



BSI Standards Publication

Ergonomics — Recovery model for cyclical industrial work

National foreword

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Ergonomics — Recovery model for cyclical industrial work

*Ergonomie — Modèle de récupération pour les activités cycliques
dans l'industrie*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 3, *Anthropometry and biomechanics*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

0.1 General

The literature contains numerous methodologies for measuring physical stress in manual work. Studies from different disciplines and research groups have concentrated on diverse external factors, workplaces, and jobs. Factors most often cited include forceful exertions, repetitive motions, sustained postures, strong vibration and cold temperatures.

The ISO 11228 series, ISO 11226 and ISO TR 12295 establish ergonomic recommendations for different manual handling tasks, repetitive movements and working postures. They apply to occupational and non-occupational activities and provide information for designers, employers, employees and others involved in work, job and product design, such as occupational health and safety professionals.

- The ISO 11228 series relates to manual handling, including lifting and carrying, pushing and pulling and the handling of low loads at high frequency.
- ISO 11226 gives recommended limits for static working postures with no or minimal external force exertion, while taking into account body angles and duration.
- ISO TR 12295 serves as an application guide of the ISO 11228 series and ISO 11226 and offers a simple risk assessment methodology for small and medium enterprises and for non-professional activities. ISO/TR 12295:2014, C.5, is very relevant for this document, since there is a reference to the EAWS system, which is extensively described in [Annex A](#), being the first available ergonomic tool meeting the requirements of the EWA model.

This document can be used by 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 or her capacity for the same amount of work for the next and following days^[26]. 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 document, 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.

0.2 Recovery

In the field of ergonomics there is a special interest in predicting fatigue dependent on the intensity, duration and composition of stress factors and to determine the necessary recovery time. [Table 1](#) shows those different activity levels and consideration periods, possible reasons for fatigue and different possibilities of recovery.

Table 1 — Fatigue and recovery dependent on activity levels

Level of activity	Period	Fatigue from	Recovery by
Work life	Decades	Overexertion for decades	Retirement
Phases of work life	Years	Overexertion for years	Holidays
Sequences of work shifts	Months or weeks	Unfavourable shift re-gimes	Weekend, free days
One work shift	One day	Stress above endurance limits	Free time, rest periods
Tasks	Hours	Stress above endurance limits	Rest period
Part of a task	Minutes	Stress above endurance limits	Change of stress factors

In ergonomic analysis of stress and fatigue for determining the necessary recovery time, considering the period of one working day is the most important. In this document, this type of recovery is named “recovery external to the work cycle” and is defined in ISO 11228-3.

In case of cyclical industrial work, where awkward static body postures are relevant, a strategy to reduce the stress level is to allow short recovery periods within each work cycle. This type of recovery is named “recovery within the work cycle”.

The proposed model concerns the quantification of recovery periods within the work cycle and considers recovery periods outside the cycle (normally defined as pauses) as an exogenous variable, evaluated within the factors characterizing the work organization.

0.3 Purpose and justification

The industrial sector is one of the sectors with the highest global employment rate (22,5 % of total employment). Despite this, the most recent research efforts about the definition of a fair day's work date back to the 1980s. In the last 20 years a lot of research has been carried out on the biomechanical load and many new standards have been created.

This document is a first bridge between two different fields of knowledge: work study (industrial engineering) and occupational health and safety (ergonomics). the objective is to improve the work study tools by leveraging the knowledge made available by the most recent studies about work-related musculoskeletal disorders (WMSDs).

This document provides a methodological reference for the procedures to determine the fair quantity of work within a working day in industrial operations with repetitive manual work cycles.

The goal of the model is to guide industrial engineers to keep the biomechanical load or local muscle fatigue generated by the planned cyclical work within the limits defined in the ISO 11228 series and ISO 11226.

This document proposes neither new work measurement techniques nor new ergonomic techniques or standards. Rather, it aims at merging the best available knowledge (industrial engineering and ergonomics) about human capacity of accomplishing a manual task, following a pre-defined work cycle (method description and related standard time) without generating an excess of biomechanical load (fatigue).

Present issues:

- Ergonomic allowance is neglected or assigned based on a partial evaluation of the physical load (usually body postures and forces). The calculation is not influenced by:
 - load duration (action frequency and duration of static actions);
 - work organization (shift duration, duration and distribution of the break periods) and work measurement.
- Lack of a well-recognized standard work performance to measure manual work.
- Available ergonomic evaluation systems work on different measurement scales and the difficulty of assessing the overall physical stress.
- The ergonomic approach tends to be used reactively in the industry rather than proactively (preventive ergonomics).

0.4 Expected benefits

- Support the adoption of the ISO 11228 series and ISO 11226 in the industrial manufacturing sectors.
- Support the definition of a standard work performance to standardize the work measurement.
- Improve working conditions, safety and ergonomics of workers in manufacturing industries.

- Complement the traditional set of experts' capabilities on time and motion with the ergonomic skills necessary to design safe and efficient work stations and sustain continuous improvements in productivity and ergonomics during the entire product life cycle.
- Support the ergonomic evaluation in the earliest stages of product or process development, when changes are still feasible and the cost of such changes is affordable (preventive ergonomics).
- Link ergonomic improvements with labour cost reduction (improve ergonomics – reduce costs – justify investments in ergonomic improvements).
- Reduce cost and deviation of the ergonomic risk-mapping process by linking the biomechanical load measurement with work measurement and organization.
- Be an objective reference for employers and unions when setting up gainsharing contracts based on labour productivity (industrial relations).

Ergonomics — Recovery model for cyclical industrial work

1 Scope

This document establishes an ergonomic model for any cyclical human work planned and executed in an industrial competitive environment. It also covers the process of measuring work based on the concept of normal work performance and of the assessment of risk factors commonly associated with body postures, body or hand forces, manual material handling of loads and handling low loads at high frequency.

This document applies to the adult working population and is intended to give reasonable protection for nearly all healthy adults. Those areas concerning health risks and control measures are mainly based on experimental studies regarding musculoskeletal loading, discomfort or pain and endurance or fatigue related to work organization and methods.

The scope of this document is any cyclical human work planned and executed in an industrial competitive environment. The most typical cases are within industries where there is the need to define an expected output (products or services) based on the optimization of the trade-off between labour productivity and health and safety.

The most sensitive organizations to this proposal are those within labour-intensive manufacturing industries with series and batch production systems:

- automotive (original equipment manufacturer and tier 1 and 2 suppliers);
- industrial automotive (trucks, buses, agricultural and mining equipment);
- industrial manufacturing (small domestic and industrial equipment or machinery);
- domestic appliances and consumer goods (white goods);
- plastic and rubber products (tires, doors, windows, shoes);
- consumer electronics (PCs, televisions, printers, radios, hi-fis, alarm systems);
- furniture;
- textiles and apparel;
- food preparation;
- packaging;
- aerospace and defence;
- rail and shipping;
- large domestic and industrial equipment or machinery;
- logistics.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 basic motion

manual motion performed with fingers, hands, arms, eyes, feet, legs or body, no longer decomposable as regards to content time

3.2 technical action

elementary manual action to complete operations within the cycle basic motion in which a segment of the upper limb (shoulder, elbow, wrist or finger) is involved to reach a target or to hold an object or a posture

EXAMPLE Grasp, reach, move, turn, apply pressure, hold, turn, push or cut.

3.3 real action

combination of basic motions (technical actions) performed to achieve a finite and planned state of an object

EXAMPLE Get and place an object, place a tool, activate (reach and press a button), micro finger cycle as fastening a screw with fingers.

3.4 standard work

work with the most efficient method to produce a product (or perform a service) at a balanced flow to achieve a desired output rate

3.5 standard working method

method to break down of the work into elements (operations), which are sequenced, organized and repeatedly followed

Note 1 to entry: Standard conditions as part presentation, distances, geometries, weights or tools and equipment are clearly described.

3.6 work measurement

application of techniques designed to define the time for a qualified worker to carry out a specified job at a defined level of performance

3.7 standard work performance

effort level that could be easily maintained year in, year out, by a worker with average physical capabilities, without drawing upon his or her reserves of energy

Note 1 to entry: Working at standard performance brings the worker to the end of the fair day's work without an excess of physical stress.

3.8**time allowance**

time added to the basic time

Note 1 to entry: 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.

Note 2 to entry: Time allowances are used to cover personal needs, technical and organizational planned losses and learning effect. This document refers to time allowances meaning the additional time to recover from an excess of fatigue generated by the work cycle.

3.9**basic time**

time set through a given work analysis system

Note 1 to entry: Predetermined time measuring systems (e.g. methods-time measurement) provide basic times of manual elementary motions (e.g. reach, grasp, move).

Note 2 to entry: Basic time does not include any allowance.

3.10**standard time**

time required by an average skilled operator, working at a normal pace, to perform a specified task using a prescribed method

Note 1 to entry: The difference between standard time and basic time is that basic time is the time when work should be done without any delays. Standard time is the time taken by the worker to complete the work with some unavoidable and therefore planned delays (time allowances).

Note 2 to entry: Standard time includes time allowances.

3.11**methods-time measurement****MTM**

procedure which analyses any manual operation or method into the basic motions required to perform it and assigns to each motion a basic predetermined time, which is determined by the influencing factors under which it is made

Note 1 to entry: Examples include reach or move distance, type of grasp, object weight.

3.12**cycle time**

time available at each workstation to accomplish the tasks assigned for each unit of output

Note 1 to entry: Cycle time corresponds to the pace at which an assembly line delivers its output.

Note 2 to entry: In the case of a single workstation, cycle time and standard time coincide, since there is no idle time caused by the imperfect synchronization of a sequence of workstations (balancing losses).

Note 3 to entry: Cycle time is expressed as the sum of standard time and idle time.

3.13**task assignment****line balancing**

manufacturing-engineering technique, in which the production line operations are divided into tasks, which are assigned to the minimum number of workstations

Note 1 to entry: A production line is said to be in balance when every worker's task takes approximately the same amount of standard time. Well-balanced lines minimize labour idleness and improve productivity.

3.14
work organization

way that tasks are distributed among the individuals in an organization and the ways in which these are then coordinated to achieve the final product or service

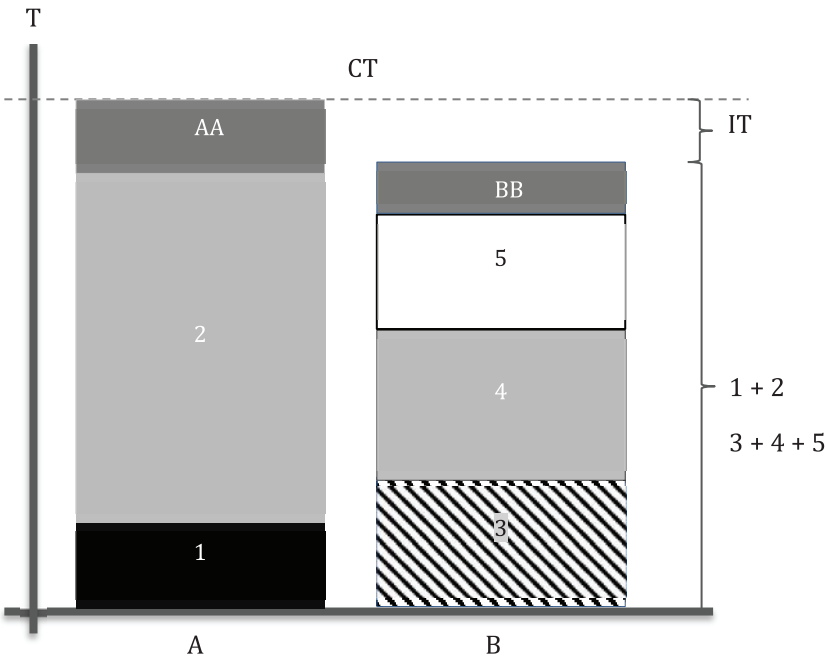
Note 1 to entry: Work organization typically encompasses the total shift duration, the quantity and distribution of the breaks, the type of man-machine interface and the level of allowed flexibility.

3.15
worker saturation

percentage of non-idle time within a cycle time

Note 1 to entry: Worker saturation is expressed as the fraction of standard time and cycle time.

Note 2 to entry: See [Figure 1](#).



Key

CT	cycle time
T	time
A, B	workstation A, B
1,2,3,4,5	operation 1,2,3,4,5 (basic time)
AA, BB	allowance A, B
IT	idle time (unsaturation)
1 + 2	task assigned to work station A (standard time)
3 + 4 + 5	task assigned to work station B (standard time)

Figure 1 — Industrial engineering terminology

3.16
biomechanical load

physical stress acting on the body or on anatomical structures within the body

Note 1 to entry: Loads originate from the external environment (e.g. the force generated by a power hand tool) or are the possible result of voluntary or involuntary actions of the individual (e.g. lifting objects).

EXAMPLE Kinetic (motion), kinematic (force), oscillatory (vibration) stress and thermal (temperature) energy sources.

3.17**transition time**

duration of the movements for changing from one body posture to another

3.18**overall load index****OLI**

index compounding the overall biomechanical load generated by the different types of physical stress

4 Proposed approach**4.1 The correct work content**

The determination of the correct work content for 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 is based on the following steps (see [Figure 2](#); T_c is the cycle time and T_{std} is used to indicate the standard time):

- design of a standard working method;
- work measurement;
- task assignment and work organization;
- biomechanical load measurement;
- ergonomic work allowance calculation (applying the model).

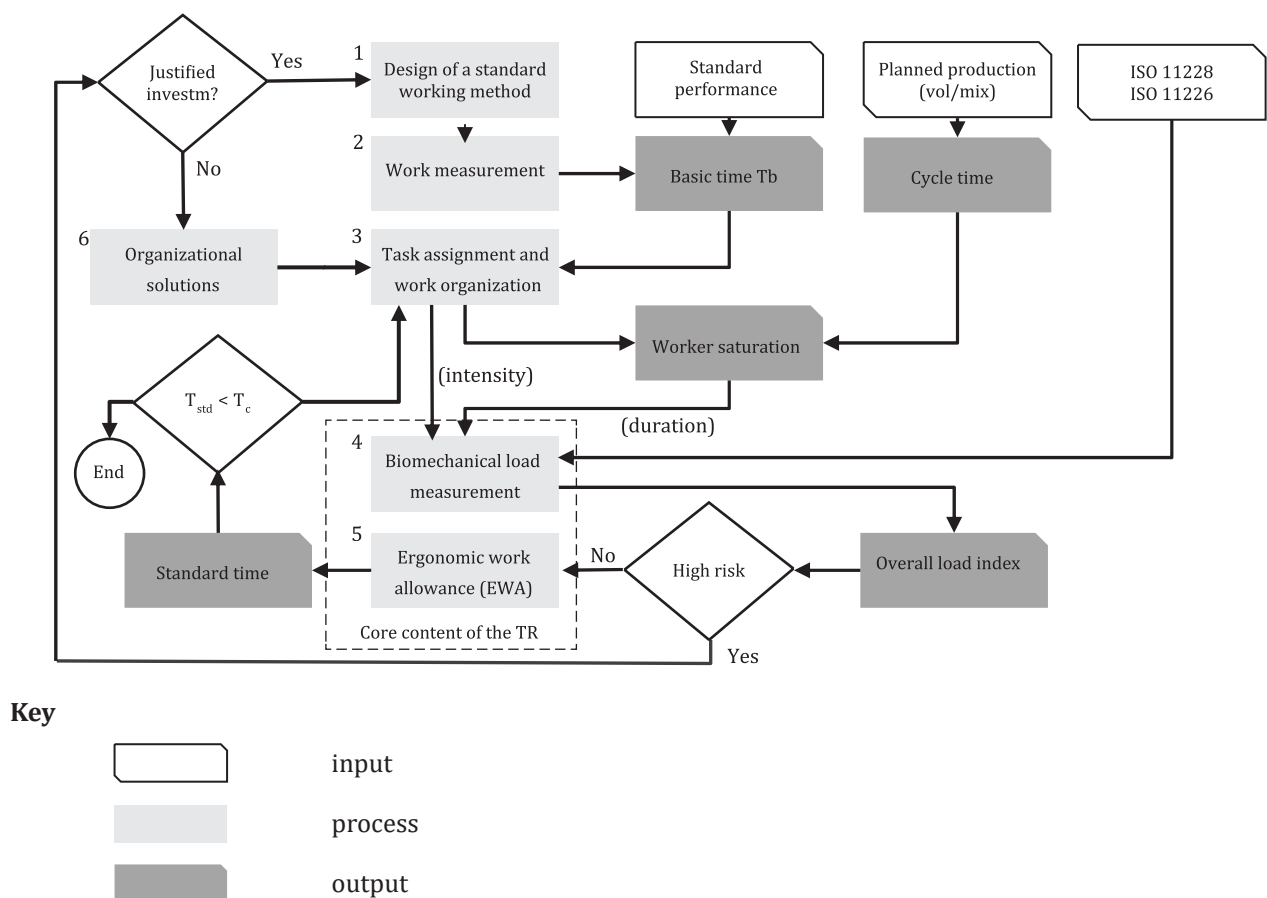


Figure 2 — Standard time setting process

4.2 Design of a standard working method

The design of a standard working method is the key driver to achieve operational excellence in levels of productivity and safety. This task is one of the main responsibilities for 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. 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 (see [Figure 3](#)).

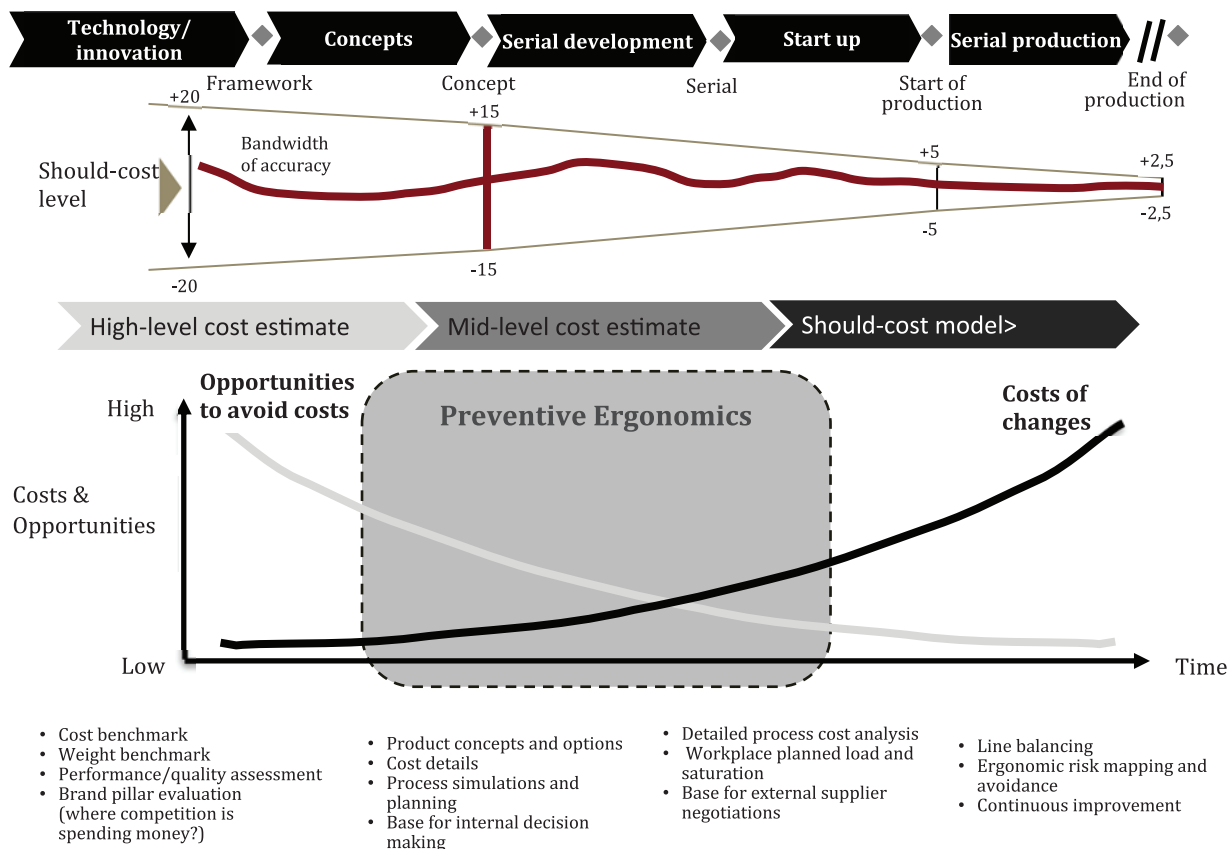


Figure 3 — Preventive ergonomics in the new product development process

To achieve such a sophisticated level of product or process development and planning process, the most advanced industrial companies use a predetermined motion-time system (PMTS). A PMTS is a set of data of elementary human motions, of which a basic time is predetermined, which is used as a reliable language to design, plan and measure a manual task.

The last developments among available PMTSs aim 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 such change is still affordable (metal has not yet been cut). Indeed, in the early phases of product or process development, investments in tools and equipment have usually 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 PMTSs. As far as ergonomics is

concerned, if there is a tool to pre-calculate the biomechanical load based on a planned working method, it becomes economical and effective to preventively reduce the risk due to an excessive workload.

4.3 Work measurement

4.3.1 General

The definition of the basic time (T_b , Step 2 in [Figure 2](#)) is built on the concept of standard work performance^[23], strictly related to the fair day's work. As mentioned previously, the standard work performance represents an effort level that could be easily maintained year in, year out by a worker with average physical capabilities without in any way asking him or her to draw upon his or her reserves of energy. Working at standard performance allows the worker to get to the end of the fair day's work without an excess of physical stress.

Most accurate work measurement techniques (stopwatch 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 (see [Figure 4](#)).

Stop-watch procedure	EXAMPLE
Stop watched time T_{sw}	Stop watched time $T_{sw} = 100$
Rated Performance $\bar{P}$	Rated Performance $P = 90 \%$
Standard performance P	Standard performance $\bar{P} = 100 \%$
Basic time $T_b = T_{sw} \times (P/\bar{P})$	Basic time $T_b = 100 \times (90/100) = 90$

Figure 4 — Stopwatch procedure to set a basic time

Some measurement techniques, such as the PMTS, are not based on the observer to rate the worker's performance. PMTS developers use performance rating in the derivation of the original data to calculate the basic times of each single elementary motion. Therefore, PMTSs, 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 PMTSs are strongly recommended for designing and planning a new work system, making a preventive approach to ergonomics possible.

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

4.3.2 Standard work performance

Due to increasing globalization, many organizations are currently using several different work measurement techniques in different geographies of the organization. This happens because different techniques have gained a greater degree of usage in specific 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 to 25 years (while the most common definitions of standard work performance date back to the 1940s).

Each of the rating systems or 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 by 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 combinations of speed, effort, skill, dexterity, consistency and conditions.

One of the common problems of rating is that it is often linked to remuneration, through setting '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 is in use in different organizations, there is no guarantee that the concepts of normal and incentive performance are the same in each one of them – this is especially true if the organizations carry out no rating validation through rating clinics.

In some countries or organizations, trade unions have a 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 ratings 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 to validate 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 for each elementary motion and consequently an expected increase in 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 the industrial engineers. Nowadays, the correlation between biomechanical load and the probability of incurring a work-related musculoskeletal disorder is proved and relevant ISO and CEN documents set clear references.

One objective of this document 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 of 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. Several tests have been run by the technical committee of the International MTM Directorate, using the MTM scale as a reference, and the results are summarized in Annex A.4.

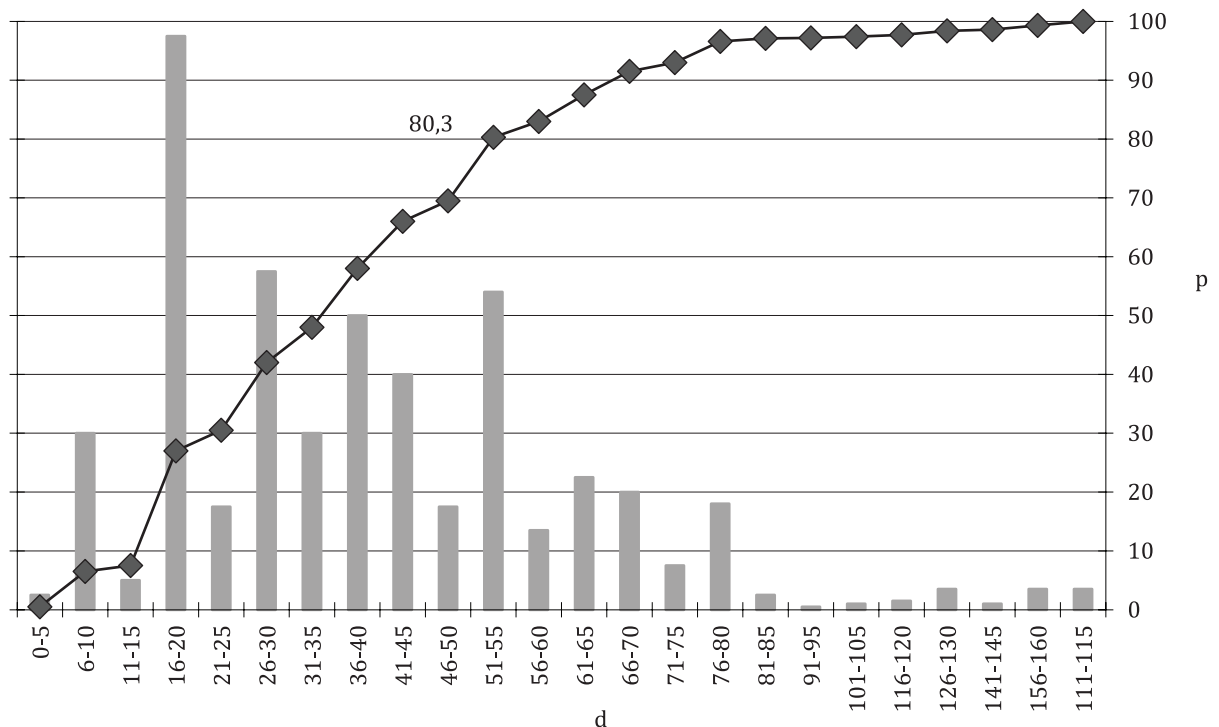
4.3.3 Real action

A real action (RA) is a combined movement of the upper limb (fingers, hand, wrist, elbow or 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^[24].

ISO 11228-3 sets the maximum number of actions at 70 technical actions per minute, equivalent to 40 real actions per minute^[19]. Considering the durations shown in [Figure 5](#), the average duration of one action is in the range of 31–35 TMU (time measurement units) (100 000 TMU = 1 hour), equivalent to 1,2 s and generating a frequency of 50 real actions per minute (equivalent to c. 87 technical actions/min).

In a real workplace, consider that there is usually 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, there is a good chance that, adopting

the MTM standard work performance, the resulting frequencies of action will not cause an excessive biomechanical load. Of course, to obtain a complete load evaluation, further influencing factors have to be considered (e.g. force levels, weights, postures).



Key

d duration range of real actions (TMU)

p percentile

NOTE 1 Histogram bars represent the frequency.

NOTE 2 Points in the line represent the percentile.

Figure 5 — Distribution of real actions duration

4.4 Task assignment and work organization

Task assignment in the manufacturing industry is very important, especially when dealing with assembly lines (line balancing, see [Figure 6](#)). 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 net working 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 the operators are to work at a controlled performance and to produce the planned output. T_c is like the capacity of a glass, the water poured into it is the set of tasks assigned to a workstation and T_{std} (standard time) is the quantity of litres of water poured into the glass. Without an accurate work measurement, it would not be possible to balance the line evenly and production would not flow smoothly along the line. Consequently, there would be 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).

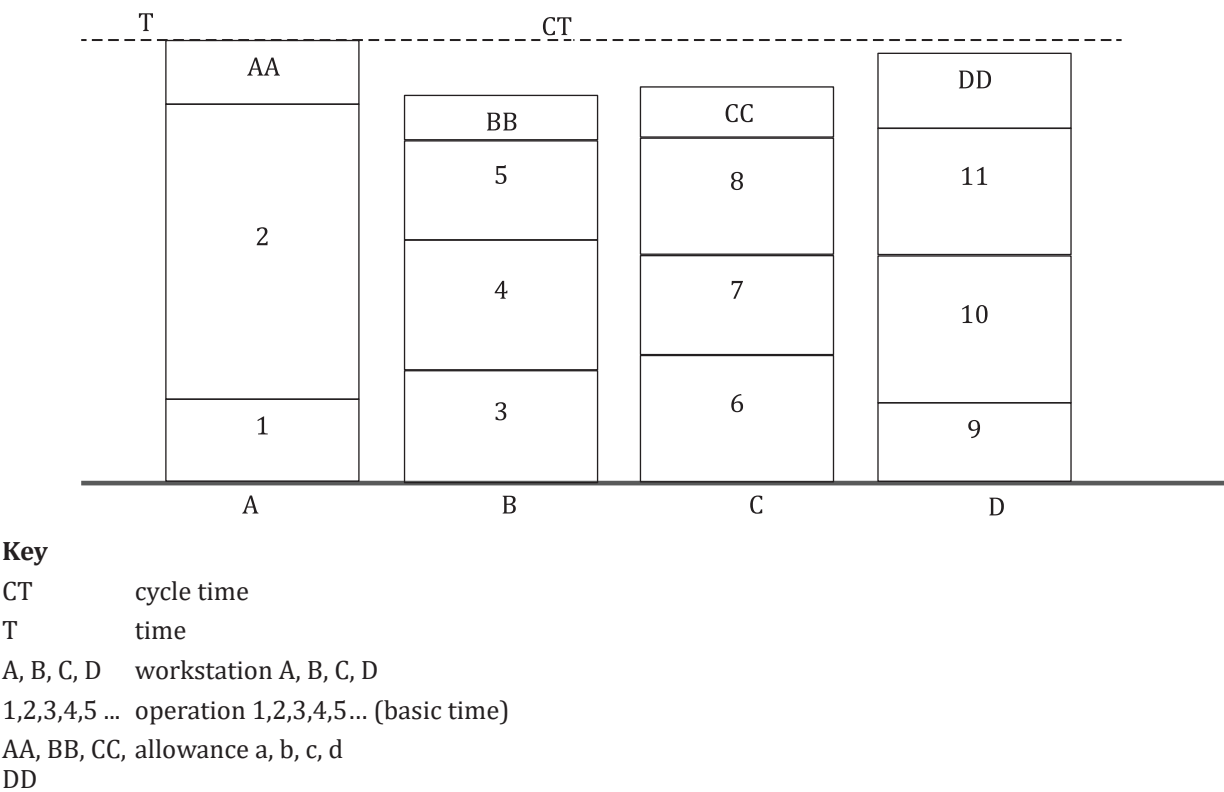


Figure 6 — Line balancing

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

4.5 Biomechanical load measurement

Load results from the intensity and the duration of the work and from the working conditions in which it is carried out. A load describes the objective demand of work, which is to be fulfilled in a period of time. 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). To apply the EWA model, it is necessary to compound all type of loads (postures, forces, manual material handling of loads, vibrations and repetitive upper limb motions) on a unique scale. In [Figure 7](#) a comprehensive approach is represented. [Clause 6](#) provides a first available solution (EAWS), which meets all the rules of the application of the EWA model.

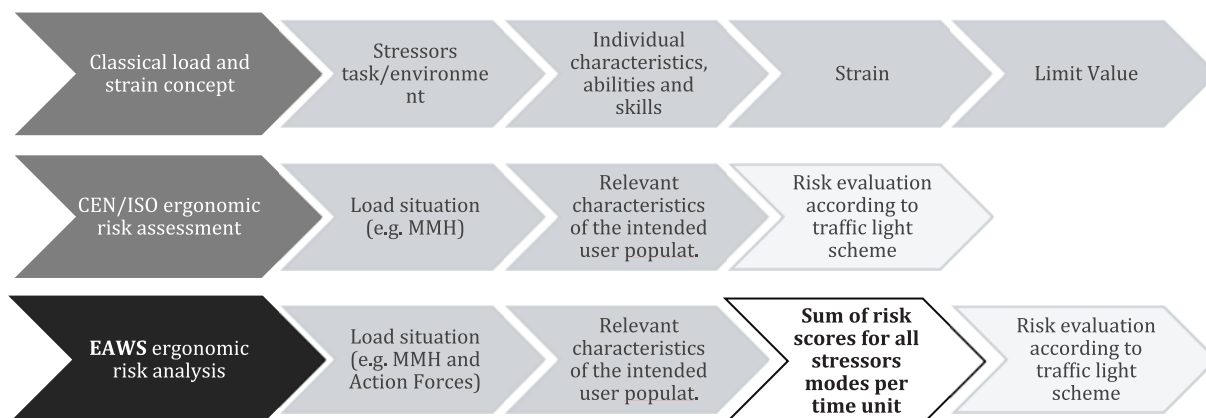


Figure 7 — Approach to an overall load index assessment

The required ergonomic measurement tool provides an overall load evaluation that includes all biomechanical risks to which an operator can be exposed during a cyclical work task. All loads are measured and compounded on a unique scale and the resulting load 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 following 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 11226 and ISO 11228 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 (e.g. 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.

4.6 Ergonomic work allowance (EWA)

4.6.1 General

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 in the basic time for each cycle, the “non-productive” time becomes planned and a worker can still be able to complete the work assigned to him or her.

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

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

This document deals only with (1) physical factors and partially with (2) mental and cognitive factors for workers assigned to cyclical manual tasks in an industrial manufacturing environment. Specifically, EWA means the allowance coping with physical factors. A few mental and cognitive factors of manual repetitive tasks are only evaluated in the most advanced work measurement techniques in the definition of 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 document (fatigue related to psychosocial issues, which the worker faces and deals with either in the workplace or otherwise).

The EWA model does not include any coverage of interruptions not related to the 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 two breaks of about 10 minutes each, distributed within a typical shift of 8 hours).

Since the definition of basic time T_b assumes there is no physical stress in the accomplishment of a 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 physical effort (biomechanical load) within the standard limits referenced by the work performance, thus reducing the likelihood of incurring work-related musculoskeletal disorders. In other words, the EWA allows more time to execute a task (diluting the basic time), thus reducing the demand for the worker's performance.

The basic time T_b is determined based on the standard work performance. In this subclause the MTM standard performance has been selected as the reference, since, if there are no other risk factors present in the work task (e.g. awkward postures and forces), it leads to having an action frequency which is likely to conform with ISO 11228-3. However, what if those additional risk factors are present?

4.6.2 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. This type of model is named "single-motion work allowance". In the eventuality that a detailed motion-time study is not available, the ergonomic work allowance is often applied as a constant percentage on all workstations, regardless of the type of task carried out (usually the percentage is based on old company agreements). In worst-case scenarios (unfortunately quite common in the real life), no ergonomic allowance is applied.

[Table 2](#) gives some examples of the rest allowance table adopted by the Fiat group from the 1960s until their global adoption of the EWA model in 2008.

Table 2 — FCA old rest allowance model

Basic body Postures		Trunk and upper limbs posture	Force exertion or weight			
			L	M	P	PP
			0 kg to 2 kg	2 kg to 10 kg	10 kg to 20 kg	20 kg to 25 kg
Allowance in %						
1		A Trunk and upper limbs in normal posture Stationary trunk	5	6 to 7	–	–
Sitting		B Trunk and upper limbs in awkward posture; Stationary trunk	7	8 to 10	–	–
NOTE	Percentages in this table do not include any allowance for physiological needs (4 %).					

Table 2 (continued)

Basic body Postures		Trunk and upper limbs posture	Force exertion or weight			
			L	M	P	PP
			0 kg to 2 kg	2 kg to 10 kg	10 kg to 20 kg	20 kg to 25 kg
			Allowance in %			
2		A Trunk and upper limbs in normal posture; stationary trunk	7	8 to 9	10 to 12	13 to 17
Standing		B Trunk and upper limbs in normal posture; moving trunk	9	10 to 12	13 to 15	16 to 20
		C Trunk and upper limbs in awkward posture; Stationary trunk	11	12 to 14	15 to 18	19 to 23
		D Trunk and upper limbs in awkward posture; moving trunk	13	14 to 16	17 to 20	21 to 25
3		A Trunk and upper limbs in normal posture; stationary trunk	8	9 to 10	11 to 13	-
Kneeling		B Trunk and upper limbs in awkward posture Stationary trunk	12	13 to 15	16 to 19	-
4		A Trunk and upper limbs in normal posture; stationary trunk	10	11 to 13	-	-
Laying		B Trunk and upper limbs in awkward posture Stationary trunk	14	15 to 18	-	-
5		A Flat surface, with or without load	10	11 to 14	15 to 19	20 to 24
Walking		B Sloped surface, with or without load	13	14 to 17	18 to 22	23 to 27
		C Pushing/pulling trolleys or carts on a flat surface	11	12 to 15	16 to 20	21 to 25
NOTE Percentages in this table do not include any allowance for physiological needs (4 %).						

NOTE Percentages in this table do not include any allowance for physiological needs (4 %).

The weaknesses of the traditional model are as follows:

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

4.6.3 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 Fiat 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 worksheet (EAWS).

The results of that study were as follows:

- 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).

Looking at [Figure 8](#), 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.

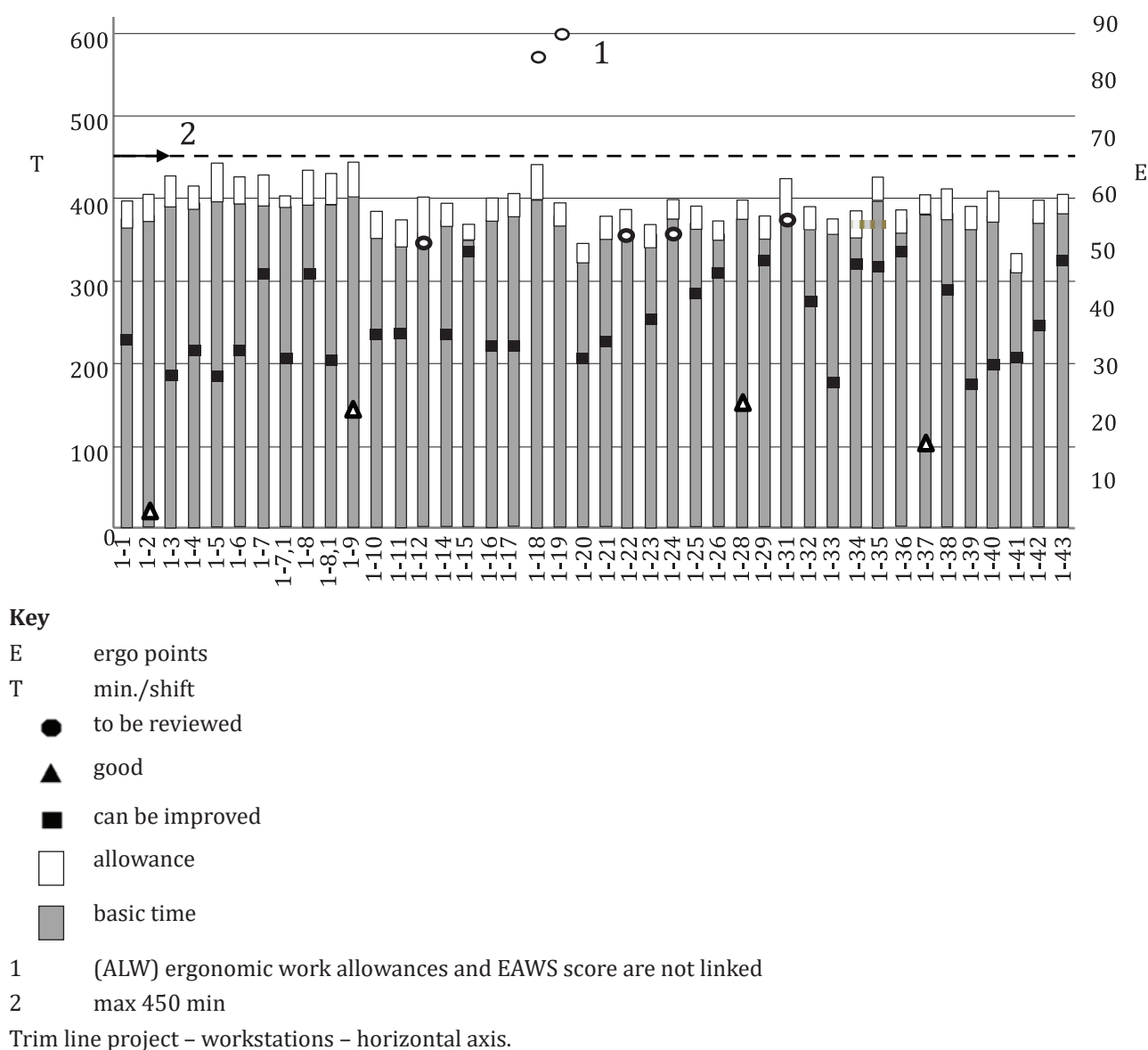


Figure 8 — Mirafiori project, step 1

— Step 2

Same line balancing but calculating the ergonomic allowances using the EWA model.

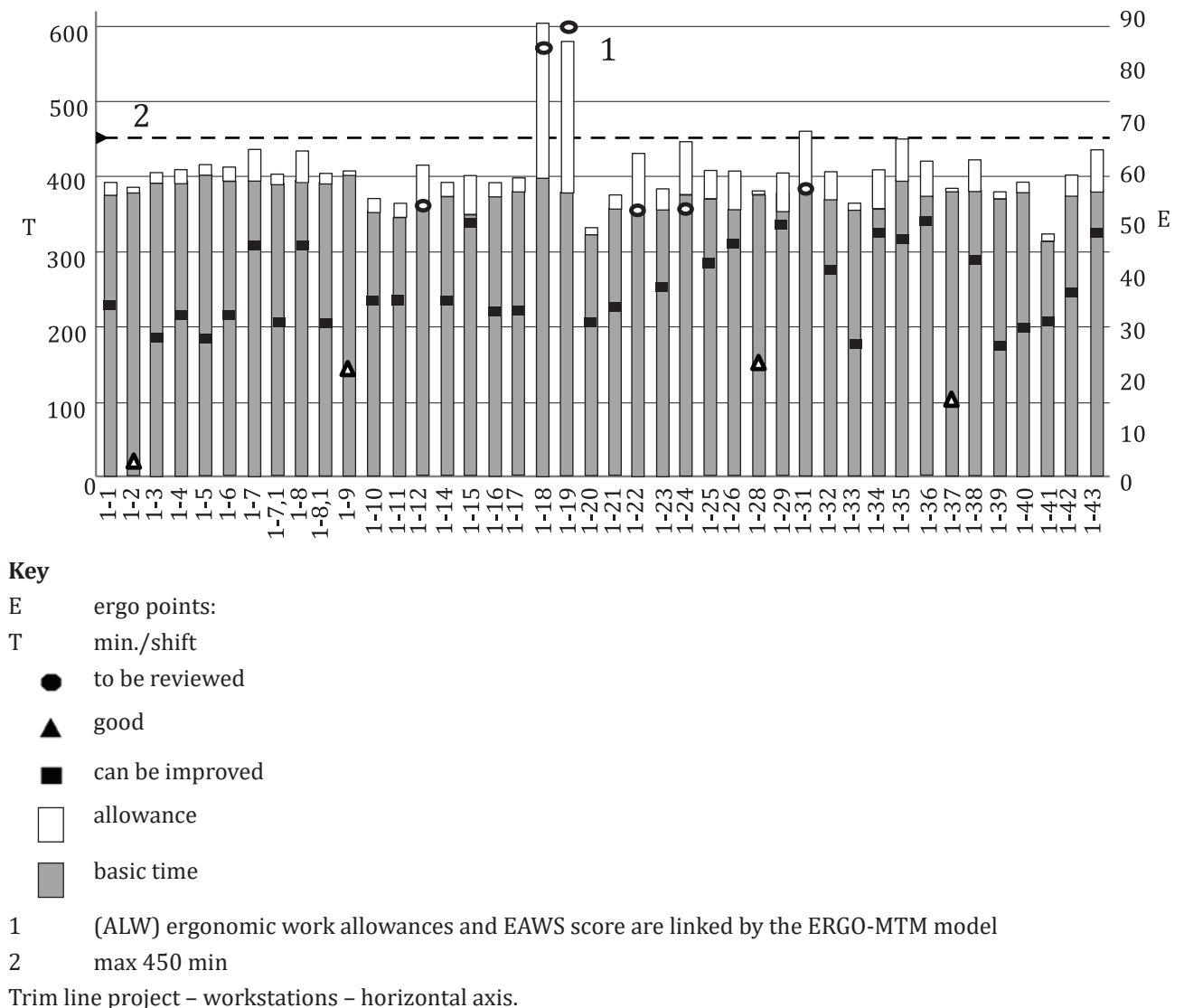


Figure 9 — Mirafiori project, step 2

The ergonomic work allowance model was designed with the main objective of calculating an allowance as a function of a fatigue index. The stronger the demanded fatigue, the higher the allowance (see [Figure 9](#)).

— Step 3

New line balancing (see [Figure 10](#)) and calculating the ergonomic factor using the EWA model (see [Figure 11](#)).

In the new line balancing configuration, task distribution among workstations was driven by the quantity of standard work (basic time) and the level of fatigue (allowance) generated by the same tasks assigned to each workstation. The key indicator to get a well-balanced assembly line is the standard time (basic time + allowance), which in [Figure 10](#) is represented by the height of the bars, limited by the total net available minutes per shift (450 min in this case). This procedure leads industrial engineers to level not just the basic time, but also to avoid peaks of fatigue on one workstation and no physical stress on another.

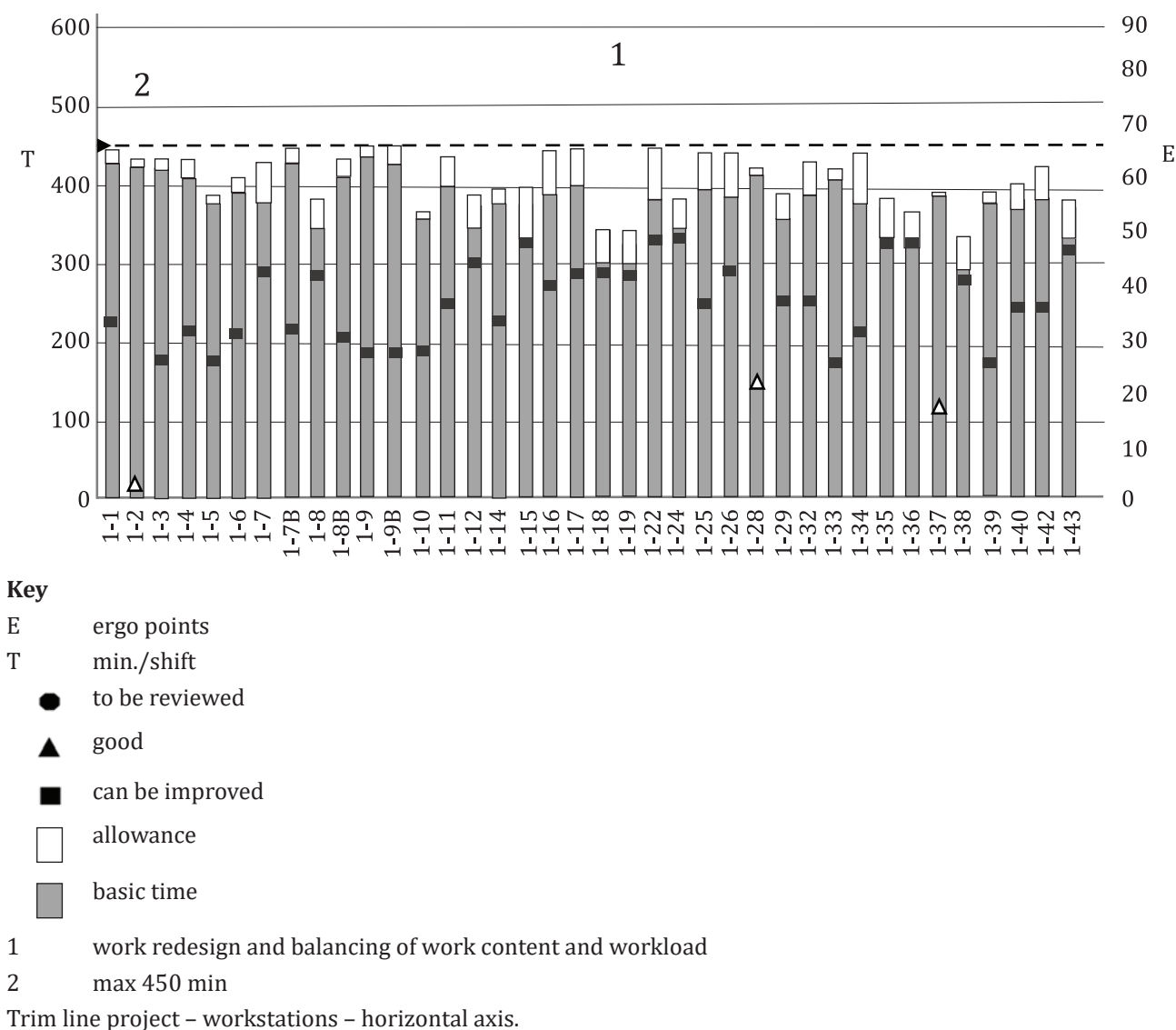


Figure 10 — Mirafiori project, step 3

The fatigue index considers the various sources of physical stress and condensates the evaluations in a unique index.

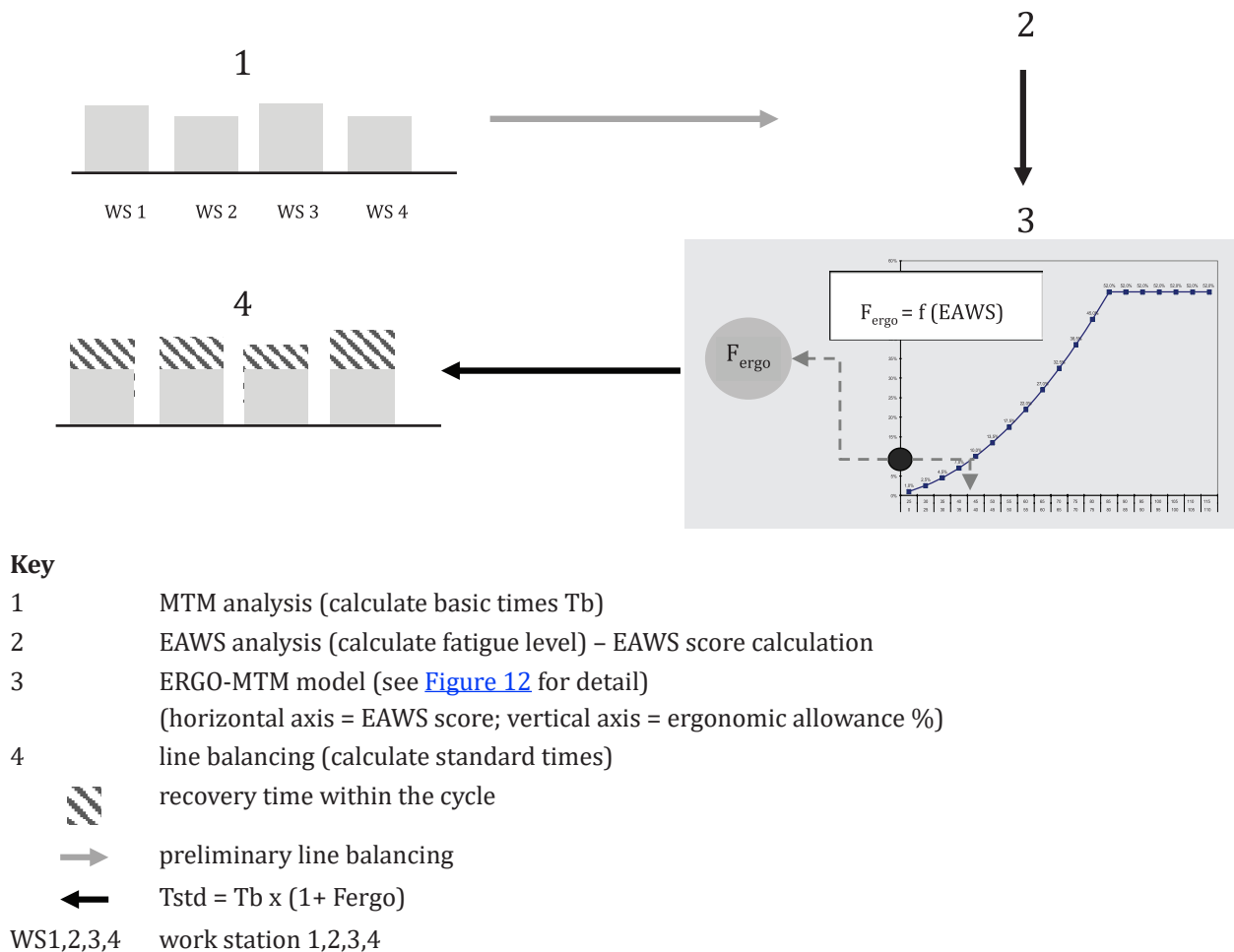


Figure 11 — Ergonomic work allowance model

The main innovation, with respect to other existing allowance systems, is the introduction of the concept of duration. Indeed, traditional methods base the determination of the allowance as a function of the main body posture and the force/load level (intensity), regardless of 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 18 kg the ILO recommended allowance gives a value of 9 %^[14], regardless of the number of repetitions of the action during the shift.

The proposed EWA model proposes 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:

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

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

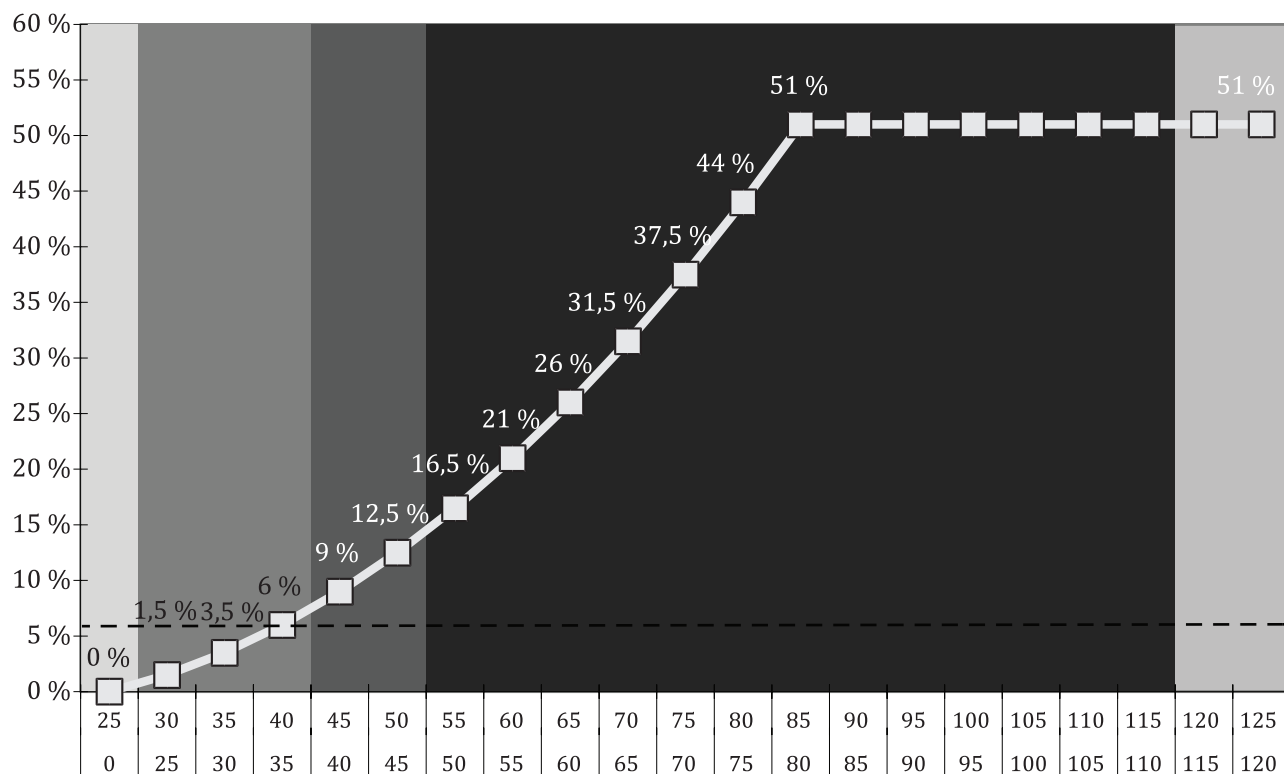
To reach a significant level of workload, it is necessary to have at least a medium intensity with a medium duration. If either one of the two factors is negligible, the resulting workload will be low, even if the other factor is high (in such cases there would be a risk of injury arising from a single identifiable event, which can 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 is built upon the fundamental principle of allowing a sufficient recovery time to keep the physical load within controlled limits (see [Figure 12](#)).



Key

EWA	ergonomic work allowance (vertical axis)
OLI	overall load index (horizontal axis)
$0 < \text{OLI} \leq 25$	low physical stress
$25 < \text{OLI} \leq 40$	medium low physical stress
$40 < \text{OLI} \leq 50$	medium high physical stress
$\text{OLI} > 50$	high physical stress

Figure 12 — Ergonomic recovery model

4.6.4 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 load variations, particularly within the medium risk zone ($25 < \text{overall load score} < 50$), 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 from 2005 to 2006. In that study, the EAWS system was adopted

by Fiat 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).
- In the middle of the medium load level (medium stress zone in [Figure 12](#)), corresponding to a 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 12](#) shows the proposed model, where the traffic light colours 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 users to continuous improvements on the ergonomic conditions to increase productivity and reduce labour costs.

In Clause 6 a summary of the study about the definition of the EWA function is reported.

4.7 Organizational solutions

4.7.1 General

The 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. The EWA model does not end with the definition of allowance. [Figure 2](#) shows that if the overall load index (output of step 4 – biomechanical load measurement) enters into the high-risk zone (with EAWS this would mean having more than 50 points), the EWA process would require a review of the work system under evaluation. This is a fundamental concept: EWA wants to support the (re)design of a safe work system. It would not even be 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 %. In cases where the overall load index is much over the threshold value, the model would not be used to find the allowance value sufficient to exit the red area, but improving the working method and conditions and run again the load calculation would be recommended until the value drops under the threshold or as close as possible to it (constrained optimization). At that point, the application of the EWA could solve the problem.

4.7.2 Strategies to reduce the overall load index

- a) Redesign of the work method in order to reduce the intensity score, for example 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 in the work process and gives precious indications as to where the work method will 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) that is used to justify a LCA improvement.
- b) If no method improvements are possible or justifiable in the short term, then organizational solutions need to be found which do not eradicate the ergonomic issue but offer a way to manage the situation. The most common organizational options are:
 - Review step 3, i.e. the task assignment (line rebalancing); when doing this, attention has to be concentrated on the operations which cause the highest load values and finding 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 take into

consideration the production sequence when moving an operation to a different workstation. It could be necessary to repeat this procedure in a loop more than once before finding a balanced scenario.

- 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 two or more workstations in order to obtain an acceptable weighted average overall load index for each concerned worker.
- 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 best strategy to consider to reduce risk:

- The economic impact of the identified solution: in general, the addition of a recovery time could increase the production cost, but the implementation is longer. On the contrary, the redesign of the workstation means maintaining a constant (or even increasing) production output, probably involving significant investments. Ideal solutions usually lie in between these two options: low cost automation helps 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, considering that the intensity and duration score curves have different behaviours in the different sections (body postures, force exertion, handling of loads and repetitive motions of the upper limbs).

5 Ergonomic assessment worksheet (EAWS)

5.1 System overview

EAWS is a risk assessment method for biomechanical load of the whole body and upper limbs used mainly in manufacturing industries as a process design tool for preventive ergonomics and adopted in the production department to map biomechanical stress (630,000 workers estimated to be mapped with EAWS worldwide).

EAWS is an open system, freely available, part of the International MTM Technical Platform, managed by the Fondazione Ergo (www.fondazionergo.it), a non-profit organization dedicated to the development of the body of knowledge regarding the scientific management of work (all official systems in the international MTM technical platform are available in the main languages, including Chinese).

EAWS offers compliance with the relevant CEN or ISO documents and it is structured in four sections, each one covering a specific risk area: body postures, action forces, manual materials handling and upper limbs in repetitive tasks.

The EAWS scoring procedure is presented in detail in [Annex A](#) and the EAWS manual is available in the main languages.

The EAWS form is freely downloadable in 10 languages from: <https://www.eaws.it/>

5.2 EAWS basic structure

5.2.1 General

EAWS is an ergonomic tool for a detailed biomechanical overload risk assessment, developed to provide an overall risk evaluation that includes every biomechanical risk to which an operator may be exposed during a working task.

In order to effectively address ergonomic issues in the workplace, develop an appreciation for the trade-offs associated with ergonomics. When one considers biomechanical rationale, one finds that it is very difficult to accommodate all parts of the body in an ideal biomechanical environment. It is often the

case that, in attempting to accommodate one portion of the body, the biomechanical situation at another body site is compromised. Therefore, the key to the proper employment of occupational biomechanical principles is to be able to consider the appropriate biomechanical trade-offs with various parts of the body associated with different workplace design options.

The above brief introduction to biomechanics is reported just to give the idea of the level of complexity there is when aiming to measure a biomechanical load index. For this reason, in the field of occupational biomechanics, researchers adopt models which do not have the same level of accuracy as other scientific measuring systems (e.g. methods-time measurement to measure the human work). It is known that all existing systems are an attempt to model the effects of forces and motions on the muscular-skeletal system and none of them currently reflects the actual situation. Proper use of these models and methods involves recognizing the limitations and assumptions of each technique so that they are not applied inappropriately. When properly used, these assessments help assess the risk of work-related injury and illness.

Nonetheless, EAWS design was done based on existing and available research with the aim of finding the most appropriate and reasonable correlation against the CEN and ISO documents dealing with biomechanical load.

The EAWS structure is as follows (see [Figure 13](#)):

a) Macro-Section “Whole body”.

Section 0: Extra points.

Section 1: Postures (ISO 11226 and EN 1005-4).

Section 2: Action forces (ISO 11228-2 and EN 1005-3).

Section 3: Manual material handling (see ISO 11228-1, ISO 11228-2 and EN 1005-2).

b) Macro-Section “Upper limbs”.

Section 4: Upper limb load in repetitive tasks (see ISO 11228-3 and EN 1005-5).

1

2

3

4

Key

- 1 page 1 - overall index and extra points
- 2 page 2 - body postures
- 3 page 3 - action forces and MMH
- 4 page 4 - upper limbs repetitive movements

NOTE See [Figure A.60](#), [Figure A.61](#), [Figure A.62](#) and [Figure A.63](#) for detail.

Figure 13 — EAWS form overview

The EAWS system calculates a load index (R), given by the product of the intensity (I) by the duration (D):

$$R = I \times D$$

where:

- R is the risk;
- I is the intensity;
- D is the duration.

In Section 1, the user selects the relevant posture in the proper row (intensity) and measures the duration (column). Intersecting the column of duration with the row of intensity, the user easily finds the score.

In Sections 2, 3 and 4, the user calculates the intensity and the duration scores of the concerned task, following specific rules, and eventually multiplies the intensity score by the duration score to find the load index.

The EAWS sheet provides one score for each macro-section. The overall load index of each macro-section is then connected to a traffic light scheme (green, yellow, red) according to the Machinery Directive 2006/42/EC (EN 614) as in [Table 3](#):

Table 3 — EAWS traffic light output

0–25 points	Green		Low risk	Recommended; no action is needed
> 25–50 points	Yellow		Possible risk	Not recommended; redesign if possible, otherwise take other measures to control the risk
> 50 points	Red		High risk	To be avoided; action to lower the risk is necessary

Whole body and upper limbs scores are evaluated on the same scale. It is therefore important to understand which is the most critical macro-section.

5.2.2 Section 0: extra points

Extra points are related to additional extraordinary loads and not considered in the other total body sections. They are therefore covered in this subclause. The standard influencing factors in Section 0 (see [Table 4](#) and [Figure A.60](#)) are:

- working on moving objects;
- difficult accessibility to the working area;
- counter shocks, impulses, vibrations;
- joint position (especially wrist and neck);
- other “special” situations, like above head control work, including looking upward (neck load).

Table 4 — Extra points whole body

Extra points “Whole body” (per minute / shift)									
0a	Adverse effects by working on moving objects	0		3		8		15	
		none		middle		strong		very strong	
0b	Accessibility (e.g. entering motor or passenger compartment)	0		2		5		10	
		good		complicated		poor		very poor	
0c	Countershocks, impulses, vibrations	0		1		2		5	
		light		visible		heavy		very heavy	
		0	1	2,5	4	6	8		
		[n]	1 - 2	4 - 5	8 - 10	18 - 20	> 20		
0d	Joint position (especially wrist)	0		1		3		5	
		neutral		~ 1/3 max		~ 2/3 max		maximal	
		0	2	2,5	4	6	8		
		[s]	3	10	20	40	60		
		[n]	1	8	11	16	20		
[%]	5	17	33	67	100				
0e	Other physical work load (please describe in detail)	0		5		10		15	
		none		middle		strong		very strong	

5.2.3 Section 1: body postures

On the left side of the page ([Figure A.61](#)), load points for symmetric body postures ([Figure 14](#)) are be assigned. If there are any asymmetric static posture ([Figure 15](#)) due to trunk rotation, lateral trunk bending or arm extension (far reach), use the right side of the page.

Standing (and walking)													
1		Standing & walking in alternation, standing with support	0	0	0	0	0.5	1	1	1	1.5	2	3
2		Standing, no body support (for other restrictions see Extra Points)	0.7	1	1.5	2	3	4	6	8	11	13	15
3	a	Bent forward (20-60°)	2	3	5	7	9.5	12	18	23	32	40	50
	b	with suitable support	1.3	2	3.5	5	6.5	8	12	15	20	25	30
4	a	Strongly bent forward (>60°)	3.3	5	8.5	12	17	21	30	38	51	63	75
	b	with suitable support	2	3	5	7	9.5	12	18	23	31	39	48
5		Upright with elbow at / above shoulder level	3.3	5	8.5	12	17	21	30	38	51	63	75
6	/	Upright with hands above head level	5.3	8	14	19	26	33	47	60	80	100	125
Sitting													
7		Upright with back support slightly bent forward or backward	0	0	0	0	0	0.5	1	1.5	2	3	4
8		Upright no back support (for other restriction see Extra Points)	0	0	0.5	1	1.5	2	3	4	5.5	7	8
9		Bent forward	0.7	1	1.5	2	3	4	6	8	11	13	15
10		Elbow at / above shoulder level	2.7	4	7	10	13	16	23	30	40	50	60
11		Hands above head level	4	6	10	14	20	25	35	45	60	75	90
Kneeling or crouching													
12		Upright	3.3	5	7	9	12	15	21	27	36	45	55
13		Bent forward	4	6	10	14	20	25	35	45	60	75	90
14		Elbow at / above shoulder level	6	9	16	23	33	43	62	80	108	138	168
Lying or climbing													
15		(Lying on back, breast or side) arms above head	6	9	15	21	29	37	53	68	91	11	14
16		Climbing	6.7	10	22	33	50	66					

Key

basic positions:

- 1 standing
- 2 sitting
- 3 kneeling or crouching
- 4 lying or climbing

Figure 14 — EAWS symmetric body postures

On this page, static postures (which are defined in EAWS as postures maintained for at least four consecutive seconds) and high-frequency movements are evaluated, including loads weighing less than 3 kg, action forces onto fingers less than 30 N, and whole-body forces less than 40 N.

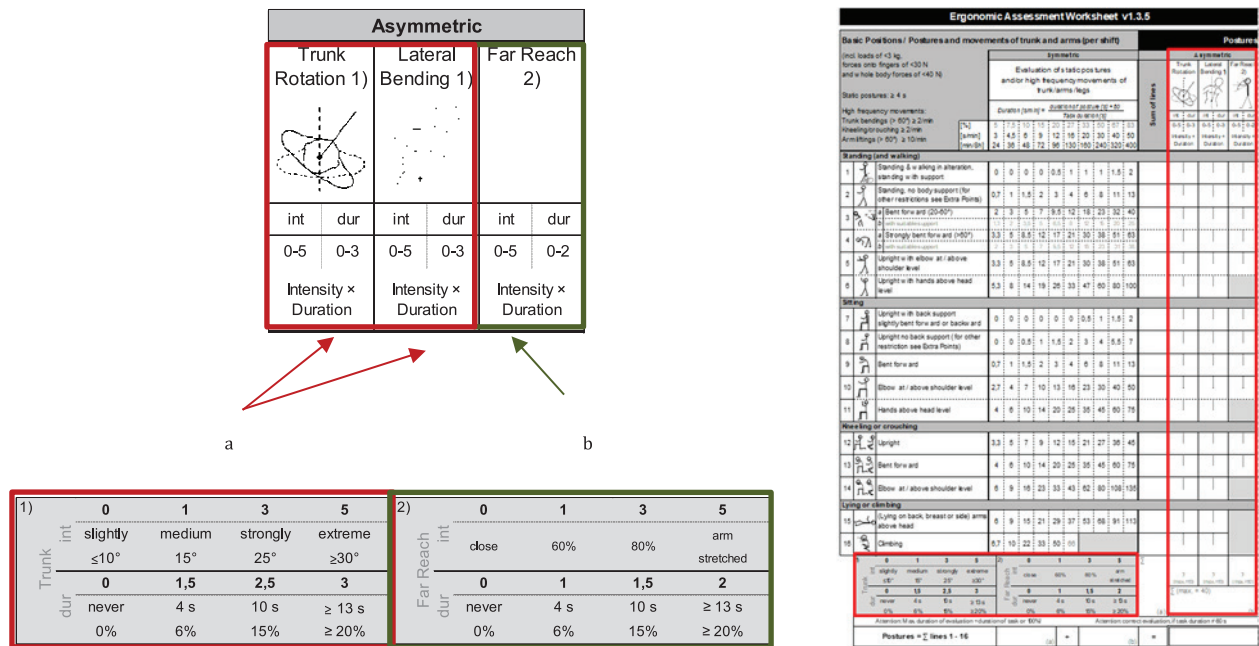
In the EAWS form, Section 2, the columns indicate the duration (in % of the cycle, s/min or % of shift) of a specific posture. The rows show a graphic visualization of different posture types (intensity).

The asymmetric body postures:

- trunk rotation (use duration table a);
- lateral trunk bending (use duration table a);
- arm extension (far reach) (use duration table b);

are evaluated on the right side of the page. At the bottom of the left side (see [Figure 15](#)) of the page, there is a table to assign the “intensity” and the “duration” points:

- trunk rotation and lateral bending table (use duration table a);
- far reach table (use duration table b).



Key

- a Trunk - duration table.
- b Far reach - duration table.

Figure 15 — EAWS asymmetric body postures

5.2.4 Section 2: action forces

In Section 2, action forces are evaluated:

- Row 17: Forces onto/with fingers if greater than or equal to 30 N;
- Row 18: Action forces onto arms and whole-body forces if greater than or equal to 40 N (excluding manual material handling evaluated in Section 3).

In the lower part of this section (see [Figure 16](#)) data are abstracted from the “Force Atlas”[27] and represented in figures and values. These values are the result of detailed German academic research about force limits at different anthropometric percentiles for each body and hand postures. In the Force Atlas, the statistical distribution of the maximum forces, depending on the postures of hand, arms and body, is established for significant percentiles. The force values assigned in section 2 of EAWS are the ones for the 15th and 40th percentile neutral gender (in the standard EAWS form neutral gender is set equal to feminine gender). 15th percentile data are used for planning, 40th percentile data for direct observational analyses.

Action forces (per minute)										Forces	
17		Forces onto fingers (e.g. clips, plugs)	Duration (s) Intensity (N)	0	7	15	25	50	Intensity × Duration		
				16.7% F _{max}	33.3% F _{max}	50.0% F _{max}	66.7% F _{max}	F _{max}			
				[s]	3	6	9	12			30
				[N]	5	10	15	20			33
				[n]	0	1.5	2	2.5			3
18		Forces onto arms / whole body forces	Duration (s) Intensity (N)	0	6	10	15	20	Intensity × Duration		
				16.7% F _{max}	33.3% F _{max}	50.0% F _{max}	66.7% F _{max}	F _{max}			
				[s]	3	6	9	12			30
				[N]	5	10	15	20			33
				[n]	0	1	2	3			4.5
				[n]	0	1	1.5	2			4
				[n]	0	1	1.5	2			4
				[n]	0	1	1.5	2			4
				[n]	0	1	1.5	2			4
				[n]	0	1	1.5	2			4
Forces F _{max} onto arms / whole body forces (neutral to gender)											
P15 for planning & P40 for observation											
Data based on the "Assembly specific force atlas" (Wakita, Berg, Schwab, Göttsch, Elengast 2009), adopted neutral to gender											
Score data are matter to change after the final completion of the force atlas project											
Action forces = $\sum$ lines 17 - 18											

Ergonomic Assessment Worksheet v1.3.5												Forces																																										
Action forces (per minute)												Intensity × Duration																																										
Forces onto fingers (e.g. clips, plugs)																																																						
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NOTE See [Figure A.62](#) for details

Figure 16 — EAWS Section 2, body forces

5.2.5 Section 3: manual material handling of loads

In section 3 (see [Figure 17](#)), efforts due to manual material handling (greater than or equal to 3 kg) are evaluated subdivided into repositioning, holding, carrying, pushing and pulling (short and long).

In the case of automotive assembly, enlarge these limits to 20 m or 15 s for easier application. This leads to:

- Repositioning (R): get and place a load within the workplace (approximately equivalent to a maximum displacement of 20 m);
- Holding (H): hold a load longer than 15 s, no carrying;
- Carrying (C): get, carry and place for a distance longer than 20 m;
- Pushing and pulling (P&P): transporting a load with a means of transport;

Short, if distance ≤ 20 m.

Long, if distance > 20 m.

Influencing factors:

- weights of loads;
- posture;
- working conditions;
- frequency/duration/distance per shift.

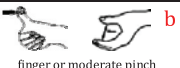
[illegible]

5.2.6 Section 4: repetitive motions of the upper limbs

- The type of grip in section 4 is evaluated for each real action jointly with the level of force and the frequency/duration of the action itself.
- The pinch-type grip without force does not generate additional load points compared to those assigned to the real action.
- In EAWS there is no step effect between different intervals of intensity or duration level of the influencing factors. The value curves are the result of continuous linear interpolations between known benchmark points.

- frequency of dynamic real actions/duration of real static actions;
- force or load level of each real action;
- type of grip of each real action.

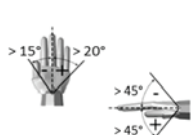
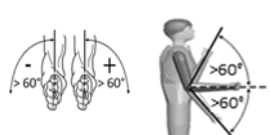
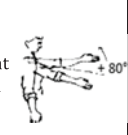
Table 5 — EAWS Section 4: force-frequency-grip score

Force & Frequency & Grip (FFG)					Basis: number of real actions per minute or percent static actions (analyze only the most loaded limb)																								
 power grip/contact grip		Legend	%SA = Percentage of Static Actions										%DA = 100% - %SA																
			FDS = Force-Duration Static										FFD = Force-Frequency Dynamic																
 finger or moderate pinch (thumb to >2 fingers, finger)			GS' = Modified Grip Points Static (Grip x %SA)										GD = Grip Points Dynamic																
			%FLS = Percentage of Static Actions at force level										%FLD = Percentage of Dynamic Actions at force level																
 strong pinch (thumb to 1 or 2 fingers)			SC = Static Contribution										DC = Dynamic Contribution																
			FDGS = Sum of Static Contributions										FFGD = Sum of Dynamic Contributions																
Force [N]		Calc Stat				Static actions (s/min)						Grip				Dynamic actions (real actions/min)										Calc Dyn			
		FDS	GS'	%	FLS	SC	≥45	30	20	10	5	3	0	2	4	2-5	10	15	20	25	30	35	≥40	FFD	GD	%FLD	DC		
0 – 5							1	1	0	0	0	0	abc				0	0	0	1	2	3	4	7					
> 5 – 20							4	2	1	1	0	0	ab	bc			0	0	1	2	3	4	6	9					
> 20 – 35							7	5	3	2	1	1	ab	b	c		0	1	2	3	4	6	8	12					
> 35 – 90							11	8	5	3	2	1	a	b	b		1	2	3	5	7	9	12	18					
> 90 – 135							16	11	7	4	3	2	a	ab	b		2	3	5	7	9	12	15	24					
> 135 – 225							21	14	10	6	4	3	a	a	b		4	5	6	8	11	14	20	32					
> 225 – 300							28	18	12	8	5	4	a	a	b		5	6	7	9	12	16	26	40					
20a	FDGS = ∑ SC _i				100 %	FFG = FDGS + FFGD						FFG				%DA = ∑ FLD _j					FFGD = ∑ DC _j					%DA			

The following items are evaluated in the lower part of the page (see [Table 6](#)):

- posture of hands, arms and shoulders;
- special points;
- duration of repetitive tasks;
 - work organization;
 - number of breaks;
 - shift duration.

Table 6 — EAWS Section 4: postures, additional factors and work organization

Hand / arm / shoulder postures (use duration for worst case of		wrist / elbow / shoulder)											
20b	Wrist (deviation, flex./extens.)	Elbow (pron, sup, flex./extens.)	Shoulder (flexion, extension, abduction)										
	   If shoulders are involved close to or above shoulder height without support or in awkward postures, multiply score x3 												
	Posture points	10 % 0	25 % 0,5	33 % 1									
			50 % 2	65 % 3	85 % 4	PP							
Additional factors													
20c	Gloves inadequate (which interfere with the handling ability required) are used for over half the time					2							
	Working gestures required imply a countershock. Frequency of 2 time per minute or more (i.e.: hammering over hard surface)					2							
	Working gestures imply a countershock (using the hand as a tool) with freq. of 10 time per hour or more					2							
	Exposure to cold or refrigeration (less than 0 degree) for over half the time					2							
	Vibrating tools are used for 1/3 of the time or more					2							
	Tools with a very high level of vibrations					4							
	Tools employed cause compressions of the skin (rednesses, callosities, blebs, etc.)					2							
	Precision tasks are carried out for over half the time (tasks over areas smaller than 2-3 mm)					2							
	More than one additional factor is present at the same time and overall occupy the whole of the time					3							
	Additional points (choose the highest value)					=	AF						
Repetitive tasks duration													
20d	Net Duration [min/shift]		< 60 90 180 300 420 ≥ 480						+				
	Duration Points		1 1,5 3 5 7 10										
	Work Organization		Breaks are possible at every time		Breaks are possible at given conditions		Breaks lead to a stop of the process		+				
	Work Organization Points		(Cycle time longer than 10 minutes)		(Cycle time between 1 and 10 minutes)		(Cycle time shorter than 1 minute)						
			0		1		2						
	Breaks (≥8 min) [# / shift]		0	1	2	3	4	5	6	≥7	+		
	Break points		cycle time ≤30 s		3	2	1	0	-1	-2			-3
		cycle time >30 s		0		-0,5		-1		-1,5			-2
Duration Points								=	DP				

6 EWA effect on EAWS score

6.1 General

An EAWS index higher than 50 points indicates that the workstation generates an excessive demand of load and take immediate actions to reduce the risk. These actions could involve:

- The increase of the standard time per unit, by adding a recovery time to the basic time. This has the effect of reducing the number of repetitions per cycle/shift, thus decreasing the duration score (load = intensity × duration).

- The redesign of the workstation 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).

When choosing the best strategy to reduce the risk take into account:

- The economic impact of the identified solution: in general, the addition of a recovery time could increase the product cost, but the implementation it is longer. On the contrary, the redesign of the workstation could allow to maintain constant (or even increase) the production output and involve significant investments. Ideal solutions usually lay in between these 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, considering that the Intensity and Duration score curves have different behaviours in the different sections (Body Postures, Force exertion, handling of loads and repetitive motions of the upper limbs).

The effect of the redesign of a workstation on the intensity score is not an easy topic, since it heavily depends on the specific case (there is no standard solution). On the other side, general principles can be found regarding the effect of the addition of recovery time in the different EAWS sections. This strategy, as said before, has the effect of reducing the duration score.

[Figure 18](#) shows the recovery allowance (as a percentage of the basic time) added to a certain operation to reduce the risk score of each section from a red (>50 points) to a yellow (between 25 and 50 points) level.

EXAMPLE 1

The score of section 3 (manual material handling, blue line) of a working station is 60 points. The cycle time of the station is 100 seconds. If the only action taken to reduce the EAWS score to a yellow level is the addition of recovery time, this recovery time will be at least 60 % of the basic time. The standard time of the station would therefore become 100 seconds + 60 % = 160 seconds

EXAMPLE 2

The score of section 4 (repetitive motions of the upper limb, cyan line) of a working station is 60 points. The cycle time of the station is 100 seconds. If the only action taken to reduce the EAWS score to a yellow level is the addition of recovery time, this recovery time will be at least 11 % of the basic time. The standard time of the station would therefore become 100 seconds + 11 % = 111 seconds

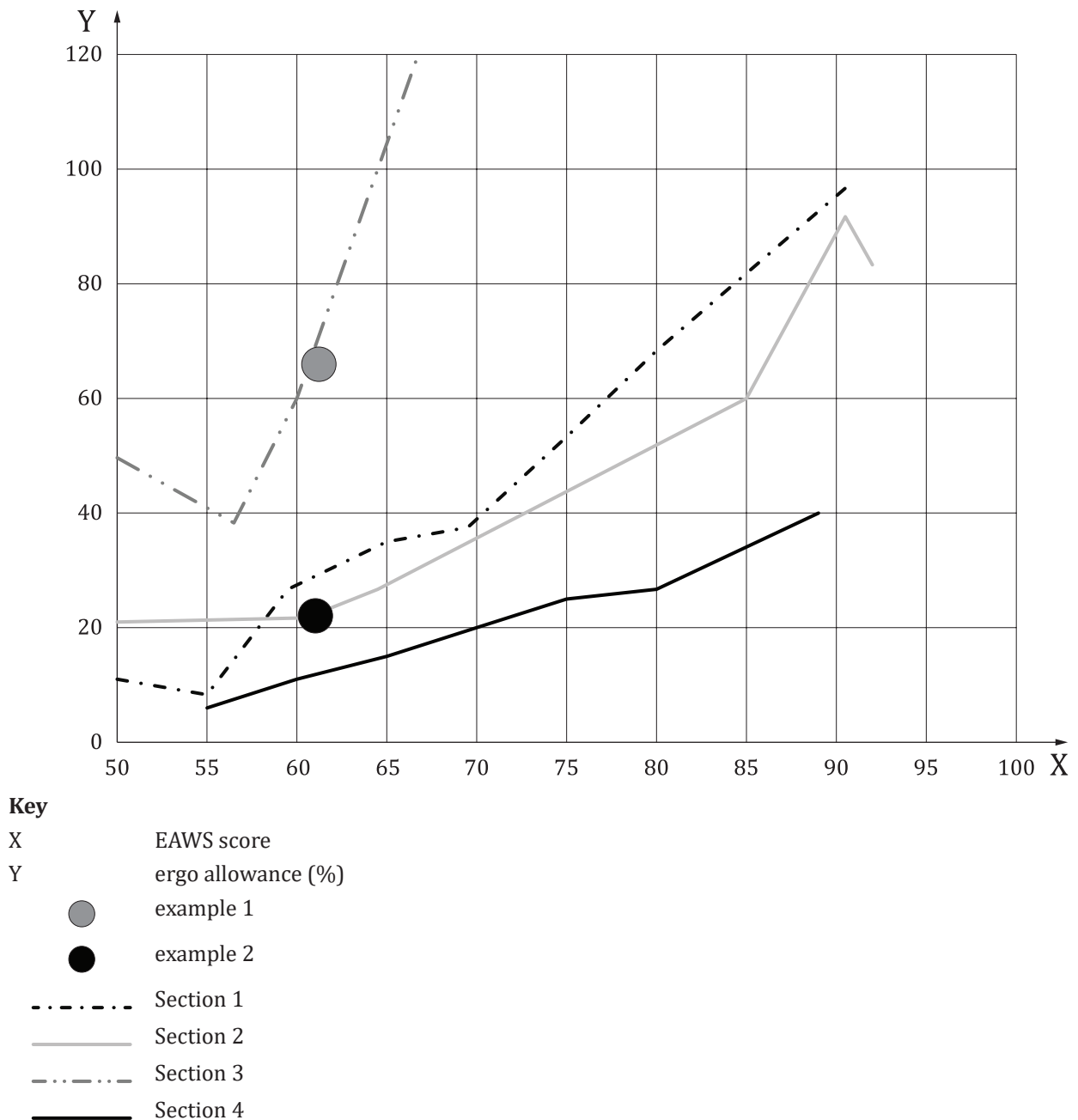


Figure 18 — Minimum allowance needed to decrease risk score to “yellow” level - single sections analysis

[Figure 18](#) clearly shows that the effect of the recovery time (generated by the EWA) in reducing the risk score below the threshold value is very different for the different sections. In particular, there is a significant reduction of the risk score for section 1, 2 and 4, while the effect on section 3 is almost negligible - a very high recovery time is generally added to the station, in order to reduce the risk to an acceptable (yellow) level.

Based on this analysis, the following approach is suggested to reduce the load in each section:

- Section 1 and 2: the simple addition of recovery time is a solution.
- Section 3: it is better to focus on the intensity score rather than on the duration, which means to focus on method redesign or line rebalancing.

- Section 4: the intensity score (driven by force, frequency, grip and postures) strongly depends on the action frequencies. Therefore, the addition of a recovery time has a strong effect of the final score. However, a similar effect is achieved also by working on the work organization and breaks distribution, thus decreasing the duration points. Please refer to the EAWS manual for more details on the score calculation.

No general recommendations are provided for Section 0, since it deals with special working conditions, which are generally analysed case by case.

6.2 Effect of recovery time on typical workstations

The previous paragraph described the effect of the EWA on the score of each EAWS section. However, real workstations usually comprehend a set of activities that involve multiple sections. For this reason, in order to define a general rule to calculate the appropriate recovery time in real workstations, a “blended” recovery allowance curve has been developed, as shown in [Figure 19](#).

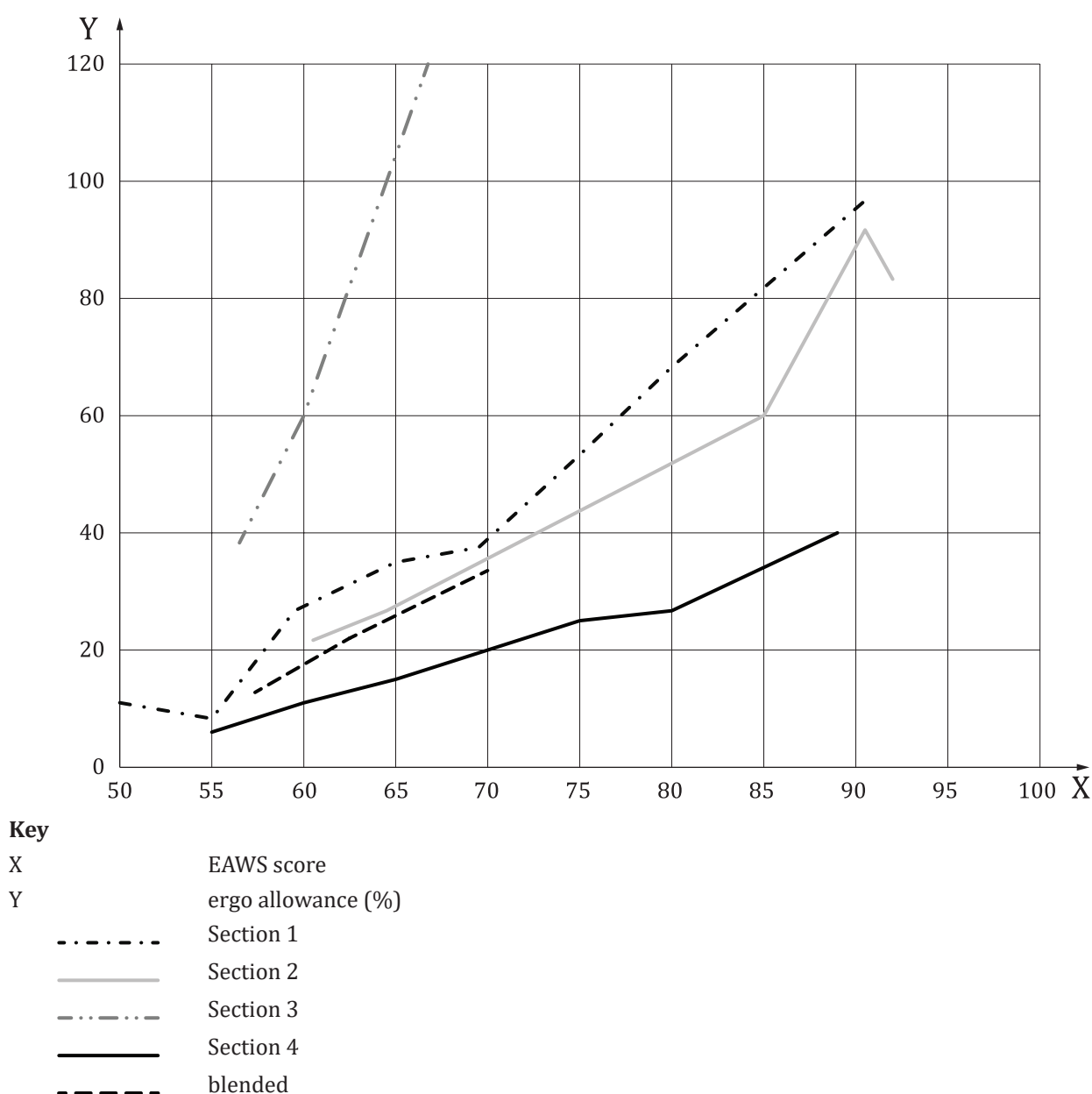


Figure 19 — Minimum allowance needed to decrease risk score to “yellow” level - single sections analysis and blended curve

The blended curve was built on a weighted average of the recovery allowance curve of each single section. Based on an application experience of 10 years of projects in the major industrial groups and the previous considerations, the following weights were used:

- 25 % for Section 1
- 30 % for Section 2
- 5 % for Section 3
- 40 % for Section 4

NOTE In cases where the total score of a workstation depends totally or mostly on the score of a single section (e.g. a logistic workstation, whose score will mostly come from [Section 3](#) only), the recovery time calculated with the blended curve could be insufficient to reduce the risk score under the threshold value.

6.3 EAWS based EWA model

The results of the analysis on the behaviour of the scores in the single sections and on numerous real typical workstations have been exploited to define the EWA model curve defined in [Figure 20](#).

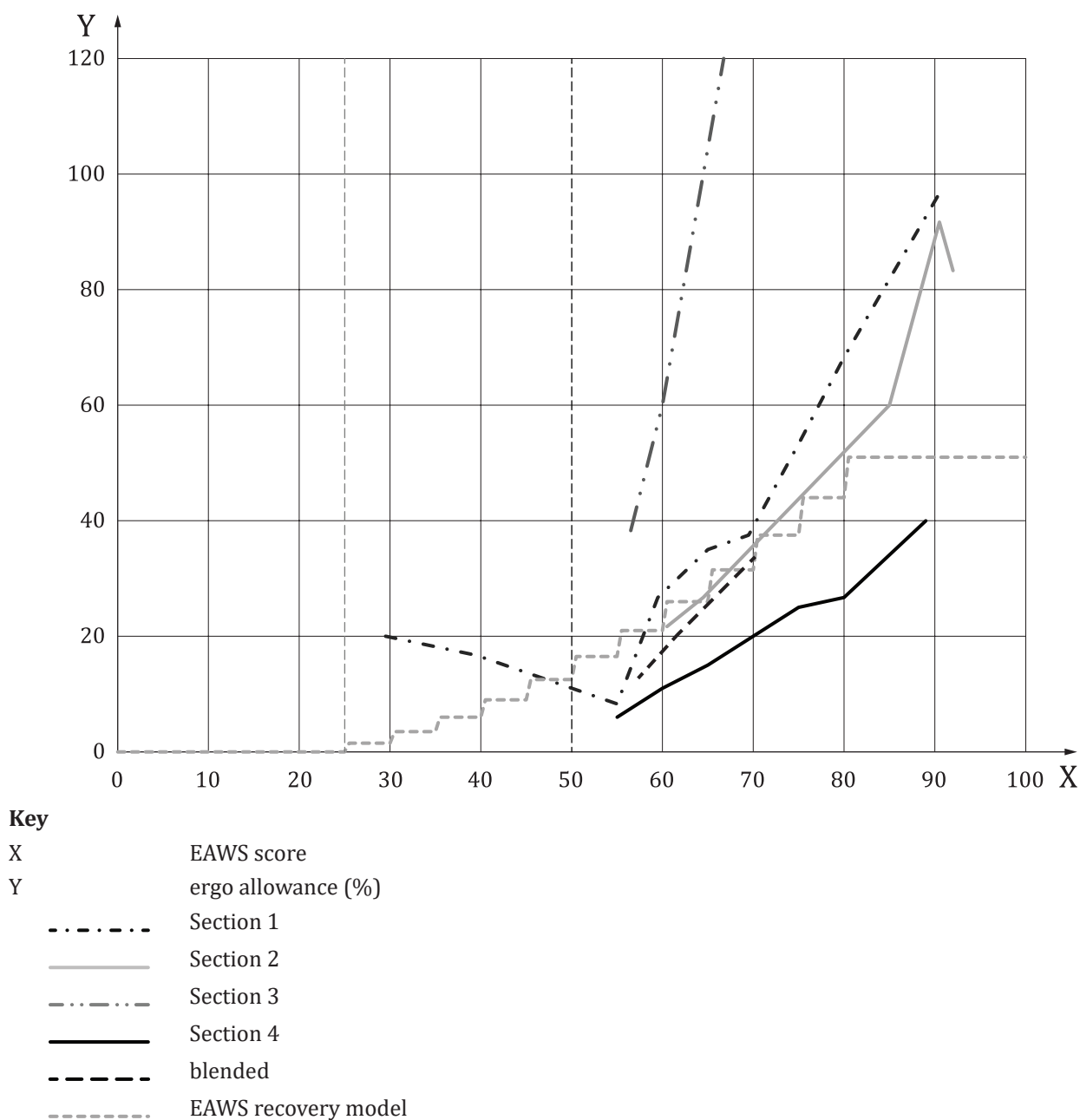


Figure 20 — Minimum allowance needed to decrease risk score to “yellow” level - single sections analysis, blended curve EWA model (EAWS recovery model)

The EWA curve was not defined using complex mathematical and statistical tools. It was a simple attempt to represent at best the trend of all the sections (matching the blended curve) and thousands of experiments were run to test its validity. From the same figure it appears evident how different the behaviour of section 3 (manual material handling) is, which then has to be treated with a specific approach, more focused on the reduction of the intensity score rather than the reduction of the duration score through the application of an allowance.

This is acceptable, since in the manufacturing cyclical work heavy material handling operations (weights > 3 kg) are the easiest to improve at justifiable costs.

A further important comment regarding the identified EWA model is that it is particularly conservative versus Section 4 (repetitive movements of the upper limbs). This choice was based on the fact that upper limbs load is strongly driven by the duration (frequency in particular) and therefore, diluting the standard times generates a slower pace and a consequent lower frequency.

Annex A (informative)

EAWS scoring procedure

A.1 Introduction to the EAWS scoring system

Biomechanics, a complex field, is the application of mechanical principles to living organisms. This includes research and analysis of the mechanics of living organisms and the application of engineering principles to and from biological systems. This research and analysis can be carried forth on multiple levels, from the molecular, wherein biomaterials such as collagen and elastin are considered, all the way up to the tissue and organ level. Some simple applications of Newtonian mechanics can supply correct approximations on each level, but precise details demand the use of continuum mechanics.

Applied mechanics, most notably thermodynamics and continuum mechanics, and mechanical engineering disciplines such as fluid mechanics and solid mechanics, play prominent roles in the study of biomechanics. By applying the laws and concepts of physics, biomechanical mechanisms and structures can be simulated and studied.

It has been shown that applied loads and deformations can affect the properties of living tissue. There is much research in the field of growth and remodelling as a response to applied loads. For example, the effects of elevated blood pressure on the mechanics of the arterial wall, the behaviour of cardio myocytes within a heart with a cardiac infarction, and bone growth in response to exercise, and the acclimatized growth, of plants in response to wind movement, have been widely regarded as instances in which living tissue is remodelled as a direct consequence of applied loads.

Relevant mathematical tools include linear algebra, differential equations, vector and tensor calculus, numeric and computational techniques such as the finite element method.

The study of biomaterials is of crucial importance to biomechanics. For example, the various tissues within the body, such as skin, bone, and arteries each possess unique material properties. The passive mechanical response of a particular tissue can be attributed to characteristics of the various proteins, such as elastin and collagen, living cells, ground substances such as proteoglycans, and the orientations of fibres within the tissue. For example, if human skin were largely composed of a protein other than collagen, many of its mechanical properties, such as its elasticity, would be different.

The study of biomechanics ranges from the inner workings of a cell to the movement and development of limbs, to the mechanical properties of soft tissue, and bones. As we develop a greater understanding of the physiological behaviour of living tissues, researchers are able to advance the field of tissue engineering, as well as, develop improved treatments for a wide array of pathologies.

Biomechanics as a sports science, kinesiology, applies the laws of mechanics and physics to human performance in order to gain a greater understanding of performance in athletic events through modelling, simulation, and measurement. In order to effectively address ergonomic issues in the workplace, develop an appreciation for the trade-offs associated with ergonomics. When one considers biomechanical rationale, one finds that it is very difficult to accommodate all parts of the body in an ideal biomechanical environment. It is often the case, that in attempting to accommodate one portion of the body, the biomechanical situation at another body site is compromised. Therefore, the key to the proper employment of occupational biomechanical principles is to be able to consider the appropriate biomechanical trade-offs with various parts of the body associated with different workplace design options.

This brief introduction to biomechanics is reported in this annex just to give the idea of the level of complexity we have when we aim at measuring a biomechanical load index. For this reason, in the field of occupational biomechanics, models are adopted which do not have the same level of accuracy as

other scientific measuring systems. All existing systems are an attempt to model the effects of forces and motions on our muscular-skeletal system and none of them currently reflect the actual situation.

Proper use of these models and methods involves recognizing the limitations and assumptions of each technique so that they are not applied inappropriately. When properly used, these assessments help identify the risk of work-related injury and illness.

Nonetheless, EAWS design was done based on existing and available research with the aim of finding the most appropriate and reasonable correlation against the CEN and ISO documents dealing with biomechanical load.

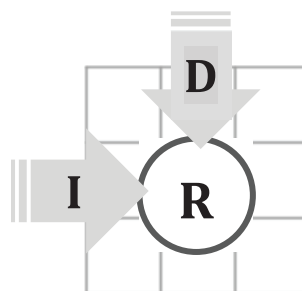
The objective of the EAWS manual is to minimize the applicator deviation when using the EAWS model to assess the biomechanical load.

A.2 Biomechanical Load EAWS Index

A.2.1 General

The EAWS system is based on a load index (R), given by the product of Intensity (I) and Duration (D):

$$R = I \times D$$



Key

D duration

I intensity

Figure A.1 — Evaluation of R (load index)

In Section 1, the user selects the relevant posture in the proper row (intensity) and measure the duration (column). Intersecting the column of duration with the row of intensity, the user easily finds the calculated score (see [Figure A.1](#)).

In Sections 2, 3 and 4, the user calculates the intensity and the duration scores of the concerned task, following specific rules, and eventually multiplies the intensity score by the duration score to find the load index.

In the following units, the generation of the EAWS score will be explained/described section by section.

A.2.2 General Rules

For the purposes of EAWS, the following general principles apply, which are subsequently identified as rules.

— General Rule G1

If the cycle has a duration that differs from 60 s, it is necessary to prorate all measured times to a 60 s cycle, in order to calculate the EAWS scores. To do so, this formula is used:

$$T_{60} = (D [s] \times 60 [s]) / (T_C [s]) \quad n_{60} = (n \times 60 [s]) / (T_C [s])$$

where:

T_{60} is the time prorated to a 60 s cycle

n_{60} is the frequency prorated to a 60 s cycle

D is the measured duration [s]

n is the measured frequency

T_C is the total Cycle Time

Prorate values to minutes in every Section, except in Section 3.

EXAMPLE 1

The cycle time is 120 s and the duration of one special Posture is 20 s.

$$\begin{aligned} \text{Conversion: } T_{60} &= (D \times 60) / T_C \\ &= (20 \text{ s} \times 60 \text{ s}) / 120 \text{ s} \\ &= 10 \text{ s} \end{aligned}$$

The result indicates that the employee, based on 60 s, is in this position for 10 s.

EXAMPLE 2

The cycle time is 30 s. During this time, a force is applied 2 times.

$$\begin{aligned} \text{Conversion: } n_{60} &= (n \times 60 \text{ s}) / T_C \\ n_{60} &= (2 \times 60 \text{ s}) / 30 \text{ s} \\ n_{60} &= 4 \end{aligned}$$

Based on a cycle time of 60 s, the force is applied 4 times.

— General Rule G2

As general principle, if there are several load situations in the same cycle (e.g. multiples dynamic action-forces)

- the duration/frequency is the sum of the individual durations/frequencies,
- the intensities are the weighted average of the individual intensities, where the weights are the respective duration/frequency.

NOTE This general rule will be utilized with examples in the individual sections.

— General Rule G3

The section 1, 2 and 3 are mutually exclusive (one effort to be considered only in one of the 3 Sections of Whole Body). See [Figure A.2](#)

Do not consider awkward postures combined with manual material handling or action forces in Section 1, but just in Section 2 or 3. Force applications are considered in section 2 and handling of loads in Section 3.