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Abstract. Industry 4.0 is characterized by the use of digital solutions and computational technologies. The proposed paper presents a workstation space plan solution using an intelligent computational approach: Genetic Algorithms. On the one hand, we have the operator's effort represented by the motion trajectories in the normal work area. On the other hand, the production flow requires some constraints on the sequence of the assembled components or their location. Considering both the constraints and the reduction of the operator's effort, the planning solution proposed in this paper ensures the improvement of the working process by applying the principles of motion economy under the conditions of the constraints required by the production process. The resulting sequence and type of the components and operator effort for the production process is indicated to the operator on the modular workstation. Furthermore, the component placement can be adapted to the characteristics of the production process or of the operator's needs (left handed, has some disabilities, etc.). The solution proposed in this paper was applied in an experimental laboratory where components from the automotive industry are assembled.

1. Introduction

Modernization of manufacturing processes to increase production efficiency and increase operator safety and comfort is the primary focus of Industry 4.0 implementation. On the one hand, it involves the modernization of the manufacturing equipment and the existing infrastructure, on the other hand, it involves the introduction of new technologies: modern IT technologies, artificial intelligence, sensor systems and IoT. These modernization directions have been the subject of research and development in recent years. Thus, interdisciplinary research and implementation projects combining concepts and results from economic engineering, quality management, organization and workplace ergonomics, information technologies, integrated systems are being developed. These projects introduce concepts of modularity and reconfigurability in manufacturing, as presented in the paper [1]. Here are presented modern IT and electronics concepts such as cloud data storage, multi-product intelligent assembly stations, administration portal for reconfiguration of manufacturing processes according to customer requirements and new standards for operator comfort and security. All these elements are specific for Industry 4.0. They have been used, according to the work, in the aeronautical industry in the UK. The project presented in our paper also adopts modern IT technologies and uses them to increase the efficiency of production and ensure user comfort. An integrated computer solution used to organize logistics in order to increase operating efficiency and reduce response time is also presented in the paper [2]. The solution combines several technologies and devices including “pick to light” (also used in our paper) and offers “build to order” and “configuration to order” services. As will be mentioned in our paper, effective deployment of specific new Industry- 4.0 technologies also involves re-engineering existing infrastructure to allow for configuration through new technologies. This mainly means modularization and multi functionality. An example of the reconfigurability of the manufacturing systems is presented in the paper [3]. Here the same machine can be used for different tasks. The paper presents a solution based on genetic algorithms (algorithms also used in our paper) for reconfiguring machines to reduce cost and minimize response time. This is an example of using genetic algorithms (artificial intelligence) to re-plan the operation of the equipment in the industry with all the benefits that arise from it. An example of the use of genetic algorithms for the selection of parts is presented in paper [4]. Here is a “pick and pass” management system for a warehouse implemented with genetic algorithms. A simulator is used to implement GA (Genetic Algorithm) then the results obtained are compared with those obtained by using other management policies - the advantage of using genetic algorithms is given by their parameterization (ease of reconfiguration to changing requirements). Intelligent information technologies are also used for management of finished parts batches as in the paper [5]. Here is an example of using genetic algorithms for developing attractive consumer product models. The algorithm considers several aspects: design, technology, aesthetics, economy, etc. As a result, we have several types of virtual finished products that are then presented to customers and their reaction is analyzed. The paper is an example of using genetic algorithms with impact on finished products. Using GA to select parts types is a feature also used in the project presented in our paper. Here are also used techniques for organizing the workplace and increasing its ergonomics. This is also a direction that can be upgraded in the light of new IT technologies that have emerged. A paper describing factors that can influence performance at work, as well as the impact between equipment used and operator is presented in [6]. Solutions that aim at reorganizing the workspace and redesigning the operator's seat are presented. Solutions are used in industry as well as in other branches (schools). The use of the genetic algorithm for multi-objective optimization of the operator's place (mainly the redesign of the chair) is presented in [7]. Here, the inputs of the algorithm are the characteristics of the user and the workplace.

The solution proposed in our paper allows the development of a work organization scheme (or schemes) using intelligent algorithms. The novelty elements brought by the research project presented in the paper are: the use of the genetic algorithm to generate workspace organization schemes and the development of an IT solution that allows the use of intelligent planning algorithm (Genetic Algorithm) in a workflow performed under laboratory conditions. This laboratory is actually an experimental laboratory developed within the project “Smart manufacturing technologies for advanced production of parts from automotive and aeronautics industries”. The solution was experimented using a stand from laboratory that contains:

- Production line for mounting a finished part: horn- steering wheel assembly. The finished part consists of the following components: wheel assembly, screws, caps, button.
- “Pick to light” system placed to identify the production (assembly) sequence. To each box with the components of the horn- steering wheel assembly are illuminated indicators and buttons.
- Controller that allows configuration of the “pick to light” sequence. In the project presented, the sequence provided by the genetic algorithm is manually entered from the controller interface.

To the existing laboratory stand the following new elements were added by the project presented in the paper:

- Computer with server application that allows input of parameters and run of genetic algorithm. It will provide details about the “pick-to-light” sequence through the web browser interface, graphical indications of how the operator will act: the hand that will use it, the color of the component to be assembled and the graphical statistics reports that will be presented in the paper.
- Terminal connected to an intranet capable of running a web browser to access operator graphics and an operator display.

The paper combines two points: research - the use of an intelligent algorithm - Genetic Algorithm - for planning a workplace organization scheme; and development - implementation in production: the proposed solution is used on a simulated production line (tested in laboratory condition). For the second point, the project presented in the paper uses typical IT technologies from production environment: web server application where the intelligent algorithm runs, graphical reporting engines for clients. The experimental case study involves the assembly of 100 horn-steering wheel parts with optimal planning of the work surface and the assembly process so that the load on the two arms of the operator is as balanced as possible and the distribution of the finished parts properties is as uniform as possible (the horn-steering wheel assembly can be of 8 types - this case study aims to distribute as finely as possible the 100 finished parts in the 8 types).

2. Block diagram of the system

The block scheme level and system components are shown in figure 1:

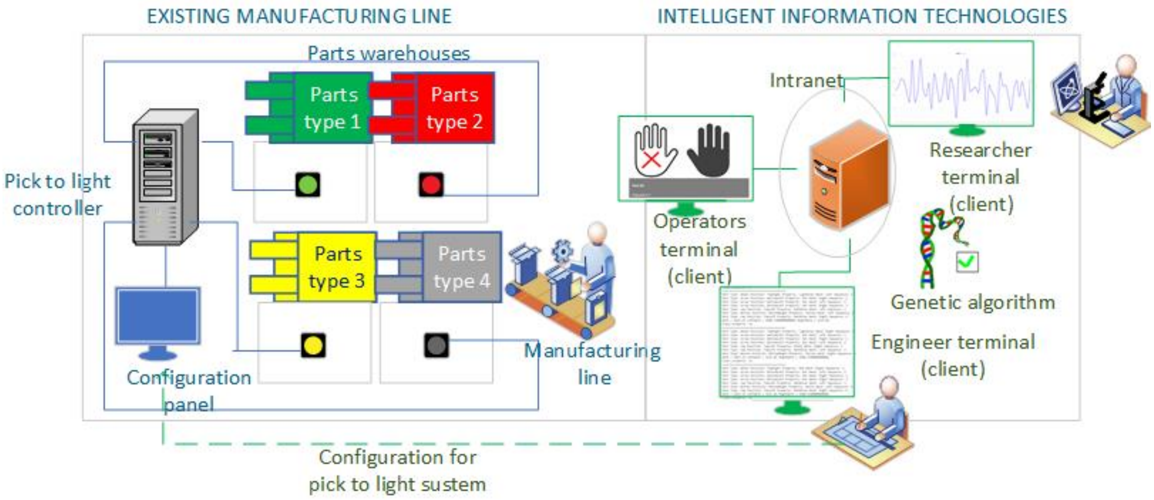

Figure 1. Block diagram of the system.

The production line allows the assembly of a horn-steering wheel part. It consists of 4 types of components: a steering wheel assembly (taken from a previous manufacturing process), cover mounting screws (3 are needed for a finished part), slot covers, horn pushbutton. All of these are available in the experimental manufacturing line. Here is also a “pick to light” system attached to the assembly point. Thus, there are LED lights and buttons on the storage compartments of the 4 types of components. All these are connected to a controller (Siemens). From the graphic panel of controller, you can program the sequence that the operator will need to complete when assembling the finished part.

A computer with a server application and a client terminal was attached to this system. The server application runs a Genetic Algorithm specialized in multi-objectives optimizations. In our case the aim is, on the one hand, to ensure operator ergonomics so that the works (load) for both operator’s arms is as evenly as possible, and on the other hand the provision of finished parts of different types (with different properties) distributed as evenly as possible. As will be shown further, a finished part can be of 8 types. In this case study, we aim to get 100 finished products that fit into the 8 types as evenly as possible. Noteworthy for the solution presented in the paper is its parameterization. Thus, both the distribution of effort on the operator’s arms and the distribution of type parts is configurable. In this case study, equally distributions are sought but, depending on the operator or production requirements, different distributions can be configured. Distributing the arms operator effort and distributing the parts by type is the objective function of the genetic algorithm. The server application is made with JS Client Side technology, the programming is in CLI Angular and the front-end framework is PrimeNG. It allows the construction of responsive web panels - so the client can access them from a tablet

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terminal- in which it can display graphical indications for the operator and graphs that show the evolution of some features generated by the genetic algorithm that are presented in this paper. As we have seen, the terminal can be a computer or tablet that has an intranet connection and a web browser.

3. Considerations related to workstation ergonomics

Workplace planning must be done considering the twenty principles of the economy of movement. Among these, the following directly concern the experimental workstation used in the project presented in this paper.
- Starts activity simultaneously with both hands;
- End the activity simultaneously with both hands;
- Use simultaneous hand movement in opposite or symmetrical directions;
- Place the tools and materials in the corresponding and identical sequence at the same workstation (fixed workstations);
- Use a minimum number of activities to get the minimum time.

The specificity of the workstation used in the paper falls to Level 1 (lowest) in terms of operator posture but can reach Level 2 or 3 in terms of operator effort: does not handle weights (the most difficult is the steering wheel assembly weighing 0.5 kg), but the assembly procedure involves a holding time between 61-80% from the total cycle time (3 bolt screws, placement caps and a button) and a repetition (frequency) that can reach 200 operations / hour. At the same time, according to MODAPTS classifications, the classes of movements that are performed are 4 and 5. For these reasons, one of the objectives proposed in the project presented in this paper is to balance the effort on both arms. Determination of effort is done starting from the working point geometry - shown in figure 2.

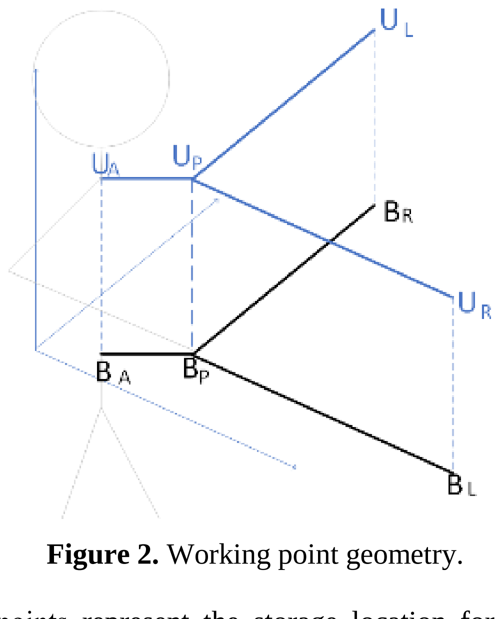

Figure 2. Working point geometry.

In figure 2, the U_L, U_R points represent the storage location for the steering wheel and caps components, B_L, B_R location for the screws and buttons, the $B_P$is the work point, the place where the components are placed to be assembled. U_A represents the position where the arms are attached to the torso. Also, the height (H) and the operator's weight (M) shall be considered. Starting from these, the mass of the arm and the length of the arm are determined according to the following estimates in equations (1) and (2):

$$m_{arm} = 5.3\% \times M \quad (1)$$

$$\mathrm{l}_{\mathrm{arm}} = 40\% \times \mathrm{H} \quad (2)$$

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The weight of the arm and its length along with the coordinates of the work point shown in figure 2 will be used to determine the work to bring the hands to the components storage locations (boxes) and to take them to the assembly point. The table 1 represents the determined works (efforts).

Even if the box with steering wheel components is located at the top side of the work point it is treated separately because the steering wheel has a weight of approx. 0.5 kg added to the arm's mass. The weights of the rest components are neglected. Starting from the works values in the table 1, it can determine total work and work on the arm for the process. The difference between arms works is a size that is considered by the genetic algorithm - one of the goals is to reduce this difference. In the case study presented in this paper, the goal is to uniformly strain the works (effort) on both arms.

Table 1. Works (W) performed by arms to take components to assembly point.

L (m)	M (Kg)	W (J)	Description	MODAPTS class
72.46	5.04	222.771024	Arm to top parts	5
79.21	5.04	243.523224	Arm to bottom parts	5
68	5.54	229.7992	Wheel to work point	5
68	5.04	209.0592	Top parts to work point	5
60	5.04	184.464	Bottom parts to work point	4

However, depending on the profile of the operator, other metering schemes of works can be followed (e.g. operators with certain disabilities may require a different effort on the arms). In this case, weight ratios can be used to calculate the works difference on the arm, which will benefit the effort on an arm. For example, a coefficient of 0.5 entered in the arm works difference expression at the right arm work will cause the algorithm to determine works distribution schemes in which the right arm works twice as much as the left arm.

4. Considerations related to assembly process

The production flow presented in the paper case study involves the following operations:
- Placing the steering wheel to the work point;
- Placing screws on the steering wheel (3 screws);
- Placing the steering wheel caps (2 caps);
- Placing the steering wheel button.

Screwing is a process that needs to be done before placing the caps and the button, otherwise the front of the steering wheel can move. The figure 3 shows an image of the components of horn-steering wheel assembly.

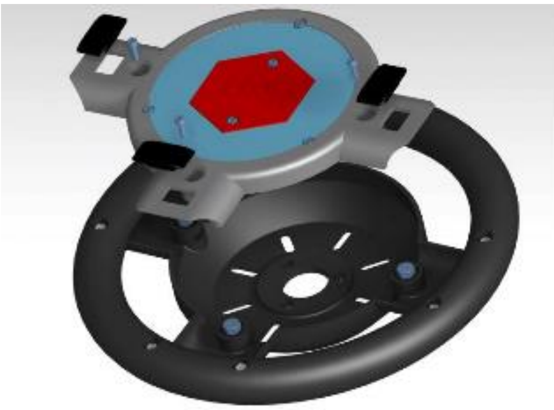

Figure 3. Horne steering wheel components.

In turn, for each component there are several options (properties) from which can be chosen, listed in the table 2. For this reason, the resulting horn-steering wheel assembly can be of several types - depending on the properties of the components. In total, we have 8 types of horn-steering wheel assemblies that can be produced.

Another objective is to distribute evenly the batch of finished parts on the 8 types. For this, dispersion was determined for each type of batch and then a sum of dispersions was calculated. Reducing the amount of dispersions is another objective pursued by the genetic algorithm.

Table 2. Work (W) performed by arms to take components to assembly point.

Part	Option 1	Option 2
Wheel	Red	Light Gray
Screw	-	-
Cap	Yellow	White
Button	Dark Gray	Black

The case study treated in the paper aimed at uniform distribution of the finished parts on the 8 types. By weights applied to the calculated dispersions different distributions by types can be tracked.

5. Genetic Algorithm

The central component of our system is the genetic algorithm. It has the following input data:
- Components types: steering wheel, screw, cover, button;
- Position of the components which are used in the workstation assembly: left top, top right, bottom left, bottom right;
- The properties (types) of the components used in the assembly: red, light gray, yellow, dark gray, black;
- Position in the assembly sequence: the steering wheel always has first position, follows the screws, then the caps or the button;
- The hand used to perform the operation: left and / or right.

The "process" entity is a complete sequence through which a completed horn-steering wheel assembly is produced. As we have seen, the process involves assembling a steering wheel, placing three screws, placing two caps and a button. As a result of these operations, a total work, a work for the right arm and a work for the left arm are made. From the works for the right arm and for the left arm the works difference for a process will be calculated. The finished part will fit into one of the 8 types.

All the processes necessary to complete a batch of 100 finished parts will constitute the genetic dowry of an individual in our genetic algorithm. An individual will be characterized by the sum of the works differences from the 100 processes and the dispersion from the average value for each of the eight types of finite parts. As we have shown, the objective function of the genetic algorithm, see equation (3), is represented by the weighted sum of the operator's works difference on the hand for the 100 processes and the sum of the dispersions per type of parts of the final lot.

$$f = P \times \Delta W + \sigma \quad (3)$$

Where:

$$\Delta W = \sum_{p=1}^{100} \left| W_{left}^{p} - W_{right}^{p} \right| \quad (4)$$

$$\sigma = \sum_{t=1}^{8} \left| nr^{t} - \overline{nr^{t}} \right| \quad (5)$$

Where ΔW represented in equation (4) is the sum of works differences for each process p, σ represented in equation (5), the dispersions from the mean value on the eight types of finished parts t for a batch of 100 parts and P represents a weight factor given by the equation (6):

$$P = \frac{\mathrm{Max}^{t}(|nr^{t} - \overline{nr^{t}}|)}{\mathrm{Max}^{p}(|nr^{t} - \overline{nr^{t}}|)} \quad (6)$$

This factor is used to give in the expression of the objective function the same importance for the difference of works and dispersion by type. If it is desired that the importance of the two components of the objective function be different, different weights will be introduced.

The coding scheme used for the genetic algorithm contains a gene associated with a process. The structure of a gene is presented in the table 3:

Table 3. Structure of the gene.

Component	Description	Options
1. Wheel	Hand for wheel	Left, Right
2. Screw 1	Sequence	1 or 2
	Hand	Left, Right
3. Screw 2	Sequence	2 or 3
	Hand	Left Right
4. Screw 3	Sequence	3
	Hand	Left, Right
5. Part 1	Type	Cap, Button
	Property	Yellow, White, DarkGray, Black
	Sequence	3 or 4
	Hand	Left, Right
6. Part 2	Type	Cap, Button
	Property	Yellow, White, DarkGray, Black
	Sequence	3 or 4
	Hand	Left, Right
7. Part 3	Type	Cap, Button
	Property	Yellow, White, DarkGray, Black
	Sequence	4
	Hand	Left, Right

An individual - the chromosome - is made up of 100 genes, so all the processes necessary to produce a batch of finite parts. A generation is composed of 50 individuals. Parent selection is done using the roulette method. For a generation, 2 parents are selected. There is only one crossover point that is chosen at the parent chromosome level. For one generation there is only one crossover operation. Following the crossover will result an offspring that will be added to the population of a generation. Mutation involves random changes in a gene. The mutation rate is 0.2.

The result of mutation replaces the individual to whom the mutation applies. The number of individuals in a population remains constant (50). After one generation, the individual with the weakest note - the highest fitness value - will be eliminated from the population.

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6. Experimental results

As we have seen, the case study from this paper presents the assembly of a 100 horn-steering wheel batch. The IT solution achieved in this project determines a technological flow that makes the batch assembly process efficient from two points of view: to equally request the operator's two hands respecting the principle of economy of movement and to distribute the types of finished parts as evenly as possible.

The IT solution is centered on a web server application that provides to the client with a simple web browser application the flow of the 100 processes selected as the most optimal in terms of equal distributed works on the hands and uniformity of the batch of finished parts, as well as visual indications of the sequence to be followed by the operator along with the pick to light visual indications.

In figure 4 are photos with the manufacturing line and a detail with controller panel.

Figure 4. Manufacturing line (left) and detail with controller panel (right).

To the left photo it can be seen pick to light indications for the boxes with components. Pick to light sequence is manually loaded from optimal flow generated by GA using controller panel. The steps taken to determine the most efficient production process and operator planning are the following:

1. The input parameters are entered: the working point geometry, the height and weight of the operator and the weight ratios for the objective function.
2. The genetic algorithm is running. It is determined the individual who corresponds to the most efficient process resulting in 100 finished parts.
3. A report is generated (via the web interface) that allows the “pick-to-light” system to be programmed through the controller panel.
4. The visual sequence that will run in parallel with “pick to light” is generated. The visual sequence will run on a terminal also placed near the operator. The “pick to light” indication shows the operator where are the components to be taken to the work point while the visual indications in the terminal show to the operator which hand to use and which is the color of the component. If two pick-to-light indicators are on, then the operator will use both hands. The colors of the components to be taken with both hands will be displayed on the terminal. If a single pick-to-light indicator is lit, then the operator will use only one hand, on the terminal will see indications of which hand and what is the color of the component to be picked up.

Along with the functional indications, "technical" details of the algorithm are also provided through the same web interface. The figure 5 shows the variance of the works difference on the operator's arms for one generation (production of a 100 part/individual batch).

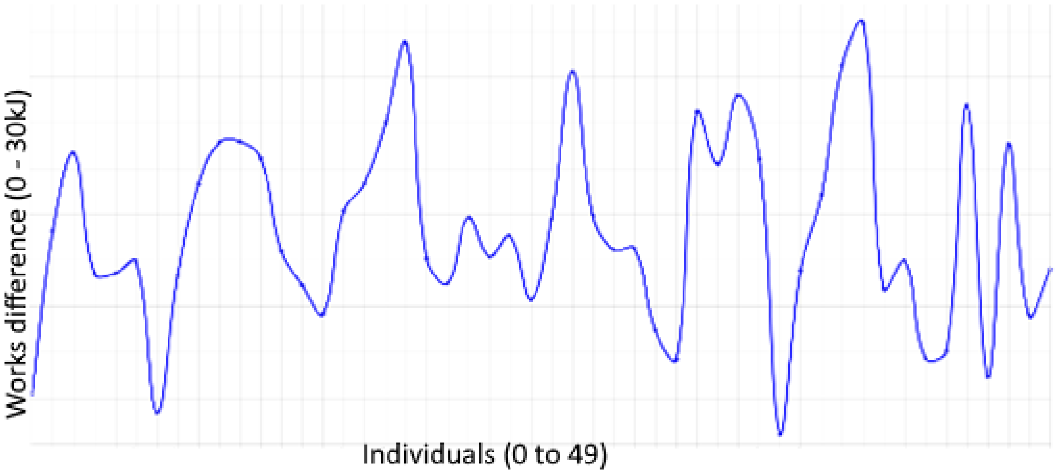

Figure 5. The works difference for one generation.

On the horizontal axis are the individuals of the generation and on the vertical axis the difference in effort (measured in Joule). A minimum of 2430 J can be seen at individual 36.

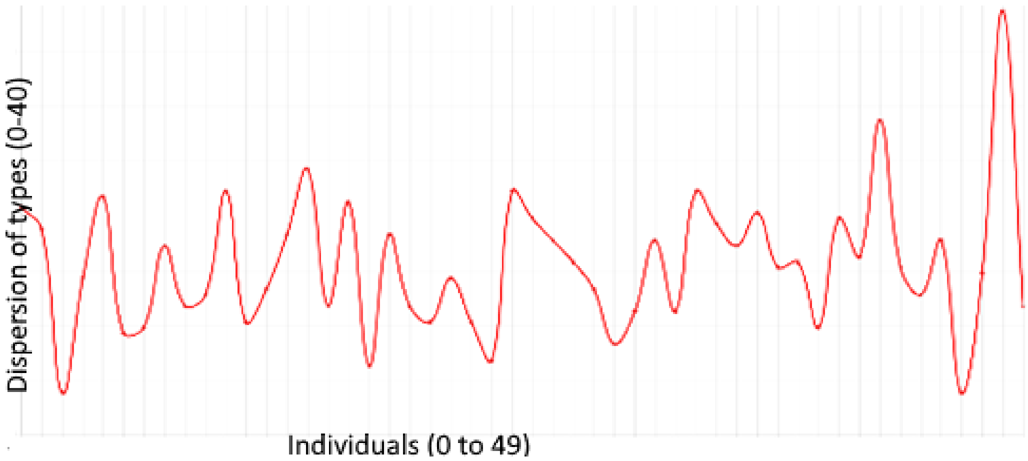

Figure 6. Dispersion of finished parts types for one generation.

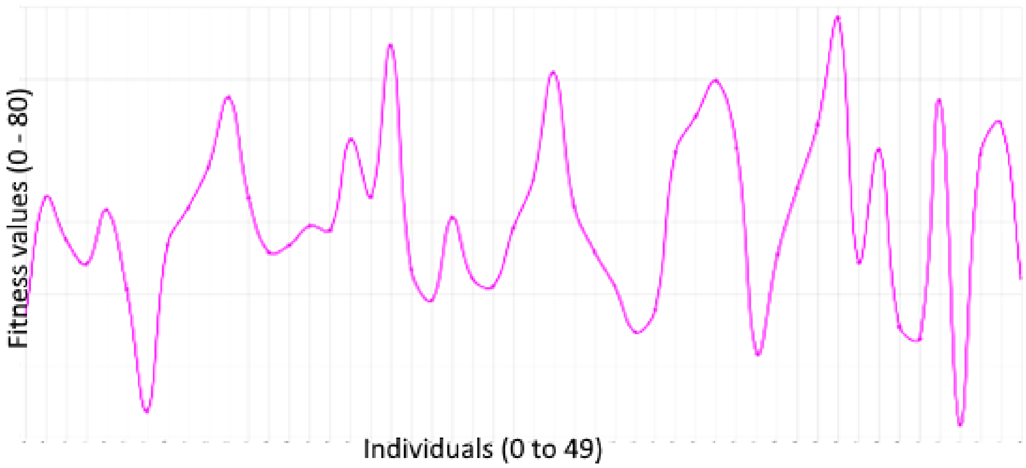

Figure 7. Fitness values for each individual in a generation.

The figure 6 shows a sum of dispersions for each batch generated by individuals. Here we can see a minimum for the individual 46 (a dispersion value of 18.75 which means on average fluctuations of +/- 2 for each of the eight types of finite parts).

However, the individual 46 had a total difference of 4919 J of the effort but the individual 36 has a dispersion of 35.25. Here comes the role of the algorithm - the determination of the individual having low values at both factors (batch dispersion and works difference). This is where the fitness assessment takes place. The figure 7 shows the evolution of fitness for one generation. The minimum is reached by the individual 46 having the fitness value 31.75 so is individual with the most efficient scheme. The figure 8 shows how the operator receives additional indications. The left hand and the right hand indicate that both hands will be used (there are two "pick to light" indications).

Figure 8. Operator's visual indications from terminal.

The hand color indicates the color of the part to be taken with that hand (or x sign indicates without color such as the screws).

7. Conclusions

This paper presents a project that combines research with production. On the one hand, using an intelligent algorithm, the Genetic Algorithm, as a multi-objectives search solution for an optimum between evenly distributed effort on the hands and the uniform distribution of the types of finished parts on a batch, the project addresses several disciplinary research themes: Artificial Intelligence, mechanical engineering, economic engineering, workplace ergonomics. On the other hand, the paper is not just about presenting a solution, but goes on to implement it and testing it in the production environment.

The efficiency of the solution lies in its parameterization. Thus, weights can be changed to the works differences on the hands or to the distribution of types of finished parts. A future research direction may be to obtain efficient processes for certain categories of operators who can work less with a hand or to obtain batches of finished parts of only a certain type by changing the weights to the objective function of the algorithm genetic. Another direction of research would be to use the solution in other production processes. The development directions of the IT solution would be the automatic introduction of the pick-light sequences into the controller and the taking of feedback from the controller.

8. References

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