Semi-automated Assembly Process Using Arm Manipulator

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Abstract

Today's global market requires the ability to adapt to high production volumes, product variety, increase product quality and decrease production time to market for the assembly system. The increase of demand for the product quality and variety is 2P product related requirements, meanwhile increase of demand for the production volume and decrease production time to market time is 2P production related requirements. This paper defines these requirements as "2+2P" a main research problem of the assembly system. As well as, the future assembly systems need to fulfill capability and capacity flexibility of the market. The empirical studies have documented that human is the most flexible element of the manufacturing systems and they are responsible for capability flexibility, while machines are good at repetitive tasks and they enhance the capacity flexibility. Therefore, the aim of this paper is to examine the increase of human centered automation levels in manual assembly system, with the integration of ARM manipulator using System Modeling Language. In this study, an assembly, conventionally having a lower degree of automation, is investigated for human and arm interaction for productivity gains keeping constant flexibility. The integration methodology is based on System Modeling Language (SysML), for specifying analyzing, designing and verifying hybrid system. The station layout, tooling design and manipulator programming are elaborated using digital Solid works and Process Simulator tools. The motivations as well as the benefits derived from the employment of the arm manipulator into industrial case are discussed. The proposed methodology allows decrease of cycle time from 900 seconds to around 470 seconds, increase productivity, ergonomics of the assembly cell and increases the product quality by reducing human involvement by 23%.

Keywords
Automation, Human and Arm collaboration, Task allocation, assembly systems

1. Introduction
Manufacturing systems have continuously evolved over time together with changes of market trends and technological advances: one can observe that paradigm shifts in production were always triggered by great innovations, referred to as industrial revolutions, and had great impacts on both society and economy (Dalenogare, Benitez, Ayala, & Frank, 2018; L. Yang, 2017; Vaidya, Ambad, & Bhosle, 2018). The automobile production cannot be excluded from this competition. The assembly of automobiles, experience several challenges, such as the different product mix, thousands of different parts, growing complexity of their processes and supply networks, increasing customer expectations for quality, lead-time and customization (Salmi, David, Blanco, & Summers, 2015; Scholz-Reiter & Freitag, 2007). In order to response "2+2 P" industrial problems in Figure 1, recently several advanced technologies have been emerged. For instance, the assistant technologies of the manual assembly systems, for higher automation (Gorlach, Wessel, Mandela, Elizabeth, & Africa, 2008) multiple performance aspects have to be investigated into and optimized with respect to metrics such as cost, productivity, quality, safety and ergonomics (Guney & Ahiska, 2014). Besides, the final assembly operations require more flexible and robust process (Hermawati et al., 2015) and humans are recognized as the most flexible element in a production system (Müller, Vette, & Mailahn, 2016). Therefore, in order to keep flexibility of the assembly systems, we cannot exclude humans. Flexibility is needed in assembly systems because of "2+2 P" industrial problems. According to Malik & Bilberg (2019) there are two types of flexibility exist: the capability flexibility and the capacity flexibility. The capability

flexibility refers to the system ability to rapid react to market changes in terms of product variants and quality. The capacity flexibility of an assembly system is its ability to react to changing market demands in terms of the quantities and time to market period.

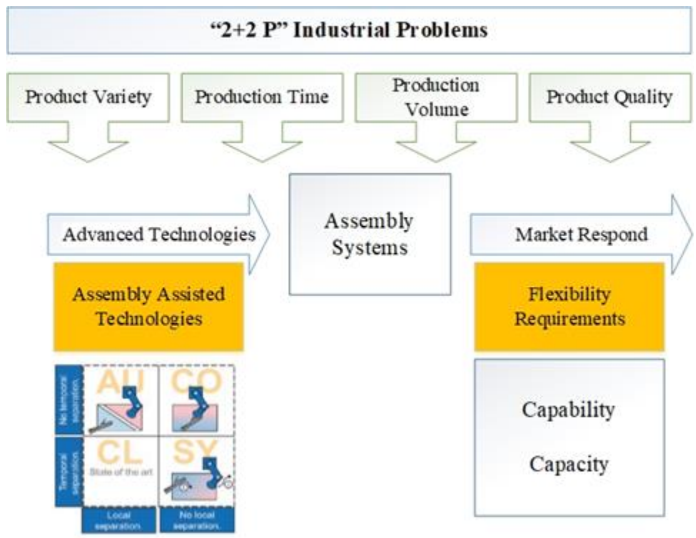

Figure 1. Challenges of the assembly systems

Table 1. Capability and capacity flexibility

	Capability Flexibility	Capacity Flexibility
Definition	Ability to react the system to change product variant	Ability to react the system to changing product amount
2+2 "P"		
Reason	Product Quality Product Variety	Production time Production Volume
Possible solution	Human Dexterity Skills	Robotics and Flexible Automation
Type of assembly	Manual Assembly	Fixed Purpose automation
Integrated solution	Human Robot Collaboration	

Table 1 summarizes the definition and possible solutions for capability and capacity flexibility. The need assembly system to be capability flexibility is that demand for product quality and variety, so due to human dexterity skills we can reach these requirements, while to fulfill the production time reduction and production volume increase, we need robotics and as well as automation system. Finally, we can conclude that by integrating both human and robot systems into one system we can reach all four requirements of the assembly systems.

Therefore, the aim of this paper is to examine the increase of automation levels in manual assembly system, with the integration of ARM manipulator using System Modeling Language that can offer precision, repeatability and increased production rates as well as dexterity being closer to human-like performance.

Based on the above-mentioned goal of the paper, the remainder of this article is organized as follows: Section 2 summarizes the current state-of-the-art in collaborative manufacturing Section 3 describes how System Modeling Language method can be implemented to integrate ARM into manual assembly system to take into account analysis, design and verification phases. Then, in section 4, we will discuss investigated methodology with industrial case study in order to fix suspension systems into automobiles.

2. Literature Review

Automotive industries are gradually introducing robots in their manual assembly systems, nevertheless a crucial question continues: how should a human robot collaborative assembly system is designed? Recent human robot

collaborative research focuses on the investigation of physical human-robot interaction (Bicchi, Peshkin, & Colgate, 2008; De Luca & Flacco, 2012). The purpose of this study enables close cooperation between human and robot, in industrial tasks, that require high performance of robots in terms of precision, speed and payload. Moreover, Papakostas, Michalos, Makris, Zouzias, & Chryssolouris, (2011) discussed the key features of the human robot cooperating cells in automotive assembly, and give two simulated comparisons: a conventional welding robotic cell and one with cooperating robots. Pedrocchi, Vicentini, Malosio, & Tosatti, (2013), a new cell production assembly system, with human-robot cooperation is developed. The three key automation technologies comprise in the cell; parts feeding by double manipulators on a mobile base, production process information support for the operator and safety management for cooperation between human and robot. Bänziger et al. (2020) proposed a method for optimizing task distribution among humans and robots. The method is approved by using an ABB Dual Arm Concept Robot in a PLC input/output module assembly scenario. Some researchers have focused on industrial applications. For instance, an industrial robot controller, incorporating compliance of the joints with the environment, is presented by Lange et al. (2013). The wanted position of the tool center point is computed from the force error. Parallel control considers a reference trajectory while allowing feed forward in force-controlled directions. However, the method is designed for industrial assembly tasks, and it does not take into account the presence of a human in the loop. Some other researchers have addressed manually guided robot operation (Ferretti, Magnani, & Rocco, 2009; Ficuciello, Romano, Villani, & Siciliano, 2014). Ferretti et al., (2009) model which an operator teaches tasks to a robotic manipulator by manually guiding its end effector. On the other hand, Ficuciello et al., (2014) investigated the problem of controlling a robot arm, executing a cooperative task with a human, who guides the robot through direct physical interaction.
Moreover, the recent investigations have showed that many researchers have focused on the safety requirements for industrial robots when design Human Robot Collaboration over the last decades. Nevertheless, these solutions have not yet been transferred to the industry. Joe et al., (2015) assessed the five alternative safety designs by covering both hardware and control design, as well as a human-robot collaboration prototype cell for cable harness assembly. The main target of Pedrocchi et al., (2013) is safety of the shared work cell, in the absence of physical fences between human and robot. Since safety options provided by basic infrared sensors are limited, the authors design network architecture of these sensors for tracking user positions, while avoiding collisions. As outlined in most of the cited works, efficient automation and design robot centered automation. However, an increased level of automation is expensive and rigid, it requires human interventions in surprising situations. In addition, higher level of automation makes it harder for the humans to intervene since the system is designed to keep humans from the automation. Such problems of increasingly automation can be solved by taking humans as an integral and central part of the automation and design human centered automation. Therefore, the authors propose a new ARM integration methodology for manual assembly process using System Modeling Language. A conventional assembly has a lower degree of automation is considered for human and arm interaction.

3. Methodology

The arm integration process is started with requirements analysis coming from the market and it associated with “2+2 P” problems mentioned in introduction part. The System Modeling Language (SysML) graphical modeling is used to model the assembly operations in different steps. This structure helps the designer to identify the possibility of automating all the steps, the problems that may arise, possible redesigns of the station, etc. The Systems Modeling Language (SysML) is a general-purpose graphical modeling language for specifying, analyzing, designing, and verifying complex systems. Using Solid works and Process Simulator novel approach to design by digital twin technology human arm assembly system discussed for checking Hierarchical Task Analysis (HTA), lay out design. In addition to this, based on capability characteristics task allocation methodology is proposed between human and robot systems. Finally industrial integration results of the ARM manipulator studied in order to compare the simulation, manual and integrated results (see Figure 2).

3.1. Industrial requirements

R1: Increase in the final product quality. The product quality is principal as it is directly related with customer satisfaction. Issues that can affect the quality are related to assembly errors that in manual assembly systems are common due to human factor.
R2: Reduction in the cycle time leads to achieve higher production rates. Automation can reduce cycle time.
R3: Improvement on production performance. The one of an important performance is technical efficiency for automotive industry. Such features are desired to be improved by increasing the automation level (Tsarouchi et al., 2014).

R4: Increase product variety. Current assembly systems challenges "customized automation" (Müller et al., 2016).

3.2. Analysis

An assembly, conventionally having a lower degree of automation, is investigated for human and arm interaction for productivity gains keeping constant flexibility. In the selected assembly scenario, the tasks are currently performed by a human operator using hands or tools such as screw drivers. This investigation presents the potential of setting up an arm robot cell for the assembling of a vehicle's suspension systems. The initial cycle time of the manual system was 900 seconds and it is performed by three operators.

3.3. Design process

Observed studies have reported some skills that make humans superior to machine in various context while keeping them inferior some others, nevertheless; humans are recognized as the most flexible and agile element in the system (Fast-Berglund, Palmkvist, Nyqvist, Ekered, & Åkerman, 2016; Froschauer et al., 2021). In this framework, authors assigned the physical, ergonomic task and tasks difficult to automate for human. Meanwhile, the repetitive and non-ergonomic as well as value added tasks scan be benefited by the use of ARM manipulators, taking advantage of ARM speed, power and precision. Simulation model investigates outcomes of the integrated system. Once a model developed, the effect of manipulation of variables over time checked.

3.4. Verifying

Finally, the proposed methodology was verified by industrial environment which is shown in Figure 2. The verification process performed in "GM TAPOICH" Tashkent plant. Where different final assembly models with different fixing moments.

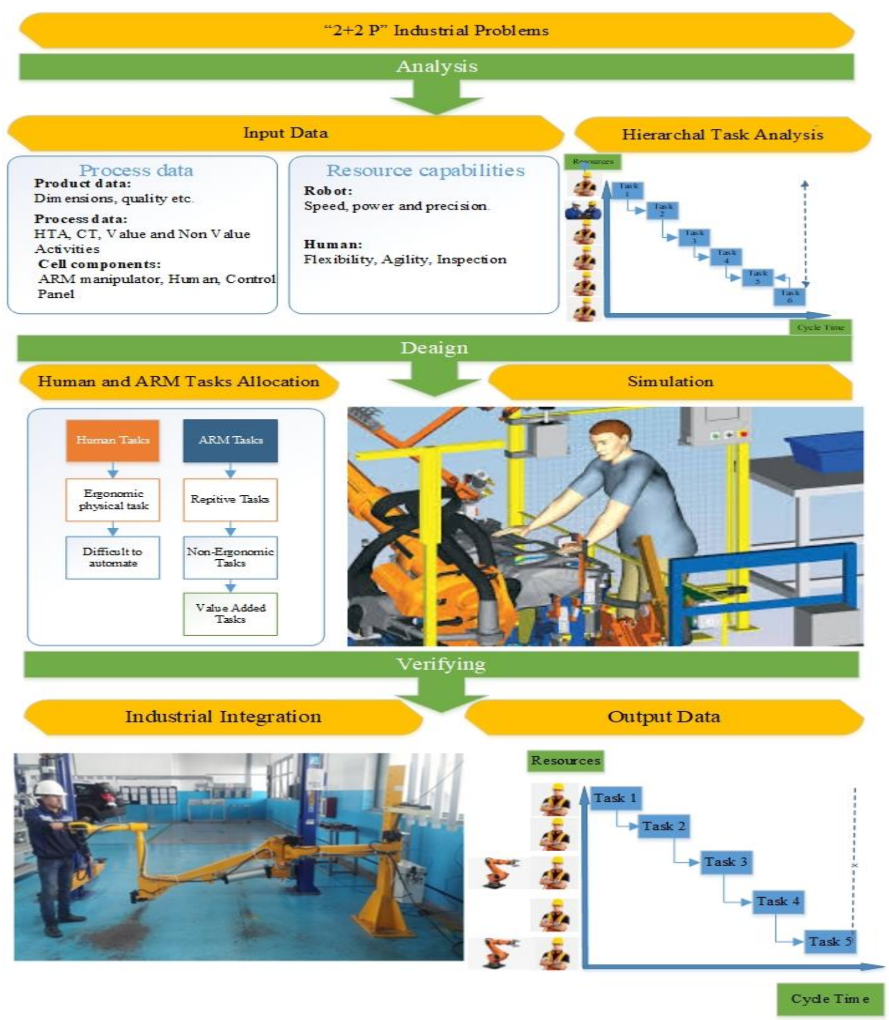

Figure 2. SysML ARM integration methodology

4. Results and Discussion

4.1 Automotive industry: a case study

In the selected assembly scenario, the tasks are currently performed by a human operator using hands or tools such as screws 12 bolts to fix suspension other two operators help to support to lift fixing tool. The following Table 2 and Figure 3 summarizes the original assembly system:

Table 2. Input data of the manual assembly cell

Number of operators	3
Cycle time (sec)	900
Number of bolts to be fixed	12

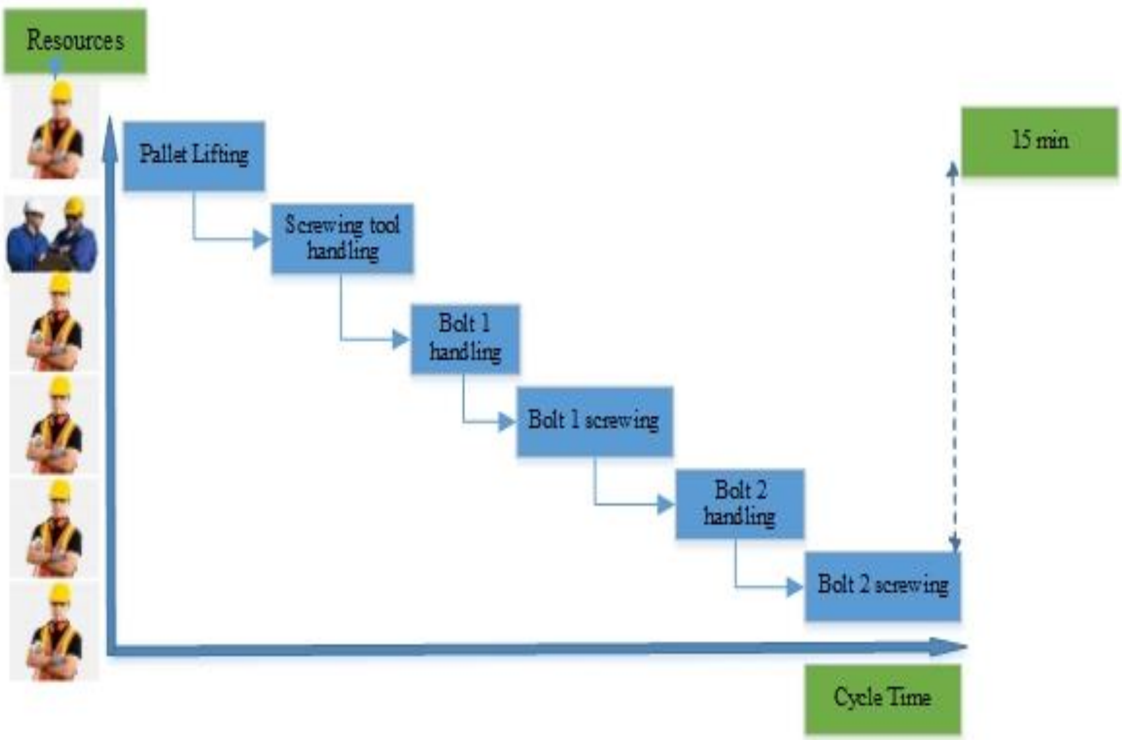

Figure 3. Hierarchical Task Analysis of the manual assembly process

These two global problems are linked with final assembly in automotive industry, where 12 bolts are fixed by operators;

1. Product mix. With different products in final automobile assembly process varying between 4-5 models, fixing momentum also differ. For several models in this case momentum, varies 250-400 Nm. This is difficult to detect precise value by human worker, so it causes to product quality.
2. Process complexity. While fastening the bolts, two operators lift the fixing equipment, and the third fixes. Every day, workers must fasten 12 bolts at least 30-35 pieces of cars. (30 * 12 = 360 bolts). During the day, the worker receives a heavy load, his hands get tired, and ultimately the likelihood of the apparatus falling increases, which leads to accidents with the plant personnel and breakdown of the device.

Then authors analyzed the manual assembly process and categorized them in terms of value (see Table 3)

Table 3. Manual Assembly data

Task	Cycle Time (sec)	Value	Operator
Pallet lifting	60	Non-Value added + Ergonomic	Operator 1
Screw tool handling	40	Non-Value added + Non-Ergonomic	Operator 2 and 3
Bolt 1 handling	15	Non-Value added + Ergonomic	Operator 1
Bolt 1 screwing	385	Value-added + Non-Ergonomic	Operator 1
Bolt 2 handling	15	Non-value added + Ergonomic	Operator 1
Bolt 2 screwing	385	Value-added + Non-Ergonomic	Operator 1

4.2 Human and ARM Task Allocation

As noticed, we assigned the physical, ergonomic task and tasks difficult to automate for human. Meanwhile, the repetitive and non-ergonomic as well as value added tasks for ARM. Thus, Figure 4 summarizes the task allocation and respective required characteristic of the elements of the manual assembly system.

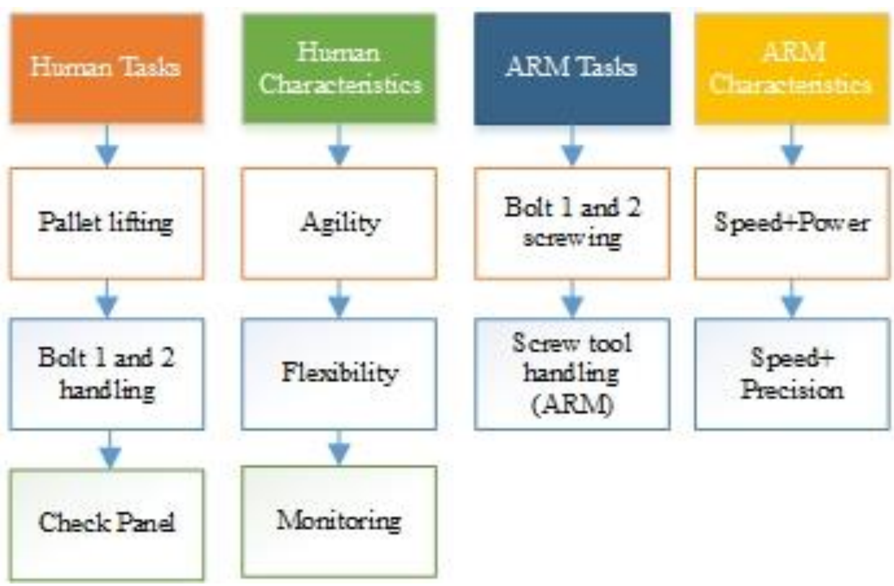

Figure 4. ARM and Human physical task allocation framework

4.3 Simulation

By using the recorded cycle time from the analysis, a discrete event simulation was developed to compare the manual and Human ARM cooperation. Simulation analysis was conducted using Solid works and Process Simulator, and the results depicted that the use of an ARM for assembly collaboration of physical tasks can increase productivity. The estimated simulation times are 740 and 470 seconds for manual and hybrid case. The outcome of the simulation and the estimated time for each separate task can be found in the Table 4.

Table 4. Simulation results for Manual and Hybrid assembly cycle time comparison

Manual Assembly			**ARM+Human**		
Tasks	**Cycle Time (sec)**	**Operation**	**Tasks**	**Cycle Time (sec)**	**Operation**
Pallet lifting	50	OP1	Pallet lifting	50	OP1
Screw tool handling	70	OP2/OP3	Bolt 1 handling	10	OP1
Bolt 1 handling	10	OP1	Bolt 1 screwing	195	OP1/ARM
Bolt 1 screwing	300	OP1	Bolt 2 handling	10	OP1
Bolt 2 handling	10	OP1	Bolt 2 screwing	195	OP1/ARM
Bolt 2 screwing	300	OP1			
TOTAL	**740**		**TOTAL**	**470**	

The simulation environment helps to validate the project results from an ergonomic point of view. For this purpose, the current manual assembly line was quantified using the embedded Process Simulate Ergonomics analysis for the human tasks. Figure 5 shows the simulation model.

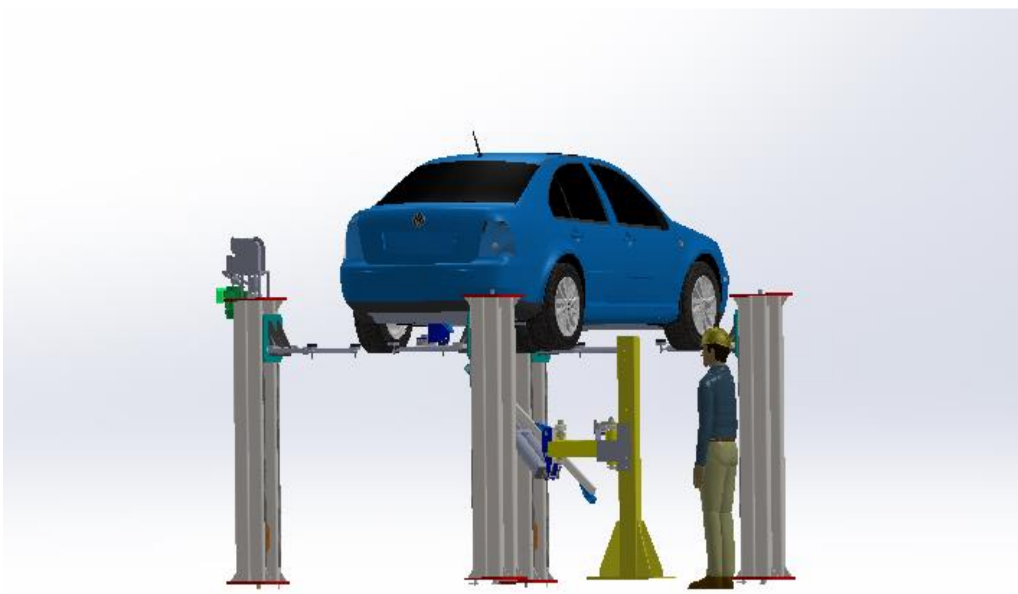

Figure 5. ARM and Human simulation model

4.4 Verifying

The verification of the methodology performed in "GM TAPOICH" Tashkent plant. Where different final assembly models with different fixing moments. According to task allocation framework the new hierarchal task allocation has been developed in Figure 6.

According to this figure we can say that, number of operators, cycle time and number of tasks have been reduced by integrating ARM into manual assembly cell. The total cycle time of the assembly system with Arm integration is decreased until around 470 seconds. The final layout of the assembly case has been reported in Figure 7 with a detailed description of all devices and components used in the scenario. Based on this, we performed several experiments in order to check the efficiency of the new cell.

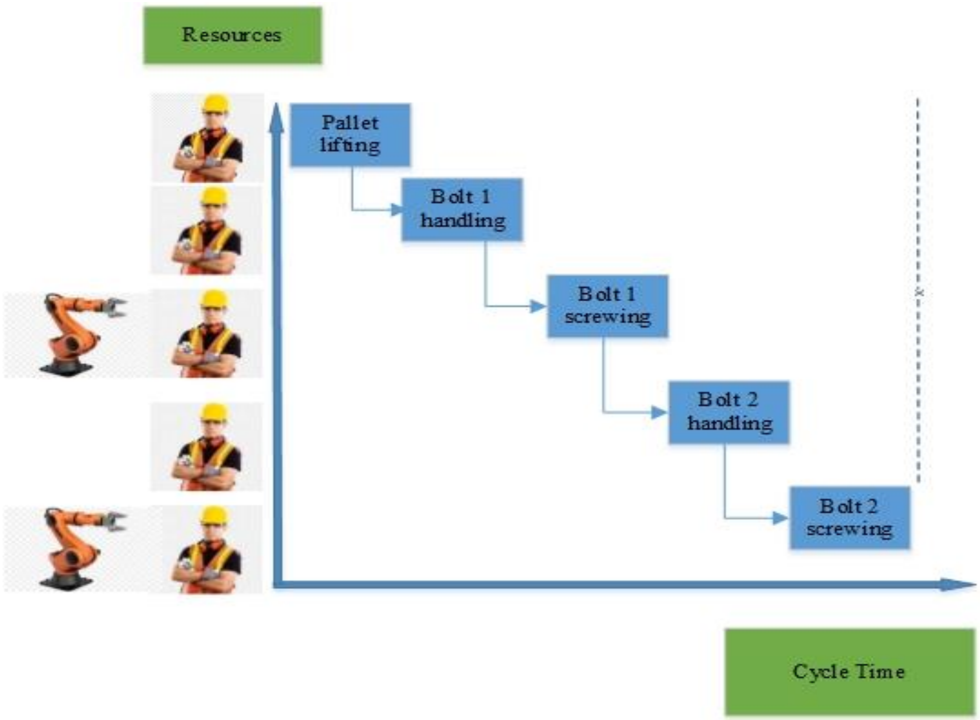

Figure 6. ARM and Human assembly system HTA

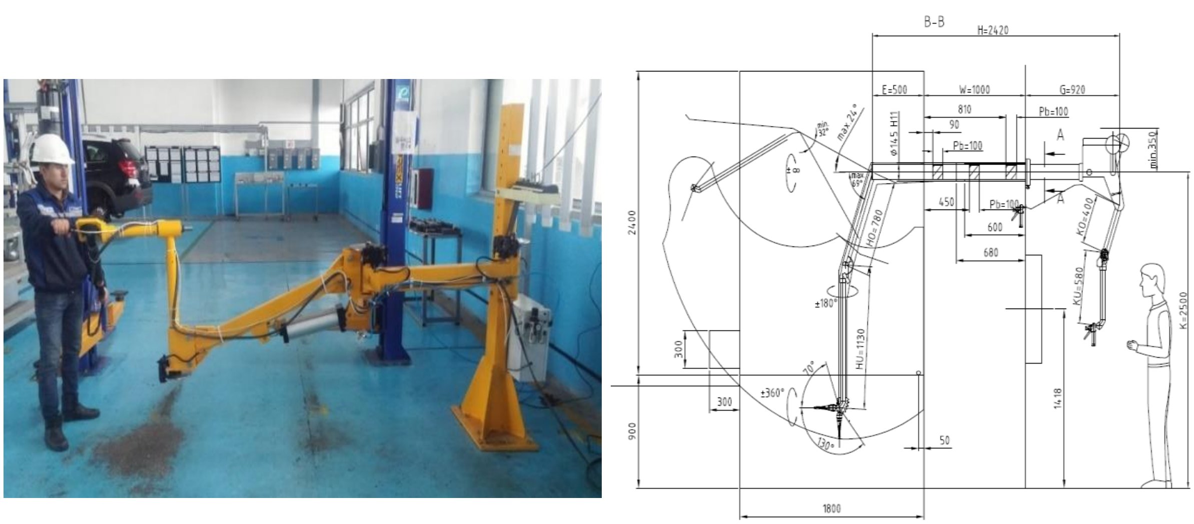

Figure 7. Industrial application of ARM manipulator.

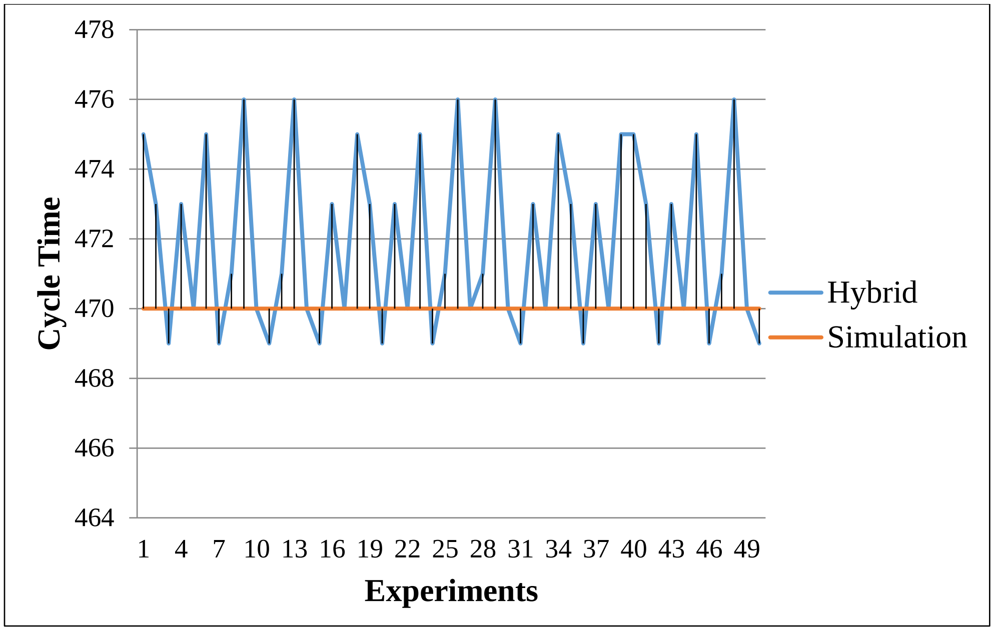

Figure 8. Experimental results

The Fig.8, represents us final industrial experiment result for ARM and human integration. The blue line represents the actual results the cycle time while red line is the simulation result. From the figure we can say that actual cycle time is varying between 469 and 476 seconds for ARM and human collaborated system, while the actual cycle time for manual assembly system was 900 second, so we can say that cycle time is about halved with hybrid system.

5. Conclusion

The proposed methodology for ARM robot and human collaboration in an assembly cell enables the introduction of a robot and human task model in a unified structure. The intelligent decision-making algorithm allows human to robot physical task allocation and cooperation in the same workspace. In addition, the proposed method is oriented towards the human task allocation and execution, taking into consideration the safety aspects according to the related safety norms. The average resource utilization per task for the selected alternative scheduling is illustrated in Figure 9. In comparison to the manual assembly case, the time required for a human to perform a task is reduced by 23%.

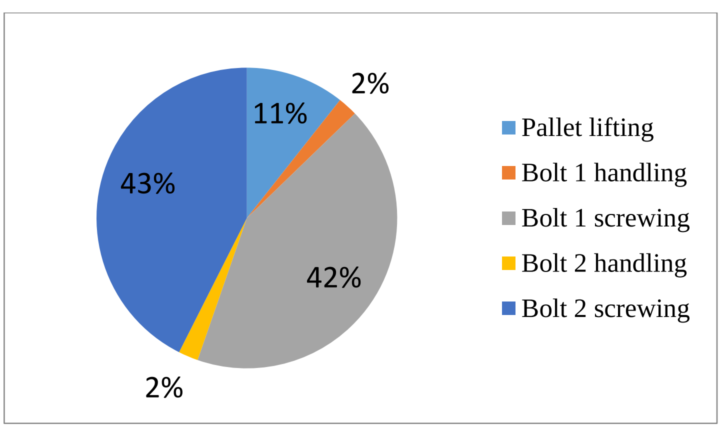

Figure 9. Average resource utilization (%) per task

The identified advantages of this study can be summarized as follows:

- The potential improvements on suspension assembly cell would help in reducing the cycle time of the process, but without keeping the cost of tooling low, as in the proposed layout. The actual cycle time is varying between 469 and 476 seconds for ARM and human collaborated system, while the actual cycle time for manual assembly system was 900 second.
- The ARM and human physical task allocation methodology was proposed based on capability characteristics.
- Since human being is more responsible for product quality, by decreasing 23% human tasks, the quality of the final product increased.
- Increase automation level in manual assembly stations.
- The cost-efficient cell by decreasing the number of operators from 3 to 1.
- Improving ergonomics for human.
- ARM workspace can be extended as it is equipped with an external rotary axis that allows the ARM to rotate 180^o around its base.

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Biographies

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