https://doi.org/10.4322/rae.v17n2.e202315.en

ABERGO 2023
XXIII CONGRESSO BRASILEIRO DE ERGONOMIA
XVI FÓRUM DE CERTIFICAÇÃO DO ERGONOMISTA BRASILEIRO
XVII FÓRUM DOS GRUPOS TÉCNICOS DA ABERGO

Improvement proposal for a company in the metallurgical sector: an application of DMAIC considering Ergonomics/Human factors

Ana Beatriz Souto Perry, PUCPR, Curitiba, PR, Brasil, ana.perry@pucpr.edu.br
Rosimeire Sedrez Bitencourt, PUCPR, Curitiba, PR, Brasil, rosimeire.bitencourt@pucpr.br
Osiris Canciglieri Junior, PUCPR, Curitiba, PR, Brasil, osiris.canciglieri@pucpr.br

Summary

The industry has undergone an evolution, moving from personalized artisanal work to mass production with high yields, quality and focusing on low costs. However, throughout this process, human beings stopped being the main focus and became just a supporting element in terms of cost, quality and deadlines. As a result, the search for greater productivity ended up leaving human beings in a secondary role in companies. In this context, aiming to highlight human beings and improve the accuracy of the inventory process in a company in the metallurgical sector in the metropolitan region of Curitiba. To this end, the DMAIC method was applied together with the AMT Method. The result of the project consists of an improved inventory process, taking into account the company's reality. During the application of the DMAIC cycle, the AMT method was used to identify the possible root causes of the opportunities identified. Furthermore, with AMT, employees were found to be dissatisfied with the organizational climate and leadership. Furthermore, high rates of discomfort and pain due to repetitive work have been identified. With the causes defined, solutions were sought for the problems. These were analyzed, prioritized and tested. With the implementation of the solutions, there was an increase of 1.68 percentage points in the accuracy of the inventory process, reaching 94.68% (target of 95%). To keep the project sustainable, a control plan was developed with actions and recommendations, in a cycle of continuous improvement.

Keywords: DMAIC; Lean; Human Factors; Ergonomics; AMT method.

1. Introduction

The appreciation of human factors has gained more and more prominence in the industrial sector since more and more individuals have been recognized in different stages of company processes, from product development to after-sales, becoming parts fundamental within the production system (BITENCOURT et al., 2020).

It is not new that the balance between organizations, technologies and human resources has been studied. For more than 70 years, the Tavistock Institute has studied the concept of the socio-technical system that addresses the balance of these three factors (THE TAVISTOCK INSTITUTE, 2022). However, over time, the recognition of the value of the work carried out by employees in a company, which was previously indisputable, was gradually neglected in favor of prioritizing other aspects, such as productivity and cost reduction.

When talking about Lean, the first idea that comes to mind is cost reduction and customer prioritization. Even in its most famous application, the combination of Lean with Six Sigma and created by Motorola in 1986, focusing on product quality and using the cycle for continuous improvement, DMAIC (Define, Measure, Analyze, Improve and Control); Known as Lean & Six Sigma, there is no emphasis on the importance of human beings and their well-being in production processes, despite being present at all stages of this process.

Within the application of Lean & Six Sigma there is the standardization of tasks, elimination of unnecessary activities and improvement of the workflow, which often does not directly consider the needs and skills of workers.

However, over time there has been an evolution in business thinking, with a growing understanding that human factors play a crucial role in the efficiency and quality of processes. This context highlights the importance of combining the two fields of application, that is, integrating human aspects, such as training, engagement and satisfaction of employees (ergonomics as a whole), in the context of Lean process improvement, using tools such as DMAIC.

In order to meet customer demands and reduce waste, many companies are adapting and transforming their processes, and this also applies to the logistics sector. For customers, expenses related to storage, movement and control of materials do not add value. Therefore, any reduction in waste in these activities represents a significant gain for the company.

1.1. Goal

Therefore, as an objective, the project aims to propose and implement improvements to the current inventory and material recording process of a company in the metallurgical sector, addressing the concepts of lean production, continuous improvement and ergonomics, through the application of the DMAIC process.

1.2. Methodology

This work is characterized as applied research, of a quantitative nature and exploratory objective (NASCIMENTO, 2016). In order to meet the proposed objective, the DMAIC method was followed, integrated with the AMT Method (Macroergonomic Work Analysis), to propose an improved future process.

The DMAIC cycle is a Six Sigma tool, in which the acronym refers (in English) to the following steps: define, measure, analyze, improve & control. This tool serves to direct the application of work in the company, as its phases are structured and can be monitored by the company, which is the main stakeholder in the project. Considering that the focus of the work is human factors, we opted for the Macroergonomic Work Analysis (AMT) method, proposed by Guimarães (1998). Figure 1 demonstrates how the applied methodology will work, integrating the AMT methodology with the DMAIC cycle.

Figure 1 - Applied methodology integrating AMT and DMAIC.

DEFINE		MEASURE		ANALYSE		IMPROVE		CONTROL	
ETAPA	**MÉTODO**	**ETAPA**	**MÉTODO**	**ETAPA**	**MÉTODO**	**ETAPA**	**MÉTODO**	**ETAPA**	**MÉTODO**
Definição do problema	Conversa com o gestor logístico	Estratificação do problema	Árvore de estratificação e Pareto	Mapear o processo	A partir do mapa de raias	Proposição de soluções	Brainstorming e Fase 3 da AMT: proposta de soluções	Verificar o alcance da meta específicas e global	Análise do indicador atual vs inicial
Contextualização da empresa	Informações do site	Confiabilidade dos dados estratificados	Coleta de dados foi realizada	Levantamento das causas raiz	A partir do método AMT até a fase 2: análise ergonômica	Priorização das soluções	Tabela de oportunidade de melhorias	Verificar ganhos financeiros	Quantificação dos ganhos pelo indicador proposto
Definição da métrica	Indicador do problema	Definição dos estratos mais significativos	Agrupamento dos dados que compõem 80% de significância no indicador	Priorização das causas raiz	Matriz GUT, 5 porquês e diagrama de ishikawa	Detalhamento e implementação de soluções	Testes das soluções implementadas, 5W2H e fase 4 da AMT: validação das soluções	Plano para manter o resultado	OCAP (out of control action plan – plano de ação para anomalias) e fase 5 do AMT: detalhamento ergonômico
Justificativa do projeto	Análise dos dados históricos do indicador	Análise do comportamento dos focos ao longo do tempo	Utilizando Pareto	Quantificar a causa	Constatação das causas				
Definição da meta	Conversa com o gestor logístico	Definição das metas prioritárias	A partir do comportamento histórico dos focos						
Ganhos do projeto	A partir da melhoria do indicador								
Mapa de processos SIPOC	Definido em conjunto com o gestor								

Source: The Authors, 2023

2. Development, Results and Discussion

To better demonstrate the results, the topics were separated into the same structure presented by the DMAIC methodology.

2.1. Define

To start the project, we understood a little about the company that is a reference when it comes to oil and gas extraction systems and, currently, due to the generation of new types of energy, the company decided to cover the new niches generated by using new technologies, promoting sustainable energy.

When production is planned, the resources available from the SAP® system (System Applications and Products in Data Processing) are optimized. If there is a discrepancy between the physical materials versus the quantity indicated in the system, it is necessary to carry out new planning to determine the demands arising from the obstacle of lack of the physical part. Due to this, the accuracy indicator is of great importance within a process, since it is the factor that indicates how well adjusted the physical stock is in relation to the system and, for this reason, this is the metric used in the project. This indicator is measured according to Equation 1. This indicator is subject to internal and external audit, which brings greater reliability to the data presented.

$$Accuracy\ (\%) = \left(1 - \frac{Theoretical\ Value - Real\ Value}{Theoretical\ value}\right) x\ 100$$

Equation 1. Formula for calculating the percentage of accuracy.

For the 2022 cycle, the company made three people available on both shifts to carry out the count. The analysis of the company's historical data (average of 90%) demonstrated that there is a large variability between the accuracy data, since each material has different sizes, quantities and arrangements on the shelves, which can facilitate or complicate the counting process, as It is done manually by stockists. Gains will be measured in working hours recovered due to a higher level of accuracy. To better understand the company's process, a SIPOC (Suppliers, Inputs, Process, Output and Customers) process map was created of the flow of the main process studied (Figure 2).

Figure 2 - SIPOC Matrix

Fornecedores Suppliers	Insumos Inputs	Processo Process	Produtos Outputs	Consumidores Customers
Fornecedor	Peça enviada	Receber a peça	Peça recebida	Área de recebimento
Área de recebimento	Peça recebida	Atualizar status no SAP	Status da peça atualizada no sistema	Área de inspeção de qualidade
Área de inspeção de qualidade	Status da peça atualizada no sistema	Inspecionar peças	Peça aprovada Peça reprovada	Inspetor de qualidade Inspetor de qualidade
Inspetor de qualidade	Peça aprovada e reprovada	Atualizar status no SAP	Status da peça atualizada no sistema	Peça aprovada - estoquista Peça reprovada - Fornecedor
Estoquista	Status da peça atualizada no sistema	Alocar peças no estoque conforme o MRP	Peça alocada no estoque conforme o MRP	Estoquista
Estoquista	Peça alocada no estoque conforme o MRP	Solicitar materiais do conjunto de montagem	Material solicitado	Gerente de projeto
Gerente de projeto	Material solicitado	Localizar peças no estoque	Peças localizadas	Estoquista
Estoquista	Peças localizadas	Separar peças para conjunto de montagem	Conjunto separado	Estoquista
Estoquista	Conjunto separado	Atualizar status no SAP	Status da peça atualizada no sistema	Gerente de montagem
Gerente de montagem	Status da peça atualizada no sistema	Posicionar na linha de montagem	Conjunto posicionado	Linha de montagem

Source: The authors, 2023.

2.2 Measure

The process was stratified based on the results of the last cycle count. Stratification showed that 20% of requested materials are not located, causing "lost" hours of work to increase. In this way, we analyzed which are the main points that are affected by this non-location of the material, without this, we have: incorrect count (53%), incorrect address (20%), no definition (13%), divergence of consumables (6%), shipping error (5%) and incorrect material (3%). Therefore, as the first two (incorrect counting and incorrect address) make up 73% of the cause, these were defined as the focus of the project. The priority goals were defined by the behavior of these focuses over time, validating the achievement of the global goal proposed by the company (Figure 3).

Figure 3 - Specific goals for each focus

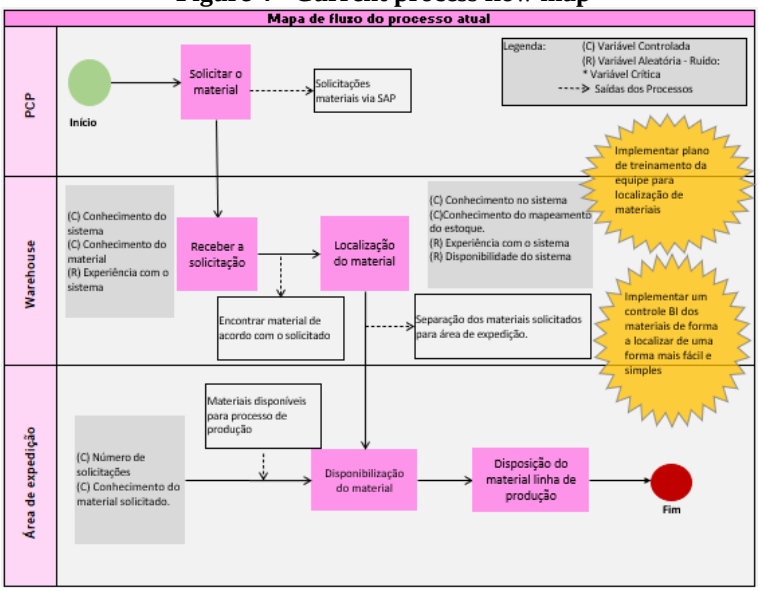
	Estrato	Atual	Meta
Meta 1	Contagem Incorreta	53%	30%
Meta 2	Erro de endereçamento	20%	15%
	Sem Definição	13%	13%
	Divergência de consumíveis	6%	6%
	Erro de expedição	5%	5%
	Material Incorreto	3%	3%
Total		100%	72%
% de não localizados		20%	14,50%
% de não acuracidade		7%	5%
% acuracidade		93%	95%

Source: The Authors, 2023.

2.3 Analyze

To identify the points of improvement for each stage of the process, a lane map was created – as shown in Figure 4.

Figure 4 - Current process flow map



Source: The Authors, 2023.

To better understand the causes of the problems, considering human factors, the survey was carried out using the AMT ergonomics method proposed by Guimarães (998), see Figure 5.

Figure 5 - Application of the AMT tool.

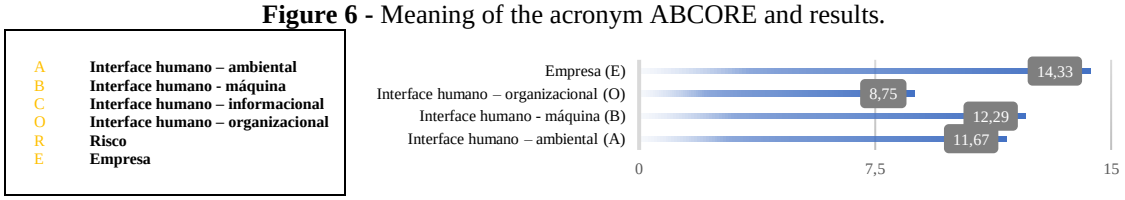
Phase		Description
Phase 0	Project launch and field survey planning	As the company does not have an ergonomics committee, the survey took place in the form of interviews with the logistics operators of the stock shed to be analyzed. 6 interviews were carried out on 05/17/2022, among those interviewed there were 5 stockists and 1 logistics manager.
Phase 1	Initial survey or ergonomic assessment	To develop the initial survey, direct observations from users were used. The questions were asked openly so that interviewees could place their observations, in accordance with Guimarães' (1998) suggestion, in the order in which they found most relevant. From recording the answers given by each of the interviewees, it was possible to tabulate the answers and order them according to the degree of prioritization (order in which the problem was mentioned), defining the importance weights for each item mentioned.
Phase 2	Situation analysis or ergonomic diagnosis	A questionnaire was applied in which employees respond on an agree and disagree scale, in 15 cm lines, where the distance represents the employee's level of agreement. Based on these results, it is possible to analyze which are the main opportunities within FDIs, which could be affecting the indicator studied and which are the areas in which employees are satisfied.

Source: The Authors, 2023.

Within the material stock process, there are 6 employees and all 6 were interviewed. They were asked through open interviews: “Tell me about your work: what are the positive and negative points and make suggestions for improvements”. Afterwards, a questionnaire was applied that presents general points about the job in order to evaluate employee satisfaction in relation to the items referring to the ABCORE classification (Figure 6), developed according to the constructs proposed by Guimarães

(1998) . The questionnaire was applied to 5 people, as they participated in the activity directly.

Figure 6 - Meaning of the acronym ABCORE and results.



Source: The Authors, 2023.

For the Ergonomic Demand Items (IDEs) A, B, O and E studied, none presented below average results, which is considered a very positive result. For the questions of discomfort (R) and work content (C), the result is presented inversely – since it presents criteria, such as work pressure, that the lower the value placed, the better. For the job content construct, the average satisfaction score was 7.60, which shows a niche opportunity, as it highlights the need for employees to feel satisfied with their work. For the Risk category, questions were used regarding the discomfort of carrying out the tasks. As the result of this pillar has an average of 5.82, it is encouraged to look for solutions to these discomforts in order to prevent future injuries to employees.

After analyzing the results raised by the AMT, Figure 7 provides a summary of the causes raised.

Figure 7 - Summary of the causes raised.

ABCORE Factor	Ergonomic Demands Item (IDE)
Human – environmental interface (A)	Temperature of your work environment
Job Content (C)	Amount of work you do (workload)
	Is your work limited?
	Is your job stressful?
	Do you feel psychological pressure from your superiors?
	Is your work creative?
	Is your work dynamic?
	Is your work stimulating?
	Does your job involve responsibility?
	Does your work make you feel valued?
Human – organizational interface (O)	Relationship with customers
	Flexibility of working hours
	available time to carry out your daily work activities
	clarity in the distribution of daily professional activities (e.g. who separated notes, etc.)
	How your work is planned (goals and activities)
	How management is carried out when receiving orders from customers (e.g., separation of activities)
	Leadership way of acting
Discomfort (D)	Mental effort required
	Discomfort or pain in the arms
	Discomfort or pain in the hands
Causes raised by the interviews	High demand
	Trainings
	Interruption during counting
	Long counting times

Source: The Authors, 2023.

The causes raised in red will not be addressed at work, as they are part of an organizational culture that needs to be restructured and, therefore, bring a more complex change to be implemented.

To prioritize the causes raised, the Severity, Urgency and Trend (GUT) matrix was carried out (Figure 8), considering the items scored by employees in the interviews as priority, since they are the causes that most bother employees. Furthermore, as a prioritization criterion, the causes that were above 75 points (in bold) were considered.

Figure 8 - GUT Matrix.

Classificação	GUT	Causas	Gravidade	Urgência	Tendência
8 º	75	**Falta de dispositivos ergonômicos**	5	5	3
11 º	45	Trabalho repetitivo	3	3	5
6 º	80	**Clareza na distribuição das atividades diárias**	4	5	4
1 º	125	**Planejamento das atividades (metas e objetivos)**	5	5	5
1 º	125	**Gestão no recebimento de pedido do clientes (exemplo: separação das atividades)**	5	5	5
1 º	125	**Forma de agir da liderança**	5	5	5
12 º	36	Temperatura do meio ambiente	3	3	4
6 º	80	**Dificuldades no uso dos softwares e sistemas - falta de treinamento**	5	4	4
10 º	48	Longos tempos de contagem	4	3	4
12 º	36	Falta de fomas de medições automáticas da acuracidade	3	3	4
5 º	100	**Esforço físico**	5	5	4
15 º	24	Trabalho monótono	4	3	2
16 º	18	Trabalho pouco criativo	3	3	2
17 º	12	Trabalho pouco dinâmico	3	2	2
12 º	36	Trabalho pouco estimulante	3	4	3
9 º	60	Trabalho cansativo	5	4	3
1 º	125	**Desconforto e dores no corpo**	5	5	5

Source: The Authors, 2023.

For work planning (goals and activities), management of receiving customer orders (e.g., separation of activities) and leadership's way of acting, these are more complicated causes and are outside the scope, as they involve cultural change within of the company and must be work developed in a more detailed, slow and gradual manner. These opportunities highlighted by employees were communicated to the manager in order to understand the employees' points of dissatisfaction. It is worth mentioning that this dissatisfaction presented by employees can influence the level of counting errors, since this error can occur due to the fact that employees feel pressured by leadership.

To address them, it is suggested to implement flexible working hours and plan the activities carried out by employees, including: activity, description, responsibility, average completion time (to balance the workload between employees) and goals (expectation of the result of that activity).

Therefore, there are four main causes prioritized and defined: Lack of ergonomic devices, Difficulties in using software and systems, Physical effort and Discomfort and

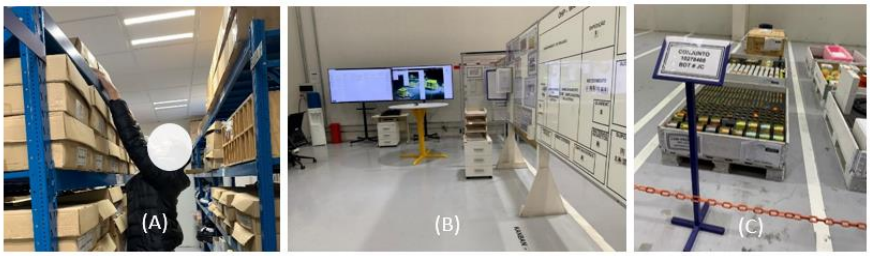
body pain. To quantify these causes, the focuses were correlated with the prioritized causes and each of them was described (Figure 9) highlighting them (Figure 10).

Figure 9 - Quantification of prioritized causes

Incorrect count	Addressing error	Prioritized cause	Description of the cause	Evidence
X		Lack of ergonomic devices	Difficulty performing tasks due to lack of ergonomic devices.	Figure 10 (a)
	X	Difficulties in using software and systems	Due to not knowing how to use the system, materials are incorrectly addressed within the SAP® software.	Figure 10 (b)
X		Physical effort	Materials positioned in difficult-to-reach locations with few tools or devices to aid storage and separation of materials	Figure 10 (a)
X		Discomfort and body pain	Due to repetitive work being carried out over long periods of time, there is discomfort and pain caused by this.	Figure 10 (c)

Source: The Authors, 2023.

Figure 10 - Detailed evidence.



Source: The Authors, 2023.

When observing the posture that the employee needs to position themselves in to be able to pick up the material (Figure 10 A), there are several opportunities for improvement. In a monitored period of 1 hour, employees searched an average of twelve times for materials weighing an average of 6 kilograms, on a rack with its shelf 2.00 meters high, which will be placed on a cart 0.50 meters from the floor . To reach the 2.00 meter high shelf, a three-level ladder is used that reduces this height to 1.50 meters high. The employee must stretch their arms to pick up the material, staying 0.55 meters away from their body. Because they are boxes, the handle is poor, as it does not have good support for your hands. An analysis was carried out using the NIOSH method, which resulted in a survey index of 2.53, which fits into a moderate increase in this risk (index is between 1 and 3). It is suggested to use ergonomic devices and position smaller, lighter items that are less frequently needed on the highest shelves.

When analyzing Figure 10 B, it is possible to notice that the system access location does not have any type of work instructions (whether visual or written), close to the

computers, therefore, there is no standardized way to guide the use of the software. , which creates difficulty when running the program. To register the address, requesters print a report with the requested materials and send it to their supervisor to sign, approving the request. Afterwards, the requester takes the document to the warehouse. The stocker separates and delivers the material, collects the papers and records the withdrawal in the SAP® system.

When analyzing Figure 10 C, it appears that employees do not have a specific place, such as a bench, to count and separate materials. The materials are arranged in buckets and pallets on the floor, causing the employee to have to bend down and get up constantly during the work day – generating physical effort.

3.4 Measure

At this stage, the solutions were identified after brainstorming by the group together with the company's logistics management. Afterwards, the ideas that best addressed the causes were prioritized as a way to mitigate the opportunities found in the project (this stage encompasses Phase 3: proposed solutions) - to this end, Figure 11 was obtained.

The solutions were based on tools available within the company, such as Microsoft 365®, and on tools that are not applied, but are proven solutions - as is the case with the application of RULA and OWAS or NIOSH in cycles, which is recommended since it acts not only reactively, but also preventively. Within this analysis, a Likert scale from 1 to 5 was considered, with 1 being low or bad and 5 being high or excellent.

Figure 11 - Improvement opportunity matrix, proposed solutions and risks.

INCORRECT COUNT	ADDRESSING ERROR	PRIORITIZED FOCUS	CLASSIFICATION	PROPOSED SOLUTION	BENEFIT	COVERAGE	INTERNAL SATISFACTION	OPERATIONALIZATION	PRODUCTIVITY	INVESTMENT	TOTAL	PROBABILITY	IMPACT	RISK	CONTINGENCY PLAN
X		Lack of ergonomic devices	7	Develop ergonomic devices (such as carts, ladders and support tools) for the inventory process.	4,7	4,3	4,7	3,0	4,7	5,0	**16,4**	75%	8	Alto	Request budget adjustment and present financial return
	X	Difficulties in using software and systems	8	Conduct training with employees on the SAP® tool. Conduct training with employees on the SAP® tool.	4,3	4,7	4,3	3,6	3,0	4,3	**15,6**	-	-	'	-

			5	Implement an integrated and automatic flow request system through the integration of Powerautomate and SAP®.	5,0	4,3	4,7	3,6	4,7	4,3	**18,0**	5%	9	Baixo	Use a warehouse to place data intermediately in systems
			2	Development of a standard procedure for using the software, so that the employee can easily and quickly check how the addressing is carried out.	4,7	5,0	3,6	5,0	4,7	3,0	**20,0**	30%	7	Médio	Seek to train and encourage employees to always follow the planned process
			3	Develop a dashboard in PowerBI with the location of items in the logistics warehouse layout.	4,7	4,5	4,3	4,7	4,5	3,0	**19,7**	40%	8	Baixo	Publicize the change and constantly make employees aware of the importance of adhering to the new method
X		Physical Effort	1	Provide a bench or table so that the employee can separate and count materials.	4,5	3,6	5,0	5,0	5,0	2,1	**21,0**	75%	9	Alto	Revisit the layout to reduce "dead" spaces
X		Discomfort and body pain	6	Application of ergonomic assessment tools, such as RULA and OWAS or NIOSH, with application cycles every 3 months.	4,7	5,0	4,7	3,0	4,5	4,3	**17,6**	45%	9	Médio	Show success stories with the application of the tool to raise awareness and gain the support of senior management
			4	Implementation of breaks, activity rotation to reduce repetition of the same activity and position over long intervals of time.	4,3	5,0	4,3	4,7	4,3	3,0	**19,6**	60%	8	Médio	Make good operational planning, leaving extra time for scheduled breaks

Source: The Authors, 2023.

For the investment, both the value of applying the solution and the time spent developing the proposed solution were considered. Only the training solution was disregarded, as it would require several rounds of training with employees, hiring a specialist to carry out the training.

To define tests and validate the proposals (this being phase 4 of the AMT method), a 5W2H matrix was developed for the test plan – as shown in Figure 12 and the costs involved are described in time.

Figure 12 - 5W2H of testing the proposed solutions and tests

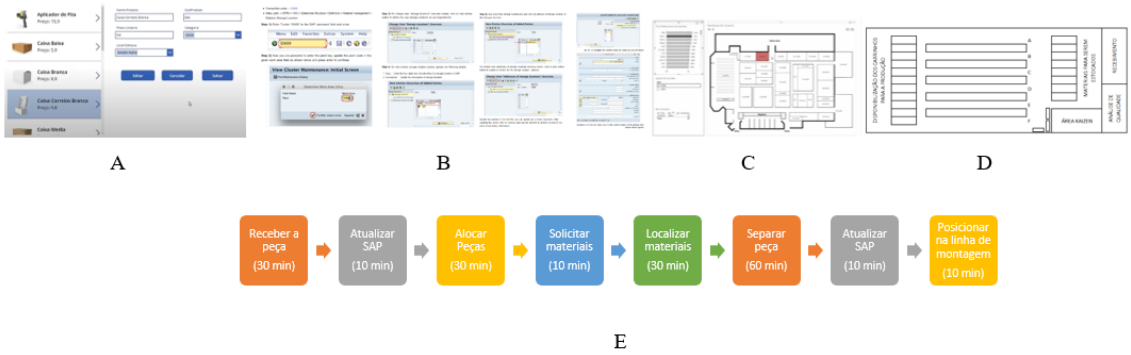
Contagem incorreta	**Erro de endereçamento**	**Causa fundamental**	**Solução a ser implementada para teste**	**5W2H**							**Status**	**Evidências dos Testes**
				What (Atividade)	**Who (Quem)**	**When (Quando)**	**Why (Por Quê)**	**Where (Onde)**	**How (Como)**	**How Much (Quanto Custa)**		
X		Falta de dispositivos ergonômicos	Desenvolver dispositivos ergonômicos (como carrinhos, escadas e ferramentas de apoio) para o processo de estoque.	Analisar a atividade realizada, desenvolver protótipos de dispositivos ergonômicos	(Analista de EHS)	02/09/2022	Para ajustar os dispositivos às necessidades dos funcionários	Barracão logístico	Criação de protótipos para validação das soluções	400 horas	Em andamento	Em Andamento
	X	Dificuldades no uso dos softwares e sistemas	Implementar um sistema de requisição integrado e de fluxo automático a partir da integração do powerautomate e o SAP®.	Realizar um projeto piloto com os funcionários para adaptar o sistema de forma a ficar mais próximo das necessidades	(Assistente Logístico)	10/09/2022	Para ajustar o novo processo de acordo com as necessidades e com a devida acessibilidade aos funcionários	PowerApps	Criação de um aplicativo no powerapps	100 horas	Concluído	Figura 13 A
			Desenvolvimento de um procedimento padrão de utilização do software, de forma que o colaborador consiga verificar de forma fácil e rápida como realização o endereçamento.	Reuniões com os funcionários	(Estagiária Logística)	02/09/2022	Para abranger as dificuldades dos funcionários dentro do procedimento padrão	Barracão logístico	Realizar um rascunho do procedimento padrão com os funcionários, verificando as maiores dificuldades encontradas no dia a dia	150 horas	Concluído	Figura 13 B **Erro! Fonte de referência não encontrada.**
			Desenvolver um dashboard em Power bi com a localização dos itens no layout do barracão logístico.	Realizar um projeto piloto com os funcionários para adaptar o sistema de forma a ficar mais próximo das necessidades	(Assistente Logístico)	15/09/2022	Para ajustar o novo processo de acordo com as necessidades e com a devida acessibilidade aos funcionários	Power BI	Criação de um dashboard de localização das peças no mapa no Power BI	100 horas	Concluído	Figura 13 C

X		Esforço Físico	Disponibilizar uma bancada ou mesa para que o funcionário possa fazer a separação e contagem dos materiais.	Revisão do layout	(analista de projeto de fábrica)	10/09/2022	Para verificar a disponibilidade de espaço físico no barracão	Barracão logístico	Revisão do layout de forma a verificar a possibilidade de inclusão de bancadas para os funcionários	50 horas	Concluído	Figura 13 D
X		Desconforto e dores no corpo	Aplicação de ferramentas de apreciação ergonômica, como RULA e OWAS ou NIOSH, com ciclos de aplicação a cada 3 meses.	Pesquisa e benchmarking	(Analista de EHS)	12/09/2022	Para constatar as vantagens da aplicação das ferramentas	Barracão logístico	Análise de cases de sucesso com a aplicação das ferramentas e definição da ferramenta utilizada	400 Horas	Em Andamento	Em Andamento
			Implementação de pausas, rotatividade de atividades para reduzir a repetição da mesma atividade e posição em longos intervalos de tempo.	Crono análise das atividades	(Analista de PCP)	08/09/2022	Para verificar a possibilidade de inserção das pausas sem impacto nas atividades do processo produtivo	Barracão logístico	Análise do impacto das pausas ao longo do dia para o processo do estoque	150 horas	Concluído	Figura 13 E

Source: The Authors, 2023.

To detail the tests, the 5W2H matrix was presented. Therefore, there are two actions in which the tests are more elaborate and are still in progress and, therefore, the effects of these actions will not be evaluated.

Figure 13 - Illustrative figure of the material registration and inventory control application developed.



Source: The Authors, 2023.

In order to respect the company's privacy issues, merely figurative images were placed. The flow worked satisfactorily and was well accepted by employees, therefore, the solution will be implemented. Figure 13 C represents the stock map to facilitate the location of materials. The employee looks for the part number, checks where it is located and the available quantity of the material. With the layout shown in Figure 13 D, it is feasible to make tables and benches available so that employees can separate and count the parts. Finally, from the chrono analysis carried out (Figure 13 E), which totaled 240 minutes for the complete process, it was possible to verify that there is the possibility of inserting 2 rounds of 15 minutes of stretching and changing activities within the process, without impacting the operational process.

With the round of testing completed, a solution implementation plan was created in order to carry out this implementation gradually and incisively. The solution for

implementing breaks was met, as the company has already reduced demand in order to make more time available for employees to change activities and take breaks. In relation to other activities, these present a very positive scenario, with risks well mapped and mitigated. To verify the results of the actions, Figure 14 was created.

Figure 14 - Verification of the results of the implemented solutions.

Incorrect count	Addressing error	C Root cause	Solution deployed	Implementation result	Status
X		Lack of ergonomic devices	Develop ergonomic devices (such as carts, ladders and support tools) for the inventory process.	-	Não iniciado
	X	Difficulties in using software and systems	Implement an integrated and automatic flow request system through the integration of Powerautomate and SAP®.	Figura 13 A	Implementado
			Development of a standard procedure for using the software, so that the employee can easily and quickly check how the addressing is carried out.	Figura 13 B	Implementado
			Develop a dashboard in Power bi with the location of items in the logistics warehouse layout.	Error! Reference source not found. 13C	Implementado
X		Physical Effort	Provide a bench or table so that the employee can separate and count materials.	Está no processo de compras das bancadas.	Em Andamento
X		Discomfort and body pain	Application of ergonomic assessment tools, such as RULA and OWAS or NIOSH, with application cycles every 3 months.	-	Não Iniciado
			Implementation of breaks, activity rotation to reduce repetition of the same activity and position over long intervals of time.	There was a reduction in daily demand, in order to make more time available for employees to take breaks. The results will be demonstrated qualitatively in the long term.	Em Andamento

Source: The Authors, 2023.

As the actions with the applications and standard procedure implemented were to validate the proposed pilot and refine the system according to employee feedback, the results of the actions remain the same as those presented in the testing phase.

3.5 Control

For the final stage of the application, it was verified whether the defined goals were achieved (Figure 15).

Figure 15 - Description of goal achievement.

	Estrato	Inicial	Atual	Meta
Goal 1	Incorrect Count	53%	33%	30%
Goal 2	Addressing error	20%	16%	15%
	Without definition	13%	13%	13%
	Consumables divergence	6%	6%	6%
	Shipping error	5%	5%	5%
	Incorrect Material	3%	3%	3%
Total		100%	76%	72%
% of not found		20%	15,20%	14,50%
% non-accuracy		7%	5,32%	5%
% accuracy (global target)		**93%**	**94,68%**	**95%**

Source: The Authors, 2023.

The specific targets were achieved and the result is satisfactory, as they are only 0.32% below the global target. With the reduction in the percentages of unlocated materials and the increase in stock reliability, it is possible to estimate that there was a gain of 2,400 productive hours per year – considering the gain of 2 hours of productivity

per day, for 20 working days, for the 5 stockists. Despite the relatively low value of financial return, it is worth highlighting that there was an improvement in the quality of life at work for employees, which cannot be measured in monetary terms. To complete the application of the DMAIC cycle, there is a definition of ways to keep the process sustainable, therefore, key actions were defined so that this result obtained is maintained (Figure 16).

Figure 16 - List of variables and forms of monitoring.

Variable	Way of monitoring
Accuracy	Annual monitoring reports
No location of engines	Weekly reports of time spent not locating materials and why
Work Standards	The logistics intern must check whether the work instructions are being used, as well as whether these instructions are updated
Tools developed	The logistics intern must check whether there are opportunities to use the tools, as well as update these
Ergonomics	The EHS analyst must carry out the ergonomic assessment on a cyclical basis

Source: The Authors, 2023.

For the team's recommendations, there is the final phase of applying the AMT method, Phase 5: ergonomic detailing. From the study carried out, it was possible to identify opportunities for improvement within the analyzed process.

By specifically analyzing the company's inventory process, for the development of this activity, it was identified that it is a highly repetitive process that requires many movements in uncomfortable positions. It is suggested to establish more relaxed breaks, encouraging employee iteration and relaxation to evacuate the stress, tension and monotony of work.

Furthermore, an important point that employees made clear both in the interviews and in the questionnaire is their dissatisfaction with leadership. Therefore, it is suggested to carry out a survey of general satisfaction and appreciation of the organizational culture with employees, in order to identify the main points of opportunity for the company. Finally, to promote motivation and encouragement for employees, it is recommended to implement bonuses and recognition programs based on proposed improvements and work performed. Furthermore, it is suggested that leadership meetings be held more closely with employees, both for feedback and to understand the worker's growth expectations. It is suggested to expand this study to other areas of the company in order to carry out a complete assessment of the company's scenario.

3. Final considerations

Aiming to improve the inventory and material recording process in a company in the metallurgical sector, based on employee involvement, the DMAIC cycle was applied in conjunction with the AMT method. The final product of this project consists of an improved process, which takes into account the company's reality, human factors and lean production.

Through interviews carried out with employees, dissatisfaction with management and the organizational climate was found. As this problem is more complex, the feedback was reported to the company and the topic was not addressed in the proposed improvement cycle. The main opportunities identified were: temperature of the work environment, problems related to the content of work (such as limitations, workload, stress and lack of dynamism and stimulation), little time available to carry out activities, little clarity of these activities, poor distribution of responsibilities, high mental and physical effort required, discomfort in the upper limbs, lack of training and ergonomic devices and long counting times (continuous task for long periods of time).

Among these main opportunities, the causes that would receive actions in this cycle of continuous improvement were prioritized. This prioritization occurred through the GUT matrix and improvement opportunity matrix. Based on the priority causes (pain in the upper limbs, training, physical effort and lack of ergonomic devices), a detailed test, action and control plan was developed in order to structure long-term sustainable solutions and mitigate these points of dissatisfaction.

So that the results could be maintained, new processes were developed and implemented (registration using PowerApps and verification in Power BI) and a standard operating procedure was created for recording the address of materials. As the development and implementation process involved all employees who interface with the processes, the training process was carried out in a brief expository meeting that showed the final version and summarized the functioning of the processes.

As the main recommendation, it is suggested the adoption of ergonomic assessment tools and the periodic performance of these assessments. In relation to the goal established by the company, which was to achieve an accuracy of 95%, this goal was practically achieved (only 0.34 percentage points below).

Finally, it is concluded that considering the human aspect during the improvement cycle can lead to positive results for the company. Therefore, projects of this nature contribute to rescuing the importance of considering human factors in improvement projects and should be promoted in the field of engineering.

4. Referências bibliográficas

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