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Article

Analysis of Hierarchical Task Analysis (HTA) Impact on Cognitive Workload Using NASA TLX: A Study on the Assembly of a Three Jaw Chuck

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Abstract: HTA introduced by Annett and Duncan is widely recognized for breaking down complex tasks into manageable subtasks, data, and quantitative analysis confirming its effectiveness are limited. By combining the HTA with the NASA Workload Index (NASA-TLX), a subjective workload assessment tool, this study aims to provide a comprehensive assessment of task performance and workload. The project involved assembling a three-jaw chuck with HTA for process definition and subtasks, while NASA-TLX was used for workload determination. Data were collected through questionnaires and observation forms and analyzed to determine the impact of HTA on task performance and workload distribution. The results show that HTA effectively identifies task complexity and bottlenecks, which facilitates task optimization and improves performance. The NASA-TLX integration provides critical insights into individuals' subjective workload and targets areas where task performance and resource allocation can be improved. This study shows that combining HTA and NASA-TLX provides a holistic approach to understanding and improving task performance, ultimately leading to better user experience and productivity.

Practitioner Summary: This paper analyses the effectiveness of HTA in reducing the cognitive workload ona subject while performing an assembly and using the concept of NASA TLX to calculate the total workload experienced by the subject before and after the use of HTA.

Keywords: cognitive workload; Hierarchical Task Analysis; NASA Task Load Index; assembly; workload reduction

1. Introduction

Cognitive workload significantly affects the operator's performance in a workplace and it is important to optimize the process to ensure increased performance and efficiency. To calculate the workload that the operator experiences, there are multiple cognitiveassessment tools such as the NASA Task Load Index [2], Subjective Workload Assessment Tool (SWAT) [16], andCognitive Task Analysis [15]. The activity that is taken into consideration in this paper is the Assembly of a Three Jaw Chuck, and the Hierarchical Task Analysis (HTA) is employed to optimize the process by describingthe activity in terms of its specific goals, subgoals, operations, and plans [5]. By dividing tasks into hierarchical structures, HTA allows researchers and designers to identify potential bottlenecks, errors, and areas for the development and execution of tasks and onthe other hand, NASA TLX provides valuable information about the cognitive and physical demands ofthe assembly, helping the researchers and practitioners tooptimize the assembly design effectively. Therefore, by combining the concepts of NASA TLX and HTA acomprehensive understanding of task performance and workload is gained.

The assembly of a 3-jaw chuck helps for a detailed division of the tasks at multiple levels which helps in the development of a systematically designed HTA.

A 3-jaw chuck is a part of a lathe machine where it actsas a clamping device by holding cylindrical work pieces.

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Figure 1. 3-jaw chuck.

The parameters which were considered for determining the cognitive workload on the operator were Physical, Mental, Temporal, Performance, Effort and Frustration which were developed by the Human Performance Group at NASA Ames Research Center [1]. The activity of the assembly of a 3-jaw chuck was narrowed down after considering activities likeFlight Simulation in unmanned aircraft system (UAS) software [2], assembling of a clock and an assembly of a miniature car.

The activity is performed in two phases, former one without theHTA and the latter one with the HTA that helps us analyse theimprovement that has been achieved in the total workload reduction, if any. We perform comparative analysis on thedata collected that enables us to evaluate HTA's impact as a tool for improving task efficiency and management.

2. Problem Definition

Excessive workloads associated with complex tasks negatively impact human performance and increase the total workload on humans cognitively.

3. Methodology

The Three Jaw Chuck assembly process was analyzed using Hierarchical Task Analysis (HTA) to systematically break down the task into subtasks. The subject's cognitive workload was then measured using the NASA Task Load Index (NASA-TLX) both before and after the introduction of HTA. Assessment of workload included six dimensions: mental demand, physical demand, temporal demand, performance, effort,and frustration. This methodological approach allowed acomprehensive assessment of how HTA affects cognitiveworkload and provided insight into possible improvements in task performance and ergonomics.

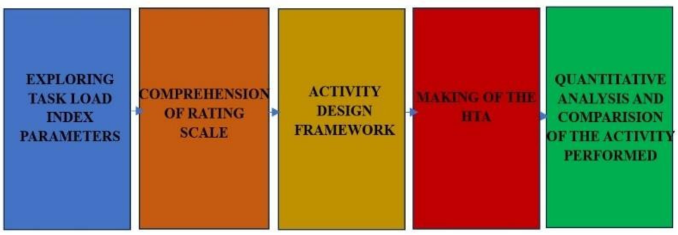

Figure 2. Methodology.

3.1. Exploring Task Load Index Parameters

Explanation of the parameters considered for the 3-jaw chuck assembly based on NASA TLX:

[i]. *Mental Demand:*

How much mental and perceptual activity was required (e.g., thinking, deciding. calculating, remembering, looking. searching, etc.)? Was the 3-jaw chuck assembly easy or demanding, simple or complex, exacting or forgiving?

[ii]. *Physical Demand:*

How much physical activity was required (e.g., pushing, pulling, turning, controlling. activating, etc.)? Was the assembly easy or demanding, slow or brisk, slack or strenuous,restful or laborious?

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[iii]. Temporal Demand:

How much time pressure did you feel due to the rate or pace atwhich the assembly of 3-jaw chuck was done? Was the pace slow and leisurely or rapid and frantic?

[iv]. Performance:

How successful do you think you were in accomplishingthe goals of the assembly set by the experimenter (or yourself)? How satisfied were you with your performancein accomplishing these goals?

[v]. Effort:

How hard did you have to work (mentally and physically) to accomplish the assembly of 3-jaw chuck?

[vi]. Frustration level:

How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the assembly?

3.2. Comprehension of Rating Scale

The NASA TLX provides us with a rating chart, which considersthe 6 parameters and the subject uses subjective rating to rate themselves thus being able to quantify their experience in performing the task.

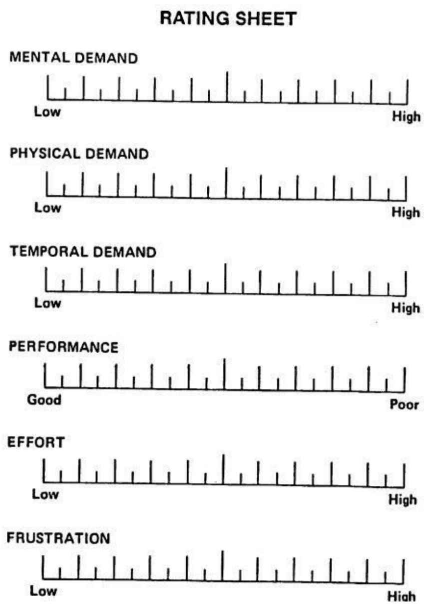

Figure 3. Rating Sheet [1].

The rating scale as shown in Figure 3, ranges from 0-100, with 0 being the lowest possible level of the parameter being ratedand 100 being the highest, thus enabling flexibility and precision in workload assessment, using which we can capture nuanced differences in workload perception among participants [1].

One of the main advantages of using rating scale from 0-100 is its ease of analysis as calculation of aggregate workload by summing or averaging individual ratings for each parameter, thus establishing a standard procedure for workload calculation,and hence enabling quantitative analysis and comparison acrossparticipants, tasks, or experimental conditions with minimalcomplexity. This simplifies the process of deriving meaningful insights from workload data collected using NASA-TLX. This granularity enables researchers to capture subtle variations in mental demand, physical demand, temporal demand, performance, effort, and frustration level, enhancing the depth of workload assessment.

From the above rating scale as shown in Figure 3, the parameters like mental demand, physical demand, temporal demand, effort,and frustration have a scale ranging from Low to High whereas the performance parameter ranges from Good to Poor because in the case of low to high if the subject rates his/her ability to complete the task as low, then it would mean that they are not satisfied with their performance which is generally associated with the higher rating on the rating scale, thus establishing uniformity in the way the parameters are rated.

3.3. Activity Design Framework

The activity that is considered for this experiment is the assembly of the three-jaw chuck which has 14 parts in total which arecategorized into 7 components. The whole activity can be broken down into two phases which is Phase 1 and Phase 2.

Phase 1:

A disassembled 3-jaw chuck is provided to the operator, along witha reference image as shown in Figure 4. The subject analyzes the given image and starts assembling the 3-jaw chuck. Irrespective ofthe subject being able to complete the assembly or not, the time isnoted down and we proceed to calculate the total cognitive workload experienced by the subject.

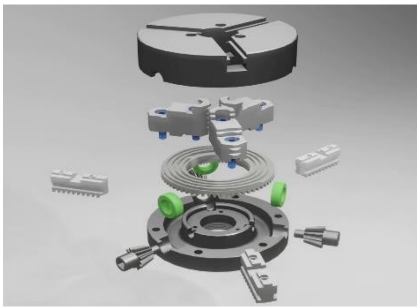

Figure 4. Reference image (provided to the subject).

We use a questionnaire table as suggested by [1] and shown in the Table 1 below, that has a list of 15 questions which are essentially a combination of two parameters considered at one instance. The parameter factoring majorly to the cognitive workload between the two instances is noted down which helps us narrow down the parameters that are major contributors to the cognitive workload.

Table 1. Questionnaire table.

EFFORT	OR	PERFORMANCE
TEMPORAL DEMAND	OR	EFFORT
PERFORMANCE	OR	FRUSTRATION
PHYSICAL DEMAND	OR	PERFORMANCE
TEMPORAL DEMAND	OR	FRUSTRATION
PHYSICAL DEMAND	OR	FRUSTRATION
PHYSICAL DEMAND	OR	TEMPORAL DEMAND
TEMPORAL DEMAND	OR	MENTAL DEMAND
FRUSTRATION	OR	EFFORT
PERFORMANCE	OR	TEMPORAL DEMAND
MENTAL DEMAND	OR	PHYSICAL DEMAND
FRUSTRATION	OR	MENTAL DEMAND
PERFORMANCE	OR	MENTAL DEMAND
MENTAL DEMAND	OR	EFFORT
EFFORT	OR	PHYSICAL DEMAND

Phase 2:

After the completion of first phase, the subject is given a HTA chart as shown in Figure 5 which is analyzed by the subject. The subject now performs the assembly while navigating through the HTA chart and the completion time is noted. The subject answers the questionnaire table as shown in Table 1 which is further usedto calculate the total cognitive workload experienced.

We now compare the subjective ratings and the total cognitive workload experienced in both the phases for different parameters,where we observe that there has been a significant decrease in thetotal cognitive workload as perceived by the subject, thus validating the concept of HTA as a tool capable of reducing the overall cognitive effort required for performing an assembly.

3.4. Making of the HTA

Hierarchical Task Analysis [HTA] is a systematic method whichis used to break down complex tasks into a hierarchy of smaller, more manageable subtasks. The process of HTA is to decompose tasks into different subtasks to any desired level of detail. Each subtask, or "operation" is specified by a goal, the input conditionsunder which the goal is activated, the actions required to attainthe goal, and the feedback indicating goal attainment [20].

The main advantage of using HTA with respect to this paper is:

i) *Systematic Approach:*

HTA provides a structured and systematic method for breaking down complex tasks into manageable components. This systematic approach ensures thorough analysis and understandingof task processes.

ii) *Interdisciplinary Collaboration:*

HTA encourages collaboration between different disciplines, suchas human factors engineering, cognitive psychology, and systems design. By bringing together diverse perspectives, HTA ensures acomprehensive understanding of task performance and fosters innovative solutions.

iii) *Visualization of Task Structure:*

HTA results in a hierarchical diagram that visually represents the structure of tasks, including subtasks, actions, and dependencies. This visualization aids in understanding the relationships betweendifferent task elements.

The process of creating a Hierarchical Task Analysis (HTA) involves several critical steps. Initially, the purpose of the analysis must be defined, whether it is for system design, developing personnel specifications, or analyzing workload. Next,the boundaries of the system description are established, specifying equipment's to be considered. To ensure the accuracy and validity of HTA, experimentation and multiple iterations needs to be performed before its finalization. Goals are linked to tasks, with detailed descriptions of the conditions that trigger each task, forming a comprehensive plan that guides the sequence and iterations of tasks. Each task is linked to different subtasks detailing out its methodology which is in turn linked to different operations mentioning about the equipment to be used for performing that specific task.

The Hierarchical Task Analysis (HTA) for assembling a three- jaw chuck is systematically divided into multiple levels, detailing the specific actions required to achieve the final assembly. The primary goal of assembling the chuck is broken down into several main tasks, each further divided into detailed subtasks and operations. These tasks include inserting components such as the scroll disk and pinions, placing the large cover plate, inserting, and tightening screws, and using tools like the wrench for final adjustments. Each main task is subdivided into specific steps to ensure precise alignment, correct orientation, and secure fastening of all parts. This structured approach provides a comprehensive and methodical plan of action, ensuring the assembly process is thorough and precise.

An action plan is included in the HTA chart which directs the subject to use the HTA as intended, thus setting up a standard procedure for all the subjects in terms of the HTA utilization. The Hierarchical Task Analysis (HTA) shown in Figure 5 has proven to be effective in lowering the cognitive workload, as it helps subjects to concentrate more on task execution rather than cognitive strain by streamlining the process and delivering information in a structured manner hence enhancing efficiencyand lowering the possibility of making mistakes during assembly.

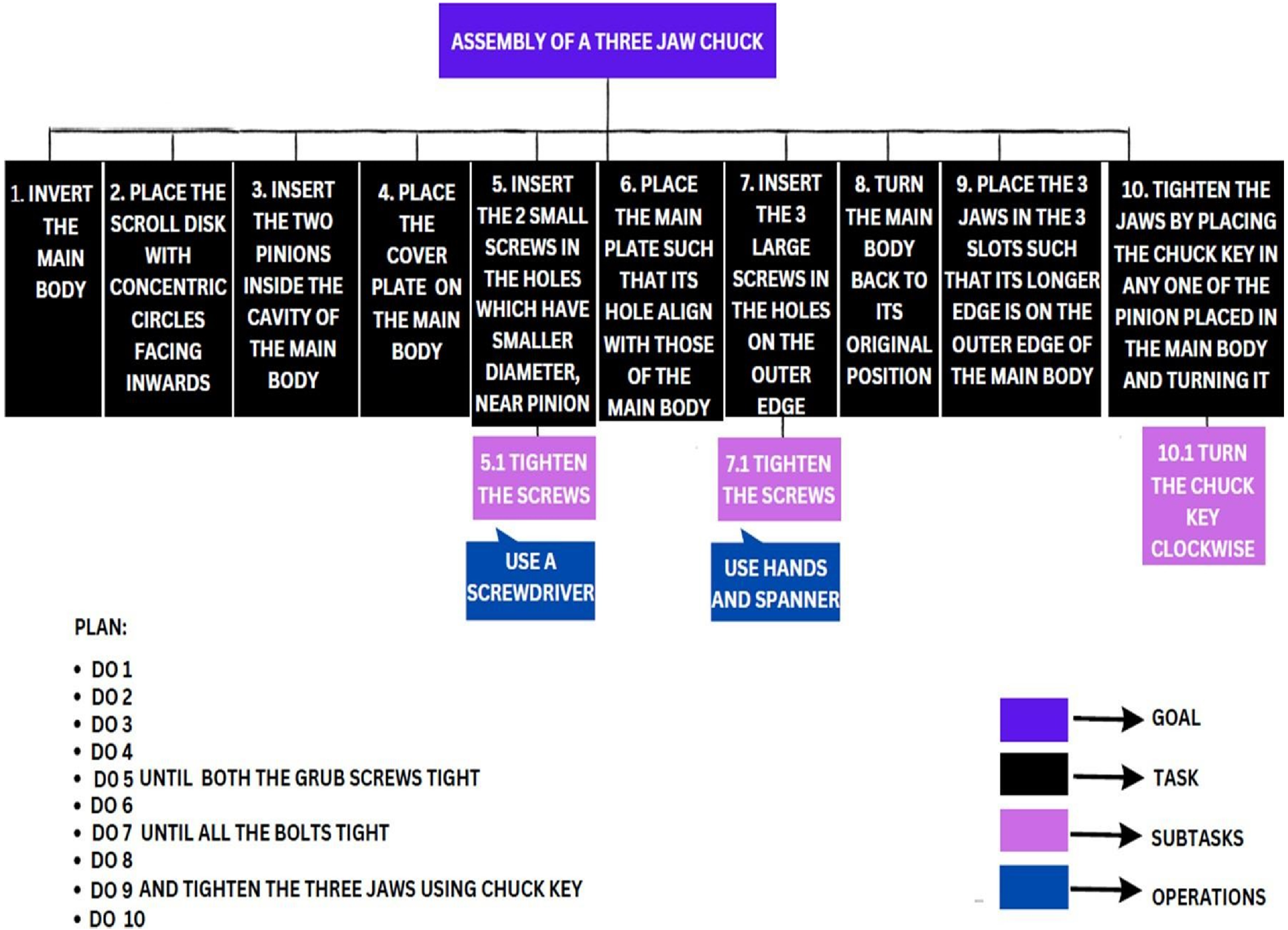

Figure 5. HTA for assembly of a 3-jaw chuck.

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3.5. Quantitative Analysis & Comparison of the Activty Performed

The readings obtained in both the phases are noted down for analysis. The below tables show the readings that are obtained before and after HTA implementation in the assembly of the 3-jaw chuck. This data helps us to plot graphs for each parameter thus helping for a better visual comprehension. The table belowis derived from the two phases mentioned previously, Phase 1 and Phase 2 which helps us identify the parameters that have decreased significantly after the implementation of HTA as shown in Figure 5, thus giving us an idea as to which parameterneeds to be focused upon while optimizing the process and hence eliminating the major contributor for increased cognitivework load.

Table 2. Parameter rating before HTA for 10 subjects.

SUBJECT	BEFORE HTA					
	MENTAL	PHYSICAL	TEMPORAL	PERFORMANCE	EFFORT	FRUSTRATION
SUBJECT 1	70	75	50	40	60	40
SUBJECT 2	50	100	70	60	100	20
SUBJECT 3	70	60	80	90	100	60
SUBJECT 4	80	90	90	75	40	40
SUBJECT 5	60	55	70	80	55	60
SUBJECT 6	80	50	80	80	90	60
SUBJECT 7	70	60	80	90	100	60
SUBJECT 8	80	100	70	80	90	60
SUBJECT 9	60	75	80	80	80	90
SUBJECT 10	50	35	80	80	40	50

Table 2 provides a comprehensive analysis of the workload experienced by ten subjects before the implementation of the Hierarchical Task Analysis (HTA) during the assembly of a three-jaw chuck. The cognitive workload is evaluated across 6 dimensions: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration. As seen fromthe table above, we can state that most of the subjects are not satisfied with their performance and all the ratings markedabove are based on subjective rating. Frustration levels, indicating emotional stress, range from 20 to 90, showing variability in how subjects coped emotionally with the task.

We can infer from Table 3 that there is a stark difference in the ratings of the parameters that is a testament as to how effective HTA as a tool is. If we compare the performance parameter of Table 3 with Table 2, we see that the subjects have given a betterperformance rating that ranges from 10 to 40. Mental Demand scores show a reduction, ranging from 20 to 60, indicating that the cognitive effort required has decreased for most subjects. Temporal Demand scores vary from 20 to 70, suggesting that thetime pressure felt by subjects has generally reduced, with some variation among individuals. Effort scores are more varied, withsome subjects reporting high effort (up to 100 for Subject 2) while others report significantly lower effort, highlighting individual differences in exertion required post-HTA. Frustrationlevels have generally decreased, with scores ranging from 5 to 30, indicating reduced emotional stress during the task. This datahighlights the positive impact of HTA on reducing both cognitive and physical demands, improving performance perceptions, and lowering frustration, thereby enhancing the overall efficiency and experience of the assembly process.

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Table 3. Parameter rating after HTA for 10 subjects.

SUBJECT	AFTER HTA					
	MENTAL	PHYSICAL	TEMPORAL	PERFORMANCE	EFFORT	FRUSTRATION
SUBJECT 1	50	50	40	20	60	30
SUBJECT 2	20	100	30	40	100	5
SUBJECT 3	50	60	50	20	60	30
SUBJECT 4	40	0	30	10	45	10
SUBJECT 5	20	25	25	15	15	10
SUBJECT 6	60	50	50	20	60	30
SUBJECT 7	60	50	50	20	60	30
SUBJECT 8	30	40	20	10	40	30
SUBJECT 9	40	75	40	15	40	10
SUBJECT 10	40	35	70	20	30	30

As seen in Table 4, before the HTA was applied, total workload scores ranged from 47.66 to 84.66. After the HTA implementation, these scores decreased across all subjects, with post-HTA workload scores ranging from 20.33 to 71. All the subjects saw a significant decrease in their workload with subject 5 experiencing the most significant reduction from 64.66 to 20.33. Similarly, Subject 4, and Subject 8 saw substantial decreases of 65.25% and 59.94%, respectively. On the other hand, Subject 2 had the smallest reduction, with an 8.18% decrease, showing a relatively modest drop in workload from 77.33 to 71. The subject answers the questionnaire table and we tally the number of times, each parameter has been selected which is multiplied with the given rating and in the case of before and after HTA, we calculate the total workload with the formula:

$$\text{Total Workload} = \sum(\text{Rating} * \text{Tally})15$$

$$\text{Percentage Decrease} = \frac{\text{Total Workload Before HTA} - \text{Total Workload After HTA}}{\text{Total Workload Before HTA}} * 100$$

Table 4. Percentage decrease in cognitive workload.

NAME	TOTAL WORKLOAD BEFORE HTA	TOTAL WORKLOAD AFTER HTA	PERCENTAGE DECREASE
SUBJECT 1	63.66	47.33	25.65
SUBJECT 2	77.33	71	8.18
SUBJECT 3	81.33	44	45.89
SUBJECT 4	78.66	27.33	65.25
SUBJECT 5	64.66	20.33	69.079
SUBJECT 6	80	46	42.5
SUBJECT 7	81.33	46	43.44
SUBJECT 8	84.66	34	59.94
SUBJECT 9	78.667	42.66	45.76
SUBJECT 10	47.66	37	22.36

The thorough analysis of HTA as tool for reducing the cognitive demand not only finds its usage in the manufacturing segment but also in other aligned fields like medical, military, aerospace etc. Further graphs can be plotted to provide a more intuitive understanding of the data.

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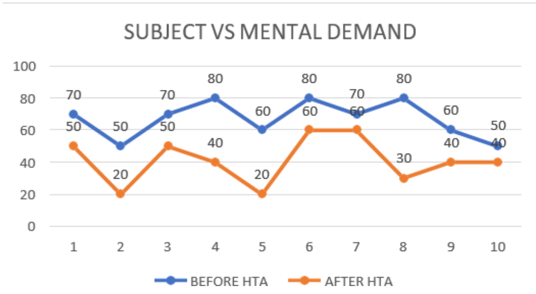

Figure 6. Subject vs Mental Demand.

This comparative line graph illustrates the impact on the mental demand before and after the application of Hierarchical Task Analysis (HTA) experienced by 10 subjects' during the assembly ofa three-jaw chuck. Before the use of HTA, the subjects' average mental demand was roughly 67, suggesting a significant cognitive load. On the other hand, following the implementation of HTA, mental demand dropped significantly, with values averaging about 40. HTA likely contributed to better task understanding, minimizederrors, and enhanced focus by breaking down the assembly processinto hierarchical steps.

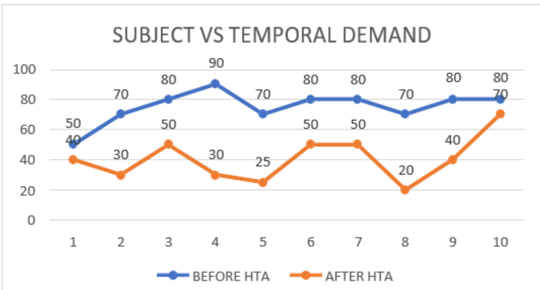

Figure 7. Subject vs Temporal Demand.

This comparative line graph illustrates the impact on temporaldemand before and after the application of Hierarchical Task Analysis (HTA) experienced by 10 subjects during the assembly of a three-jaw chuck. Before HTA implementation, the subjects experienced an average temporal demand of approximately 75,indicating substantial time pressure. Following the application of HTA, the temporal demand decreased significantly, with average values dropping to about 40.5 suggesting that the use of HTA likelyhelped streamline the assembly process by providing structured steps, thereby reducing time constraints and improving workflow efficiency.

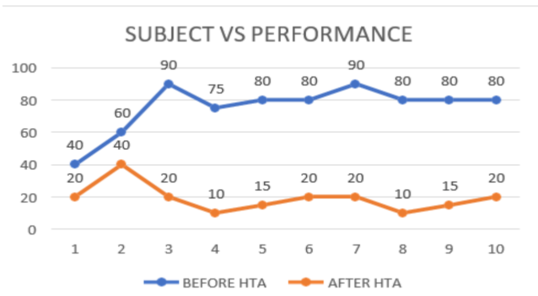

Figure 8. Subject vs Performance.

This comparative line graph illustrates the impact on performance before and after the application of Hierarchical Task Analysis (HTA)experienced by 10 subjects during the assembly of a three-jaw chuck. Before the implementation of HTA, the average performance level was 75.5, indicating poor satisfaction among the subjects withregard to their performance. After applying

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HTA, performance has improved significantly, averaging around 19, suggesting that HTA helped in decreasing the need for cognitive effort and improving overall consistency across subjects. Majorly, except for the first two subjects, most subjects reported being much more satisfied with their performance after the use of HTA.

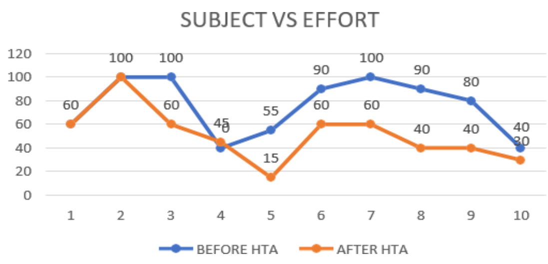

Figure 9. Subject vs Effort.

This comparative line graph illustrates the impact on effort before and after the application of Hierarchical Task Analysis (HTA)experienced by 10 subjects during the assembly of a three-jaw chuck. Subjects' effort levels before HTA deployment averaged roughly to 76, indicating high and varying levels of physical and cognitive exertion. Following the application of HTA, the average dramatically dropped to 49.5. Notably, a few subjects reported that their perceived effort remained relatively unchanged, indicating thatthe difference was not universally significant for everyone, yet stillevident for the majority.

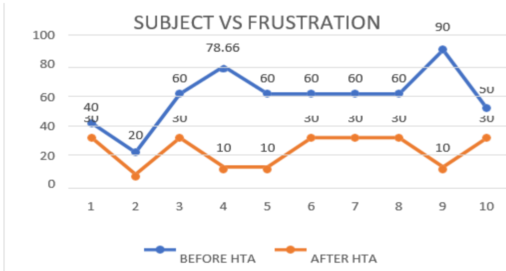

Figure 10. Subject vs Frustration.

This comparative line graph illustrates the impact on frustration levels before and after the application of Hierarchical Task Analysis(HTA) experienced by 10 subjects. Before the use of HTA, the subjects' reported high levels of frustration with an average of about 57.86, suggesting high emotional strain and discontent. After usingHTA, the average dropped to 23. Showing that the HTA has helpedreduce frustration. Notably, the majority of participants reported a significant decrease in frustration, demonstrating how HTA might improve the workplace, while few individuals reported equal levels of frustration before and after the intervention, suggesting that the impact, though significant, isn't entirely consistent.

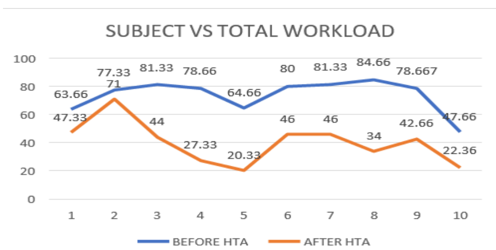

Figure 11. Subject vs Total Workload.

This comparative line graph illustrates the impact on total workload before and after the application of Hierarchical Task Analysis (HTA) experienced by 10 subjects. Before using HTA, individuals' workload levels were high, averaging about 73.8, indicating a considerable amount of mental and physical strain. The average workload decreased to roughly 40 after HTA was implemented, indicating that HTA successfully optimized the assembly process suggesting its efficiency as a technique for enhancing job satisfaction, lowering stress levels, and streamlining daily tasks.

4. Conclusion

In conclusion, the paper highlights about the significant impact of employing Hierarchical Task Analysis (HTA) in the assembly process of the 3-jaw chuck. By initially observing participants performing the assembly without reference to the HTA, followed by providing them with the Hierarchical task analysis, we observed a notable reduction in their overall workload. This decrease was evidenced by various parameters, as depicted in the graphs illustrating the before-and-after scenarios. The implementation of HTA not only streamlined the assembly process but also enhanced efficiency and accuracy. These findings underscore the importance of employing systematic task analysis methodologies like HTA in industrial settings to optimize workflow and productivity.

Our study elucidates the tangible benefits of incorporating Hierarchical task analyses into training programs or operational procedures. The clear delineation of steps provided by HTA facilitated a more systematic approach, reducing errors and minimizing the time required for completion. Additionally, the visual representation of workload parameters through graphs provided insightful quantitative evidence of the efficacy of HTA in enhancing task performance. Overall, our project underscores the practical utility of HTA as a valuable tool in improving operational efficiency and promoting a safer environment by decreasing the total workload of an individual or group.

By using a test case scenario of assembling a three-jaw chuck, HTA proves its efficiency for the manufacturing field in the assembly section by improving the overall quality of the work while decreasing the overall cognitive workload on the subject. It finds its application not only in the manufacturing sector but alsoin its allied fields like Aerospace, Nuclear Engineering and in themedical field as well.

Finally, industries must continually evaluate and improve their HTA implementation to adapt to changing needs and ensure lasting improvements in productivity and safety. By adopting HTA, industries can unlock its full potential to optimize operations, improve employee performance, and ultimately drivebusiness success.

In the age where precision and efficiency define success, HTA bridges the gap between complexity and clarity. By turning taskexecution into an art form, HTA enables industries to push boundaries, fostering a harmonious blend of human ingenuity and system precision. As we place more emphasis on human comfort within industries than ever before, Hierarchical Task Analysis proves to be an invaluable tool, acting as a catalyst for afuture where operational excellence evolves from an aspiration into an inherent reality, transforming the industrial capability landscape.

Ethical Statement

This study was conducted in compliance with all ethical standards as outlined by our institution and the broader research community. Informed consent was obtained from all participants involved in the assembly tasks, ensuring they were fully aware of the study's objectives and their voluntary participation. The participants' privacy, confidentiality, anddata protection were prioritized, and all collected data were anonymized to prevent any personal identification.

The study involved non-invasive activities focused on task performance and cognitive workload measurement using the NASA Task Load Index (NASA-TLX) during the assembly of a three-jaw chuck. No physical or psychological harm was posed to the participants, and all procedures were conducted in a controlled environment ensuring theirsafety and comfort.

Furthermore, this research did not involve any vulnerable populations, and no external funding or conflicts of interest influenced the study. The Hierarchical Task Analysis (HTA) used was strictly for the purpose of academic research to evaluate and optimize task efficiency. All protocols adhered to the ethical guidelines stipulated by the institution, and any unforeseen issues during the experiment were promptly addressed inaccordance with ethical standards.

This ethical compliance ensures that the study meets the integrity and rigor required for publication and contributes to the responsible conduct of research.

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