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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 regimes	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.

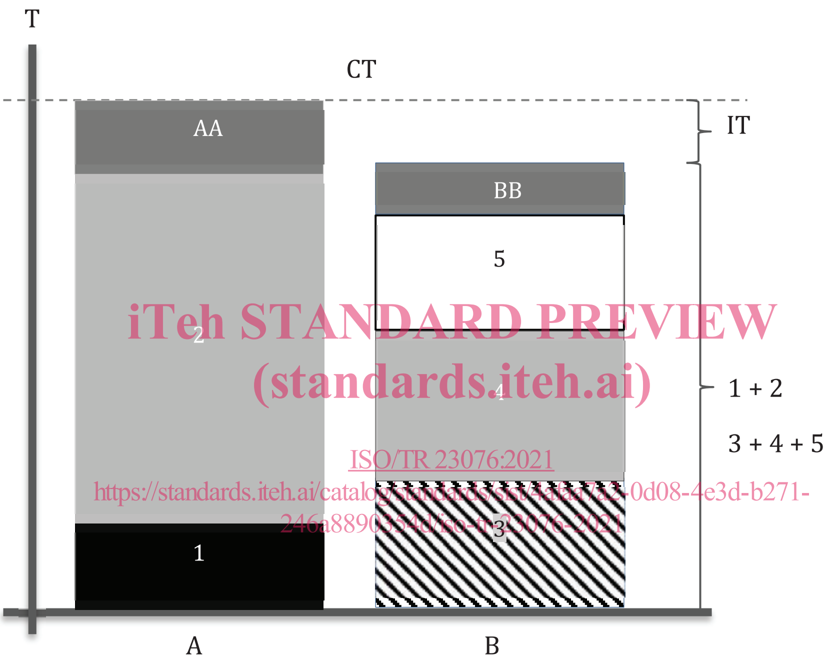
3.14
work organization
way that tasks are distributed among the individuals in an organization and the ways in which these are then coordinated to achieve the final product or service

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):

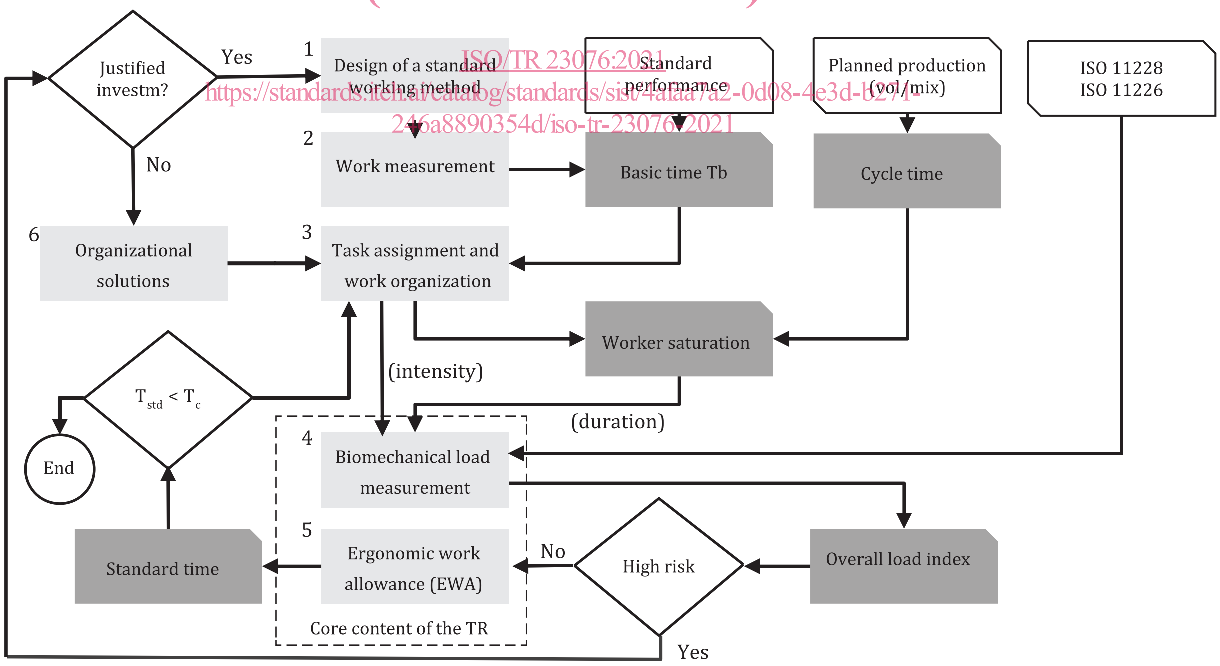
a) design of a standard working method;

b) work measurement;

c) task assignment and work organization;

d) biomechanical load measurement;

e) ergonomic work allowance calculation (applying the model).



Key

(white box)	input
(light grey box)	process
(dark grey box)	output

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).

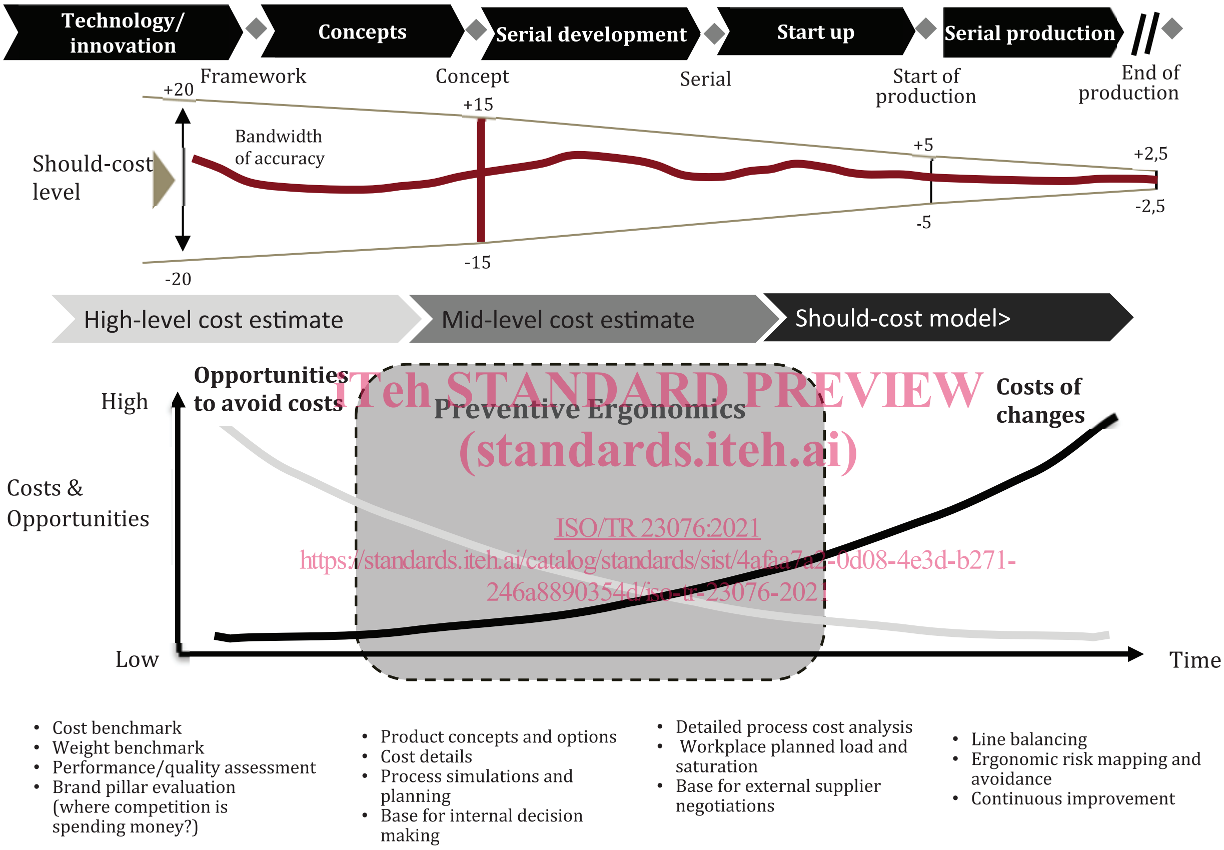


Figure 3 — Preventive ergonomics in the new product development process

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 $T_b = T_{sw}$ x (P/$\bar{P}$)	Basic time Tb = 100 x (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).