The use of design for assembly (DFA) method for ergonomics improvement of a design

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Abstract: This article introduces the use of the DFA method in a situation of ergonomics intervention in the process of product redesign in a home appliance company, helping with acquiring technical solutions to be applied to the product. The design for assembly method is used to reduce various assembly procedures lowering the number of components and favoring the assembly procedures, which are to be carried out. This methodology has been used in many situations to simplify products and reduce the cost assembly. The QFD, the analysis of Kano and the principal of Pugh are some of the other examples of the methodologies and techniques used in the industry to integrate participative methods of ergonomics with the perspective in the design as well as the DFA. However, the use of the DFA method, besides simplifying the structure of designs and reducing the assembly cost, may also be applied to product redesign situations aiming to improve ergonomics in work places.
Keywords: DFA, ergonomics, product development.

1. Introduction

When favoring workers' activities during the assembly of a determined product, through the simplification of its structure, as well as in conceptual phase as in a redesign situation, the use of design for assembly method may be one of the most indicated. That is because the method has a main purpose: to simplify the product structure with the means of reducing the number of attaching systems; factors that may maximize the suggested technical solutions after the diagnosis of an ergonomics intervention.

Considering the ergonomics intervention in product design as well as design process, the system analysis activity, sub-systems and components of product - SSC's - seals an important moment on activities of a design, therefore it allows the team to make adequate predictions at the correction of a product under intervention, in asmuch as applying what was learned (diagnosis) on development of the new product designs. Adequate diagnosis allows the ergonomist and the team to create superior solutions with satisfactory performance in every aspect. As such, it doesn't only reduce the number of redesign interactions, the development time and costs of the solutions, but it also improves the ergonomic intervention perception on part of the workers responsibility for the manufacturing of the referred product, which usually will be the ones resulted from the ergonomic intervention at work sites.

Therefore, to help the designers and engineers to evaluate the impact of the suggested solutions, companies and researchers developed many methods and tools for helping the decisions of the design, denominated as DFX (design for anything) approach. The "X" represents any of the factors referring to be problem that is to be solved, such as: quality, manufacture, production, environment, ergonomic, etc. (AMARAL et al., 2006).

The DFX may be considered as a base of knowledge with the purpose to design products which maximize every characteristic, such as: quality, reliability, service, safety, health, users, environment and solution implantation time - at the same time lowering the costs of product manufacture.

On this study, we will use DFA to strengthen the ergonomics approach in product designs, searching not only for the product ergonomics improvement - DFE (design for ergonomics) - but also other factors that may be adjoined to the final chain of the development, such as, favoring the assembly, cost reduction, productivity improvement, quality, among others.

The main contribution of this article is to show the viability of the use of DFA method in product redesign situations, targeting ergonomics improvement at work sites. This article explores the capability of the use of DFA based in a case study, in situations of product ergonomics intervention.

2. Theoretical background

2.1. Design for assembly (DFA)

DFA is an analysis methodology that supplies a structure of thinking or guidance to the designer, so that the product may be developed in a way that favors the assembly process. In other words, DFA is a method of product design with the means for a production that seeks effort and cost reduction associated to the assembly process.

This methodology comes from an idea that there are no advantages in improving the process if the product itself is problematic. Therefore, during the creation of a new product, DFA must be applied from the initial phase of the design, that is, since the concept of the product, for it is in that phase that, besides identifying the needs that the product must attend, its specifications that directly influence on the options of the methods are defined; which must be considered carefully, since the projectionist's decisions will define the characteristics of the product assembly process.

DFA may also be applied to analyze, criticize and remake the existing product designs, although researches have shown that the decisions made during the design stage determine 70% of product costs, as for decisions made during the production correspond to only 20% of these costs. Another important observation must be considered: decisions made during the first 5% of product design may determine the great majority of product costs and quality and fabrication characteristics. Therefore, the initial stage of development is crucial to the product cost definition.

Thus, the key to the success of a product is to invest in the initial phase of the design.

The methodology bases on part reduction, that is, a decrease of the number of parts per product and the number of part types (reaching a minimum number of components). Thereby, this philosophy uses simple and creative solutions. That simplification on the product structure may be a result of the elimination of parts, the adjoining of such (gathering great amount of parts in one, eliminating assembly procedures) or yet, the improvement of the part format.

"Companies that use DFA have informed a reduction on the number of parts, suppliers, tools and assembly procedures, space and time reduction needed for assembly up to 85%." (STARK, 1998).

As mentioned previously, the part reduction is not only related to the decrease on the number of parts which belong to the product (i.e. a decrease on the number of screws), but it is also related to the reduction on the parts variety (i.e. a decrease on the number of types of screws, that is, the use of a smaller number of different models). That aspect allows the use of modular focus, which defends the use of components or ordinary modules on the fabricated products. With that, it may increase the variety of products through the different combination of these modules. The idea of the modular design is to increase the diversity of products, demanded by the market, without increasing the variety of processes. The modular design provides the reduction of assembly adjustments, for the modules may be tested before being assembled on the final product, favoring the un-assembly and altering parts (less parts to be unassembled and lesser need of tools).

2.2. Ergonomics

WISNER (1987) defines "ergonomics" as being the whole of scientific knowledge related to man, needed in the conception of tools, machines and devices that may be used with great comfort, safety and efficiency at work. The author also defines "ergonomics" as the art that uses the techno-scientific knowledge and the workers' knowledge about their own work situation.

So it can be said that most definitions of ergonomics is directly related to two fundamental aspects: the health and the efficiency at work (productivity). In ergonomics, that efficiency is directly dependent of the human efficiency and usefulness. That way, the ergonomics may be used to achieve efficiency and usefulness, allowing actions in the productive process, product development design (conceptual phase) and adapting to the identified need (demand).

The ergonomics is the study of the adaptation of man's work. This work has great meaning, including not only those machines and equipments used to transform materials, but also in a situation in which occurs the relationship between man and his work. This involves not only the physical environment, but also the organizational aspects of how this work is programmed and controlled to produce the desired results.

It is noted that the adaptation always occurs from the work to the man. The reciprocal is not always true. In this case we could say that the definition would be economy (adaptation from the man to the work). That means that the ergonomics comes from the man's knowledge to do the work design, adjusting to the human capacities and limitations.

To reach its purpose, the ergonomics studies many human behavioral aspects at work and other important factors for designing the work systems. They are:

- man: physical, physiological, psychological and social characteristics of worker, sex influence, age, training and motivation;
- machine: known as machine every material help that a man uses at his work, containing the equipments, tools, furniture and installations;
- environment: studies the characteristics of the physical environment which involves man during work,

such as temperature, noises, vibrations, light, colors, gases, etc;
- information: it refers to the existing communications among the elements of a system, the transmission of information, the processing and making decisions;
- organization: it is the co-ordination of the elements above mentioned in the productive system, studying the aspects: time, work shifts and team formations; and
- work consequences: there are matters of control as inspection duties, studies of mistakes and accidents, besides the studies on energetic waste, fatigue and stress.

The practical purposes of ergonomics are safety, satisfaction and workers well being relating to the productive systems. That way, we could say that ergonomics is the balance between health and productivity.

2.3. Integration among design, design for assembly and ergonomics

The concern to integrate the product design, process design and ergonomics, surges from the evidence that in the process of conception, as well as the product as in technical devices needed for the assembly, product and processing engineers start from a representation of a man at work that will stipulate any activity, which here is known in a conceptual sense of ergonomics.

The hypothesis is supported in the technical concept: useful traditional act, which supports the work category, useful coordinated activity (DEJOURS, 1997). The consideration that the technique supposes a corporal act, which the content at work field is represented by the activity, takes the ergonomics to search for an approximation with product design and process design in the conceptual phase, and the activities of engineer and projectionists.

DANIELLOU (1994) approaches the matter of the implicit representations of industrial conception processes and the need of explicitness of these models, concerning the development of cooperation among ergonomists and the characters of conception.

GARRIGOU (1994), when discussing the positioning of ergonomics believes that, "The role of the ergonomist is in transformation; this way he is not only a supplier of ergonomics data or knowledge on functioning of men. He is also a work character on the point of view of health and its usefulness; to reach these purposes he is going to transform the representations of the acting projectionists about the human being in work situations." (GARRIGOU, 1994).

That way, from the theory which bases the Design, Ergonomics and Design for Assembly, we may create a conceptual reference for the ergonomics intervention, that, in its material dimension will assume the different forms of products and components, which its aim will be associated as well as inner clients (phases of product execution - assembly) as external clients (final consumers of the product).

The process of obtaining a product starts with its conception, in which surges from the idea of the product and is defined, among other factors, its main characteristic. After its conception, the product is conceptualized, detailed and, at last, fabricated and/or assembled.

Various times, at the moment of production, difficulties during the performance of suggested methods and the use of equipments, tools and established devices come up, impairing and even not sanctioning the functioning of the productive process. Thus, the need to remake the design, which, apart from wasting monetary resources, may delay the launching of the product, implying on competitive losses.

Apart from the influence of the work procedure and equipment characteristics, it must also be considered the human factor. In general, many assembly procedures are performed by people who introduce subjectivity and uncertainties in the process. That occurs because, first of all, the human nature is diversified, that is, people are different (they see, think, rationalize and perform the activities in different ways); yet, the human being is not constant, during the day, people suffer from many physical variations such as emotional, then, consequently, this same worker doesn't always works the same way, at the same rhythm all the time. These variations, connected to the complications of the productive process, contribute to the appearance of wastes that may be represented by delays and assembly errors. These wastes are revealed in costs, of which researches made in this area show that more than 40% of total production costs occurs due to manual assembly process.

That way, the process of fabrication and/or assembly and the people who perform them are some of the main responsible ones for the productivity, that is, they define the quantity of products produced for a determined use of resources. This volume of production is related to the time of processing that, in its turn, depends on the way the process was designed, on how it is performed, and, mainly, the product design, since the development of fabrication and/or assembly methods is based on the characteristics of the product.

For these reasons, we must believe that the projectionist must be capable of seeing these consequences and effects that his decisions will cause in the assembly process. Thus, during the development of the product, the projectionist must consider the process limitations as well as human limitations, that is, he must consider the workers' restrictions. With that, it is concluded that, if the product design seeks the simplicity of the product structure (lower number of parts and types of parts) as well as the format of the product and its parts, the process will be less complex, more comprehensible and, therefore, more productive.

3. Case study

The company from the case study - one of the biggest in home appliances sector - uses DFA methodology in the processing of product development, being an integrant part of its methods portfolio and quality tools available for the designing teams. The demand for the design at hand was originated during a manifestation at Management Manufacturing of the company on how to qualify a group of people in the accomplishment of ergonomics design, through the WEA (work ergonomics analysis), so that, afterwards, they may perform improvements in the existing processes and products. After the accomplishment of WEA, three work sites were chosen for the appliance of DFA method during the product redesign phase, to certify the possibility of accomplishing ergonomics interventions at work sites through the simplification of the structure of the product (altering in the design of the product).

The demanded work involved an analysis of several work sites of an assembly line. However, for this article, we will be presenting the appliance of DFA on the product redesign at only one site: **Work Site 110. DISPENSER ASSEMBLY.**

Table 1 presents some movements and postures at site 110 during assembly process and Table 2 presents the analysis of physical overcharge.

3.1. DFA analysis on systems, sub-systems and components: SSC's

Through the identification and posterior separation for analysis of involved SSC`s in the process, it was elaborated the product structure related to the pertaining components from the activity of the work site. This way, in this work site the operator will go to interact with three different components, in a four total (two screws). After elaborated the partial product structure, was fed with a software DFA with the purpose to organize and systemize the analysis of the product. The Figure 1 presents the product structure and the Figures 2 and 3 show the charging of the information in software DFA.

The required information fed to the charging of the software was based on following DFA methodology, which the following criteria are adopted to obtain the variable answer - minimum part criteria.

3.1.1. Minimum part criteria: DFA methodology

A determined item, theorically, must be separated from another because:

a) different material: does the part in analysis need to be of a different material from its interface?
b) possess relative movement: does the part in analysis possess relative movement related to its interface?

Figure 1. Structure of the product at work site 110.

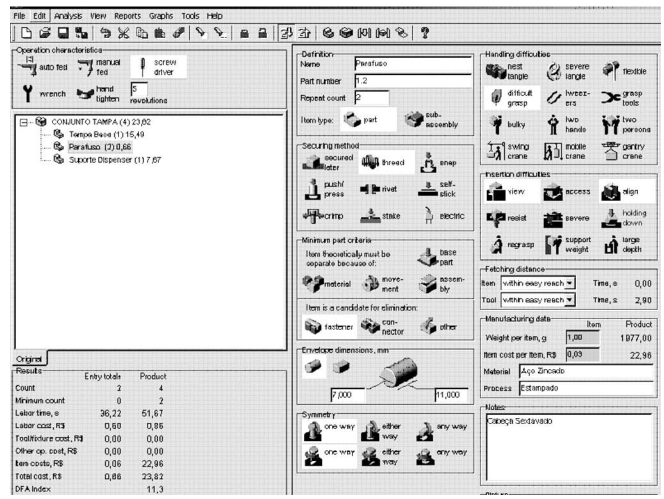

Figure 2. Main screen of software DFA at Boothroyd Dewhurst, Inc.

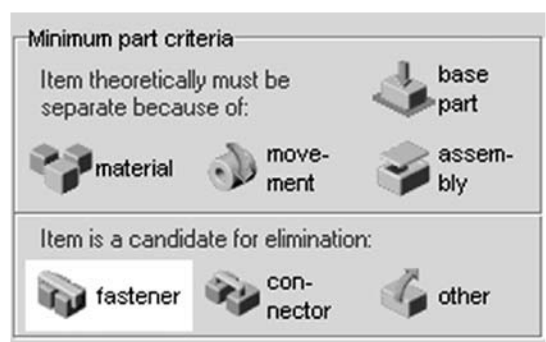

Figure 3. Minimum part criteria.

c) base part: will the part in analysis be able to support the assembly of other components? and
d) assembly: won't the part in analysis, once separated, allow the following procedure?

If all the answers to the four questions above is "No", then that means that the item in analysis is a candidate for elimination, because, most likely, it is:

a) fastener;
b) connector; and
c) other reason.

At this moment, other types of information were added to DFA analysis to obtain the DE (Design Efficiency) index, a number that measures the design efficiency considering the following equation:

Table 1. Main movements and postures at site 110.

Work site 110 - dispenser attachment	
Movements/postures	**Observations**
1.Bringing the tool closer to the body, making an intern rotation in the right shoulder. Afterwards, the screw is placed into the socket of the angular screwgun. It occurs the elbow flexing, an intern rotation of the let shoulder.	Holding the screw in a bidigital tweezers.
2. Side view - It is noted that in order to put the screw, the worker keeps his right shoulder at a 23 degree extension, and the cervical spine flexed close to 20 degree.	The right shoulder extension is kept during the entire procedure with the pneumatic screwgun (screw placing and attaching). Except in certain situations which the worker rotates the torso to the right.
3. Side view - The worker holds the angular screwgun at whole palm grasp.	The tool switching is done by flexing of the second toe.
4. Side view - The first screw fixed on the outer part of the lid. It occurs the rotation of the torso to the right, side tilting of the torso to the right, static cervical flexing above 30 degrees, static outer rotation of the right shoulder and elbow flexing.	
5. Side view - It is noted the radial detour of the right wrist of 25 degrees and the ulna of the left wrist of 19 degrees.	
6. A screw is put into the socket of the screwgun, and, afterwards, the second screw is attached on the outer part of the lid. It is possible to note that some workers flex the torso during the attachment reducing the needed elbow flexing angulations during the attachment of the screws.	Movements 1 and 4 are repeated.
7. The angular pneumatic screwgun is released. First of all the outer rotation of the right shoulder and the extension of the right elbow take place and, afterwards, the detour of the right shoulder is greater than 45 degrees.	

Table 2. Analysis of physical overcharge at site 110.

Dispenser attachment - work site 110			
Structure/segment	**Activity**	**Contraction/movement**	**Risk**
Scapular belt	Screwing	Static contraction	Muscle fatigue
Left wrist	Screwing	Palm compression strength	Compressive neuropathies
Right wrist	Screwing	Isometric compression + strength	Muscular fatigue, tendonitis
Forearms	Placing screws in the screwgun	Lifting the forearm + elbow static flexing	Muscular fatigue, tendonitis
Right forearm	Screwing	Compression of the lid on the medial forearm region	Compressive neuropathies
Shoulders	Getting the screwgun/screwing	Repetitive movements, flexing inner rotators and abdductors	Bursitis, tendonitis miositis
Right superior member	Screwing	Isometric contraction	Muscular fatigue
Neck	Screwing	Static contraction of the flexing muscles	Muscular fatigue, tension

$$DE = \frac{3 \times \text{Theoretical Part Number} \times 100\%}{\text{Total Assembly Time}} \quad (1)$$

In the equation, 3 is the time in seconds needed to reach a part in the grasping zone.

Figure 4 illustrates that in the activity at work site 110, the efficiency index was of 11.3.

3.2. Analysis of the design data at work site 110

The analysis of the obtained data when applying DFA methodology to redesign the project targeting the simplification of its structure and consequently eliminating the critical factors referring to ergonomics, were obtained directly on the analysis of the results.

When 0 (zero) is obtained in the minimum item criteria, it means that we can eliminate or incorporate such part, without its product function being impaired.

In the case of this analysis, we obtained "zero" for the two attaching dispenser screws, indicating that we can redesign the product, simplifying its structure and contributing to the elimination factor of ergonomics risk.

It is important to comment that, during the accomplishment of the cinesiologic analysis, the activity of attaching the dispenser on the settles lid has pointed a potential of ergonomics risk, meaning that DFA analysis was adherent to one of the accomplished studies in work ergonomics analysis.

Other related ergonomics factors were also revealed on DFA analysis during the evaluation on work site 110, for, besides contributing to the solutions of the potential problems at range, insertion and ergonomics, eliminating the two attaching screws, we obtained a gain of procedure time, allowing a future regulation in work activities (reaching and procedure time).

3.3. Product redesign at work site 110: DFA method

The stage of the redesign at the work site was based on the suggested DFA analysis entries of the product's structure. There is a variable answer denominated "Suggestions for Redesign" which are suggested a few options at altering the product design, targeting to eliminate the identified components as candidate for elimination. The obtained data analysis applying DFA methodology to redesign the product seeking simplification of its structure and consequently eliminating the critical factors referring to ergonomics, were acquired simultaneously on the analysis of the results.

It was verified in this section that the following suggestion for the product redesign was issued: "Incorporate integrally the attaching elements (screws) inside the functional parts of the product (dispenser or top), or change the attaching method, in order to eliminate the attaching elements separately."

Following the suggestion, the design team was united once again with the purpose of converting the suggestions into specifications.

Based on the suggestion of incorporating the attaching elements (screws), the design team chose the incorporation on the dispenser, eliminating the two components.

The Figures 5, 6 and 7 exemplify the technical solution found to eliminate the attaching elements (screws), incorporating in the dispenser two pins with the same function of attaching and support.

Note that the attaching system on the dispenser is achieved by the two screws so that the torque must be controlled. Another present cognitive factor in this design concept is the fact that the worker has to make the visual inspection of the screws and has to guarantee the minimum value of the grasping torque.

Note that the two pins were incorporated in the dispenser with the function of attaching and supporting the component in the settled top (Figure 7). With this concept, two attaching screws were eliminated and the whole process involved in this activity.

In Figure 7, note that the incorporated pins in the dispenser which are to accomplish the function of attaching and supporting the settled lid, show an assembly easiness, because now the part is only fixed on the lid, without any resistance to insertion, attaching and other factors that surged in the cinesiologic analysis of the activity.

We can note that the structure of the product was altered, for two components now are not part of the new structure, once the simplification was executed.

With that, a new DE - design efficiency index was obtained, going from 11.3 to 42.6 and representing that the design is much easier to be assembled. Figure 8 presents a new DE index after redesign.

In this redesign situation, the theoretical number of parts for the sub-set to keep its function has lowered from four to two, as the new suggested product structure by the design team for simplification and elimination of the ergonomics risk activities (dispenser attaching on the lid). Figure 9 presents the new product structure after redesign.

It is important to mention that another side effect of this new design proposal, in spite of not being the focus of this case study, was the product cost reduction, eliminating stock, means of control, screwguns, etc.

Therefore, the main benefit was the elimination of the ergonomics risk activities and the physical overcharge at work site 110.

3.4. Summary of the obtained results on the product redesign at work site 110

The following results were obtained by the design team when adopting the technical solution for incorporating the attaching elements on the dispenser:

- elimination of the ergonomics risk factors, for the attaching activity or adjoining parts no longer take place, leaving only the fixing procedure without acquiring physical efforts, tool reaching (screwgun), insertion, among other movements;
- simplification of the product structure (minus two items);
- cost reduction on the sub-set;
- greater flexibility and activity regulation, for the remaining part fixing can be done in another work site, because it does not require exclusive tools such as the pneumatic screwgun;
- physical overcharge reduction;

DFA index

Theoretical minimum number of items	2
DFA index	11.3

Figure 4. Design efficiency index.

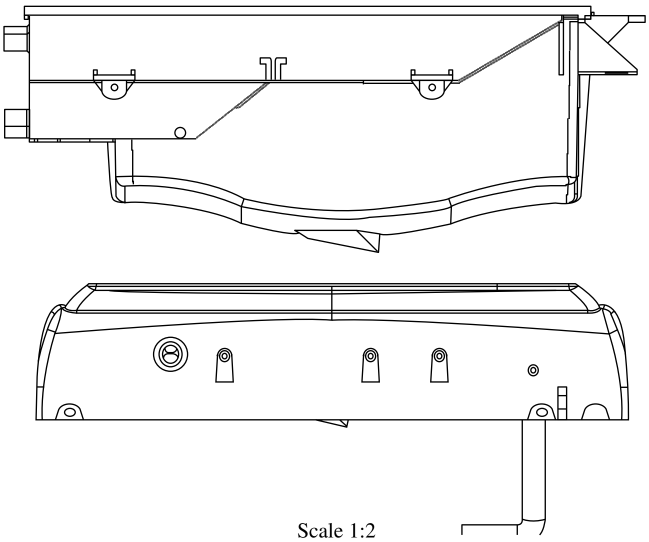

Figure 5. Drawing of top/dispenser set (original design).

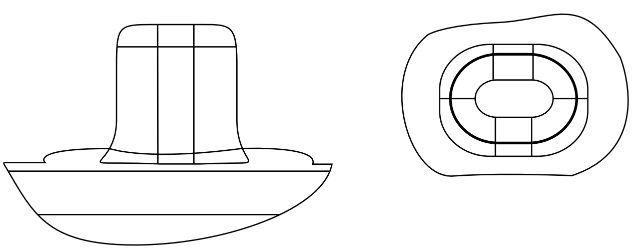

Figure 6. Detail of dispenser pin (redesign of top/dispenser set).

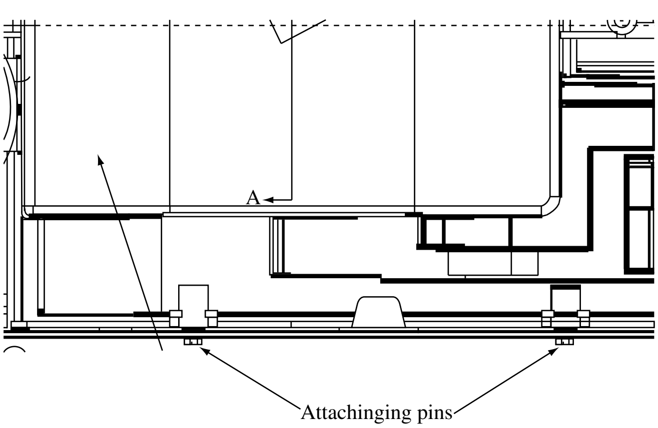

Figure 7. Drawing of redesigned dispenser.

DFA Index

Theoretical minimum number of items	2
DFA Index	42.6

Figure 8. DE index after redesign.

Figure 9. New product structure after redesign - SSC's.

- quality improvement (torque variations and control were eliminated, lack of screws, inadequate attaching, etc.); and
- system reliability increase: the lesser the number of parts, the lesser the probability of interaction and consequently the greater the reliability.

4. Conclusions

The use of DFA method for the product ergonomics improvement was preliminarily presented. In spite of the main contribution of the method which is to simplify the product structures and reduce the assembly cost, we were able to prove that DFA may also be applied in product redesigning situations, seeking an ergonomics improvement at work sites.

The case study indicated a great opportunity of DFA method use in situations of ergonomics intervention in product design, contributing to the simplification of the product structure through the elimination of unnecessary components that may cause complaint demands related to the ergonomics problems at work sites.

At the work sites where DFA was used, it was possible to identify positive aspects related to the integration of the design and ergonomics, especially the opportunity of predictability of possible problems, design related to the ergonomics which the design team identified during the use of the method and in the variable answers for a technical solution addressed to the problem (suggestions for redesign).

The obtained results after the implantation of the technical solutions found by the design team, using DFA, confirmed the hypothesis that we can benefit from the use of DFA method to help on the development and product redesigns seeking to eliminate the critical factors related to ergonomics.

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