Automated Method Time Measurement System for Redesigning Dynamic Facility Layout

Salam Alzubaidi, G. Fantoni, F. Failli, M. Frosolini

Abstract**—**The dynamic facility layout problem is a really critical issue in the competitive industrial market; thus, solving this problem requires robust design and effective simulation systems. The sustainable simulation requires inputting reliable and accurate data into the system. So this paper describes an automated system integrated into the real environment to measure the duration of the material handling operations, collect the data in real-time, and determine the variances between the actual and estimated time schedule of the operations in order to update the simulation software and redesign the facility layout periodically. The automated method-time measurement system collects the real data through using Radio Frequency-Identification (RFID) and Internet of Things (IoT) technologies. Hence, attaching RFID- antenna reader and RFID tags enables the system to identify the location of the objects and gathering the time data. The real duration gathered will be manipulated by calculating the moving average duration of the material handling operations, choosing the shortest material handling path, and then updating the simulation software to redesign the facility layout accommodating with the shortest/real operation schedule. The periodic simulation in real-time is more sustainable and reliable than the simulation system relying on an analysis of historical data. The case study of this methodology is in cooperation with a workshop team for producing mechanical parts. Although there are some technical limitations, this methodology is promising, and it can be significantly useful in the redesigning of the manufacturing layout.

Keywords**—**Dynamic facility layout problem, internet of things, method time measurement, radio frequency identification, simulation.

I. Introduction

The dynamic facility layout is one of important industrial and manufacturing issues; so, in order to solve this issue, many parameters should be taken in consideration such as reliable and real time data, robust simulation and sustainable design. New manufacturing systems, especially in the last decade, such as agile and lean manufacturing systems, face facility layout problems due to the dynamic environment, and rapid customer requirement changes [1]. Dynamic facility layout design shall work inefficiently over time due to different conditions. The traditional facility layout design focuses on many parameters, such as the distance between the machines (or departments), the frequency of material or human movements, and the cost of each material movement. These parameters do not reflect the real condition of the manufacturing environment from a facility layout perspective for many reasons; on top of these reasons, the human\worker movement and manual material handling operations; the human\worker movements could be not predictable and manual material handling for different material weights, which take different material handling times for same distances or takes same material time for different distances [2]. Therefore, involving Method Time Measurement (MTM) in dynamic facility layout is reasonable and crucial for designing the robust layout. The traditional MTM could be not practical, especially in smart manufacturing systems and industry 4.0 environment due to involving the human who uses a stopwatch for each movement and material handling operation. Thus, we designed and implemented an Automated MTM system aligning with Industry 4.0 concepts called Method Time Measurement 4.0 (MTM4.0).

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MTM4.0 system is based on enabling technologies: RFID and IoT and operation management tools to support the system in doing its tasks efficiently (Time measurement accurately in real-time) [3]. After collecting the manual material handling operation times, we take the average durations and input the time data to the Genetic Algorithm (GA), which helps the designer to re layout the facility periodically; after getting the new layout, we test it in simulation software to take other consideration in the account.

Computation time is also essential in this stage, especially when the designer has tens of machines (or department), so GA could take a long time to be executed in particular when the initial population is randomly chosen, so we suggest an algorithm (for some cases) to reduce the computation time, which relies on heuristic initial population and modified fitness function [4].

The case study represents the manual material handling and worker movement on the shopfloor to demonstrate the efficiency of MTM4.0 in collecting real-time data.

The proposed system has potential in the practical part and introduces promising solutions for redesigning the competitive industrial markets' layout. The limitations of the proposed system are controllable, which are organizational, legal, and technical.

The next paragraphs will generally discuss the facility layout problems and solution techniques, time estimation and real\actual time consideration for facility design modified GA, and mathematical models, which is programmed in a programming language (Python). Then we discuss the case study's initial results, which were applied in the workshop for producing mechanical parts.

II. Facility Layout Problems & Solution Techniques

In this section, we generally introduce problems and solution techniques.

A. Facility Layout Problems

Facility Layout Problem (FLP) deals with arranging various facilities of a manufacturer, plant, company, or organization in the most effective way to allow greater efficiency in the combination of resources to produce a product [5]. The layout problem is one of the evident and complex NP-hard problems, integrating multidimensional issues and information in one model or problem. Practically and economically, for U.S. manufacturers, material handling costs 50% of total operating expenses in some cases. Appropriate facility design can reduce these costs by at least 30%; these issues represent more than $250 billion per year assigned to the design of facility systems, layouts, handling systems, and facility locations [6].

Layout problems are classified into two main categories: Static Facility Layout Problem (SFLP) and Dynamic Facility Layout Problems (DFLP); in the static problem, given a group of departments, the material flow between each pair of departments, and the cost per unit of flow per unit distance with one layout plan for the whole period of the production, the departments have to be arranged into a layout such that the sum of the costs of flow between the departments in the layout is minimized. In the dynamic approach, the layout plan is based on a multiperiod time horizon. During this time, if the material flow changes warrant it, layout rearrangements may be planned in one or more periods [7]. This work will focus on DFLP.

B. Solution Techniques

Several methods are used for designing facility layout considering the conceptual and the main driver (Tools and Techniques Drivers). The most widely employed facility layout design methods are Systematic Layout Planning (SLP), which can be divided into four classes: evolutionary approach, exact, metaheuristic, and heuristic algorithms. Other tools used for solving FLPs are ALDEP, CRAFT, CORELAP, etc. These techniques are manipulated to formulate a new facility layout [8]. The facility layout domain shows integrating information, many advanced technological systems, and optimization tools in different manufacturing systems, especially in this century. Besides, many considerations and factors support the design quality (ergonomics, safety, and economic) that were engaged in facility layout design and problems; these considerations, tools, technologies, and manufacturing systems are classified into four layout drivers (Enabling Technologies, Tools and Techniques, Manufacturing Systems, and Supporting Factors) [4]. This research will focus on meta-heuristic (GA) drivers, enabling technologies, and ergonomics (MTM4.0) drivers.

III. Methodology: Time Data Gathering, Suggested Mathematical Model & Modified GA

A. Time Data Gathering Using MTM4.0

The accuracy of time estimation plays an essential role in the outcome of the facility layout designer, jobs and material handling time estimations have a significant impact on the facility planning; it is difficult to estimate the manual material handling times accurately, especially in the dynamic manufacturing environment and for long periods, so it is necessary to measure the time and collect the data from the shop floor in the real-time, the proposed MTM4.0 system takes the responsibility to gather the time data accurately. This system consists of hardware and software components; the hardware consists of an RFID reader- Antenna attached to the worker's hand and belt, PC with microprocessor for data processing, RFID tags attached to them (important destinations) such as tables, workstations, indoor, outdoor, warehouse and machines.

When the worker collects (Loading) the material from the table, the RFID reader will detect the tags attached to the table or the machine at a specific time and drops (Unloading) the material on the table or the machine within seconds or minutes; the RFID reader will detect other tags, the different times will be calculated and documented immediately in the microprocessor, this MTM can occur to all operations performed by workers on the shop floor. This system will enable the designer to know the exact time instead of relying on the estimated data.

Operation management tools (5S, Poke Yoke, Plan-Do-Check-Act) play an important role in supporting MTM4.0 for working efficiently [3].

The collected data can appear online in a single file for each RFID reader and the detected tags. The designer can take the average durations (times) of each manual handling operation to be considered in the next stages of the facility layout design (fitness function and algorithm).

B. Suggested Mathematical Model

Each facility layout design has its objectives, so different objective functions (or fitness functions) are used for designing facility layout; however, most of the functions rely on distance, frequency, and cost parameters [9] as shown in the mathematical model (1):

$$Min\ Z = \sum_{i=1}^{m} \sum_{j=1}^{m} F_{ij} D_{ij}\, C_{ij} \tag{1}$$

While in this research work, we modify this mathematical model to include the time parameter instead of distance and frequency for three reasons: accurate real-time data, the human behavior is difficult to be estimated, the time is more realistic than the distance for handling the weigh; hence, some material handling operations take a longer time for the same distance or take the same time for different distances. Equation (2) shows the suggested mathematical model (fitness function):

$$Min\ Z = \sum_{i=1}^{m} \sum_{j=1}^{m} T_{ij} C_{ij} \tag{2}$$

Z: Objective Function, F: The amount of movements between machines, D: The distance between machines, C: The cost of each movement between machines, T: The time of movement between machines, ij: The number of two machines from machine i- to machine j.

C. Modified GA

Genetic Algorithm

GA is a stochastic search method for solving optimization problems based on a natural selection process; it explores the solution space by using natural genetics and evolution theory. The general procedure of GA can be summarized by six steps [10]: Initial population, fitness function calculation, selection, crossover, mutation, and evaluation as shown in Fig. 1.

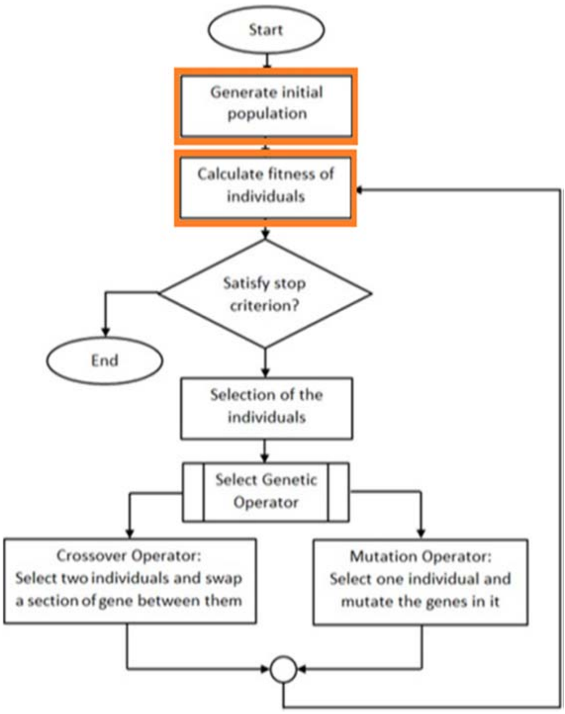

Fig. 1 General flowchart of GA

In this research, we focus on modifying the GA for the first (Initial Population) and second (Fitness Function) steps to speed up the solution execution and get more practical results by inserting the time parameter instead of the frequency and distance parameters in the fitness function equation.

In the past research works, the authors get used to input estimated data in the fitness function [10], while in this research work, we input real-time data using MTM4.0.

Heuristic Initial Population Algorithm

One of the drawbacks of the GA is the random initial population that causes long solve execution and takes a large number of iterations [10], [11] To fill this gap, we suggest a heuristic initial population algorithm to speed up the solution execution. This is reasonable due to the highly competitive industrial market environment, especially in agile manufacturing systems, which aim to satisfy the customer demands and deliver the orders as soon as possible.

Most agile manufacturing systems have retractional material flows; therefore, this algorithm could be applied to this dynamic facility layout [12], [13].

Before explaining the initial heuristic algorithm deeply, we explain material flow systems in the industrial factories [14], [15]:

1- Directional material flow system: the material items can be handled regularly with directional paths without return to the past line or in conflict with the other items (from machine to machine- from line to line) on the shop floor. The assembly lines are an example of this system of material flows.
2- Unidirectional material flow system: the material items can be handled irregularly, and the material can move between two lines or more, but the material items do not return to the past machines (Zigzag).
3- Retractional material flow: the material items can be moved irregularly, between the lines, and return to such a past machine of the technological path machines in the shop floor.

The heuristic initial algorithm is assigned to the third class of material flow systems. Based on that, we classified the machines into three groups:

- Retractional Machines: work on the workpiece items two times or more, which means the material items pass at least two times on this machine before the technological path ends.
- Relational Machines: return the material to the Retraction machines and have operations after the retraction machines.
- Directional Machines: work on the material one time and pass to the next machines.

The most popular example of facility layout design is 3*3 matrix, which consists of 9 machines on the shop floor.

The idea of the algorithm is to fix the retraction machine in the core of the matrix in the second line and then fill the shopfloor area (upper\lower) lines due to the efficiency of the retraction machines and the closeness with the other machines, after fixing the retraction machines, we fix the relational machines close to the retraction machines and then the directional machines as per the logical sequence of the technological path.

Fig. 2 explains the heuristic initial population algorithm, which relies on the shortest possible path of the material and minimum time duration.

The idea of this algorithm seems to work with more than 9 machines like (3*4), (4*4), (4*5) matrices. Hence, we can fix the retraction machines in the middle lines and then the relational and directional machines could be distributed on the shop floor areas.

Many examples were tested to know the efficiency of the algorithm. We will explain a simple example to show how the initial population can be selected heuristically.

IV. Theoretical Example

Imagine that a shopfloor has nine machines with a retraction material flow system, the time between each straight neighbor machine is 4 time unit, while between diagonal neighbor machine is 5 time unit, the other times are 8, 9 and 10 as per the duration of the worker movement.

The default technological path can be represented, as shown in Fig. 3, having a facility layout and genetic chromosome representation.

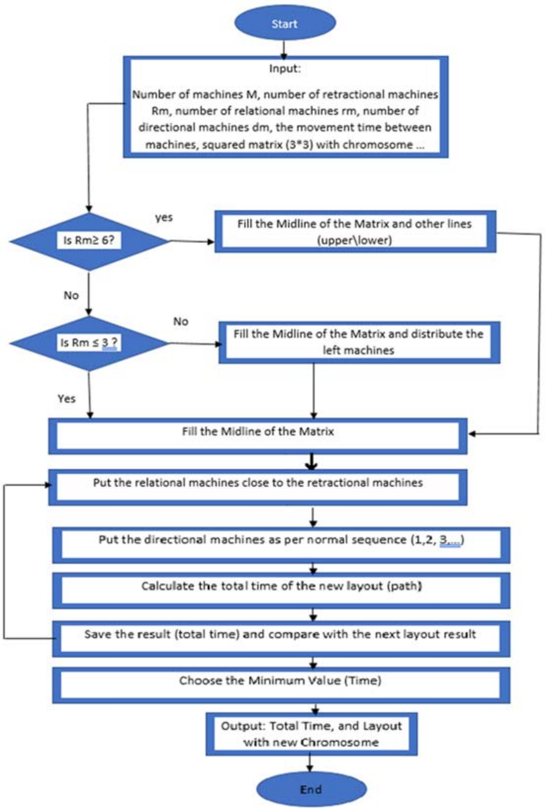

Fig. 2 Heuristic Initial Population Algorithm

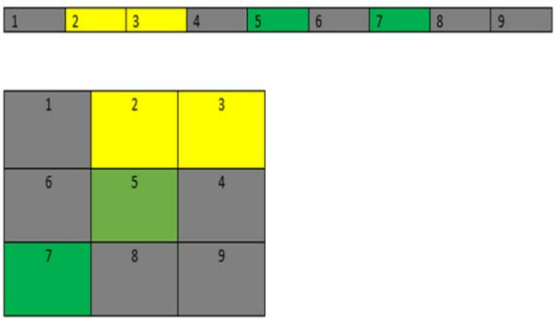

Fig. 3 A representation of the technological path on the layout and chromosome

- The retraction machines in the yellow color are 2 and 3.
- The relational machine in green color is 5, which returns the material to 2, and the relational machine 7, which returns the material to 3.
- The left machines in gray are directional, which are: 1, 4, 6, 8, and 9.
- The total time of produced one item is (32+4+10) = 46.
- The total movement times between all the machines are 32.
- The retraction time between 5 and 2 is 4.
- The retraction time between 7 and 3 is 10.

We can get better results with the implementation of the heuristic initial population algorithm, which can be summarized as:

- Fix the retraction machines (2 and 3) in the midline.
- Put the relational machines close to the retraction machines (5 and 7). And then
- Position the directional machines (1, 4, 6, 8, and 9) as per the logical sequence of the technological path in the blank areas, as shown in Fig. 4.

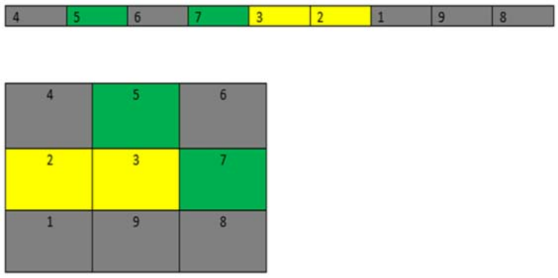

Fig. 4 Heuristic Initial Population

- The total time of producing one item is (33+5+4) = 42
- The total times between all the machines are **33**
- The retraction time between 5 and 2 is **5**
- The retraction time between 7 and 3 is **4**

So, the above solution represents a good initial population for GA to start with instead of starting with the random initial population.

VI. Case Study

The case study shows the operation relative to the monitoring of the manual material handling operations of small mechanical parts and the worker\human movements on the shop floor to measure the times for each movement from workstation to another (machine, table, store, etc.), the automatic measurement is not only for material handling, the manufacturing and inspection processes are also included such as drilling, dimension measurement, quality control, documentation and storing the material, besides the material handling operation times. The MTM4.0 system (hardware + software + passive tags) can recognize the operations that are carried out by detecting the presence of the worker in the areas delimited by the tags and keeping track of the statuses crossed by the operator and of the use of the drilling machine. As soon as the RFID reader detects the tag on the container, the operator status changes, and this allows an understanding of which activity is carried out. The same happens for the other activities, so that, at the end of the process, it is possible to use the time in which the state remains in the interesting statuses to measure the execution times. If a worker\human can carry out activities in multiple cells, it is necessary to monitor his movements: this can be done through the RFID anklet (RFID antenna reader + ESP32 and Battery). Moreover, it is possible to calculate the time spent to move from one place to another by subtracting the times between two timestamps.

If we consider the collection of PPEs from a cabinet, it is possible to detect the presence of the worker in the collection cell through a tag placed on the ground.

Three different workers\human have performed the activity (each assembler did the activity about five times, so in total, the experiment was done 15 times for each scenario) to collect reliable data and compare the operation durations that are involved.

12 Passive RFID tags have been used to identify the entrance of the shop floor and PPE locker, drilling machines, store places (raw material + finished-produced parts), measurement table, quality control, and documentation table, the antenna is attached to the right hand and the belt of each person that carries out the experiment. When the worker passes his right hand to take or handle a part, the RFID tags are detected. Then, the RFID reader transfers the signal to the central system (software) to collect the data and get the required information, especially that dealing with the time measurement. After having carried out the experiment, the time measurements have been summarized.

The experiment was done for four different scenarios, for different machines and facility layouts to compare the time spend for each layout and decide which one is more useful to work with. The facility layout of the existing shop floor is, as shown in Fig. 5.

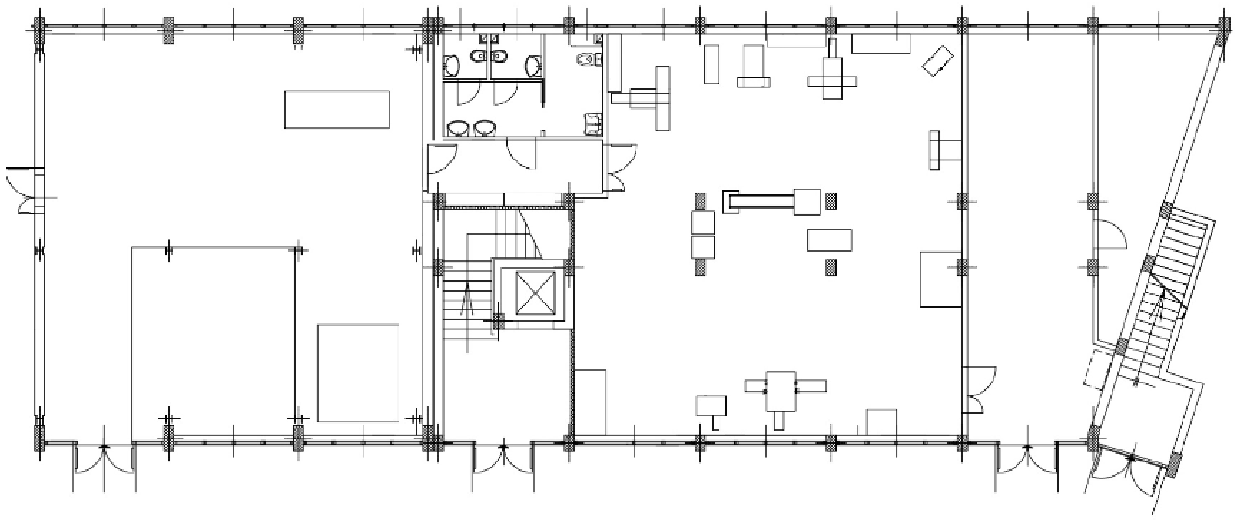

Fig. 5 Shop floor layout

VII. Discussion

MTM4.0 proves its efficiency in collecting the real-time data and demonstrates it as a key element for redesigning the dynamic facility layout through input the time in the fitness function instead of the distance and the frequency parameters; some controllable limitations can be taken in consideration such as the harsh manufacturing environment that probably causes damage to the RFID tags. Hence, the manufacturing processes that require robust operations will probably destroy the RFID tags; also, the workstation condition could be affected by the weather or the external environment, where the high humidity influences the efficiency of the communication between the antenna and the RFID.

The automatic system is based on the electromagnetic radio concept, so the communication between the antenna and RFID can be affected by the external waves (signals) that decrease the efficiency of the system too.

Manufacturing environment has different materials and conditions, so that requires using different types of tags; hence the metallic parts need special tags to avoid miscommunication with the antenna. Also, some tags need to be embedded inside the materials or the parts, so that requires using different frequencies.

Modified GA proves its reliability in solving some examples deal with dynamic facility layout with retraction material flow, and it can be compared with other solution approaches to conclude which is most suitable (best-fit) for this kind of problem.

VII. Recommendations and Future Work

We advise to use a different type of antenna to collect the data easier than using a big antenna, which is attached with an RFID reader; we also recommend using this methodology on different cases (3*4), (4*4), (4*5) matrixes to test the reliability of this algorithm.

The future work will focus on different examples and finish the programming language codes, and we shall take another real-life problem (not a workshop) to demonstrate this effort well; simulation is very important to be included after designing the dynamic layout to consider different issues such as safety, congestion, and interfaces.

The mathematical model can be modified to include other parameters (not only human movements and manual material handling), but other tools to engage the forklift or other equipment to measure the material handling operation times.

Digital Twin architecture to improve this methodology could be useful for research perspective at this time regardless in which domain manufacturing or warehouse department.

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