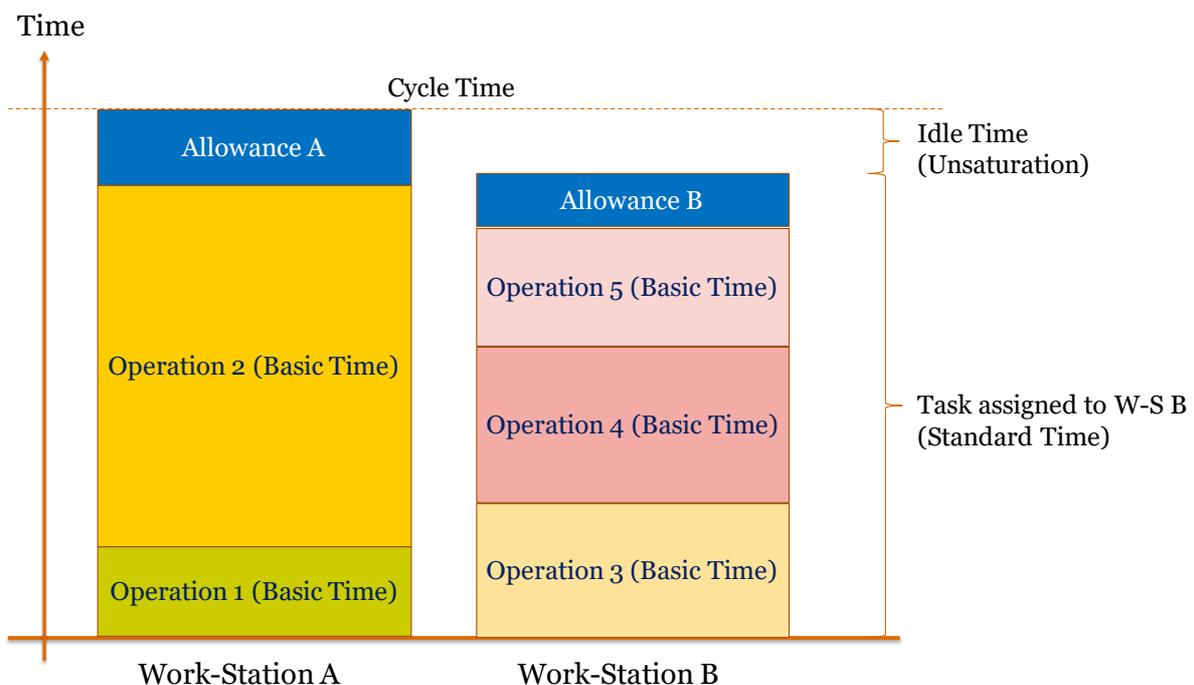


Figure 1: Industrial Engineering - line balancing process

- Standard Work: detailed definition of the most efficient method to produce a product (or perform a service) at a balanced flow to achieve a desired output rate.
- Standard Working Method: break down of the work into elements (Operations), which are sequenced, organized and repeatedly followed. Standard conditions (e.g. part presentation, distances, geometries, weights), tools and equipment are clearly described.
- Work Measurement: the application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance.
- Performance Rating Factor: the step in the Work Measurement Process in which the analyst observes the worker's performance and records a value representing that performance relative to the analyst's concept of standard performance. Most common drivers of the performance rating are speed, effort and precision (level of control).
- Standard Work Performance: an effort level that could be easily maintained year in and year out by the worker with average physical capabilities, without in any way requiring him/her to draw upon his/her reserves of energy. Working at standard performance brings the worker to get to the end of the fair day's work without an excess of physical stress.
- Allowances: when carrying out work over a complete shift or working day, workers obviously suffer from the fatigue imposed both by the work undertaken and the conditions under which they are working. The normal practice is to make an addition to the basic time (commonly referred to as an "allowance") to allow the worker to recover from this fatigue and to attend to personal needs. The amount of the allowance depends on the nature of the work and the working environment and it is often assessed using an agreed set of guidelines and scales.
- Basic Time: also known as Normal Time, Basic Time of a job is determined by multiplying performance rating factor to the observed time (see Figure 4, page 5).
- Standard Time: the time allowed to an operator to carry out the specified task under specified conditions and defined level of performance (Standard Time = Basic Time + Allowances).
- Cycle Time: when setting labor standards and balancing an assembly line, industrial engineers use the term 'Cycle Time' to specify the time available at each work station to accomplish the necessary tasks assigned (it is the clock time of a production line, the pace at which the line delivers its output). In case of a single workstation, Cycle and Standard Time coincide, since there is no Idle Time caused by the imperfect synchronization of a sequence of workstations. (Cycle Time = Standard Time + Idle Time).
- Task Assignment (or Line Balancing): a production line is said to be in balance when every worker's task takes approximately the same amount of time. Line Balancing is a manufacturing-engineering technique, in which the whole collection of production-line operations are divided into tasks, assigned to the minimum number of workstations. Well-balanced lines minimize labor idleness and improve productivity.
- Work Organization: the way how tasks are distributed amongst the individuals in an organization and the ways in which these are then coordinated to achieve the final product or service. It encompasses the total shift duration, the quantity and distribution of the breaks, the type of Man-Machine interface and the level of allowed flexibility.
- Worker Saturation: the percentage of non-idle time within a Cycle Time

(Standard Time/Cycle Time).

- Biomechanical Load: the term “load” describes the physical stresses acting on the body or on anatomical structures within the body. These stresses include kinetic (motion), kinematic (force), oscillatory (vibration) and thermal energy sources (temperature). Loads can originate from the external environment (such as the force generated by a power hand tool) or they may result from voluntary or involuntary actions of the individual (for example, lifting objects).

- Overall Load Index (OLI): the index compounding the overall biomechanical load generated by the different types of physical stress.

2. Standard time setting of a manual task

The determination of the correct work content of a given activity is a fundamental task for a company in order to be competitive on the market, as well as to safeguard workers’ health and to guarantee a proper quality of the performed activity. The setting of a standard time of a manual task requires the following steps (Figure 2):

1. Design of a standard working method
2. Work Measurement
3. Task Assignment and Work Organization
4. Biomechanical load measurement
5. Ergonomic Work Allowance calculation (applying the model)
6. Organizational Solutions

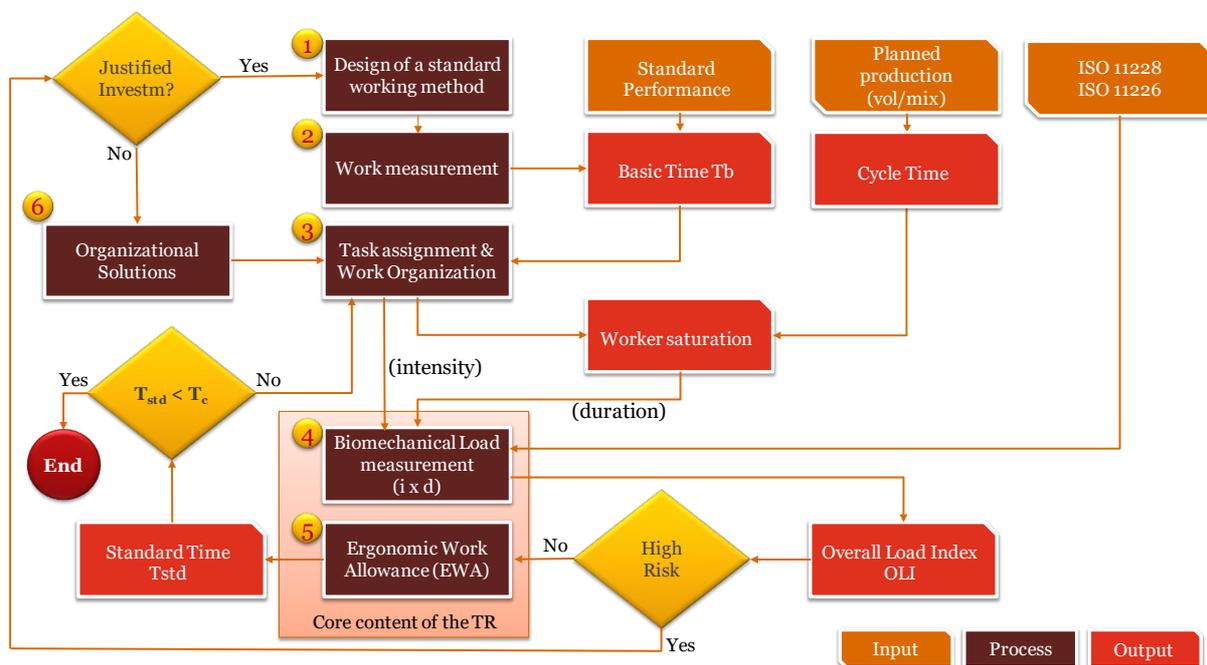


Figure 2 : Standard Work Design Process

2.1 Design of a standard working method

The Design of a standard working method is the key driver to achieve operational excellence levels of productivity and safety. This task is one of the main

responsibilities of Industrial Engineers, who have to blend wisely several fields of knowledge to coordinate humans, machines and materials to attain a desired output rate with the optimum utilization of energy, knowledge, money, and time. It employs key techniques (such as floor layouts, personnel organization, time standards, wage rates, incentive payment plans, production scheduling) and technologies (ICT, digital devices, data and analytics) to control the quantity and quality of goods and services produced. It is clear that the design and planning of a working system largely determines the ergonomic conditions of the worker and, therefore, it is fundamental to bring the ergonomic knowledge into the earliest stages of the product and process development process and the ergonomic constraints into the planning process.

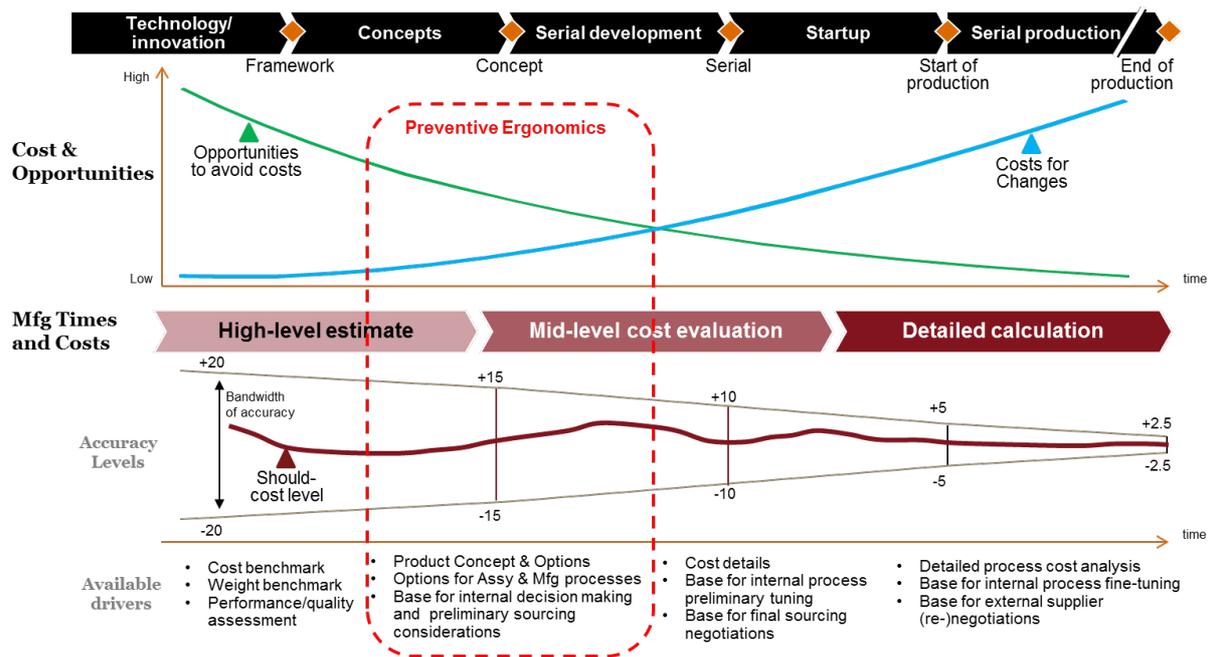


Figure 3: Preventive Ergonomics in the new product development process

To achieve such a sophisticated level of product/process development and planning process (see Figure 3), the most advanced industrial companies use a Predetermined Motion-Time Systems (PMTS). A PMTS is a set of data of elementary human motions, of which a basic time is predetermined, which can be used as a reliable language to design, plan and measure a manual task.

The last developments among available PMTS aimed at creating specific tools for designing work systems in the earliest stages of product and process development, rather than simply measuring them once they are up and running. In this way, it is possible to find the most efficient and ergonomic solutions when it is still feasible to make product and process changes and the cost of the change is still affordable (metal has not yet been cut). Indeed usually, in the early phases of product/process development, investments in tools and equipment have not yet been released and changing a CAD file or a design is not too expensive. Standard times play a key role in setting transformation process costs and purchasing costs of goods and services. World Class companies' purchasing departments monitor direct purchasing or outsourced service costs thanks to an analytical calculation based on the most appropriate PMTS. As far as ergonomics is concerned, if we have a tool to pre-calculate the biomechanical load based on a planned working method, it becomes economic and effective to preventively reduce the risk due to an excessive work load.

2.2 Work Measurement

The definition of the Basic Time (T_b , Step 2 in Figure 2) is built on the concept of Standard Work Performance, strictly related to the much-discussed fair day's work. As we said, the Standard Work Performance represents an effort level that could be easily maintained year in and year out by the worker with average physical capabilities without in any way requiring him/her to draw upon his/her reserves of energy. Working at standard performance brings the worker to get to the end of the fair day's work without an excess of physical stress.

Most accurate Work Measurement techniques (stop-watch and PMTS) make use of performance rating to ensure that times calculated or derived are times for 'an average qualified worker' to carry out the work being measured. Since this average qualified worker is not actually observed, performance rating is used to modify what is observed and thus convert it to 'basic time'.

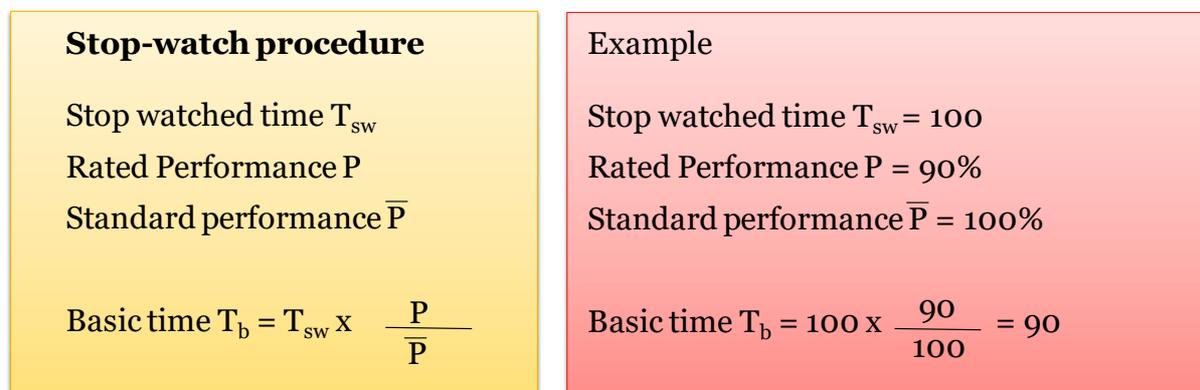


Figure 4: Stop watch procedure to set a basic time

Some measurement techniques, such as the Predetermined Motion-Time Systems (PMTS), do not require the observer to rate the worker's performance. PMTS developers used performance rating in the derivation of the original data to calculate the basic times of each single elementary motions. Therefore PMTS, once the method has been set (sequence of elementary motions), directly provide the basic times, without the need to rate the operator's working performance and, even more important, without the need to observe. This is the reason why PMTS are strongly recommended for designing and planning a new work system, making possible a preventive approach to ergonomics.

Currently, there are different performance rating systems and scales available and in use (no reference standard is defined) and it makes difficult to define a standard norm performance. Using different performance scales brings to set different basic times for the same quantity of work, causing critical deviations in the ergonomic evaluation of the work load (for example, a different basic time per motion would generate different motion frequencies in a cycle).

2.2.1 Standard Work Performance

Increasing globalization caused that many organizations are currently using a number of different Work Measurement techniques in different geographies of the organization. This happens because different techniques have assumed a greater degree of usage in particular countries. Global organizations are willing to set

comparable standard times of the same piece of work to simplify planning and control processes and to manage properly their manufacturing footprint and production allocation. That's why it is important to support the definition of a global work performance reference, exploiting the large quantity of knowledge about ergonomics, which became available mainly in the last 20-25 years (while the most common definitions of Standard Work Performance date back to the '40s).

Each of the rating systems/scales starts from a different conceptual viewpoint. For example, the Bedaux System assumed that 'normal' performance was 60 'minutes of work' per hour, that 80 'minutes of work' per hour was incentive performance and that 100 was the theoretical maximum.

All Work Measurement Systems use time units to represent work content - the quantity of work involved in carrying out a particular task, operation or job. Thus the unit, such as 'standard minute', is an expression of quantity of work, rather than of time. It only converts to an equivalent time assuming that the operator works at standard performance (with reference to the performance rating scale in use) and takes the agreed level of allowances built into the work content value (standard time). Different Rating Systems claim to rate different factors - commonly these are some combination of speed, effort, skill, dexterity, consistency, conditions.

One of the common problems of rating is that it is often linked to remuneration, through the setting of 'daywork' rates or through graduated incentive payment schemes. This results in pressure from employees and unions on work study practitioners to 'slacken' their ratings to give 'looser' time values for jobs.

Thus, even though the same rating system and scale are in use in different organizations, there is no guarantee that the concepts of normal and incentive performance are the same in each - this is especially true if the organizations carry out no rating validation through rating clinics.

In some countries/organizations, trade unions have the right to observe time studies or to carry out parallel studies to check on the times produced by industrial engineers. Where incentive payment schemes are involved, there is understandably a desire to challenge rating and allowances used by the practitioner - since most rating systems are based on subjective judgment, this debate is difficult to resolve in the absence of some means of validating ratings.

The choice of a well-known level of standard performance is crucial for the process of designing safe and ergonomic work systems, especially as far as the upper limbs risk evaluation is concerned. Indeed, a higher level of standard performance would bring to shorter basic times of each elementary motion and, consequently, an expected increase of action frequency of the upper limbs planned motions. When most of the Work Measurement Systems were developed, there were no ergonomic standards available and the good ergonomic solutions were left to the individual experience of industrial engineers. Nowadays, the correlation between the biomechanical load and the probability to incur a work-related musculoskeletal disorder is proved and relevant ISO/CEN standards set clear references.

One objective of the present paper is to take a formal position against the use of the different standard performance levels to set basic times in the industries. The availability of different performance rating scales is not an issue. When measuring a temperature, regardless the scale used, if the water starts boiling, the value read on each scale is different, but well known and equivalent (100 °C or 212 °F or 373.15 °K indicate the same level of heat). In the same way, it is important to establish a fair reference level of work performance, which keeps the biomechanical load under given limits.

2.2.2 Definition of a Real Action

A Real Action (RA) is a combined movement of the upper limb (fingers, hand, wrist, elbow and shoulder) aimed at achieving a planned state (e.g., Get and Place an object to a specific destination). The exact definition of the RA is based on the movement definitions of the building blocks of MTM-UAS.

The ISO standard 11228.3 sets the max number of actions at 70 Technical Actions per minute (see ISO 11228-3:2007 Ergonomics -- Manual handling -- Part 3: Handling of low loads at high frequency), equivalent to 40 Real Actions per minute. Considering the durations shown in Figure 5, the average duration of one action is in the range of 31-35 TMU (Time Measurement Unit – 100.000 TMU = 1 hour), equivalent to 1,2 s and generating a frequency of 50 Real Actions per minute (equivalent approx. to 87 Technical Actions/min).

In a real workplace, we should consider that we usually have a distribution of motions between the two upper limbs (left and right) and some body motions and visual controls, which do not generate any Real Action and therefore dilute the frequency of actions. Consequently, we have good chances that, adopting the MTM Standard Work Performance, resulting frequencies of action do not cause an excessive biomechanical load. Of course, to obtain a complete load evaluation, further influencing factors must be considered (e.g. force levels, weights, postures, etc.).

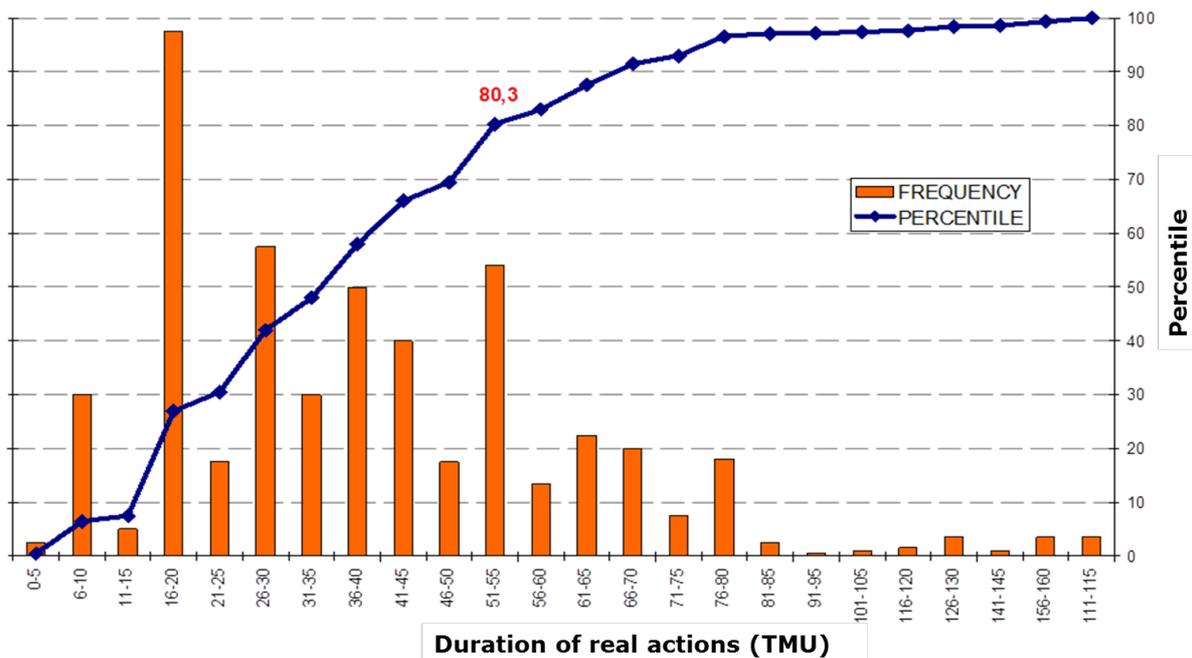


Figure 5: Distribution of Real Actions duration

2.3 Task Assignment and Work Organization

Task assignment in a manufacturing industry is very important, especially when we deal with assembly lines (line balancing). Indeed, once the total work content is calculated (total basic time of all the actions necessary to accomplish the complete task), given a targeted quantity of units to produce and the networking time available in a shift (shift duration minus breaks and non-productive time), it is possible to set

the pace of our production flow (Cycle Time, T_c). Cycle Time, then, becomes the maximum capacity of each workstation along the flow, if we want the operators to work at a controlled performance and to produce the planned output. T_c is like the capacity of a glass: the water we pour in it is the set of tasks we assign to a workstation and T_{std} (Standard Time) is the quantity of liters of water poured into the glass. Without an accurate Work Measurement, it would not be possible to balance the line evenly and the production would not flow smoothly along the line. As a consequence, we would have lower productivity levels and an uneven distribution of work among the workers, forcing the most saturated workers to work harder and faster to cope with the line pace (T_c).

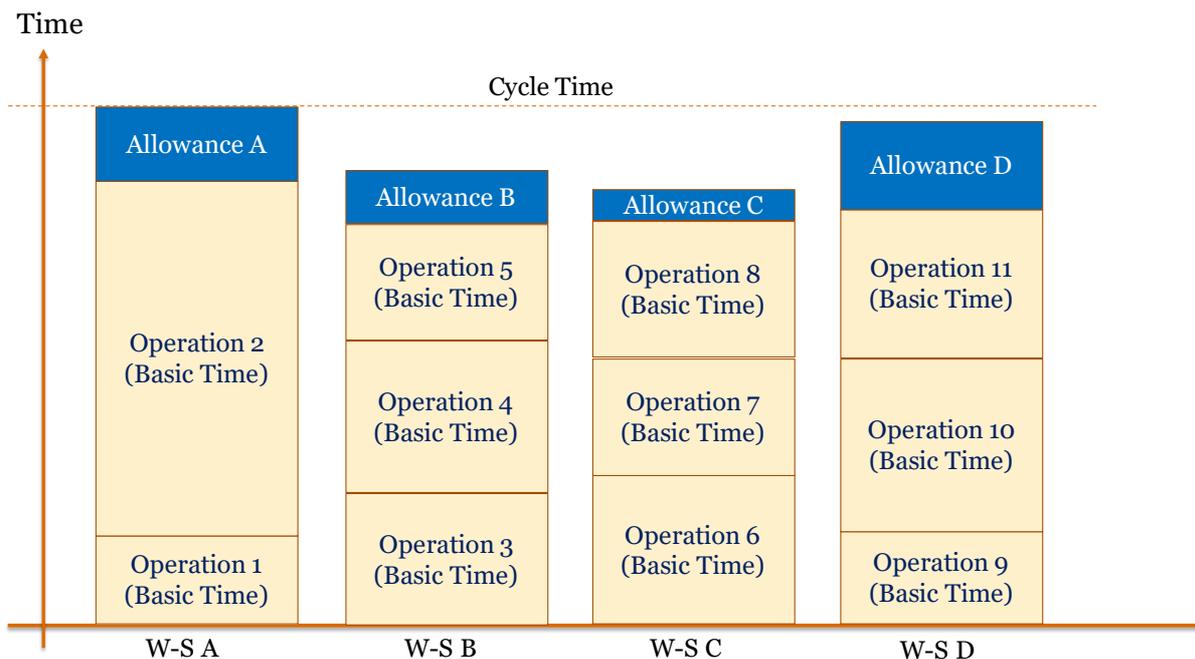


Figure 6: Line Balancing

Once the tasks are assigned to a workstation and the T_c is set, the duration of each action (times per minute in case of dynamic actions or seconds of duration per minute in case of static actions) is determined and the calculation of the workload can be accurately accomplished.

2.4 Biomechanical load measurement

Load results from intensity and duration of the work and the working conditions in which it is carried out; it describes the objective demand of work, which is to be fulfilled in a period and it is independent from the individual who performs the activity.

At present, several ergonomic analysis systems are available to measure the workload. Each system was designed to deal with a specific risk area and it works with its own measurement scale (e.g. NIOSH Lifting Index, OCRA Index, ACGIH TLV, HAL, RULA, Strain Index etc.). To apply the EWA (Ergonomic Work Allowance) Model, it is necessary to compound all type of loads (postures, forces, manual material handling of loads, vibrations and repetitive upper limbs' motions) on a unique scale. In Figure 7, a comprehensive approach is represented. The first available solution which meets all the requirements of the application of the EWA Model is the Ergonomic Assessment Work-Sheet (EAWS).

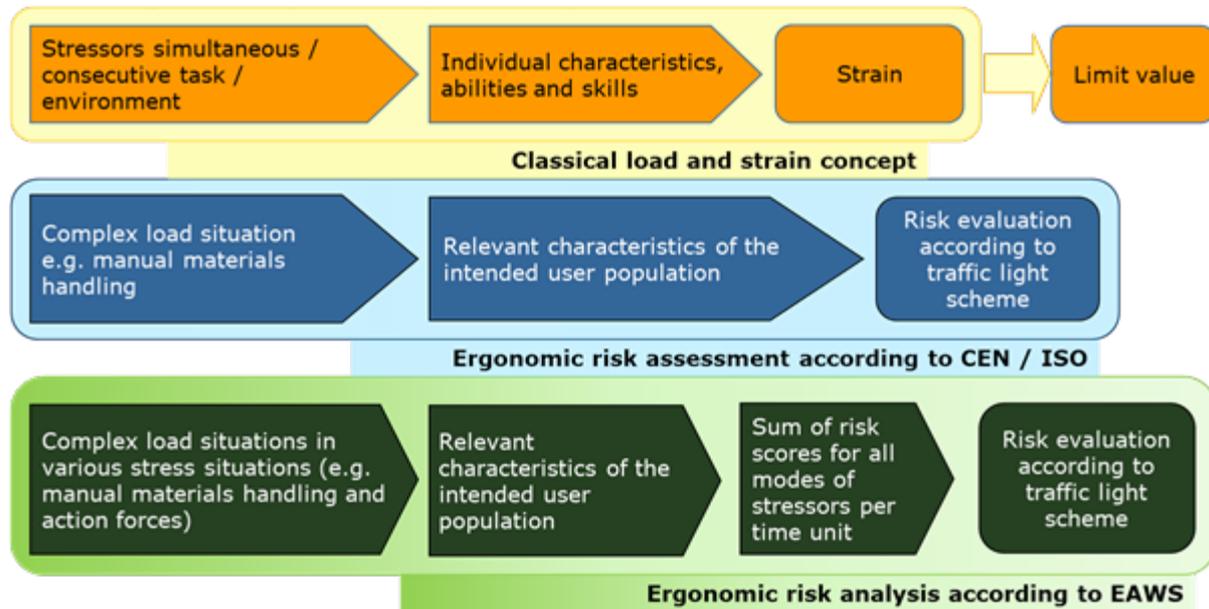


Figure 7: Approach to an overall load index assessment

The required ergonomic measurement tool has to provide an overall load evaluation that includes all biomechanical risks to which an operator may be exposed during a cyclical work task. All loads must be measured and compounded on a unique scale and the resulting load is expressed through a final index, the Overall Load Index (OLI), which is then used in the EWA Model to determine a proper allowance factor.

The load is given by the result of the formula:

$$\text{Load} = \text{Intensity} \times \text{Duration}$$

- Intensity is mainly driven by the awkwardness of postures (body, upper limb and grip), intensity of forces (force exertion and manual material handling) and vibrations.
- Duration is driven by the action frequency (dynamic actions) and action duration (static actions).

ISO standards 11228 and 11226 offer models to assess the level of exposure to ergonomic risk by providing a measure of the biomechanical load. These provide a means of measuring loads that are not simple to measure given the numerous and related influencing factors (for example, the intensity of an upper limb motion depends on the force level with respect to the type of grip used to get the control over the object being moved and to the direction of the movement).

The requirements of the EWA Model are even higher, since it needs in input the measurement of the total load generated by the composition of all types of load.

2.5 Ergonomic Work Allowance (EWA)

An allowance is the adjustment of the basic time to obtain the standard time for the purpose of covering the time spent for personal needs, recover from fatigue and unavoidable delays. By providing a small increase of the basic time in each cycle, the

“non-productive” time becomes planned and a worker can still be able to complete the work assigned to him/her.

There are two types of interruption: (1) related to work and (2) not related to work. For example, a machine breakdown, rest break to overcome fatigue and receiving instructions from the manager are related to work, but personal needs and lunch breaks are not. However, the two types of interruption are both essential for the worker, because it is almost impossible to work continually during a regular shift.

The fatigue allowance is intended to cover the time that the worker should be given to overcome fatigue due to work related stress and conditions. There are three factors that cause fatigue: (1) physical, like standing and use of force, (2) mental and cognitive, like mental strain and eye strain, and (3) environmental and work, like poor lighting, noise and heat.

This paper deals only with (1) physical factors and partially with (2) mental and cognitive factors for workers assigned to cyclical manual tasks in industrial manufacturing environment. Specifically, by EWA we mean the allowance coping with physical factors. A few mental and cognitive factors of manual repetitive tasks are evaluated only in the most advanced Work Measurement techniques in the definition of the basic time (high precision motions require visual and mental control and, for this reason, are given more time). Most of the mental and cognitive factors are not dealt with in this paper (fatigue related to psychosocial issues, which the worker faces and deals with either in the workplace or otherwise).

In the EWA Model, we do not include any coverage of interruption not related to work. Specifically, EWA does not include any physiological need allowance, which is a constant value, independent from the type of work and, typically, ranges from 4% to 5% of the shift time (equivalent approximately to 2 breaks of about 10 minutes each, distributed within a typical shift of 8 hours).

Since the definition of the Basic Time T_b assumes there is no physical stress in the accomplishment of the daily task, if the working task generates stress, industrial engineering practices recommend the allowance of a recovery time sufficient to compensate the extra effort. The objective is to level the physical effort (biomechanical load) within the standard limits referenced by the work performance and thus reducing the likelihood to incur work-related musculoskeletal disorders. In other words: the EWA would allow more time to execute a task (diluting the basic time), thus reducing the demand of performance of the worker.

The T_b is determined on the basis of the definition of standard labor performance. In the paragraph “Work Measurement” (2.2, page 4), we have selected the MTM standard performance as the reference, as, if there are no other risk factors present in the work task (e.g. awkward postures and forces), it brings to have an action frequency, which is likely to be compliant with the ISO 11228.3. However, what if those additional risk factors are present?

2.5.1 The Traditional Approach

In the best traditional Industrial Engineering practices, Ergonomic Work Allowances (often named Rest or Fatigue Factor) are determined and applied on each single motion. We named those type of models “Single-Motion Work Allowance”. In case a detailed Motion-Time study is not available, often the Ergonomic Work Allowance is applied as a constant percentage on all work-stations, regardless the type of task carried out (usually the percentage is based on old

company agreements). In the worst cases (unfortunately quite common in the real life), no ergonomic allowance is applied.

As an example, in Figure 8 we report a copy of the Rest Allowance Table adopted by FCA Group since the '60, until their global adoption of the EWA Model in 2008.

	Basic Body Posture	TRUNK AND UPPER LIMBS POSTURE	FORCE EXERTION OR WEIGHT			
			L 0-2 Kg.	M 2-10 Kg.	P 10-20 Kg.	PP 20-25 Kg.
ALLOWANCE IN %						
1		A TRUNK AND UPPER LIMBS IN NORMAL POSTURE; STATIONARY TRUNK	5	6-7	-	-
		B TRUNK AND UPPER LIMBS IN AWKWARD POSTURE; STATIONARY TRUNK	7	8-10	-	-
2		A TRUNK AND UPPER LIMBS IN NORMAL POSTURE; STATIONARY TRUNK	7	8-9	10-12	13-17
		B TRUNK AND UPPER LIMBS IN NORMAL POSTURE; MOVING TRUNK	9	10-12	13-15	16-20
		C TRUNK AND UPPER LIMBS IN AWKWARD POSTURE; STATIONARY TRUNK	11	12-14	15-18	19-23
		D TRUNK AND UPPER LIMBS IN AWKWARD POSTURE; MOVING TRUNK	13	14-16	17-20	21-25
3		A TRUNK AND UPPER LIMBS IN NORMAL POSTURE; STATIONARY TRUNK	8	9-10	11-13	-
		B TRUNK AND UPPER LIMBS IN AWKWARD POSTURE; STATIONARY TRUNK	12	13-15	16-19	-
4		A TRUNK AND UPPER LIMBS IN NORMAL POSTURE; STATIONARY TRUNK	10	11-13	-	-
		B TRUNK AND UPPER LIMBS IN AWKWARD POSTURE; STATIONARY TRUNK	14	15-18	-	-
5		A FLAT SURFACE, WITH OR WITHOUT LOAD	10	11-14	15-19	20-24
		B SLOPED SURFACE, WITH OR WITHOUT LOAD	13	14-17	18-22	23-27
		C PUSHING/PULLING TROLLEYS OR CARTS ON A FLAT SURFACE	11	12-15	16-20	21-25

NOTE: PERCENTAGES IN THIS TABLE DO NOT INCLUDE ANY ALLOWANCE FOR PHYSIOLOGICAL NEEDS (4%)

Figure 8: FCA previous Rest Allowance Model

The weaknesses of the traditional model are the following:

- Despite the wide range of allowance values (1% to 23%) in the table, the resultant average value of the allowance at a workplace is fairly constant (in the automotive assembly lines we found values in the range 5,5% - 6,5%).
- Single Motion models do not consider the frequency of actions, which is one of the key drivers in the ISO 11228 standards.
- Single Motion models do not consider the sequence of the actions and, therefore, tend to neglect or underestimate the duration of the static actions (average motion duration ranges from 1 to 2 s).

2.5.2 The Proposed Approach: EWA

The first study which drew attention to the weakness of the correlation between the Ergonomic Work Allowance assigned with the Single Motion models and the overall physical stress (fatigue) was carried out in the FCA Mirafiori plant (Turin), on the Trim line of the vehicle models Musa, Punto and Idea in 2005. The objective of that project was to test the effects of the introduction of the Work Measurement System MTM-UAS and of the newly developed comprehensive ergonomic tool Ergonomic Assessment Work-Sheet (EAWS).

The results of that study were the following:

Step 1: Same line balancing (unchanged task allocation), work measured using MTM-UAS and calculation of the ergonomic factor using the traditional method (Single Motion model shown in Figure 8).

Looking at Figure 9, it is quite evident (especially for workstations 18 and 19, where the EAWS Index reaches the highest values) that the correlation between EAWS Index and the applied allowance (almost constant around the value of 6%) is very poor.

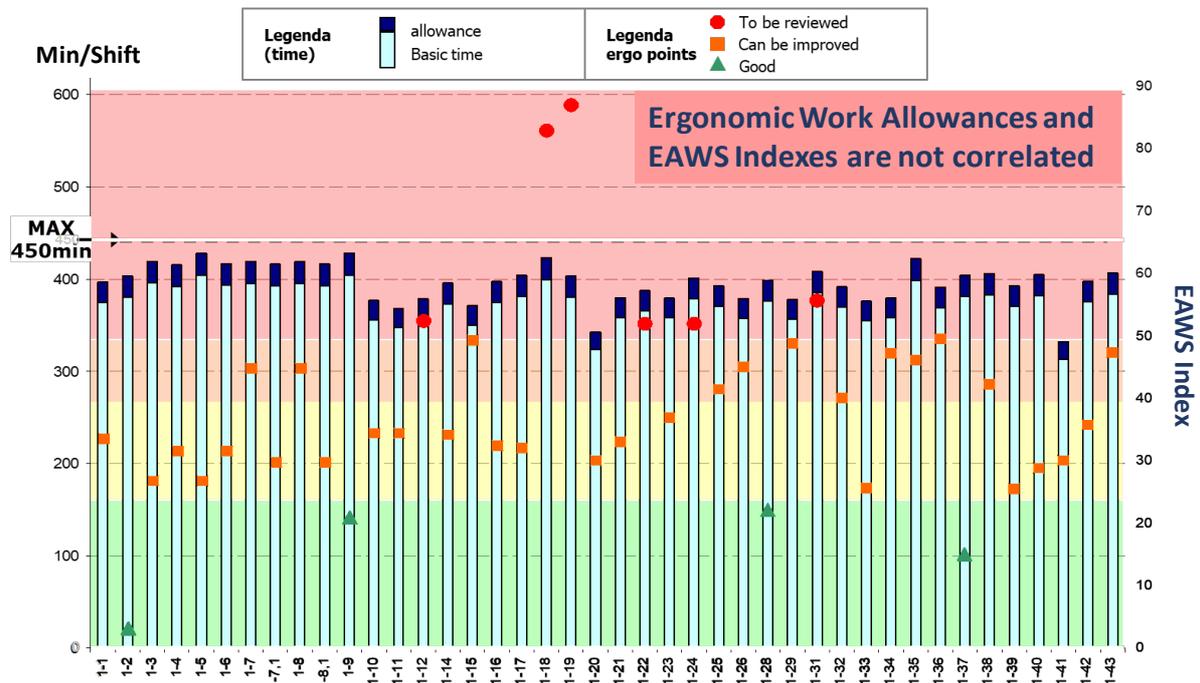


Figure 9: Mirafiori project, Step 1

Step 2: Same line balancing but calculating the ergonomic allowances using the EWA Model.

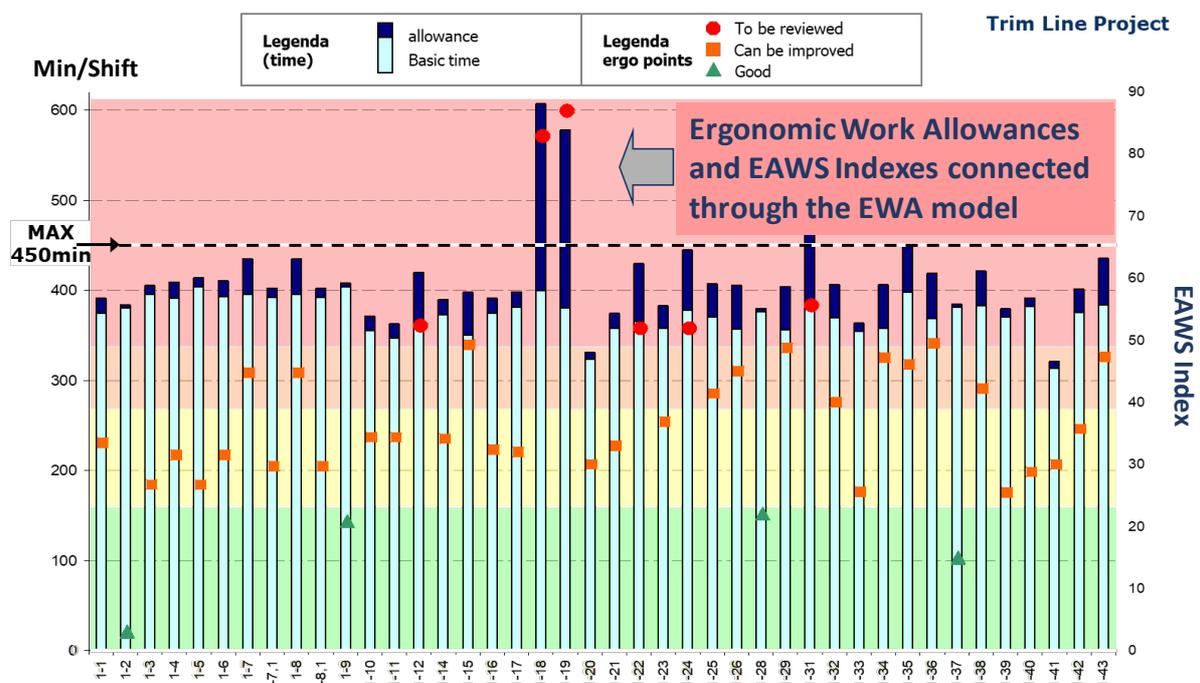


Figure 10: Mirafiori project, Step 2

The Ergonomic Work Allowance Model was designed with the main objective to calculate an allowance as a function of a fatigue index. The stronger the demanded fatigue, the higher the allowance (Figure 12).

Step 3: New line balancing and calculating the ergonomic factor using the EWA Model.

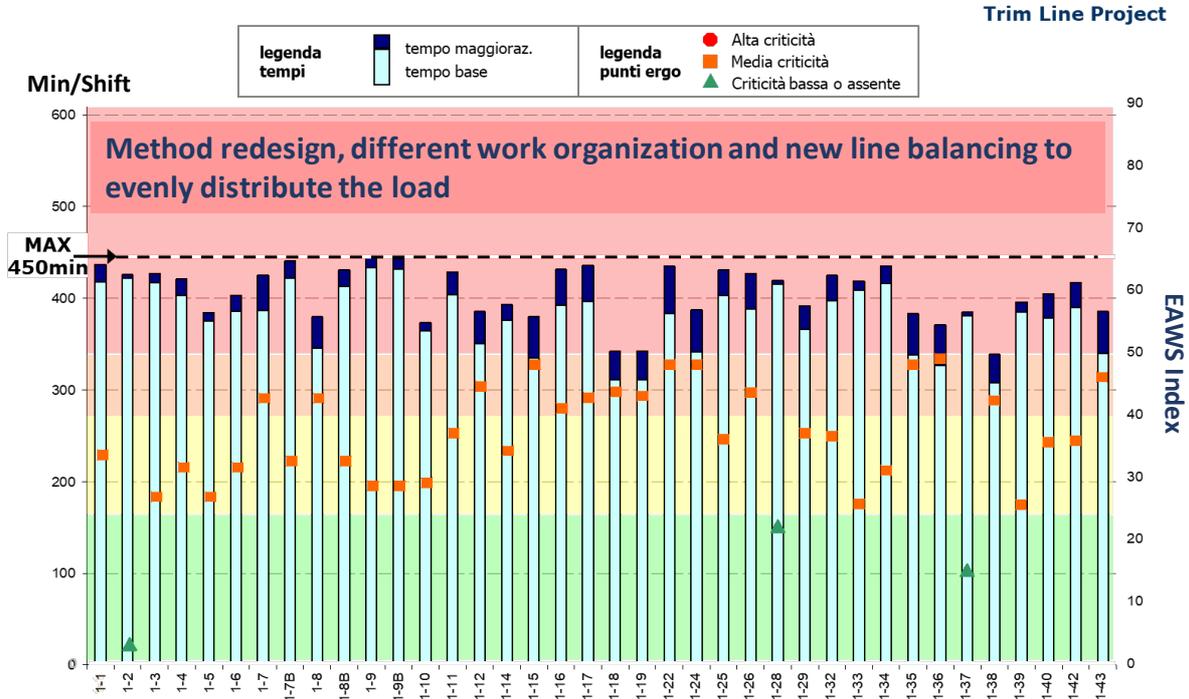


Figure 11: Mirafiori project, Step 3

The fatigue index has to consider the various sources of physical stress and it condensates the evaluations in a unique index.

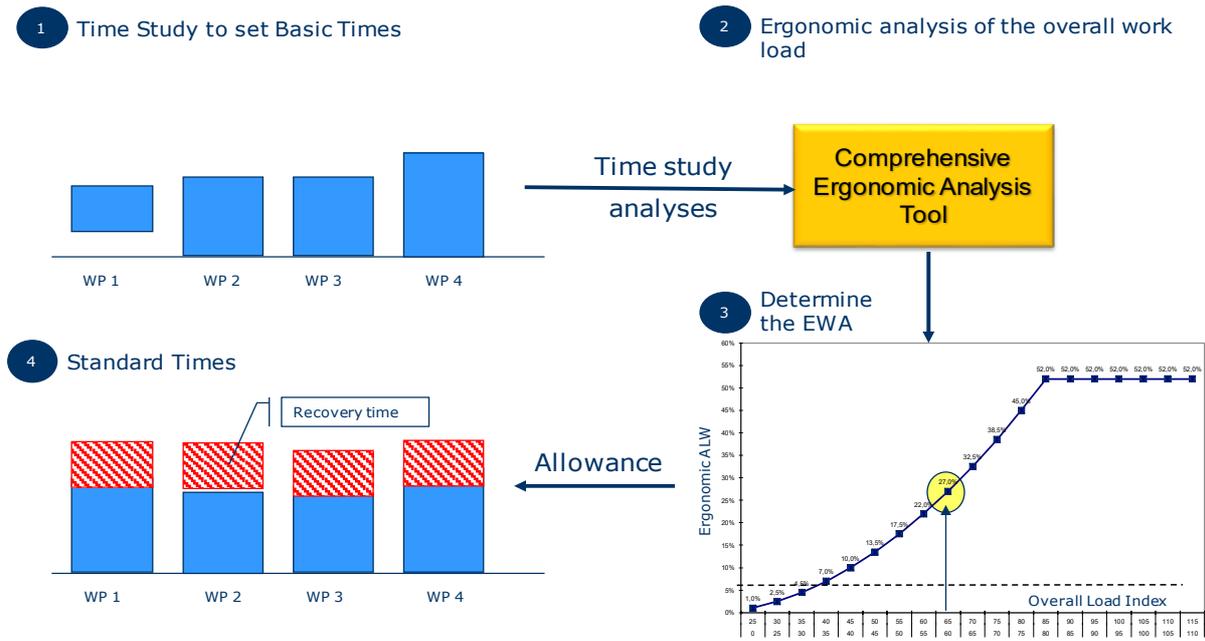


Figure 12: EWA Process Steps

The main innovation, with respect to other existing allowance systems, is the introduction of the concept of Duration. Indeed, the traditional methods base the determination of the allowance as a function of the main body posture and of the force/load level (intensity), regardless the duration or the frequency of the motions. The allowance is then applied on each single motion, and, for this reason, the model is called "Single-Motion Allowance". For example, to lift a load of 40 pounds, the ILO Recommended Allowance gives a value of 9%, regardless the number of repetitions of the action during the shift.

The proposed EWA Model assigns an Ergonomic allowance (fatigue allowance) as a function of the Overall Load Index, which is an index tightly linked to the concept of physical workload. In the EWA Model, the physical workload is calculated as follows:

$$\text{Work-load} = \text{Intensity} \times \text{Duration}$$

- Intensity is proportional to the degree of awkwardness of the postures, to the force intensity or the load weight etc.
- Duration depends on the duration of the static actions and the frequency of the dynamic actions.

To reach a significant level of workload, it is necessary to have at least a medium intensity with a medium duration. If either one of the two factors is negligible, the resulting workload would be low, even if the other factor is high (in such cases, there would be a risk of injury arising from a single identifiable event, which must be lowered through a better method design).

The ergonomic allowance is necessary to dilute standard times and recover from physiological strain (maximum worker's saturation level is limited, or extra breaks are allowed). The nature of physiological strain depends on the type of muscular contraction involved. There are two types of muscular contractions:

- Dynamic, involving rhythmical contractions of large muscle groups where the length of the muscles is changing (isotonic).
- Static, involving prolonged contraction without a change in the length of the muscles (isometric).

The core of the EWA Model (Figure 13) was built upon the fundamental principle to allow a sufficient recovery time to keep the physical load within controlled limits.

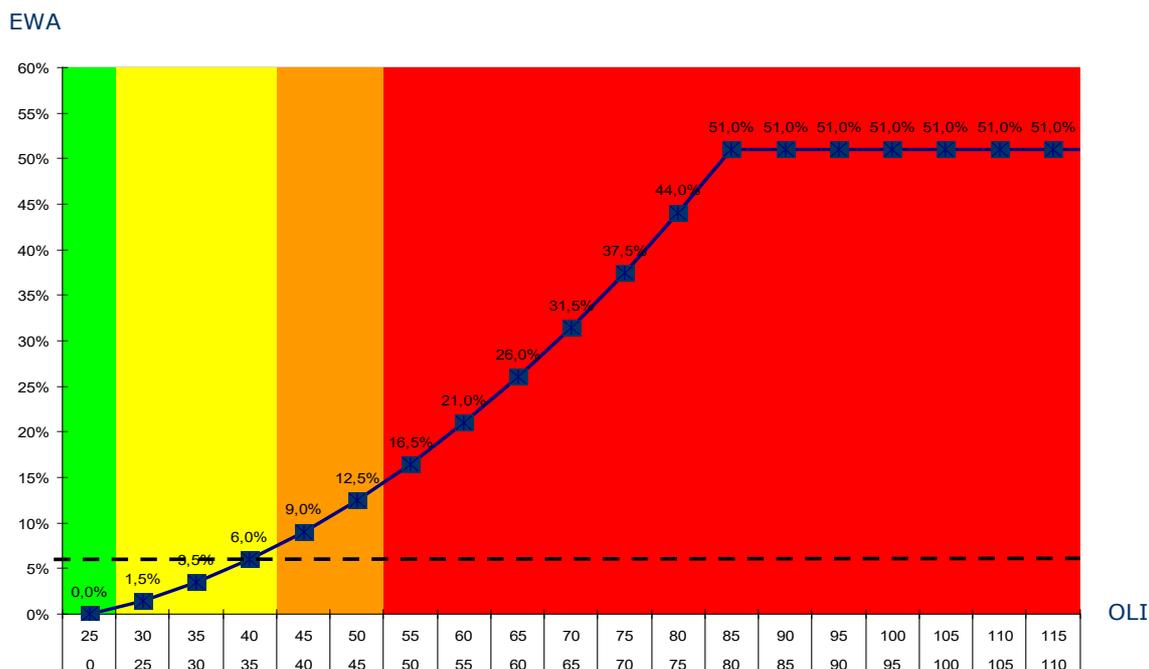


Figure 13: Ergonomic Recovery Model

Legenda:

- EWA is the Ergonomic Work Allowance (vertical axis)
- OLI is the Overall Load Index (horizontal axis)
- 0 < OLI ≤ 25 Low physical stress (green color)
- 25 < OLI ≤ 40 Medium low physical stress (yellow color)
- 40 < OLI ≤ 50 Medium high physical stress (orange color)
- OLI > 50 High physical stress (red color)

2.5.3 Design Criteria

The EWA Model was determined setting a curve that starts from 0% and increases exponentially up to 51%, trying to match the plotted values and generating a set of points very sensitive to the variations of load, particularly within the medium risk zone (25 < overall load score < 50), which represents the most common case in the manufacturing industry. To identify the best fitting EWA curve, numerous calculations were run during a research project, which took place at the FCA Mirafiori automotive plant on the Musa-Ideal final assembly line in the period 2005-06. In that study, the EAWS system was adopted by FCA as the comprehensive ergonomic tool to calculate the overall load index. The drivers in the identification of the function were the following:

- Start from 0%, since, if there is no significant load, the Standard Work Performance sets the basic times on a level corresponding to the no-stress area (see definition of Standard Work Performance, page 1).
- In the middle of the medium load level (Yellow zone in Figure 13), corresponding to an overall load index of 37.5, set the EWA at 6%.
- Define the “speed” of the function (first derivative), in order to reduce the workload enough to exit from the red area. An exponential model was selected, since linear models failed.

Figure 13 shows the proposed model, where the traffic light colors indicate three load levels corresponding to three risk zones: low risk (green), medium risk (yellow) and high risk (red).

Since 2006, hundreds of real field applications of the EWA curve have proved its validity, pushing the users to a continuous improvement of the ergonomic conditions to increase productivity and reduce labor costs.

2.6 Organizational Solutions

EWA Model was designed to support and guide industrial engineers to design efficient and safe working methods and set standard times in order to put the worker in the best conditions to operate productively and safely. EWA Model does not end with the definition of an allowance. If we look back at Figure 2 (page 3), we can realize that, if the Overall Load Index (output of step 4 - Biomechanical Load Measurement) enters into the High Risk zone (with EAWS – this would mean to have more than 50 points), the EWA Process would require a review of the work system under evaluation. This is a fundamental concept: EWA must support the (re-)design of a safe work system. It wouldn't be even economic trying to increase the allowance, thus reducing the work pace, until the Overall Load Index decreases under the threshold value. This is the reason why the EWA curve flattens at 51%. If we have a case where the Overall Load Index is much over the threshold value, we would not use the model to find the allowance value sufficient to exit the red area, but we would recommend to improve the working method and conditions and run again the load calculation until we decrease the value under the threshold or we get as closer as possible to it (constrained optimization). At that point, the application of the EWA should solve the problem.

2.6.1 Strategies to reduce the Overall Load Index

a. Redesign of the work method in order to reduce the Intensity score, e.g. by allowing the operator to work with a better body posture or by reducing the amount of force needed to perform a certain task (e.g. using a tool). In most of the cases, provisions are "Low Cost Automation" (LCA) initiatives, i.e. small investments with a short payback period (usually shorter than 1 year). The EWA Process helps the identification of the critical steps of the work process and gives precious indications as to where the work method should be improved. Another key benefit of the application of the EWA Model is that an ergonomic improvement directly generates a cost reduction (less load would mean less allowance and therefore less cost), which can be used to justify a LCA improvement.

b. If no method improvements are possible or justifiable in the short term, then we need to find organizational solutions, which do not eradicate the ergonomic issue, but offer a way to manage the situation.

2.6.2 The most common organizational options

1. Review Step 3, i.e. the task assignment (line rebalancing); when doing this, of course we have to concentrate our attention on the operations which cause the highest load values and find an alternative workstation with enough room to receive the additional load without generating a new ergonomic issue and with the necessary idle time so that, even with the additional operation, its total standard time would not

exceed the cycle time of the line. Of course, also the production sequence must be respected when moving an operation to a different workstation. It could be necessary to repeat this procedure in a loop more than one time before finding a balanced scenario.

2. If task assignment cannot be changed or has no effect and no method redesign is possible, one organizational solution is to plan a job rotation among 2 or more workstations, in order to obtain an acceptable weighted average overall load index for each concerned worker.

3. Another option is to review the quantity and distribution of the breaks. This option would have a significant impact where repetitive motions of the upper limbs represent the most critical ergonomic area.

The choice of the best strategy to reduce the risk should take into account:

– The economic impact of the identified solution: in general, the addition of a recovery time could increase the product cost, but it can be taken in a very short time. On the contrary, the redesign of the workstation could allow to keep (or even increase) the production output but may involve significant investments. Ideal solutions usually lay in between the two options: “low cost automation” help to remove critical loads (focused improvements) and the rest is done through organizational solutions (line rebalancing is the most common).

– The effect of the actions on the Intensity\Duration score: its curves have different behavior in the different sections (Body Postures, Force exertion, handling of loads and repetitive motions of the upper limbs).

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