MENTAL WORKLOAD CALCULATION USING VACP METHOD AND DISCRETE EVENT SIMULATION

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Contents

Abstract

VACP stands for visual, auditory, cognitive & psychomotor. It is used to calculate the mental workload of different personnel at work. It was initially implemented by the US Armed forces. They started from the air force crew to check and reduce their workloads. VACP method is based on these four demands, and they equally contribute to predict the workloads of the specific individuals or crews. For VACP method, the environment is completely observed, and all attributes of the environment are created in the simulation software i.e., IMPRINT, IPME. The evaluation of VACP method is done based on the tasks and subtasks. The actual tasks are sub-divided into secondary tasks and every subtask has a rating from 0 to 7, where 7 being the highest. These subtasks are detailed steps being taken by the operator in connecting rod manufacturing process. Numerical values are rated considering the intensity of subtasks in the manufacturing of connecting rod and the workload experienced by the operator using the VACP standard chart. The ratings are separate for all four demands of the forty-two subtasks. The sum of all four demands is taken and is analyzed in the IPME software. Workload of three subtasks were found critical i.e., more than 27. The critical subtasks included holding heated metal with the help of tong, peel off extra corners and edges, and the grinding subtask. These critical subtasks were reduced using the workload reduction techniques i.e., parallel tasks, parallel operators, and automation. Workload of the subtasks were reduced using the techniques along with the reduced times and cost. Total workload of the tasks was reduced 15% and the time reductions was 30% using these techniques.

1. Introduction

VACP stands for visual, auditory, cognitive & psychomotor. It is one of the methods to calculate the mental workload of different personnel at work. VACP method was developed by McCracken & Aldrich back in 1984 and was initially implemented by the US Armed forces. They started from the air force crew to check and reduce their workloads. In the modern day it is also being implemented in the form of simulations for the workload calculations of different sectors. From the 90s, the calculations were analyzed on software and with time that software became better and better.

Back in 90s several methods to calculate the workload were proposed. Those methods were complex to adopt due to excess of tasks. Those task attributes were different levels of individual demands, the tasks to be completed in a specific time, and the competition between the non-individual demands. Twenty-two methods of estimating workload were compared to determine the values of these attributes. A workload evaluation can be a helpful tool in analyzing the concept behind the design of the equipment. This paper emphasizes on verifying which of these 22 methods is the most effective one developing and evaluating the design decisions. The study analyses the models by comparing them and concluded that all methods have different way of calculation, and the answers are approximately the same [18].

The purpose of this research is to signify the usage of an analytically generated workload model. To execute this, we explore different potential areas for the workload model that could not be effectively achieved using empirical measures alone. To be more certain, these thrust areas are presented in the context of the workload model, which cover phases before, during, and after task execution. The thrust areas are, specify workload for a task, distinguish how task & subtask management strategies have an impact on task achievement, examine anticipated effects of automation and system design, assess manpower allocations, and enhance physiological computing and neuro-ergonomic research.

In further development of VACP method, it was said to be that the method is based on a tailored version of the task analysis/workload (TAWL) methodology [19]. The first step in TAWL is to identify the important tasks which are necessary to run the system. Identifying the important task is also a challenge for the designer who is creating VACP IMPRINT model, because incorporating all the tasks will be difficult to calculate and waste the time. After the task selection, the operators completing that task are selected. Then the tasks are completed in a specific order. The system operator expert (SME) helps the designer to estimate the workload for every task. The system designer estimates the workload with the help of the mental resources which the operator uses and that are visual, auditory, cognitive, and psychomotor. When the system designer knows exactly which resources every operator utilized, then he comes up with numerical values that are scaled by the developers of VACP method. System designers have used the VACP workload option for several military applications to model the U.S. Army's Land Warrior system, to model joint base station variant (JBS VI) missions.

A VACP method was applied on a vehicle and there were 68 subtasks designed. These subtasks were rated while driving the vehicle and the mental workload was calculated. The ratings were validated from the US Army IMPRINT modeling tool. The most demanding tasks were calculated by adding their ratings. Demands levels of the subtasks were correlated i.e., visual, cognitive etc. Demands level had variation when driven on different roads, different ages, and gender of operators [22].

With the years passing and technology beings advanced. The workload calculations are being carried out of the drivers that are in autonomous driving conditions. Here the workload is increased because in autonomous driving the vehicle shifts the control to the human operator when it is difficult for the system, and that usually happens too quickly. It can be a sharp turn or a sudden braking situation too. Here the concentration level of operator is high which makes a higher workload. The system is divided into 6 levels. Level 0 is fully operator controlled and level 6 is the system controlled. The environment was completely simulated on the ProScan simulation tool. Nine secondary tasks were created but the operators were allowed to choose five of them. The ratings for the demands were calculated. The conclusion that was derived was that Driver's mental workload first decreases from level 0 to level 1 and then increases from level 1 to level 2, but level 2 causes lower mental workload than level 0 [8].

NASA-TLX is also a workload assessment tool which has six dimensions: mental, physical, temporal, frustration, performance, and effort. It was designed by NASA in three-year time by simulating more than 40 labs. NASA-TLX has a standard reading for every of its aspect and the workload is compared to the standard readings. There is a scale of 100 and the people rate their scores at an increment of 5. Then these scores are added and formed as weighted aggregate scores. This tool is helpful in narrowing down the potential sources for large workloads through its dimensionality.

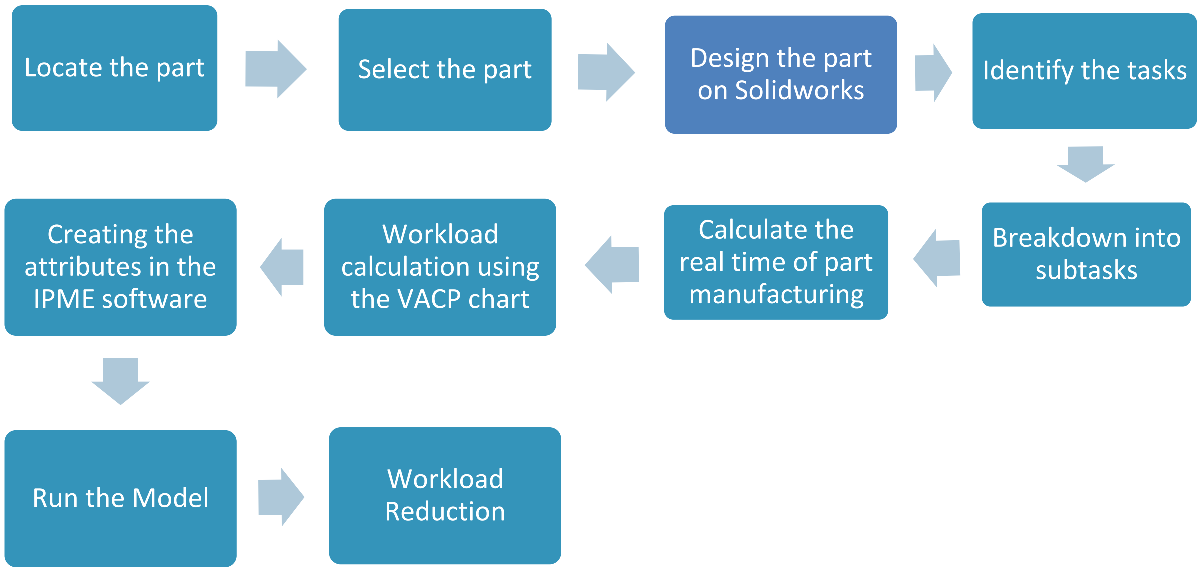
Taking in mind the different methods to calculate the mental workload. Discrete event simulation and VACP method were relatively new fields. In the manufacturing sector, VACP method was applied very less. Most of the research was conducted on the drivers and pilots using different simulation software. Autonomous and partially autonomous conditions were being tested in different research. Novelty of this research is to be implemented on the operators working on different machines. The use of IPME software is due to it being the domestic version of IMPRINT. IMPRINT is said to be the pioneer software in terms of workload calculation. It was developed back in 90s and it is getting improved with time. The improvement in the software is due to the demand of the technology. As the technology gets complex, the mental workloads on the operators keep on increasing.

2. Literature Review

The mental workload was determined by making workload profiles. IMPRINT software was used to find out the workload of five thrust area. Neuro ergonomics research was conducted and continuous estimation of workload was measured without affecting the worker efficiency [1]. The estimation of physical and neurological responses to find workload is through finding cognitive workload. This can be done experimentally by finding the brain activity using electroencephalography. This can be used regarding where spoken problem of operator [2]. The maximum VACP scores of subtasks are 28, if V, A, C and P as ranked as 7 each. The threshold value is 28, so workload should be less than 28 in our case, below 28 workload will be manageable with respect to operator [3]. The paper is about the study of methodology in which discrete event simulation was studied and implemented. Same method is used in this research. In this the method is used by find the critical tasks and VACP value and in IPME workload calculation was done. In this multi-tasking of a worker was implemented in IPME and identified critical tasks and then find workload with the help of IPME software. The excess workload was suggested in different ways to reduce the excess workload [4]. Discrete event simulation is utilized to determine the designs of workflow and process. All the workload attributes are validated to subjective workload questionnaires and physiological moments by operators executing the same task [5]. The man-power requirements can be determined using IMPRINT, while doing simulations. In this task performance and combined workload of team were evaluated using IMPRINT software and in output operator to system ratio was determined. Now a days, these researches are mainly focused on arm forces [6]. VACP method also implemented on evaluation of workload on pilots flying areophane's. These were than compare with SWAT analysis and workload experimentally measured by using questionnaire for VACP. Then VACP method was visually analyzed in software and was near to experimental workload measured by questionnaire [7]. Driver workload was analyzed using NASA-TLX software in which driver workload was compared with different levels of difficulty. Mental workload was also calculated while driving a car [8]. Mental workload was also calculated using OWAT (objective workload assessment technique) at traffic signals. Results revealed that traffic management can be done to reduce workload [9]. IMPRINT was used to evaluate the mental workload of driver, a discrete event simulation, using VACP method. This study investigated the driver workload simulation model to provide different mental workload of driver during different driving conditions [10]. NASA-TLX was used to measure the mental workload of driver using crossing different cars. VACP values are calculated and then compared with actual situations [11]. In nuclear power plants, emergency operation procedure is usually designed and considered to be a part of mental workload. Seven mental workloads were measured and critical were analyzed [12]. Driver cognitive requirement is measured using human performance model. Mental workload was measured for driver performance on different combinations using same simulations [13]. In some researches, mental workload was measured by improving some of the processes while assigning some tasks and regularly improvement in process. [14]. IPME software was used to make a tasks network model for Navy sonar subject matter expert. This network can be used in future if design or tasks were changed, so just by changing a model it can lead to different outputs of different situations of mental workload [15]. IMPE model was created for Ran aircraft crew condition to both fly the aircraft and UAVs simultaneously. The network model was created and results showed that 3 crew person can do this tasks rest all exceed the maximum VACP values which is critical and may cause damages in terms of property and increase mental workload [16]. Imprint software was used to analyze the unmanned air system. All the attributes of the system were incorporated in the IPME software [17]. In complex systems, to calculate operator’s workload is quite difficult. For this, different methods are compared and defined for different workload calculations [18]. To execute a mission, solders require weapons and equipment that lead them to extensive workload. To assess their mental workload, VACP method was used and system designers conducted the research and found suitable systems and situations in which they can provide relief to solders [19]. The train driver was also examined with the help of VACP method to find the mental workload. In this, driver’s interaction with infrastructure was evaluated and model was created to quantify driver’s performance in relation to infrastructure and in operational conditions [20]. Some part of research is done while observing different tasks, workload was calculated and different OWAT (objective workload assessment technique) were used. Results show that mental workload can be optimized and formulated [21].

3. Methodology

To calculate the mental workload of the operators, the procedure used was a thorough one. It covered all the aspects which could be incorporated to calculate the workload. The comprehensive method consisted of the following steps:



3.1 Locate the part

First challenge was to look of a part or a product which requires more operator's interference. It should be a complex part in which operator feels intense workload. It should be a part which has parallel operations and requires more operators. Simple or generic product won't have higher workloads. The part that had less than fifty subtasks was to be selected due to the limitation of the software that had to be used. Locating the part is just like market survey before manufacturing a product. A comprehensive search was done to find the part which needed to be selected.

3.2 Select the part

Part location being a comprehensive process, some of the parts were selected but being too simple and generic they were rejected. Initially, piston and connecting rod's assembly was selected as a process to be considered but due to limitations of resources I had to select connecting rod as a final part on which the workloads were to be calculated.

Figure 1: An image of a connecting rod

Connecting rod had that complexity which met my required specifications. Connecting rod's manufacturing process required delicacy and proper surface finish which makes it a perfect fit for my research.

3.3 Design the part

Designing of the part was done on the designing software SOLIDWORKS. A solid modeling computer-aided design and computer-aided engineering program. SOLIDWORKS is widely used in different sectors of designing, manufacturing, research and development, modeling, planning, assembling, feasibility assessment, prototyping, and project management. Being a user-friendly software, it was easy for me to design the connecting rod with all that details and depth complexities.

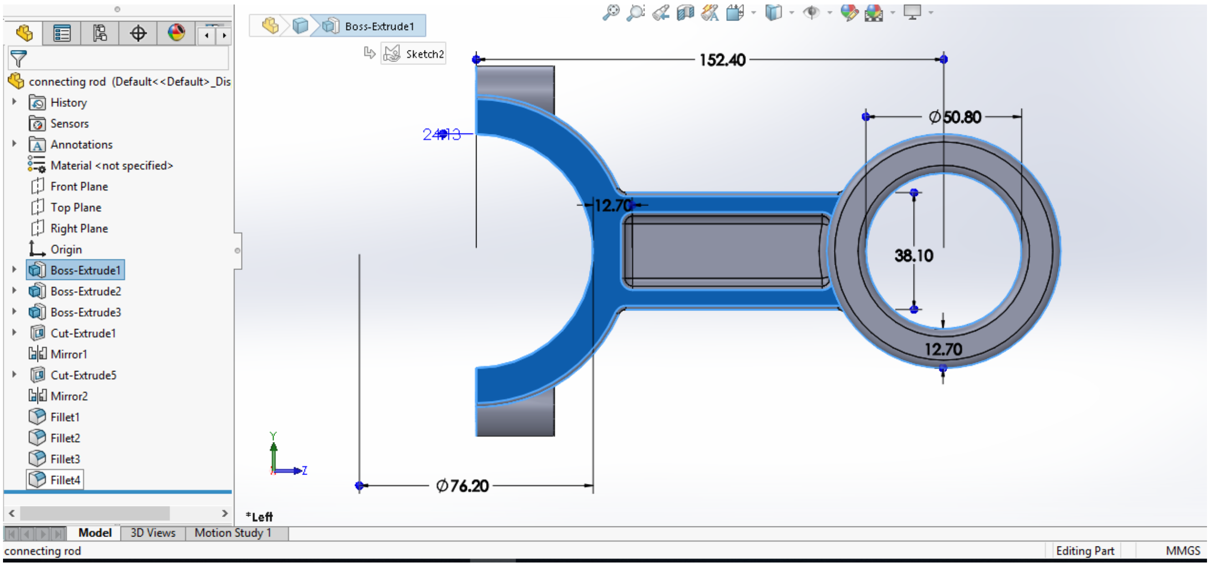


Figure 2: A design of the connecting rod in Solidworks

It was designed on the standard measurements and specifications used throughout the manufacturing industries in the world. Designing was according to the selected manufacturing process and tasks. It was not the fixed hole on the shorted end of the connecting rod, instead it was had tight-able bolt holes on the short side of the connecting rod.

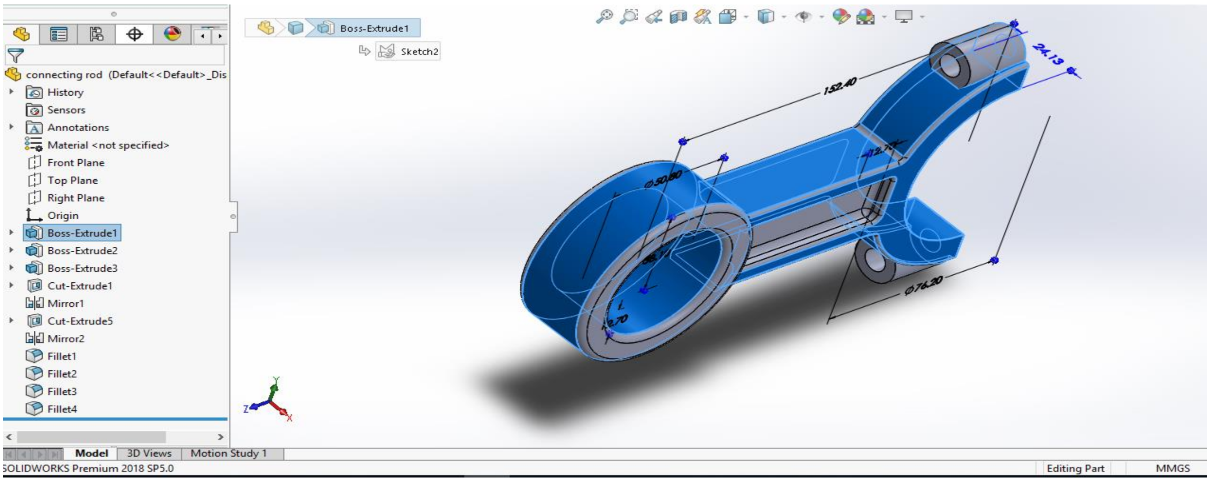


Figure 3: A design of the connecting rod in Solidworks

3.4 Identify the tasks

As the method being implemented is operator oriented so the connecting rod manufacturing is sorted out into the tasks. All the tasks are classified into the sequence of their manufacturing. Some tasks require machining, and some are done by conventional methods. The breakdown of tasks is validated from different resources and discussed and approved by the NUST MRC experts. Total number of tasks were eleven. The task breakdown is as follows:

- Cutting of material with help of hacksaw machine
- Heating billets at 500-600°C
- Drop forge the metal
- Piercing
- Trimming
- Shot peening
- Grinding the surfaces
- Drilling bolt holes
- Make internal grooves for bolts
- Intersection of bearing shells and bushes
- Inspection

3.5 Breakdown into subtasks

After the identification of tasks, those tasks are further divided into subtasks. Those subtasks include every moment being done by the operator. The subtasks are precisely broken so that they cover all the aspects of the connecting rod manufacturing. Every subtask is properly sequenced according to the order of manufacturing. Total subtasks are forty-three and are properly organized according to the software's requirement. The purpose of the choosing connecting rod is due to the subtasks being in the range of the software's limit. The subtasks are as follows:

	Process	
Main Task	**Cutting of material with help of hacksaw machine**	
	Sub Task	Measure the cut dimensions
		Mark the cut dimensions
		Clamp the metal
		Start the hacksaw cutting
		De-clamp the metal
	Process	
Main Task	**Heating billets at 500-600°C**	
	Sub Task	Switch the furnace on
		Set the required temperature
		Put the metal inside the furnace with help of tong
		Heating inside the furnace
		Shifting towards the drop forging machine
	Process	
Main Task	**Drop forge the metal**	
	Sub Task	Hold heated metal with tong while press machine strikes
		Lubricate quickly
		Change the sides in quick successions
		Pass the connecting rod to cooling bay
	Process	
Main Task	**Piercing**	
	Sub Task	Switch the punching machine on
		Fix the punch of the required hole dimensions
		Put the rod against the punch
		Lubricate and shift it to the next station for trimming
	Process	
Main Task	**Trimming**	
	Sub Task	Switch the grinding machine on
		Peel off the extra corners and edges
		Visually inspect and switch the machine off

	Process	
Main Task	**Shot peening**	
	Sub Task	Switch the peening machine on
		Open the peening box in which rods are kept
		Provide values to the machine
		Take out the peened rods and visually inspect
	Process	
Main Task	**Grinding the surfaces**	
	Sub Task	Start the grinder
		Grind the side faces where required
		Visually inspect and switch the machine off
	Process	
Main Task	**Drilling bolt holes**	
	Sub Task	Mark the position on which drilling is to be done
		Clamp the rod on the working table of drill
		Switch the drill on
		Drill bolt hole of required shape
		Lubricate and change the side of the rod
		Drill bolt hole on second side
		De-clamp the rod and pass it after visual inspection
	Process	
Main Task	**Make internal grooves for bolts**	
	Sub Task	Fix the internal grooving tool in toolbar of milling machine
		Clamp the connecting rod
		Set the feed and start groove cutting
		Lubricate and then change the side, cut the second groove
		Visually inspect and shift to next bay
	Process	
Main Task	**Intersection of bearing shells and bushes**	
	Sub Task	Place bearing shell on larger end
		Press the bearing shell after proper placing
	Process	
Main Task	**Inspection**	

Table 1: Subtasks for the manufacturing of connecting rod

3.6 Measure the real time of part manufacturing

Real times were taken for each subtask. Times were taken in terms of minutes. Each subtask's time was taken from the applied research and was approved by the experts of NUST MRC. The real times of subtasks are as follows:

			Time (m)
	Process		
Main Task	**Cutting of material with help of hacksaw machine**		**20 min**
	Sub Task	Measure the cut dimensions	2
		Mark the cut dimensions	3
		Clamp the metal	3
		Start the hacksaw cutting	10
		De-clamp the metal	2
	Process		
Main Task	**Heating billets at 500-600°C**		**60 min**
	Sub Task	Switch the furnace on	0.5
		Set the required temperature	1.5
		Put the metal inside the furnace with help of tong	3
		Heating inside the furnace	50
		Shifting towards the drop forging machine	5
	Process		
Main Task	**Drop forge the metal**		**25 min**
	Sub Task	Hold heated metal with tong while press machine strikes	12
		Lubricate quickly	1
		Change the sides in quick successions	10
		Pass the connecting rod to cooling bay	2
	Process		
Main Task	**Piercing**		**15 min**
	Sub Task	Switch the punching machine on	2
		Fix the punch of the required hole dimensions	8
		Put the rod against the punch	4
		Lubricate and shift it to the next station for trimming	1
	Process		**Time (m)**
Main Task	**Trimming**		**5 min**
	Sub Task	Switch the grinding machine on	0.5
		Peel off the extra corners and edges	2.5
		Visually inspect and switch the machine off	2
	Process		
Main Task	**Shot peening**		**10 min**
	Sub Task	Switch the peening machine on	1
		Open the peening box in which rods are kept	2
		Provide values to the machine	5

		Take out the peened rods and visually inspect	2
	Process		
Main Task	**Grinding the surfaces**		**54 min**
	Sub Task	Start the grinder	1
		Grind the side faces and also where required	50
		Visually inspect and switch the machine off	3
	Process		
Main Task	**Drilling bolt holes**		**30 min**
	Sub Task	Mark the position on which drilling is to be done	4
		Clamp the rod on the working table of drill	3
		Switch the drill on	1
		Drill bolt hole of required shape	7
		Lubricate and change the side of the rod	2
		Drill bolt hole on second side	7
		De-clamp the rod and pass it after visual inspection	6
	Process		
Main Task	**Make internal grooves for bolts**		**60 min**
	Sub Task	Fix the internal grooving tool in toolbar of milling machine	5
		Clamp the connecting rod	5
		Set the feed and start groove cutting	20
		Lubricate and then change the side, cut the second groove	25
		Visually inspect and shift to next bay	5
	Process		
Main Task	**Intersection of bearing shells and bushes**		**10 min**
	Sub Task	Place bearing shell on larger end	5
		Press the bearing shell after proper placing	5
	Process		
Main Task	**Inspection**		**10 min**

Table 2: Subtasks for the manufacturing of connecting rod

3.7 Workload calculation using the VACP Chart

VACP chart was developed by McCraken and Aldrich back in 1984. It is a standard chart in which seven demand levels of VACP are given. Researchers compare their subtasks with those chart values. In VACP method, the researcher can use any of the four demands i.e., visual, auditory, cognitive, psychomotor or the combined demands of any of these. After the selection of operators, tasks, subtasks, and times. The researcher incorporates the number values of the resources from the VACP chart. The VACP chart is as follows:

Visual

0.0 No visual activity
1.0 Visually register, detect occurrence
3.7 Visually discriminate
4.0 Visually inspect / check
5.0 Visually locate / align
5.4 Visually track / follow
5.9 Visually read (symbol)
7.0 Visually scan / search / monitor

Auditory

0.0 No auditory activity
1.0 Detect / register sound
2.0 Orient to sound (general)
4.2 Orient to sound (selective)
4.3 Verify auditory feedback
4.9 Interpret semantic content (speech)
6.6 Discriminate sound characteristics
7.0 Interpret sound patterns

Cognitive

0.0 No cognitive activity
1.0 Automatic, simple association
1.2 Alternative selection
3.7 Sign / signal recognition
4.6 Evaluation / judgement
5.3 Encoding / decoding, recall
6.8 Evaluation / judgement
7.0 Estimation, calculation, conversion

Psychomotor

0.0 No psychomotor activity
1.0 Speech
2.2 Discrete actuation
2.6 Continuous adjustment
4.6 Manipulative adjustment
5.8 Discrete adjustment
6.5 Symbolic production (writing)
7.0 Serial discrete manipulation (keyboard entries)

Figure 4: VACP standard values chart

The subtasks are validated using the VACP chart above and the subtasks are assigned the values accordingly:

	Process		**V**	**A**	**C**	**P**
Main Task	**Cutting of material with help of hacksaw machine**					
	Sub Task	Measure the cut dimensions	4.0	0.0	7.0	2.6
		Mark the cut dimensions	4.0	0.0	1.0	4.6
		Clamp the metal	1.0	0.0	0.0	5.8
		Start the hacksaw cutting	1.0	0.0	0.0	2.2
		De-clamp the metal	1.0	0.0	0.0	5.8
	Process		**V**	**A**	**C**	**P**
Main Task	**Heating billets at 500-600°C**					
	Sub Task	Switch the furnace on	1.0	0.0	0.0	2.2
		Set the required temperature	4.0	0.0	7.0	2.2
		Put the metal inside the furnace with help of tong	5.0	0.0	6.8	5.8

		Heating inside the furnace	4.0	0.0	0.0	2.2
		Shifting towards the drop forging machine	5.0	0.0	6.8	5.8
	Process		**V**	**A**	**C**	**P**
Main Task	**Drop forge the metal**					
	Sub Task	Hold heated metal with tong while press machine strikes	7.0	7.0	7.0	7.0
		Lubricate quickly	1.0	0.0	1.0	2.2
		Change the sides in quick successions	5.0	0.0	6.8	5.8
		Pass the connecting rod to cooling bay	1.0	0.0	4.6	5.8
	Process		**V**	**A**	**C**	**P**
Main Task	**Piercing**					
	Sub Task	Switch the punching machine on	1.0	0.0	0.0	2.2
		Fix the punch of the required hole dimensions	5.0	0.0	4.6	5.8
		Put the rod against the punch	5.0	0.0	4.6	5.8
		Lubricate and shift it to the next station for trimming	1.0	0.0	1.0	4.6
	Process		**V**	**A**	**C**	**P**
Main Task	**Trimming**					
	Sub Task	Switch the grinding machine on	1.0	0.0	0.0	2.2
		Peel off the extra corners and edges	7.0	7.0	7.0	7.0
		Visually inspect and switch the machine off	4.0	0.0	6.8	2.2
	Process		**V**	**A**	**C**	**P**
Main Task	**Shot peening**					
	Sub Task	Switch the peening machine on	1.0	0.0	0.0	2.2
		Open the peening box in which rods are kept	1.0	0.0	1.0	2.2
		Provide values to the machine	4.0	0.0	1.0	2.2
		Take out the peened rods and visually inspect	4.0	0.0	6.8	4.6
	Process		**V**	**A**	**C**	**P**
Main Task	**Grinding the surfaces**					
	Sub Task	Start the grinder	1.0	0.0	0.0	2.2
		Grind the side faces and also where required	7.0	7.0	7.0	7.0
		Visually inspect and switch the machine off	4.0	0.0	6.8	2.2
	Process		**V**	**A**	**C**	**P**
Main Task	**Drilling bolt holes**					
	Sub Task	Mark the position on which drilling is to be done	4.0	0.0	1.0	4.6
		Clamp the rod on the working table of drill	1.0	0.0	0.0	5.8
		Switch the drill on	1.0	0.0	0.0	2.2
		Drill bolt hole of required shape	5.0	0.0	7.0	5.8
		Lubricate and change the side of the rod	5.0	0.0	1.0	2.2
		Drill bolt hole on second side	5.0	0.0	7.0	5.8
		De-clamp the rod and pass it after visual inspection	4.0	0.0	6.8	4.6
	Process		**V**	**A**	**C**	**P**
Main Task	**Make internal grooves for bolts**					
	Sub Task	Fix the internal grooving tool in toolbar of milling machine	1.0	0.0	0.0	5.8

		Clamp the connecting rod	1.0	0.0	0.0	5.8
		Set the feed and start groove cutting	5.0	0.0	6.8	5.8
		Lubricate and then change the side, cut the second groove	5.0	0.0	6.8	5.8
		Visually inspect and shift to next bay	4.0	0.0	6.8	4.6
	Process		**V**	**A**	**C**	**P**
Main Task	**Intersection of bearing shells and bushes**					
	Sub Task	Place bearing shell on larger end	5.0	0.0	4.6	2.2
		Press the bearing shell after proper placing	1.0	0.0	1.0	2.2
	Process		**V**	**A**	**C**	**P**
Main Task	**Inspection**		4.0	0.0	6.8	4.6

Table 3: Subtasks for the manufacturing of connecting rod

3.8 Creating the attributes in the IPME Software

IPME stands for Integrated Performance Modelling Environment. IPME is the domestic version of IMPRINT. IPME is a Unix-based integrated environment of simulation and modeling. It provides representation of humans in complex environments. It has a user-friendly graphical user interface. IPME provides a full-featured discrete event simulation environment built on the Micro Saint modeling software. It includes all the aspects required to be simulated in a manufacturing environment. It is a discrete event simulation software covering all the aspects of my research.

The sequence of the attributes to be programmed in the software are same as that of the methodology. Starting from the tasks, subtasks, real times and then the VACP values. Tasking and sub-tasking flow chart drawn in the software is given below:

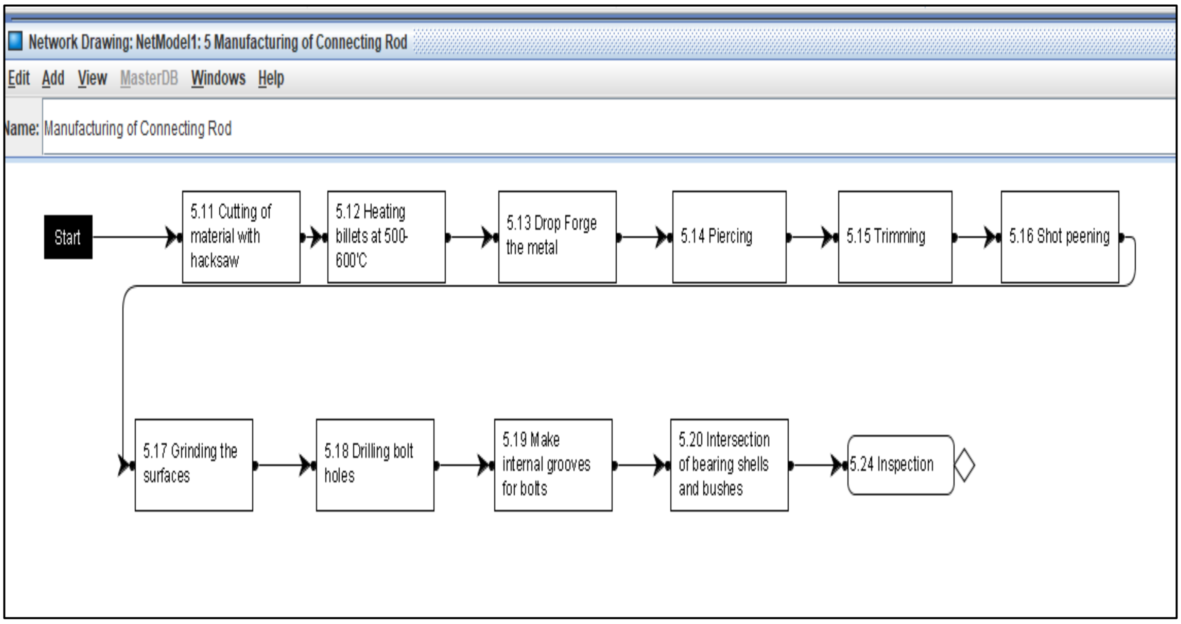


Figure 5: Task flow chart in the IPME software

By clicking on the task, the subtask of that task will appear. Subtasks are termed as networks in the software. Every network is connected to the next network using the routes. The flow chart of the first subtask "cutting of material with hacksaw" is as follows:

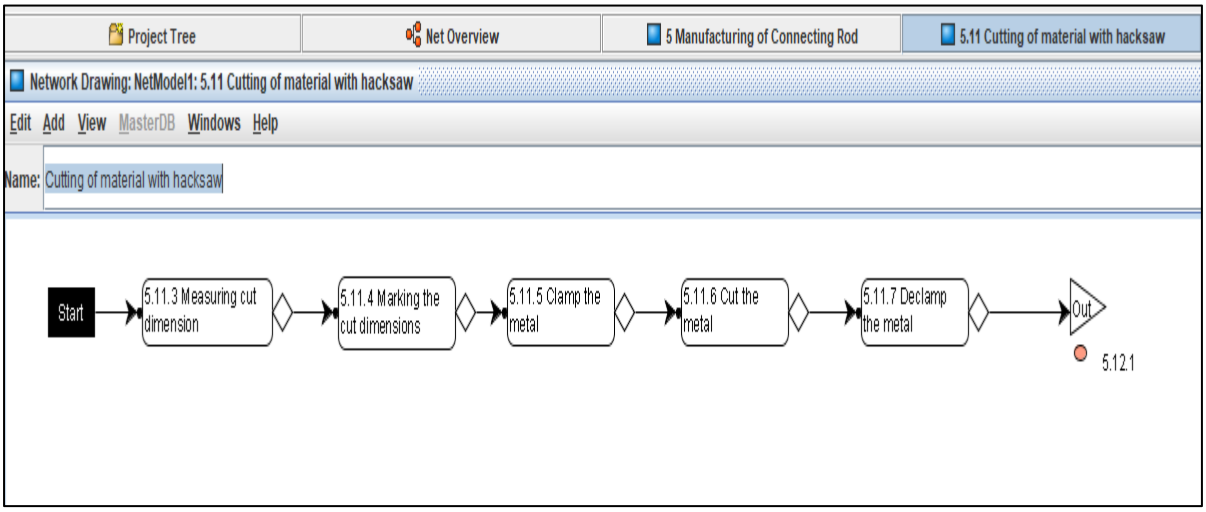


Figure 6: Subtask flow chart in IPME software

Every subtask has a further window of attributes in which the values of VACP i.e., visual, auditory, cognitive, and psychomotor are assigned according to the relevant subtask. Mean time along with the standard deviation is also assigned in this window. Mean time is the time taken to complete that subtask whereas standard deviation is the permissible deviation from the true value. The attributes sheet of the subtasks is as follows:

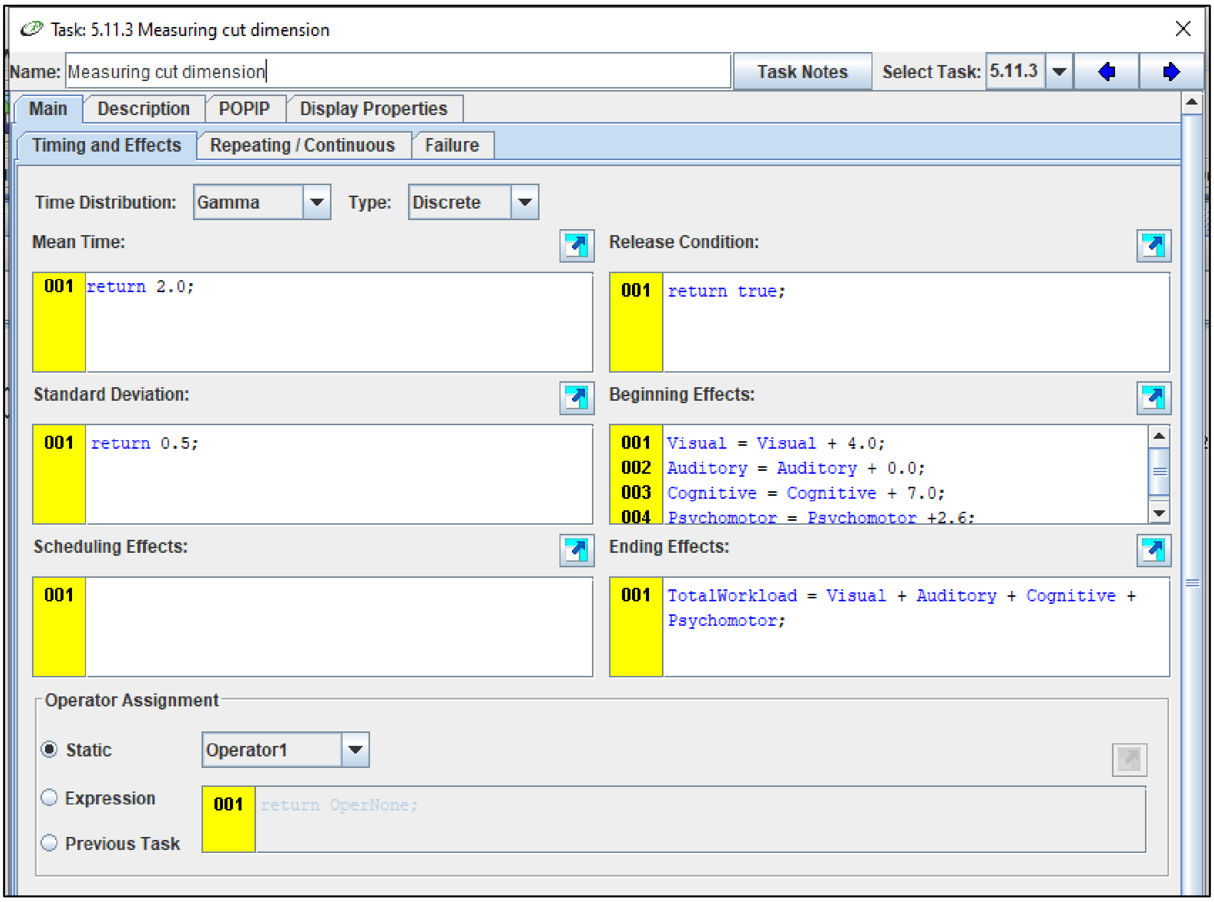


Figure 7: The programming attributes of every subtask

At the end of every subtask, total workload is added by adding all four workload demands. That total workload is generated in the results file where workloads of all subtasks are incorporated.

3.9 Run the Model

After completing the attributes in the IPME, errors were checked, and a simulation was run to get the workloads of every subtask. Modeling was done for every subtask and results for each subtasks appeared separately. Workloads of those tasks were to be reduced whose VACP values exceeded 27. The results from the simulation were as follows:

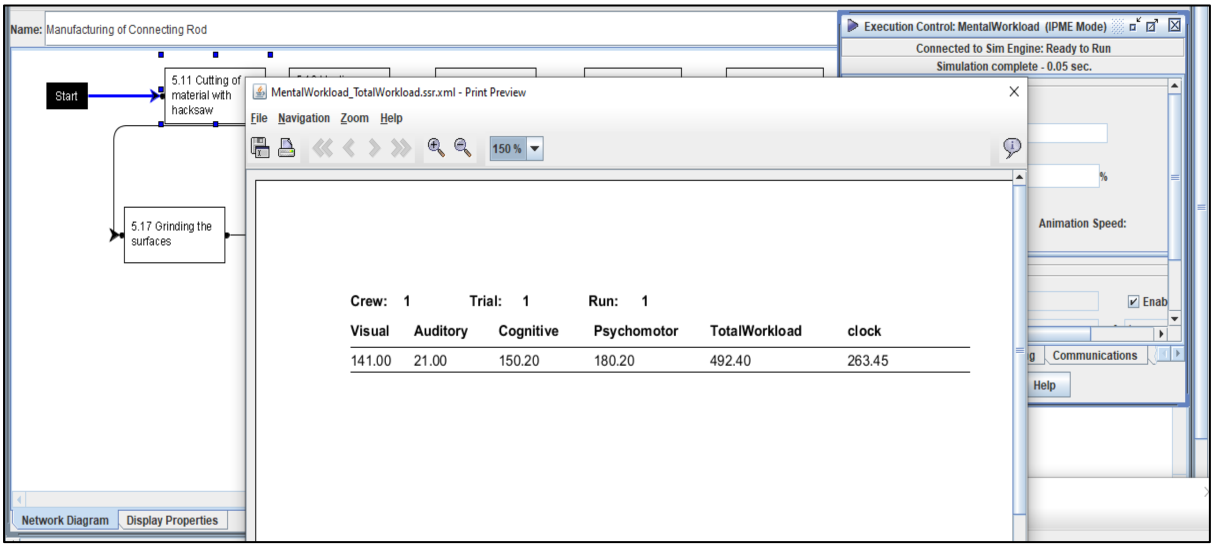
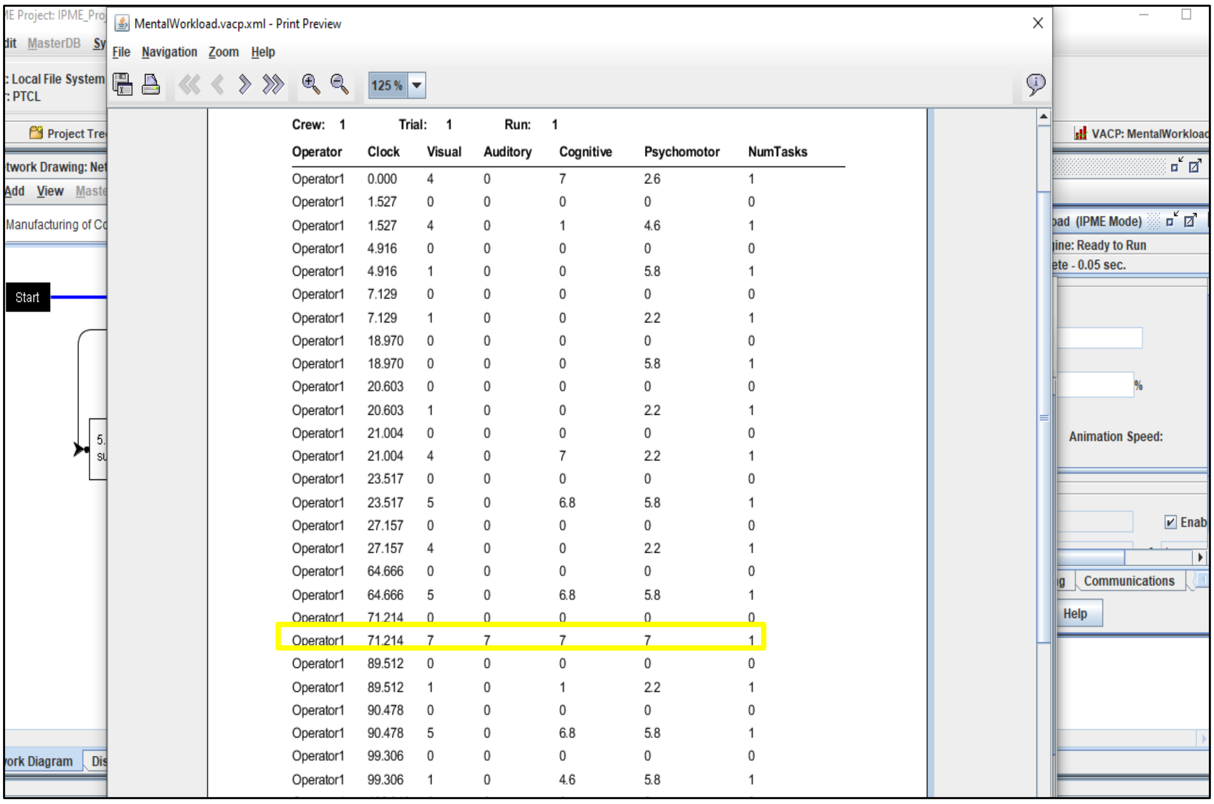
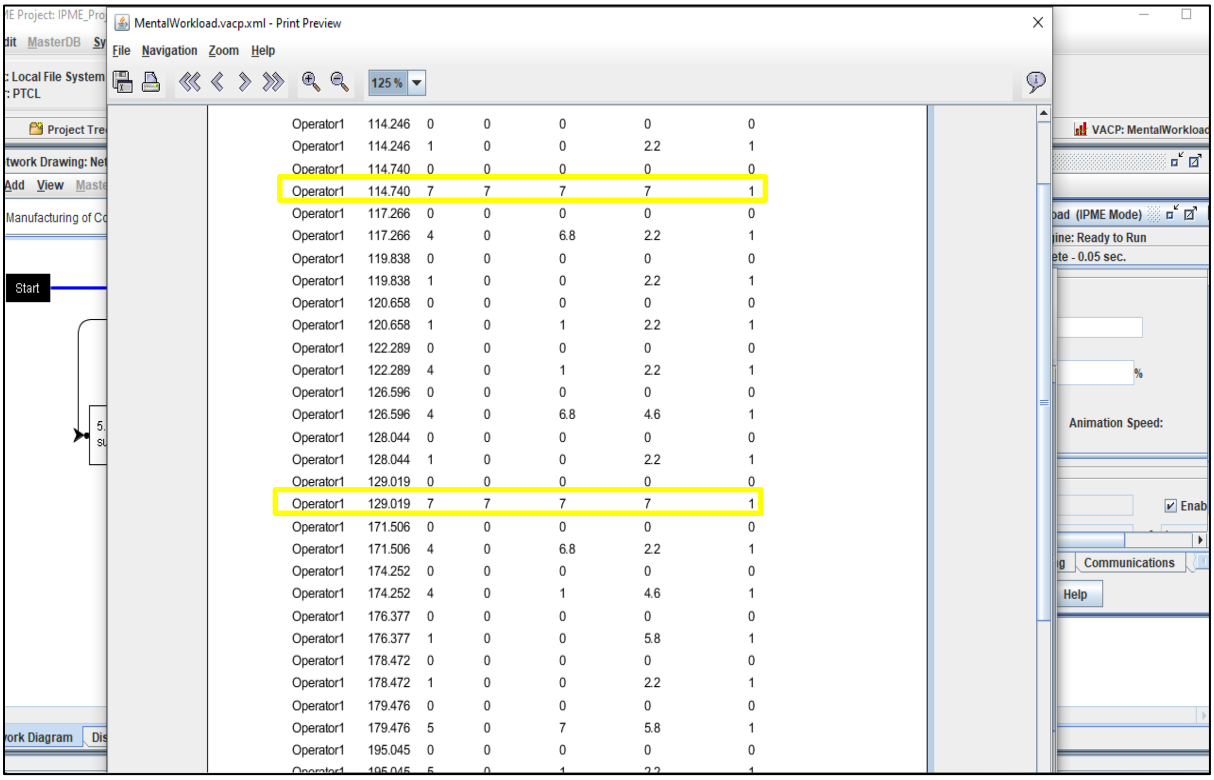


Figure 8: Results of the simulation for the novice operator

3.9.1 Workloads values of every task along with the time when executed





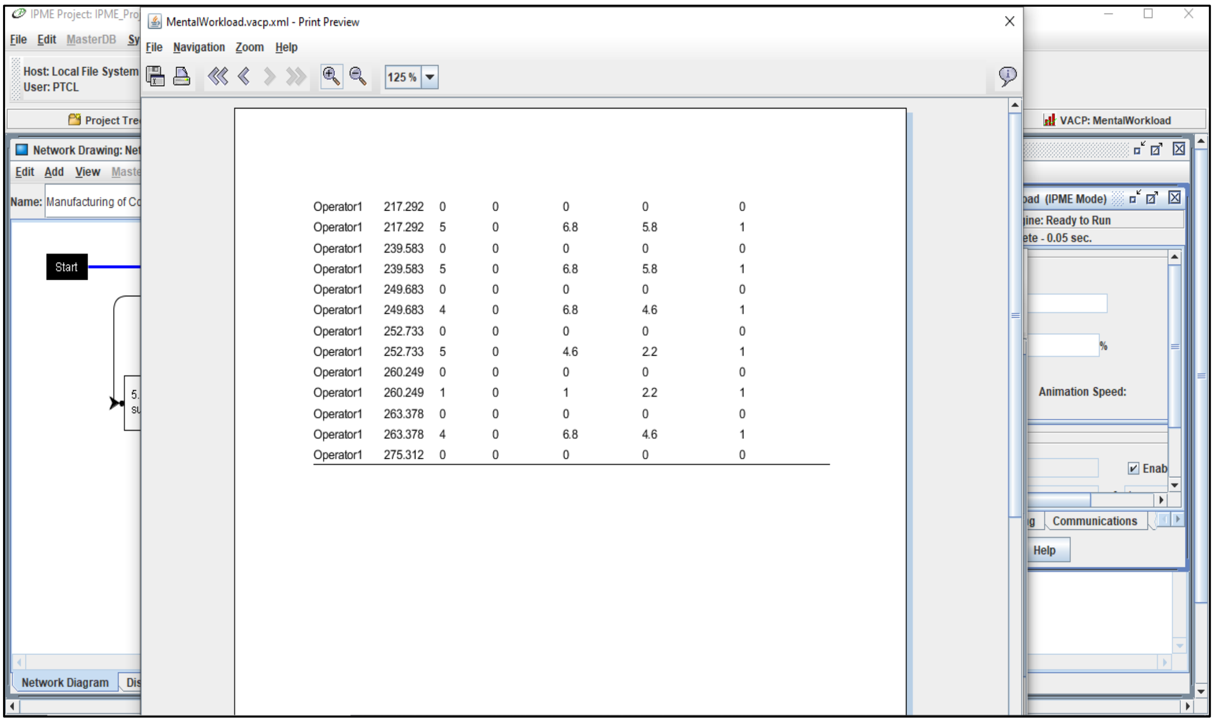


Figure 9: Workload values and times of the subtasks

From the above results of the simulation. Three subtasks were found to be critical. Three subtasks had the higher workloads than 27. Three of the critical tasks for the novice operator were:

- Holding the heated metal with the tong while the forging hammer strikes
- Trimming operation
- Grind the side faces where required

These were the tasks that required workload reduction and optimization too. Workload reduction techniques were to be implemented and a reduced outcome is expected out of it.

3.9.2 Graphical Representation of the results

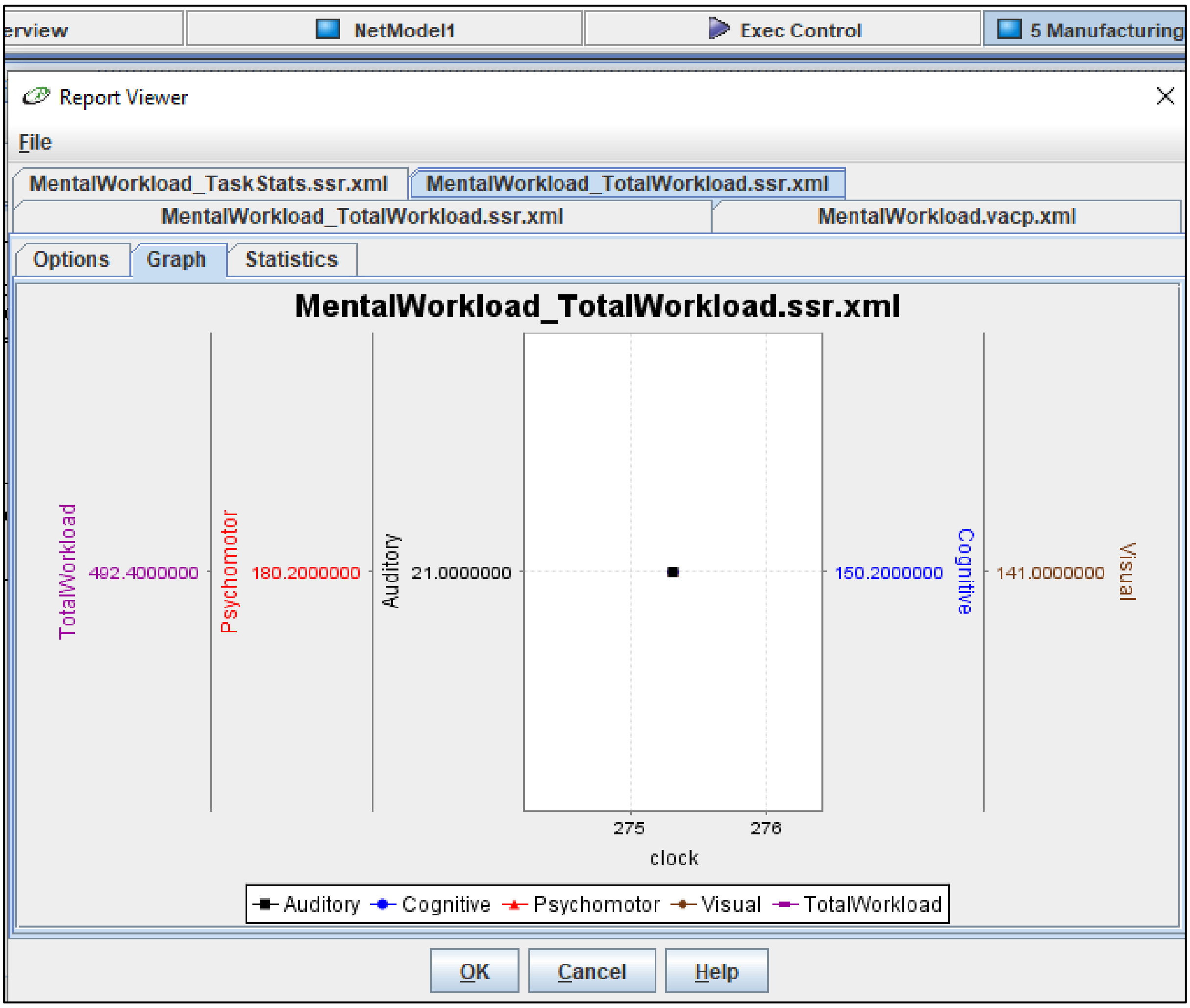


Figure 10: Graphical results of the simulation for novice operator

3.9.3 Final Report of the simulation

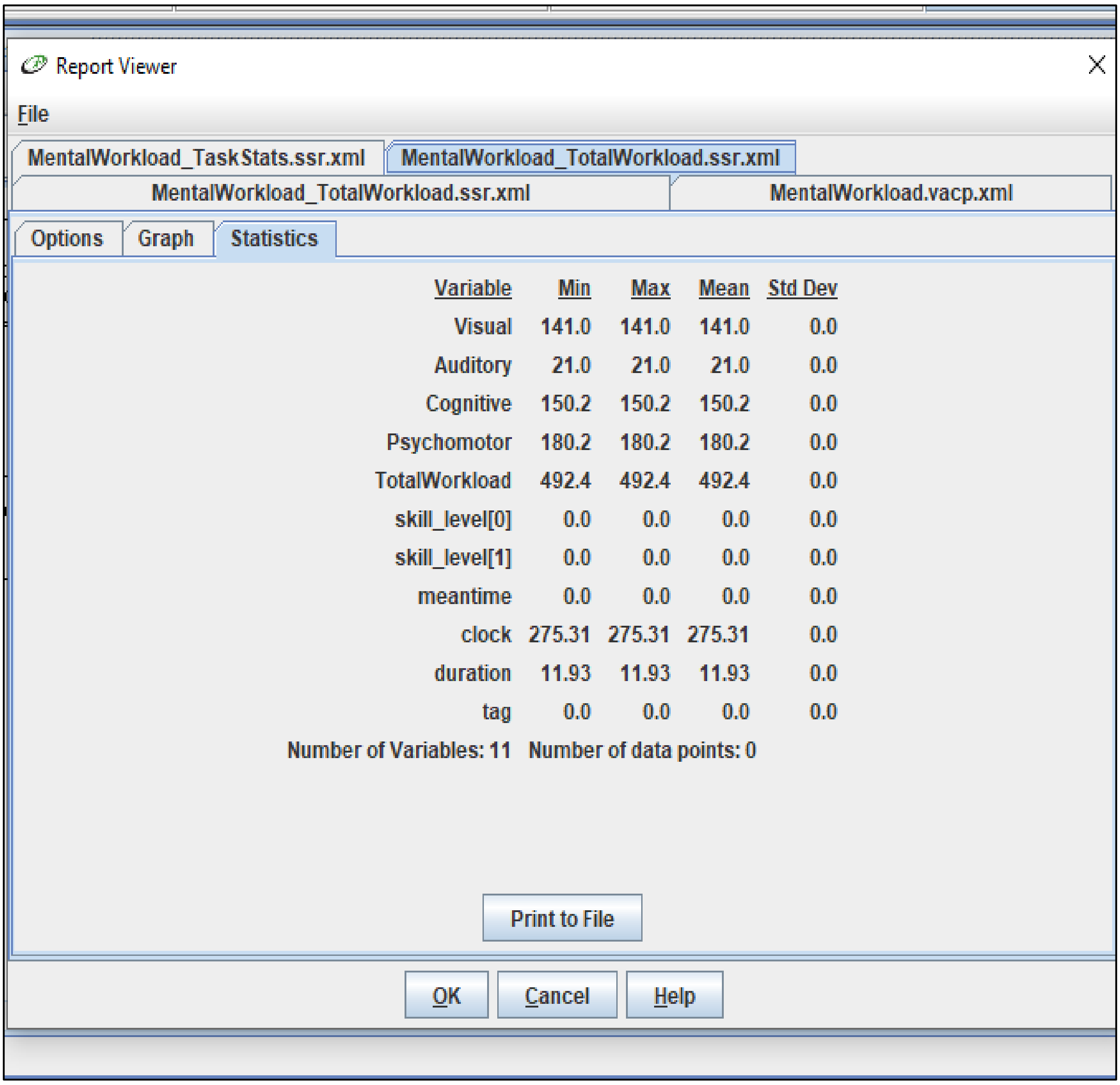


Figure 11: Complete result of the simulation for the novice operator

3.10 Comparison between novice and expert operator

The workload experienced by a novice and an expert user aren't the same. Expert user gets an extra edge of his hands on experience on the machine or the subtask. A comparison was drawn between a novice and an expert operator. The expert user takes lesser time to complete the task than the novice user. Ultimately the workload of the expert also reduces with the reduced time. The results of the simulation are as follows:

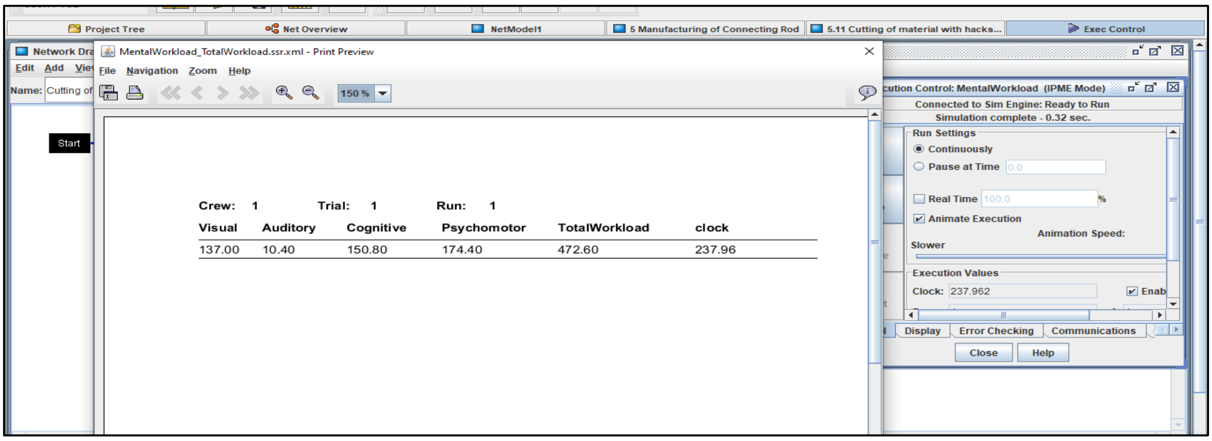
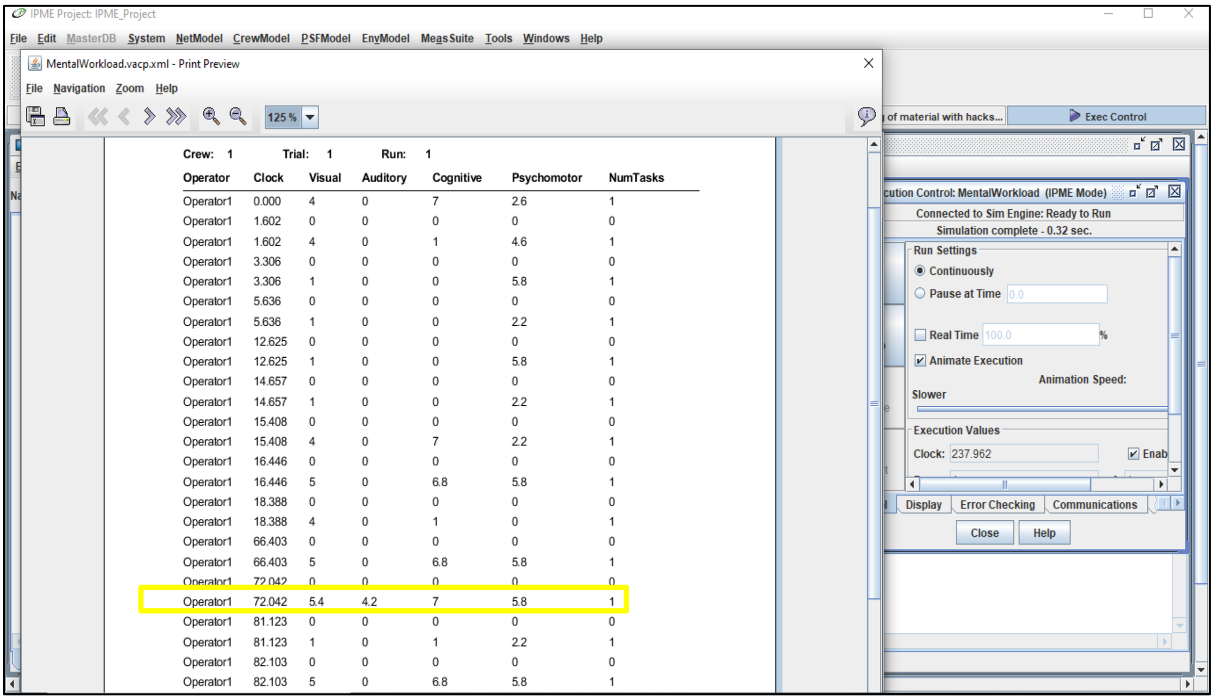
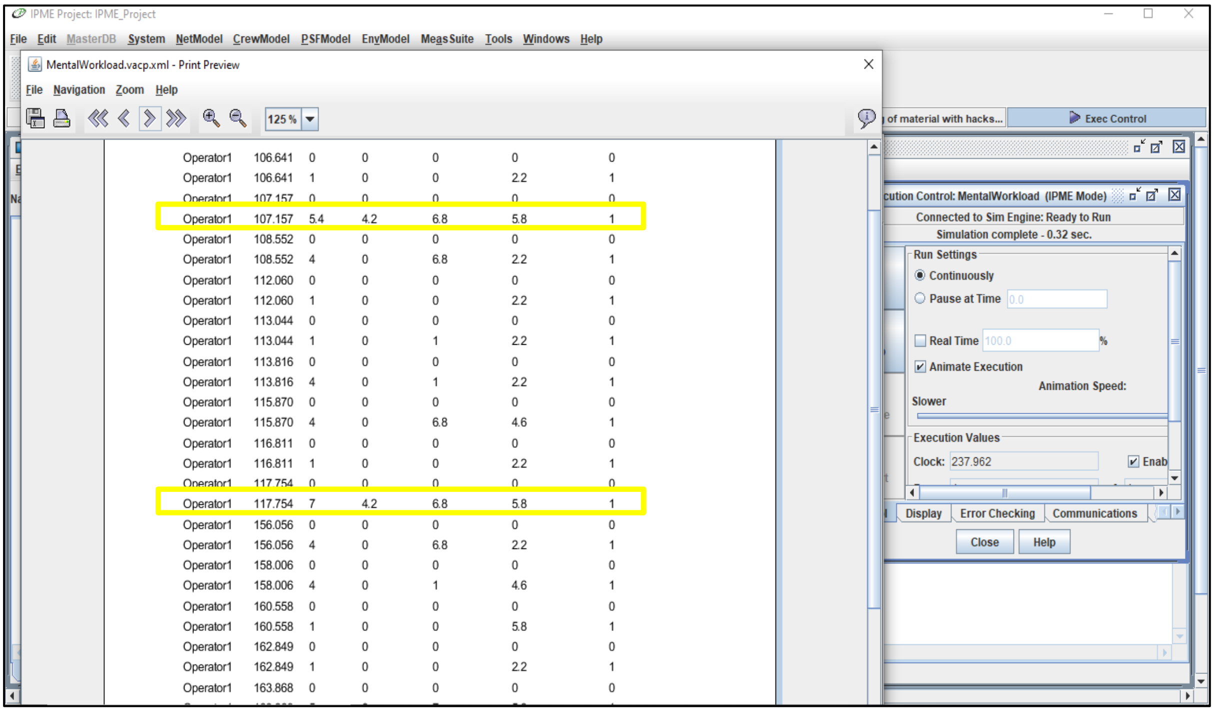


Figure 12: Results of the simulation for expert operator

3.10.1 Workloads values of every task along with the time when executed



Operator	Clock	Visual	Auditory	Cognitive	Psychomotor	NumTasks
Operator1	0.000	4	0	7	2.6	1
Operator1	1.602	0	0	0	0	0
Operator1	1.602	4	0	1	4.6	1
Operator1	3.306	0	0	0	0	0
Operator1	3.306	1	0	0	5.8	1
Operator1	5.636	0	0	0	0	0
Operator1	5.636	1	0	0	2.2	1
Operator1	12.625	0	0	0	0	0
Operator1	12.625	1	0	0	5.8	1
Operator1	14.657	0	0	0	0	0
Operator1	14.657	1	0	0	2.2	1
Operator1	15.408	0	0	0	0	0
Operator1	15.408	4	0	7	2.2	1
Operator1	16.446	0	0	0	0	0
Operator1	16.446	5	0	6.8	5.8	1
Operator1	18.388	0	0	0	0	0
Operator1	18.388	4	0	1	0	1
Operator1	66.403	0	0	0	0	0
Operator1	66.403	5	0	6.8	5.8	1
Operator1	72.042	0	0	0	0	0
Operator1	72.042	5.4	4.2	7	5.8	1
Operator1	81.123	0	0	0	0	0
Operator1	81.123	1	0	1	2.2	1
Operator1	82.103	0	0	0	0	0
Operator1	82.103	5	0	6.8	5.8	1



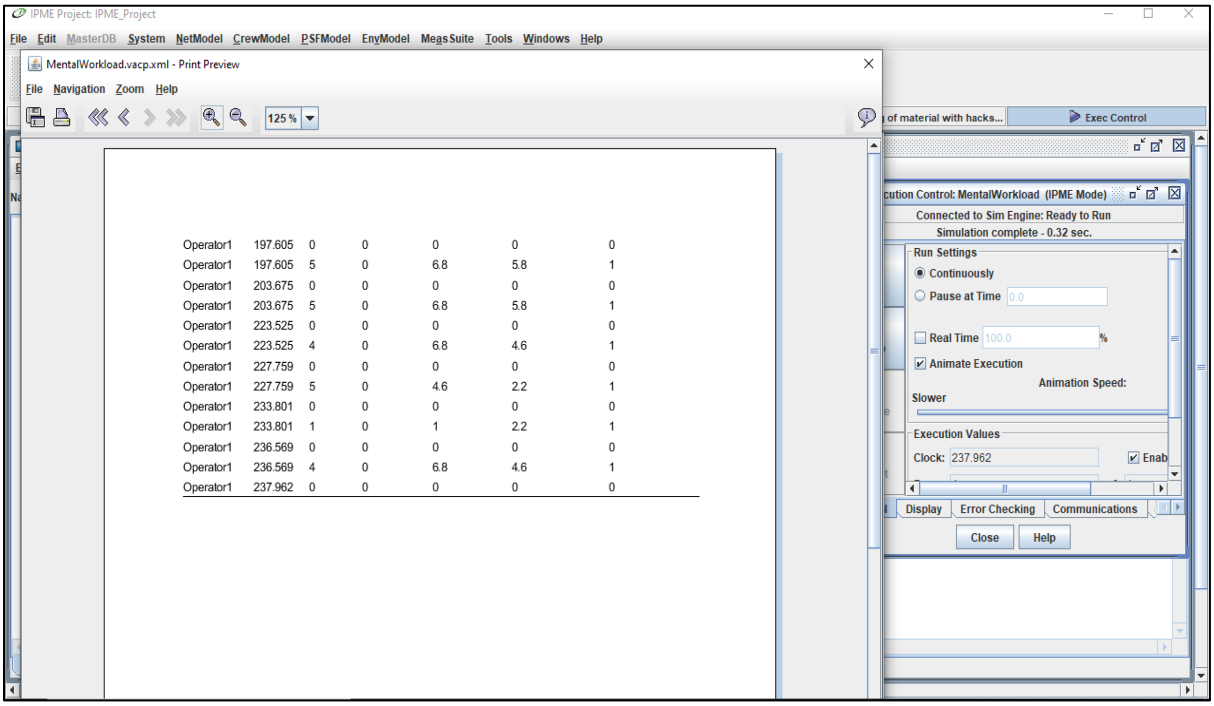


Figure 13: Workload values and times of the subtasks

3.10.2 Graphical Representation of the results

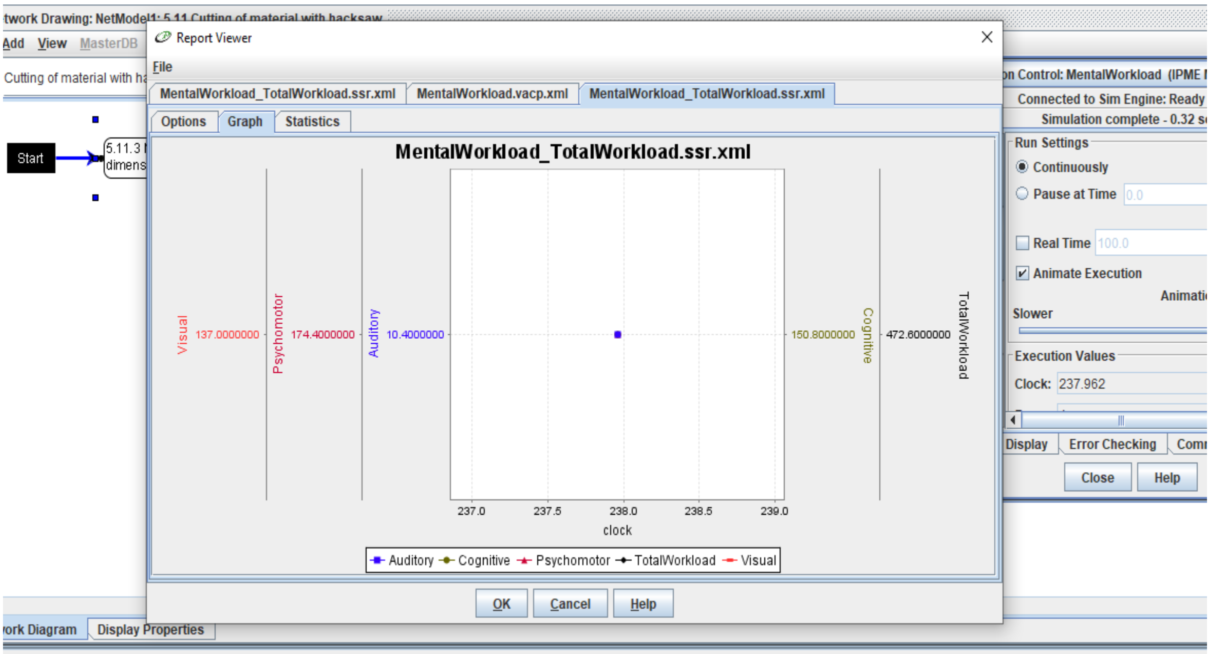
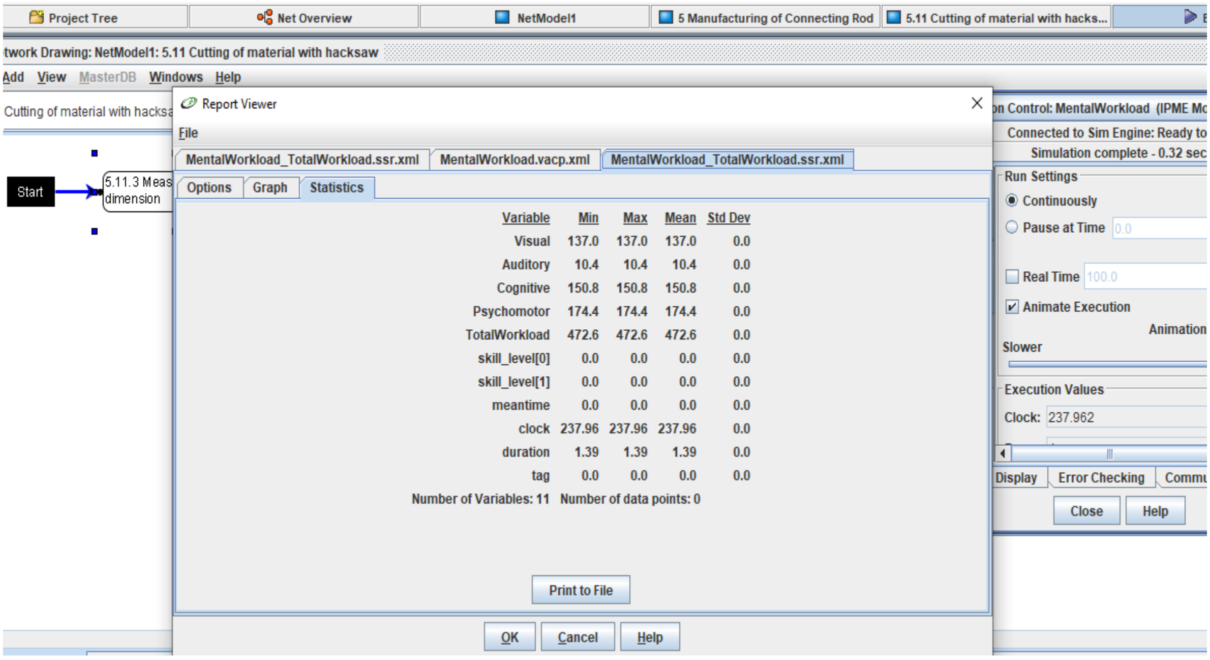


Figure 14: Graphical results of the simulation for expert operator

3.10.3 Final report of the model



Variable	Min	Max	Mean	Std Dev
Visual	137.0	137.0	137.0	0.0
Auditory	10.4	10.4	10.4	0.0
Cognitive	150.8	150.8	150.8	0.0
Psychomotor	174.4	174.4	174.4	0.0
TotalWorkload	472.6	472.6	472.6	0.0
skill_level[0]	0.0	0.0	0.0	0.0
skill_level[1]	0.0	0.0	0.0	0.0
meantime	0.0	0.0	0.0	0.0
clock	237.96	237.96	237.96	0.0
duration	1.39	1.39	1.39	0.0
tag	0.0	0.0	0.0	0.0

Number of Variables: 11 Number of data points: 0

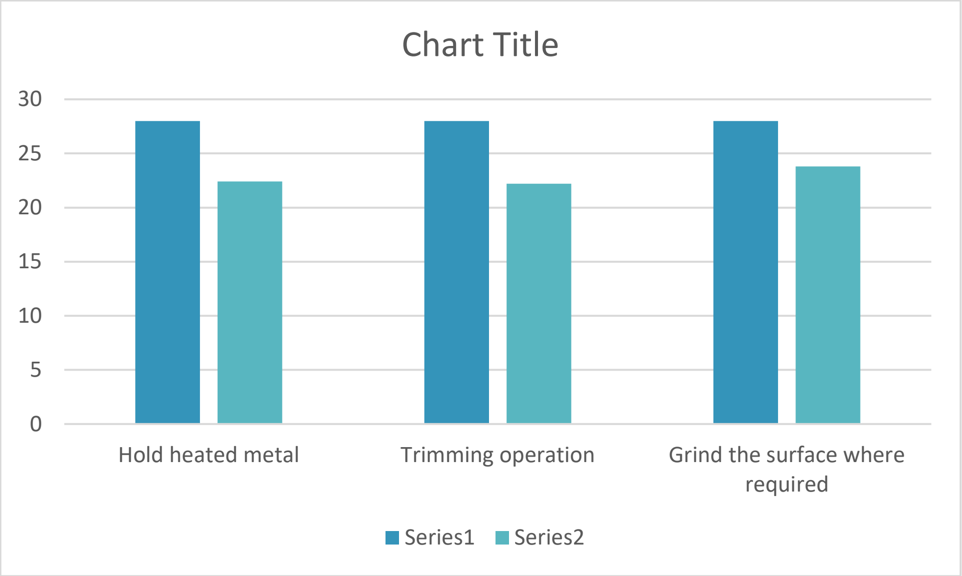
Figure 15: Complete result of the simulation for the expert operator

3.10.4 Comparison of the critical tasks

Sr. no.	Subtask	Novice	Expert
1	Hold heated metal	28	22.4
2	Trimming operation	28	22.2
3	Grind the surface where required	28	23.8

Table 4: Numerical comparison between critical subtasks

3.10.5 Comparison of the critical tasks



Graph 1: A comparison between critical tasks

3.11 Reduction of workload

Reduction of workload is the core objective of this research. Workload reduction techniques were to be implemented to reduce the workload along with the time reduction. Greater the workload, greater the time and greater the cost. Reduced workload will cause a reduction in time and cost both. In the above simulations, workload and time was reduced in the critical subtasks because of the expertise of the expert operator. The focus here was the novice operator. Operator's efficiency was of more importance. Workload reduction was done to get workloads even lesser than the expert operators. A model was proposed in accordance with the workload reduction techniques. Workload reduction techniques used were as follows:

- Parallel operators: Added parallel operators in Trimming and Grinding operation
- Parallel tasks: Switched on different machines after ending of every preceding task
- Automation: Used robotic arm instead of manual holding while pressing machine strikes
- Measuring: Used setting piece as a standard instead of measuring each time
- Clamping: Used Hydraulic Clamping instead of Manual Clamp
- Grooving: Added one machine for each side of groove

3.12 Proposed model for critical Tasks

The values of the critical tasks were reduced by proposing changes in the model. Those changes in the model caused a prominent reduction in the time and workload both. Some of the changes were to increase the operator's efficiency and to reduce human effort. Some non-critical tasks were also optimized to increase overall efficiency of the production. The proposed changes in the model are as follows:

3.12.1Hacksaw Cutting novice operator's model

In cutting task, there were six tasks which included measuring, marking, clamping, cutting and de-clamping. Measuring and marking took five minutes together. These both were time taking processes along with higher workloads. Clamping and de-clamping were also taking five minutes. It was a simple but time taking step.

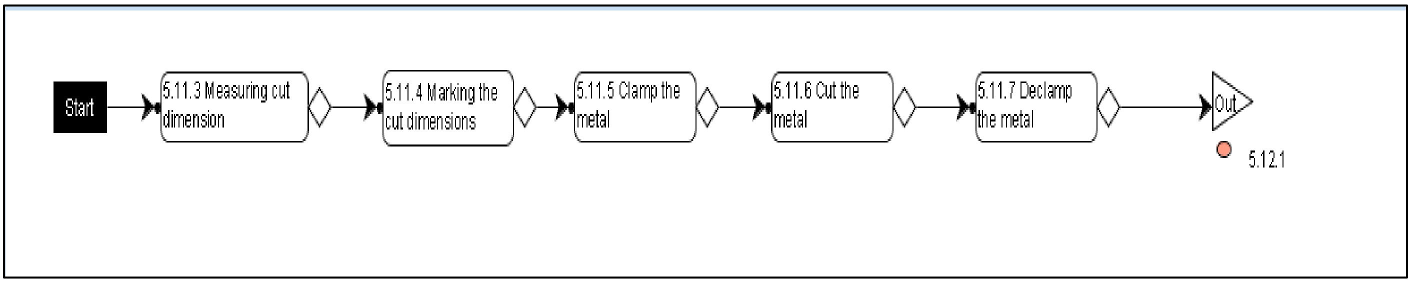
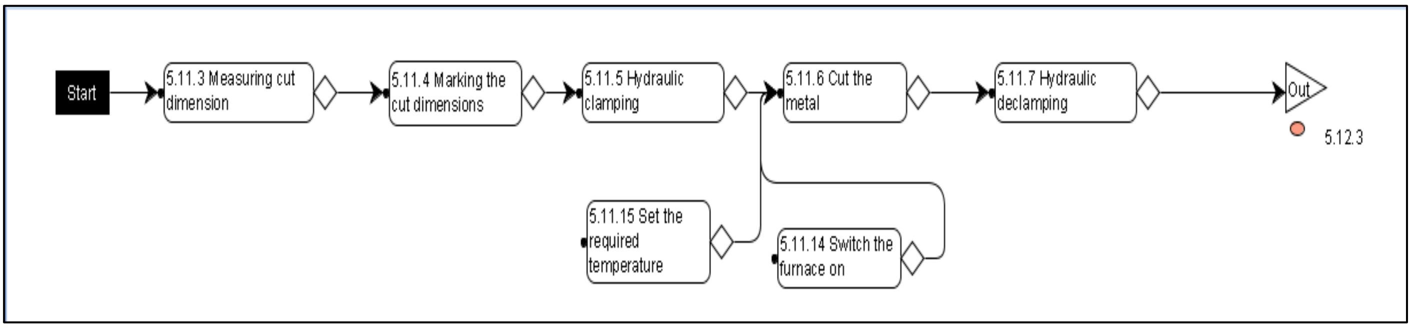


Figure 16: Model of the cutting of material task

3.12.2Hacksaw cutting proposed workload reduction model.

Using the workload reduction techniques marking and measuring were replaced by a setting piece. A standard piece, pipe, or a gauge of the required dimension of the cut. It will be just kept with the metal to mark and measure simultaneously. It will reduce the time from five minutes to two minutes. Another workload reduction technique is using a hydraulic clamp which will reduce time in clamping, and it will also help in cutting process too. Hydraulic clamps are easier to handle and are flexible in usage. Hydraulic clamping and de-clamping will reduce the time from five minutes to just two minutes which reduces the time to more than half. As the hydraulic clamps are easier to handle so the operator's workload is also reduced.

Figure 17: Reduced model of the cutting of material task



3.12.3Pressing operation novice operator's model

One of the most critical subtasks was the holding of red-hot metal while the pressing machine presses it to the required shape. In forging tasks, holding the heated metal requires great handling skills. Pressing machine strikes with great pressure and intensity and the metal becomes tough to be handled. Two operators are work on this subtask as one does the lubrication and other does the metal handling.

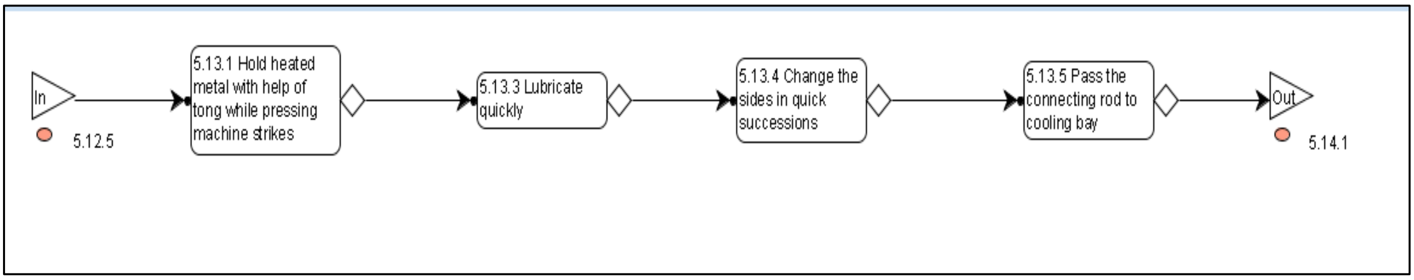


Figure 18: Model of the Drop forge the metal task

3.12.4Pressing operation workload reduction model

Workload reduction in this subtask was done by having an automatic robotic arm along with an automated lubrication system. Automation here will be more accurate and precise. By having a robotic arm human effort will be reduced, we will just require an operator which inspects the subtask being performed. By installing an automated lubrication system, the other operator will not be needed anymore. Automated lubrication system is added in the beginning effect of the subtasks in the IPME software. Ultimately the workload of the single operator will be less. Automation will reduce workload and time both.

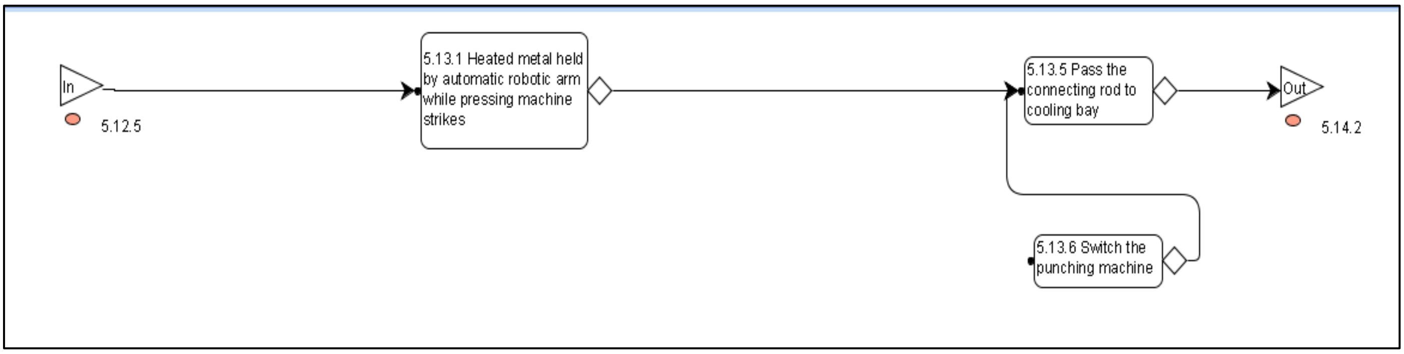


Figure 19: Reduced model of drop forge the metal task

3.12.5Grinding operation novice operator's model

Grinding operation includes three subtasks but still it is a critical task. A novice operator experiences highest workloads while working on the grinding machine due to the risk of abrasive wheel. An operator experience undergoes higher workload because he does the markings and inspection himself. It takes more time to complete all the subtasks.

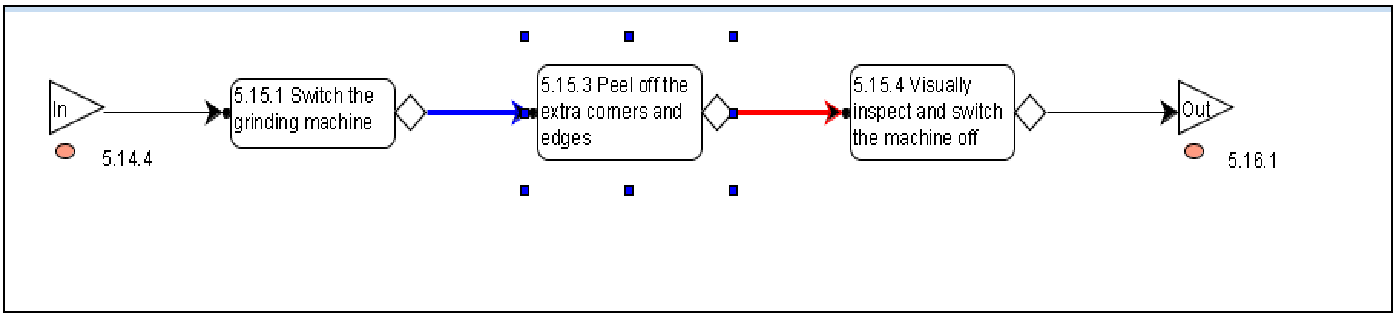


Figure 20: Model of the trimming task

3.12.6Grinding operation workload reduction model

The workload of this critical task is reduced by assigning a parallel operator on this task. One operator will complete the miscellaneous subtasks such as the measuring and marking the grinding surfaces also the inspection after the grinding is done. Second operator will only work on the grinding machine, he will get already marked connecting rods and he will peel off the extra corners and edges. In this way the workload of the operator will be reduced by dividing the work.

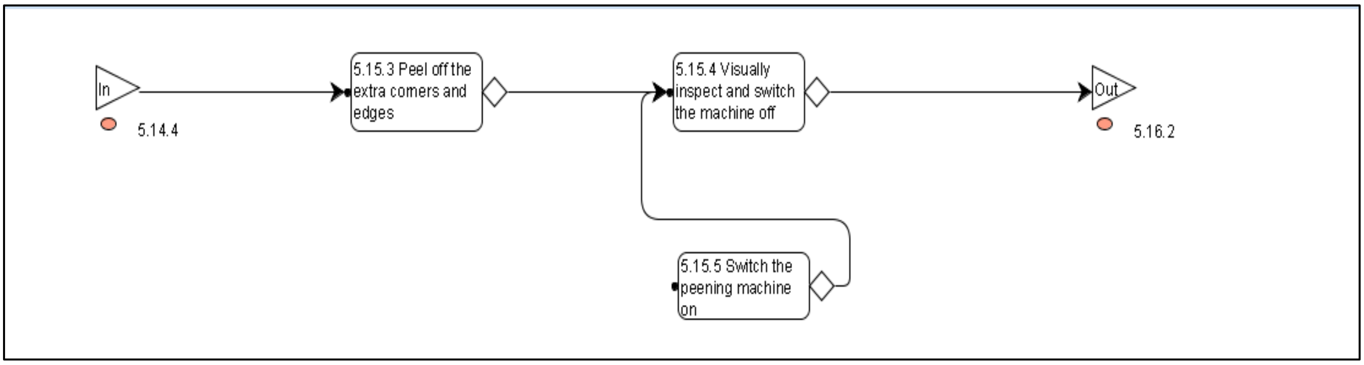


Figure 21: Reduced model of the trimming task

3.12.7Drilling operation novice operator's model

In drilling operation, the conventional drilling method was opted and still the workload experienced by novice operator was quite higher. It was a time taking task with seven subtasks and these seven subtasks taking 30 minutes. Clamping and de-clamping to change the sides was a higher workload subtask. Time reduction and workload reduction was done in this task.

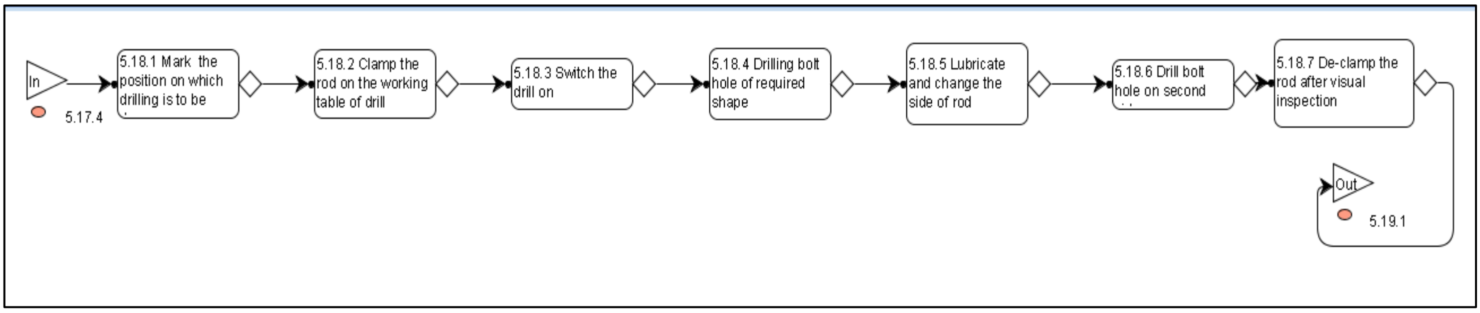


Figure 22: Model of the drilling bolt hole task

3.12.8Drilling operation workload reduction model

Time in this subtask was reduced by setting a hydraulic clamping jig. A hydraulic clamping jig made easier to change the side of the connecting rod. It made the subtask easy to machine altogether. Clamping jig eliminated the measuring and marking on the connecting rod too because the jig is as the pattern of our machining process. The time of this task was reduced to 20 minutes from 30 minutes. The workload of the first two tasks was reduced from 16.4 to 6.6 VACP values. An overlapping sub tasking technique was also implemented in all those subtasks where “switching on the machine” was a subtask. Half minute was saved by switching the machine on while the subtask of previous task was taking place.

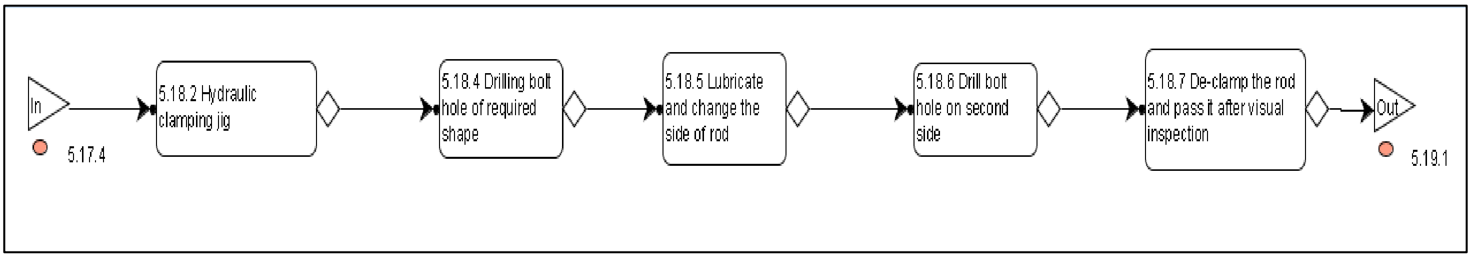
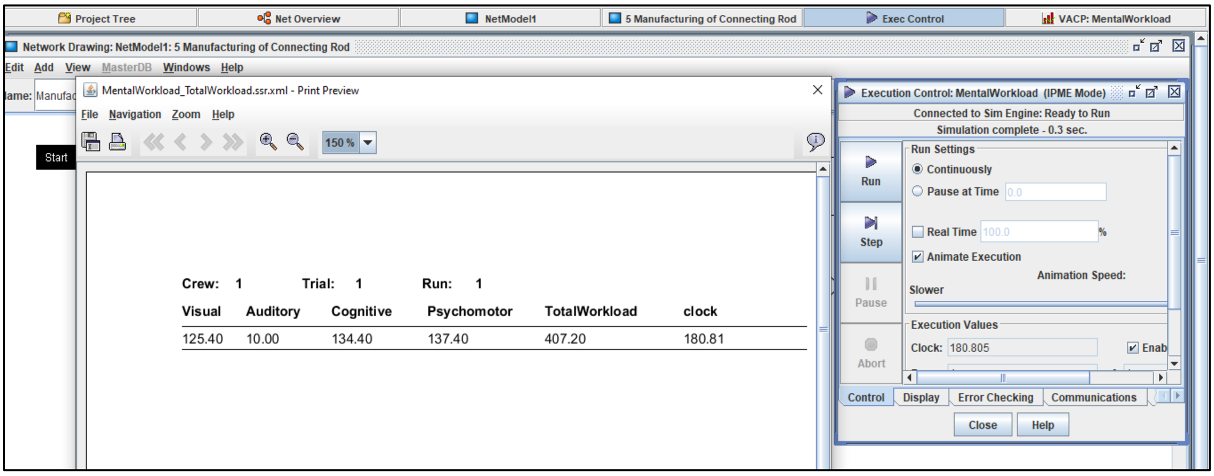


Figure 23: Reduced model of drilling bolt holes task

After running the reduced model of workload. There was a significant reduction in the workload and time both. The simulation results are as follows:

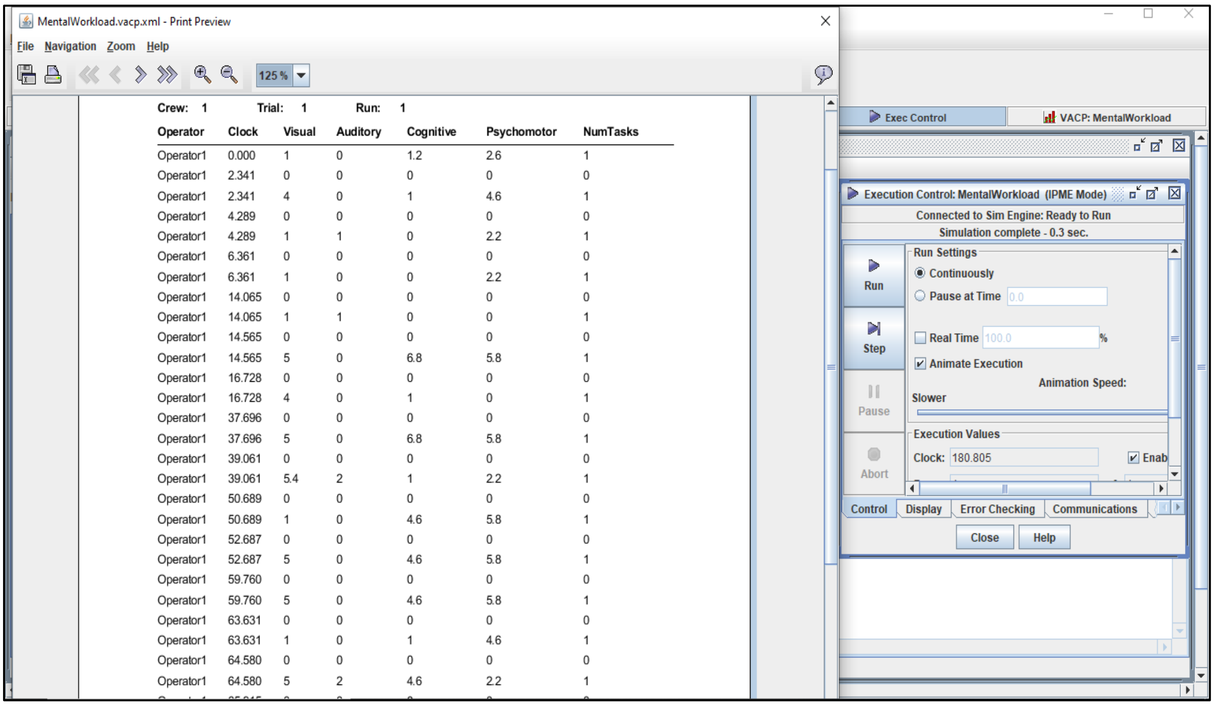


Crew: 1 Trial: 1 Run: 1

Visual	Auditory	Cognitive	Psychomotor	TotalWorkload	clock
125.40	10.00	134.40	137.40	407.20	180.81

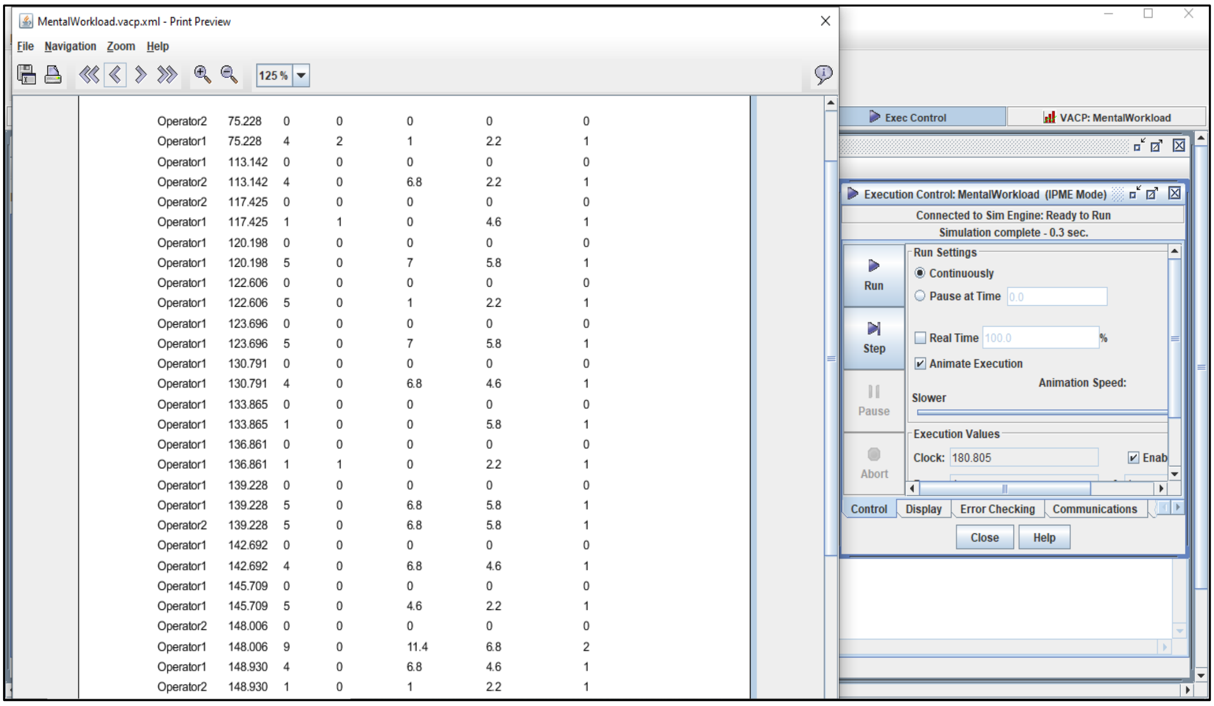
Figure 24: Results of the simulation for reduced model

3.12.9 Workloads values of every task along with the time when executed



Crew: 1 Trial: 1 Run: 1

Operator	Clock	Visual	Auditory	Cognitive	Psychomotor	NumTasks
Operator1	0.000	1	0	1.2	2.6	1
Operator1	2.341	0	0	0	0	0
Operator1	2.341	4	0	1	4.6	1
Operator1	4.289	0	0	0	0	0
Operator1	4.289	1	1	0	2.2	1
Operator1	6.361	0	0	0	0	0
Operator1	6.361	1	0	0	2.2	1
Operator1	14.065	0	0	0	0	0
Operator1	14.065	1	1	0	0	1
Operator1	14.565	0	0	0	0	0
Operator1	14.565	5	0	6.8	5.8	1
Operator1	16.728	0	0	0	0	0
Operator1	16.728	4	0	1	0	1
Operator1	37.696	0	0	0	0	0
Operator1	37.696	5	0	6.8	5.8	1
Operator1	39.061	0	0	0	0	0
Operator1	39.061	5.4	2	1	2.2	1
Operator1	50.689	0	0	0	0	0
Operator1	50.689	1	0	4.6	5.8	1
Operator1	52.687	0	0	0	0	0
Operator1	52.687	5	0	4.6	5.8	1
Operator1	59.760	0	0	0	0	0
Operator1	59.760	5	0	4.6	5.8	1
Operator1	63.631	0	0	0	0	0
Operator1	63.631	1	0	1	4.6	1
Operator1	64.580	0	0	0	0	0
Operator1	64.580	5	2	4.6	2.2	1



Operator2	75.228	0	0	0	0	0
Operator1	75.228	4	2	1	2.2	1
Operator1	113.142	0	0	0	0	0
Operator2	113.142	4	0	6.8	2.2	1
Operator2	117.425	0	0	0	0	0
Operator1	117.425	1	1	0	4.6	1
Operator1	120.198	0	0	0	0	0
Operator1	120.198	5	0	7	5.8	1
Operator1	122.606	0	0	0	0	0
Operator1	122.606	5	0	1	2.2	1
Operator1	123.696	0	0	0	0	0
Operator1	123.696	5	0	7	5.8	1
Operator1	130.791	0	0	0	0	0
Operator1	130.791	4	0	6.8	4.6	1
Operator1	133.865	0	0	0	0	0
Operator1	133.865	1	0	0	5.8	1
Operator1	136.861	0	0	0	0	0
Operator1	136.861	1	1	0	2.2	1
Operator1	139.228	0	0	0	0	0
Operator1	139.228	5	0	6.8	5.8	1
Operator2	139.228	5	0	6.8	5.8	1
Operator1	142.692	0	0	0	0	0
Operator1	142.692	4	0	6.8	4.6	1
Operator1	145.709	0	0	0	0	0
Operator1	145.709	5	0	4.6	2.2	1
Operator2	148.006	0	0	0	0	0
Operator1	148.006	9	0	11.4	6.8	2
Operator1	148.930	4	0	6.8	4.6	1
Operator2	148.930	1	0	1	2.2	1

Figure 25: Workload values and times of the subtasks

3.12.10 Graphical Representation of the results

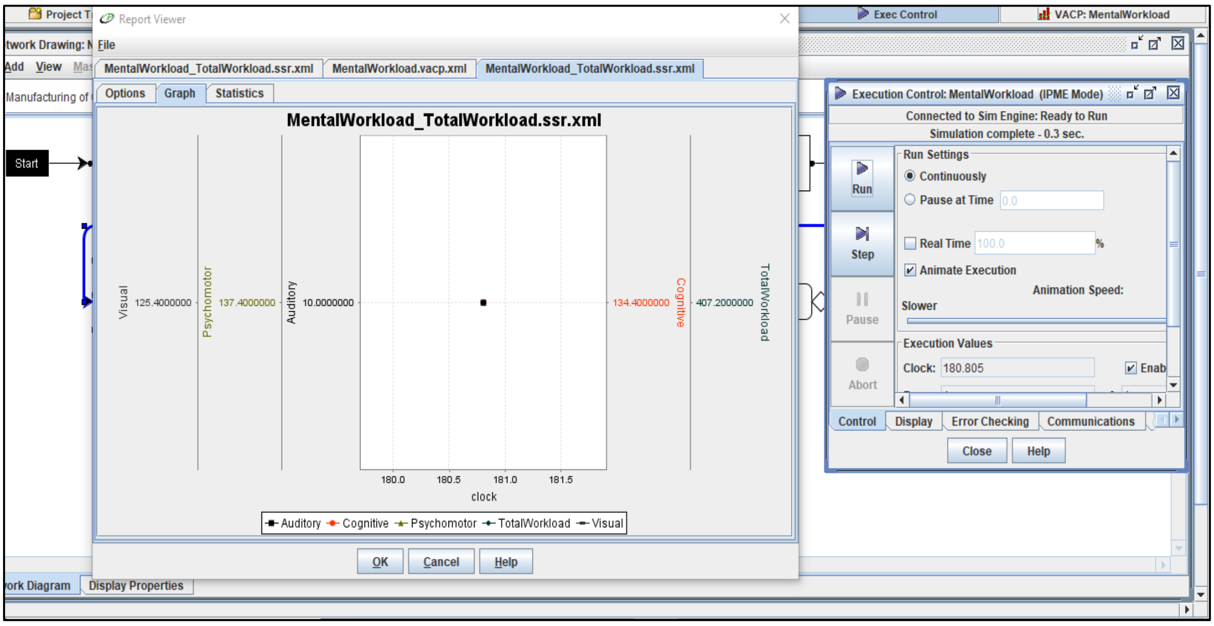


Figure 26: Graphical results of the simulation for novice operator

3.12.11 Final report of the model

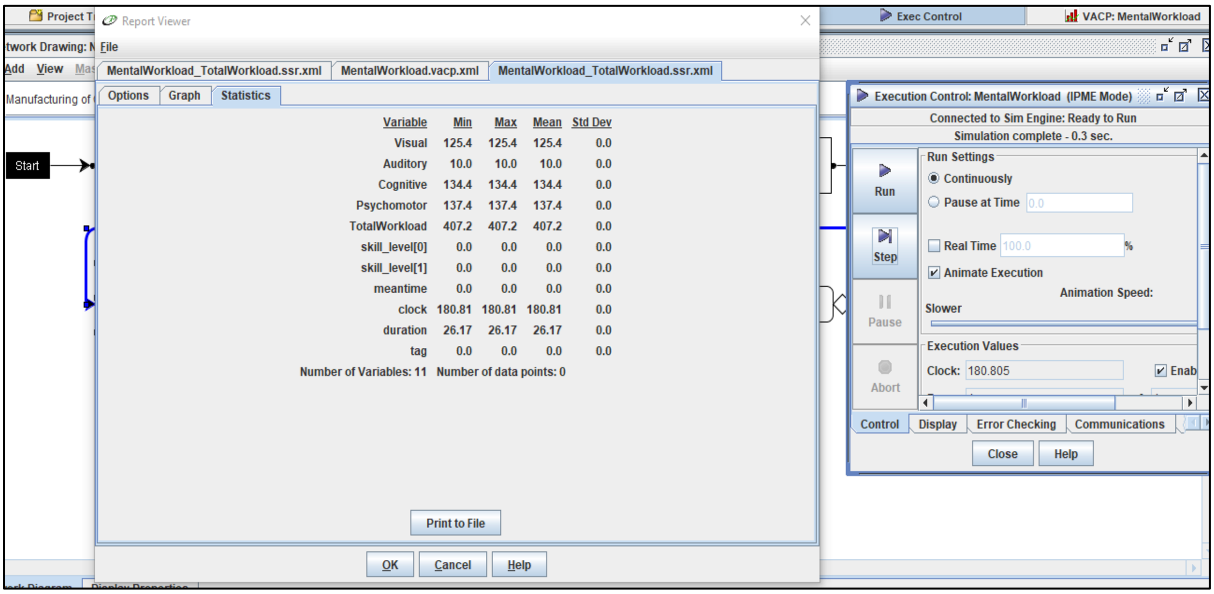


Figure 27: Complete result of the simulation for the reduced model

4. Cost Analysis

Per piece cost = $5

Pieces manufactured per hour = 25

Pieces manufactured per day = 600

Pieces manufactured per month = 18000

Pieces manufactured per year = 200000

Total cost per year = $10 lacs.

Total profit per year = $10 lacs.

Proposed reduction model:

Operator cost = $150/per month

Two operators cost = $300/per month

Operators cost per year = $4000

Robotic arm with automated lubrication system cost = $15000

Milling machine cost = $25000

Hydraulic clamping and jig cost = $3000

Total cost = $50000

Time reduction = 30%

Pieces manufactured per hour = 32

Pieces manufactured per day = 768

Pieces manufactured per month = 23000

Pieces manufactured per year = 260000

Payback time of cost = 3 months

Per piece cost = $5

Profit per piece = $5

After 3 months, profit per month = $115000

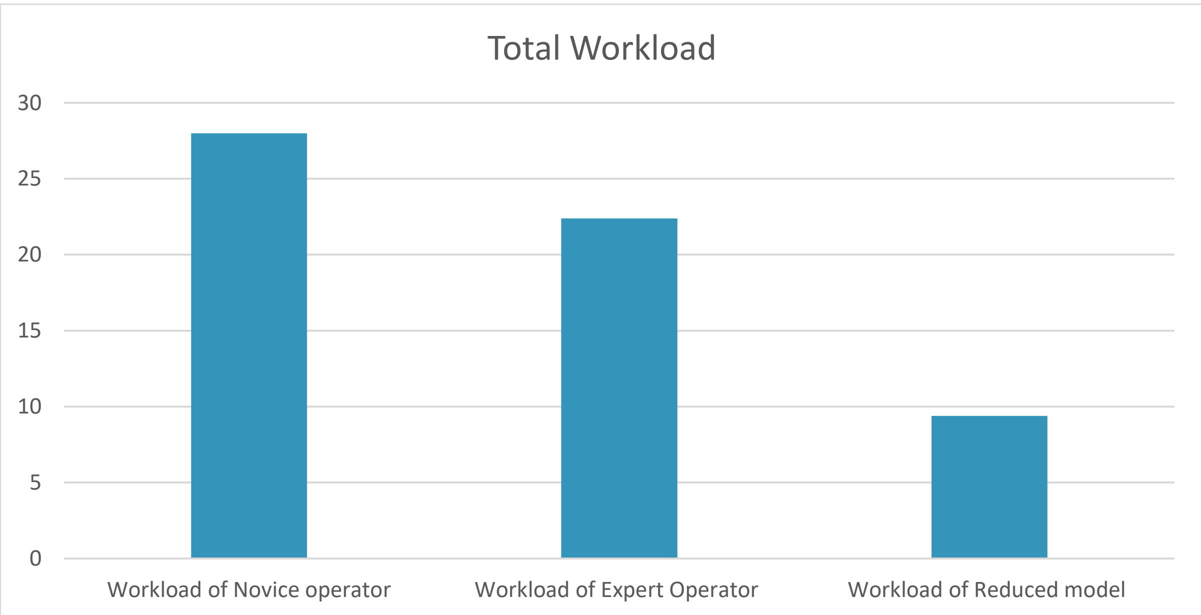
Profit per year = $1300000

5. Results and Conclusions

Workload reduction was done using the IPME Software. Research was conducted using the applied data taken from Manufacturing Resource Centre of National University of Engineering and Technology Islamabad. A model was run in the software considering two operators i.e., novice and expert. The novice operator's total workload was 492 with the mean time 263 Minutes. The expert operator's total workload was 472 with mean time 237 Minutes.

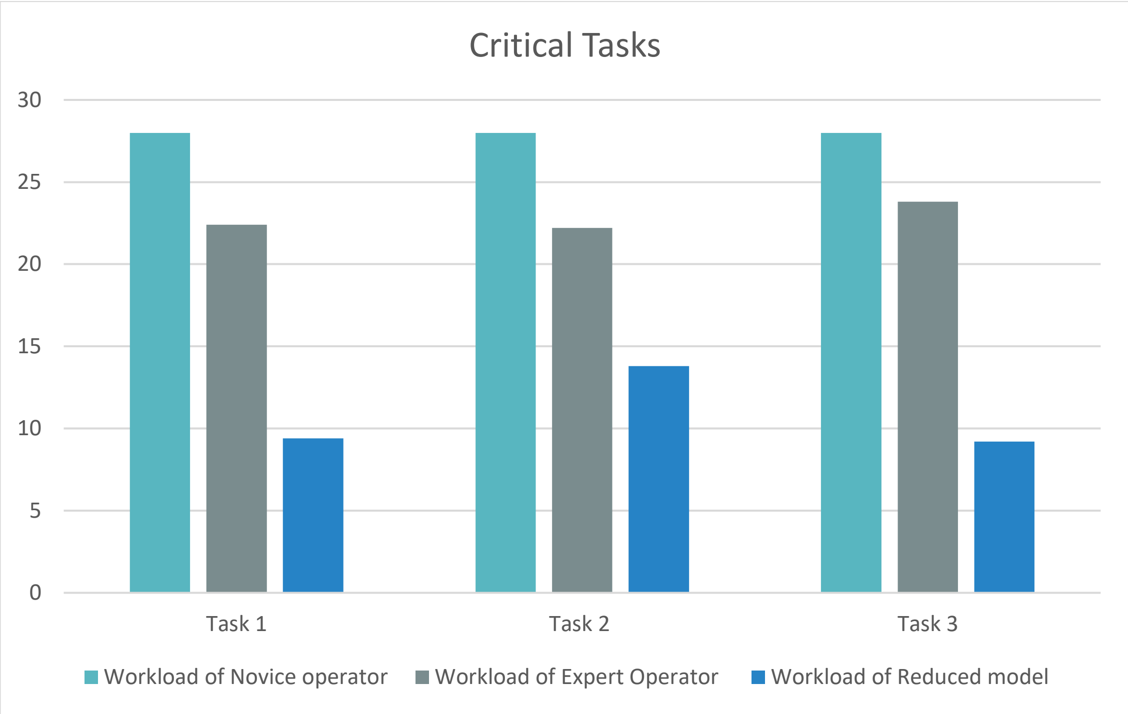
A profit of $3 lacs per year with reduced time and workload can be achieved by applying the following method. An investment of $50000 will be paid back in three months. Assuming if there would be no profit and instead, we achieved only the workload reduction of the operators, it still would have been an achievement. We would have improved our working standards. Decreasing the number of leaves of operators and higher job satisfaction level. Profit per connecting rod remains the same but the increase in production with a decrease in the meantime resulted in profits for the organization. The calculations are assumed after discussion from different industrial experts for the price of a part, also considering the market price of robotic arm, milling machine and the hydraulic clamping machines.

Cost saving for the connecting rod was done considering the yearly basis data. An intensive reduction in workload of the operator was done from 492 VACP values to 407 VACP values. with the mean time reduced to 180 Minutes. The workload comparison is drawn in the following graph:

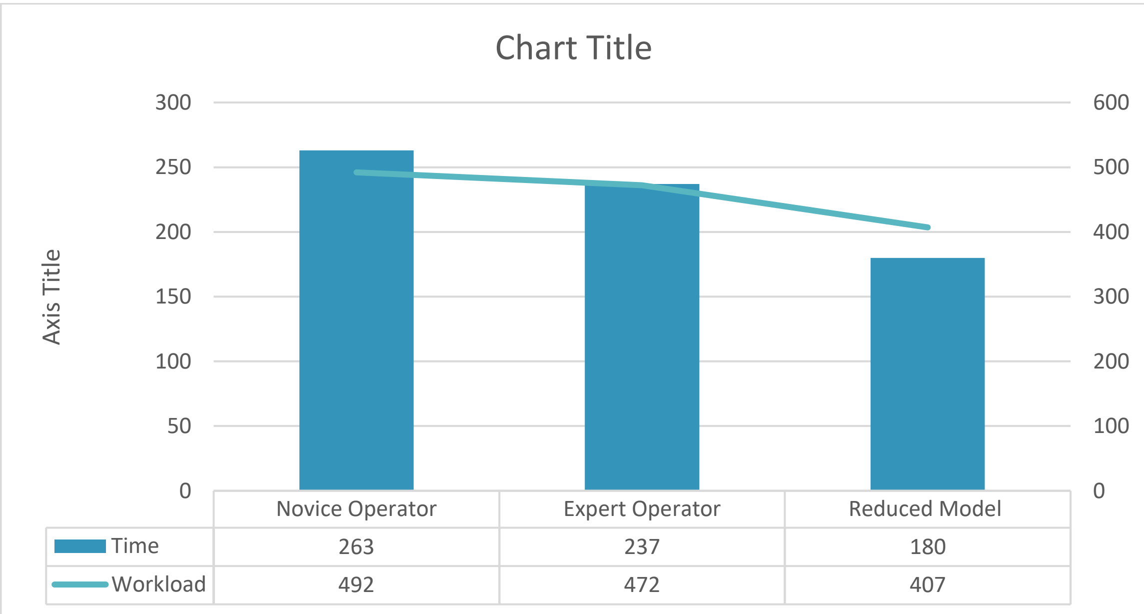


Graph 2: Total workloads of three methods

A brief comparison is expressed in terms of graph which shows the difference of the workload of the critical subtasks.



Graph 3: Comparison of all three workloads of critical tasks



Graph 4: Mean time and workloads of all three models

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