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Establishing security measures for the protection of production workers through UWB real-time localization technology

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Keywords: real-time technology, protection.
Abstract: This article discusses Sewio's real-time positioning system, which helps organizations protect workers in production areas by improving their safety, reducing the time needed for collection and rescue operations, increasing safety and simplifying the reconciliation of workplace time. The system works on the principle that every employee, supplier or visitor to the production plant receives a tag that identifies their exact location in real time. The tag can be part of a standard visitor card, such as cards issued at conferences. Optionally, the labels can also be attached to the clothing within the worker's arm or possibly to a part of the helmet. This article describes the applications of the use of the RTLS localization system in critical cases of threats to workers' health.

1 Introduction

Locating objects, vehicles and especially people is on the rise these days as it is a technology that collects real-time location data. In this case, the basic component is the aforementioned location. If we want something, we need to know what location and position it is in. If we want to point to something, we need to know the correct location. A manufacturing company can implement processes to ensure that certain items are in a predetermined location and thus increase sales.

On the other hand, a business can also ensure that processes are implemented to enable an employee to find materials or tools in significantly less time by using location technology. This case also focuses on security. This idea can be understood as the possible discovery of an injured person in large manufacturing companies and thus increase the percentage of worker survival in a dangerous situation [1,2].

2 Functionality of UWB technology in real case

RTLS technology is based on the transmission of short UWB signals that transmit tags and then on anchors that receive and evaluate these waves through software support, namely RTLS Studio. UWB technology is characterized by its ability to transmit a lot of data with low power consumption, making it an environmentally friendly and low-cost technology to operate. In the Department of Industrial and Digital Engineering, we use Sewio's RTLS technology.

The Sewio Networks company is described in this article. This company provides both hardware and software support to the Department of Industrial and Digital Engineering. The company is ranked among the European leaders in the creation of RTLS localization technologies and their applications in manufacturing enterprises around the world. Through the open API port, it is possible to create various other applications for specific use.

The Sewio UWB RTLS hardware consists of two types of hardware. The first type is signal transmitters, we know them by their name tags, which are used to track objects. The second type of hardware are signal receivers, anchors, used to receive signals from tags [3].

Tags are small electronic devices that are attached to any object or person we need to track. The tags serve as signal transmitters, which are then received by the anchors and sent to a location server where the location of the tags is calculated.

Sewio's tags are characterized by high localization accuracy, up to 30 cm, and a long battery life of up to 5 years. Durability and battery life depend on the frequency of tag location updates during use. The tag can be equipped with a group of sensors, namely: accelerometer, gyroscope, magnetometer, barometer, thermometer, dosimeter or others. The tags can operate reliably at temperatures ranging from -20 to +60 °C. Sewio's positioning technology uses three types of tags: Tag Leonardo Personal, Tag Leonardo Asset and Tag Leonardo Vehicle [4,5].

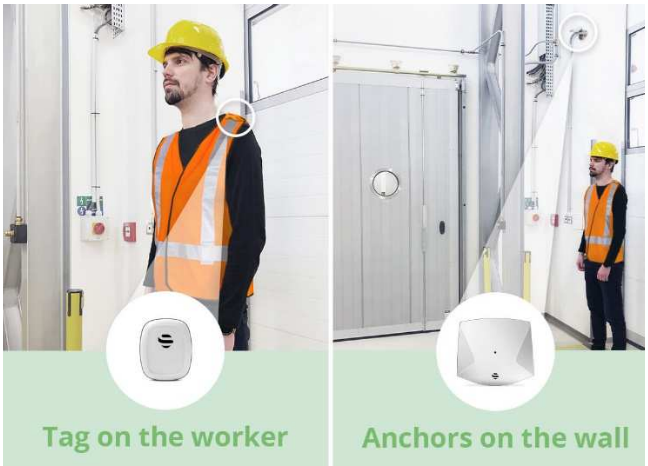

Figure 1 Tag Leonardo Personal for worker monitoring [4]

2.1 RTLS locating system use cases for worker protection

Smart Quarantine

With one click, you can find out who has been in contact with a Covid-19 positive employee.Saving lives by making sure these exposed employees are tested and receive treatment immediately Keeping critical factory operations running (quarantine applies to a selection of employees, not the entire team). "Smart Quarantine" reduces the COVID-19 reproductive number. RTLS software Sewio offers free consulting to implement "Smart Quarantine" to any company worldwide.

Faster collection time

In today's industrial world, even paper-based collection processes require a large amount of time to finally determine safely who is safe and who is still missing. The complexity of the process is directly proportional to the size of the device, but also to the number of floors within the selected building, as well as the number of assembly lines. Digitizing the assembly process greatly helps reduce the time required for completion and provides up-to-date information on those found and still missing along with an immediate evacuation list.

Figure 2 Safe zone [4]

Faster rescue of injured persons and emergency injuries

In critical cases such as fires, explosions or leaks of various gases, the RTLS system can be used to determine the exact location of people in the affected area, thus reducing the risks associated with these events. The software platform also provides a so-called emergency button with a quick call for help. In case of any health problem, the person is able to call for help and send a notification with the exact location of the person. Dispatch can send rescue units based on this instruction.

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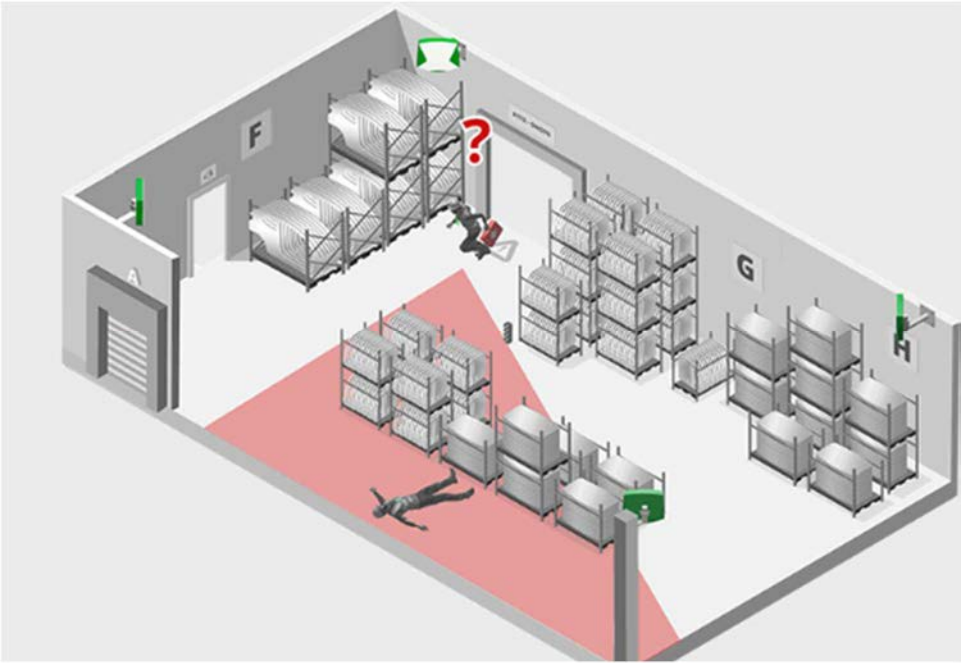

Figure 3 Injured Worker Locator system [4]

Improving emergency exercises through analysis

Real historical data on the movement of all people and possibly key items during emergency drills helps to validate evacuation routes, detect blockers in both routes and processes and make them more efficient. Facility emergency managers can use this real-life knowledge to handle special emergency scenarios in the best possible way, maximizing the safety of all people in the facility.

Geofencing and reducing movement in a confined space

Thanks to the unique function of Geofencing, which is based on the principle of RTLS localization, it is possible to set a selected number of virtual zones. These zones represent geographic boundaries and thus trigger automatic responses. This response to the system is triggered precisely with the help of tags and their bearers when entering or exiting the virtual zone. Thus, it is possible to analyze various types of danger in a collision with, for example, a collaborative robot and other mobile devices.

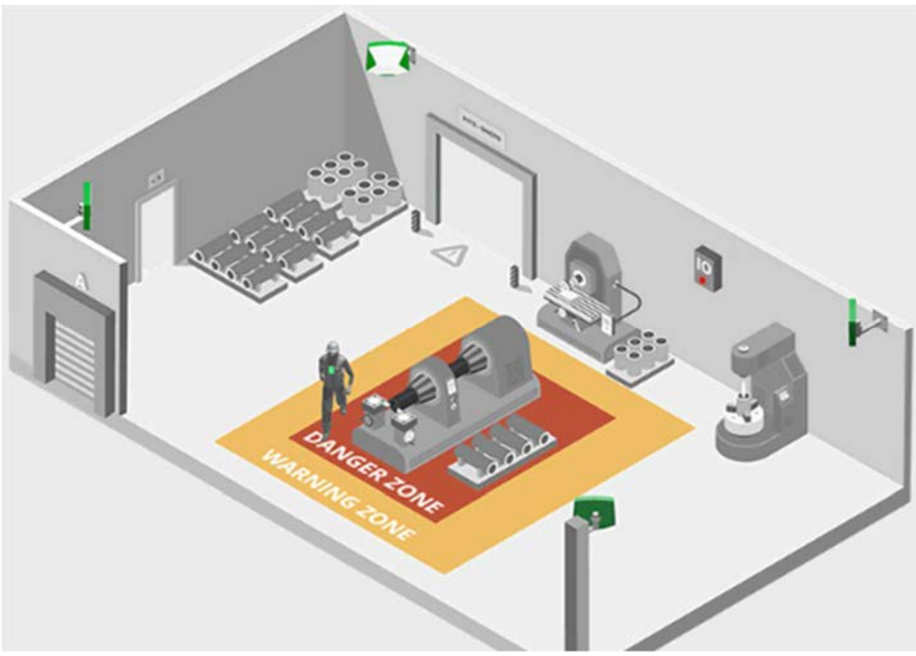

Figure 4 Dangerous zones [4]

Enhancing the safety of moving entities with dynamic zones

Dynamic zones enable alerting, reporting and tracking based on the proximity of two moving entities and the duration of their encounter. This feature unlocks employee safety scenarios where the proximity of two moving entities can generate alerts and warnings. For example, when a person is walking down an aisle and a forklift approaches from around a corner, dynamic marker zones will make these entities visible to those located around corners or around aisles and can alert them to prevent incidents or fatalities [6,7,8].

Increase safety by creating a detection zone for workers

As part of the prevention of injuries in manufacturing companies, the RTLS localization system is also used as a tool to prevent the collision of moving objects, such as a forklift truck with people. Because of these accidents, their mutual movement is monitored, for example, in the areas of the truck bed, where the highest percentage of collisions between these two elements occurs. The system on its monitor can warn the driver of the forklift truck that there is a person in his work zone and thus prevent personal injuries.

Navigation for people indoors

Indoor navigation using the RTLS localization system from Sewio provides navigation to workers but also to visitors of production enterprises or similar buildings that contain an RTLS localization network. With this technology, it is possible to direct a person to the selected destination with regard to the shortest path and in the shortest and most efficient time. The method of navigation consists in the fact that the worker or visitor is navigated using a mobile device in cooperation with a signal transmitter, namely a tag. The latest application consists in the fact that it is a great advantage even for people who are visually impaired and can be navigated to the destination using the voice from the device.

Analysis of the flow of people indoors

In engineering terminology, heatmaps and spaghetti diagrams are analytical elements for monitoring the flow of material, people, means of transport within the framework of enterprises, but also the general interaction of workers and management in physical space. These analytical elements can provide data such as downtimes, bottlenecks in material flows, and according to them, it is possible to propose a suitable optimization for each of these parameters. As a result, it is possible to create synchronization of workers and their time spent at a given workstation with, for example, automatic replenishment of materials in production lines [9,10].

Figure 5 Heatmap

3 Conclusions

Nowadays, technologies based on the transmission of UWB signals can definitely be considered as important and effective elements in the field of innovative Industry 4.0 tools. The main idea and goal of this paper was to highlight the different possibilities of their use in the concept of "smart factory" worker searches and consequently to interpret possible solutions for streamlining these processes using RTLS localization technology. Examples and pictures were used to illustrate these facts. The elements of digitalization and the exponential functions of modern industry affect not only "classic" manufacturing companies, but also companies involved in heavy industry. The importance of protecting the health of workers in hazardous situations is extremely important for manufacturing companies. There is a prediction that these parameters will be taken into account more in the future, and not only because of digitalization.

Acknowledgement
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Testing mesenchymal stem cells on biocompatible 3D scaffold

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Keywords: 3D printing, scaffold, mesenchymal stem cells.
Abstract: The composite, thermoplastic material composed of polyhydroxybutyrate (PHB) and polylactic acid (PLA) was seeded with stem cells in the experiment. Tests of the polymer were oriented towards biocompatibility in vitro using mesenchymal stem cells isolated from the chorion. PHB/PLA is a currently tested biopolymer for applications in and medicine. Using additive technology, 3D forms of scaffolds in the form of a grid were prepared, which were seeded with stem cells and cultivated in suitable conditions. After an interval of 5 days, the proliferation and viability of the mesenchymal stem cells was tested by the proliferation test. From the results, it was found that the PHB/PLA material was a suitable scaffold and 60-85% stem cell viability was observed. Testing of non-toxic and degradable biopolymers brings new solutions in therapy in clinical orthopedic practice.

1 Introduction

The trend in the field of implantology and regenerative medicine in the last decade is the gradual replacement of conventional metal implants with implants made of biodegradable, polymer, and more commercially available materials. The reasons for this trend are economic sustainability, the possibility of serial production, affordability, and, last but not least, the improvement of patient comfort. Closely related to this process is the continuous development of new materials, which, however, must meet the required criteria before being put into clinical practice.

Implantology and tissue engineering rely on several specific criteria for the study. One of them is the appropriate selection of the type of cells needed to evaluate cytotoxicity and biocompatibility, i.e., evaluation at the cellular level (required according to ISO 10993-5 (In Vitro Cytotoxicity Tests). The decision on the source of cells plays a key role in the design of a tissue engineering strategy for clinical applications. The key concern is to obtain a sufficient number of cells. The cells must be able to integrate into the scaffolds. The use of growth factors and critical signalling molecules that instruct the cells during development is important for replication itself and the creation of new tissue. A specific type is mesenchymal stem cells (Mesenchymal Stem Cells). They are among the most promising and common in the field of biomedical engineering and regenerative medicine research. The permanent presence of stem cells in tissues can help in tissue regeneration itself in therapy [1].

MSCs differentiate along a specific lineage, thus replacing damaged tissue and/or inducing tissue repair by endogenous cells. In this way, MSCs offer the possibility of spontaneous reactions in the body and create conditions for the differentiation of healthy tissue cells that replace damaged ones [2]. The placenta harbours a population of MSCs that have the potential to differentiate into any tissue type.

When MSCs are applied to the heart muscle, they acquire the phenotype of cardiac myoblasts [3]. These characteristics suggest that MSCs can be used as powerful tool in reconstructive medicine [4]. MSCs transplanted into bone and cartilage defects in combination with a polymer scaffold are able to differentiate into osteoblasts and cartilage and can repair damaged connective tissue faster [5-8].

Biomedical and tissue engineering are looking for suitable materials for bone transplantation, which, in combination with MSCs, can rapidly regenerate bone damage. There is a large number of transplant candidates, but an insufficient supply of tissues and organs from human donors. Therefore, the aim of this study is a preliminary evaluation of the biocompatibility and cytotoxicity of mesenchymal stem cells on a polymer scaffold.

1.1 Cell cultures in vitro

The use of in vitro cell cultures has several advantages and it is possible to focus on different types of cell cultures in the experiment. Multiplication of experimentally usable cell types is possible from a limited amount of tissue. On the other hand, other physiological conditions in the cell culture environment in a medium are a limitation. It is a multiple effect of oxygen pressure compared to *in vivo* conditions where the oxygen content is reduced. Cultured cells in an *in vitro* environment mimic the extracellular fluid.

1.2 3D printing

Three-dimensional (3Dimensional) bioprinting is the process of creating three-dimensional objects by precise deposition of cells, biomaterials and biomolecules in space. The objects are created layer by layer according to a computer model, which allows checking the external and internal architecture and building complex structures. By precisely organizing different cell types and biomaterials, it is possible to create not only models suitable for studying cell interactions, but also functional, tissue-like structures. The created objects can be simple shapes as well as complex models with demanding spatial construction. By combining radiological imaging techniques (computed tomography, magnetic resonance) and CAD/CAM technologies, it is also possible to create anatomically accurate models of organs with regard to a specific patient.

The selected 3D model is processed from the CAD file using the software into a series of layers and converted into G-code, which contains information for the printer about the object creation process (Figure 1).

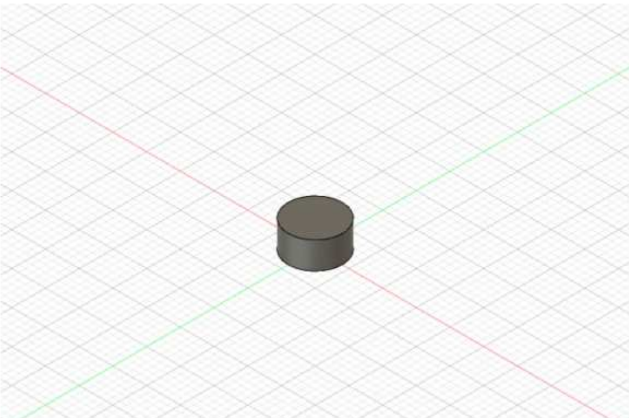

Figure 1 3D model in G-code

Procedures for printing 3D structures differ in the use of the support for the organization of cells into a structure. Procedures using a support carrier are referred to in the literature as 'scaffold-based', while 3D bioprinting of the bioink itself (a biomaterial containing cells) without the use of a support material is referred to as 'free-form farbication'. By using classic 3D printing, it is possible to create a solid support made of biomaterial, on which cells are later placed, or it is possible to print a mold from polymer and cast a structure from a suitable biomaterial according to it. The mechanical strength of the material allows building a structure with a precise architecture, but the organization of cells is limited in this model. In order to preserve the viability of the cells, softer, less viscous materials are used for their printing, but this is reflected in their poor mechanical strength. This procedure requires optimization of parameters, material and printing to create a precise structure with preserved cell viability.

1.3 Mesenchymal stem cells isolated from fetal membranes

The properties of mesenchymal stem cells (MSCs) isolated from the placenta, fetal membranes, and extraembryonic tissues, are less explored than MSCs isolated from bone marrow and fat. The development of the placenta and its coverings is started in the early embryonic stage. This organ begins to develop within a few days after fertilization. The placenta has a multifunctional role during pregnancy: nutritional, excretory, endocrine, and immunomodulatory. The placenta is the source of many hormones, growth factors and is a barrier against infection. Part of the placenta are fetal envelopes: amnion and chorion. The amnion-chorion membrane encloses and surrounds the human fetus. It is responsible for maintaining and supporting the growth of the human fetus until birth and protects the fetus from infection [9-11].

2 Methodology

2.1 Preparation of materials, design of samples and 3D printing

We performed modeling and subsequent 3D printing using the following software products: We designed, modeled and structured the samples in Fusion 360 (Materialise, Ghent, Belgium); We used Bioplotter RP (Envisiontec, Dearborn, MI, USA) and Visual Stroj (Envisionec, Dearborn, MI, USA) to slice the samples and place them on the platform (Figure 2). After modeling the sample, we proceeded to format the sample to G-code format, which is supported by a 3D printer. We did the formatting of the sample in the Simplify 3D program (Figure 3). The set print parameters are in Table 1.

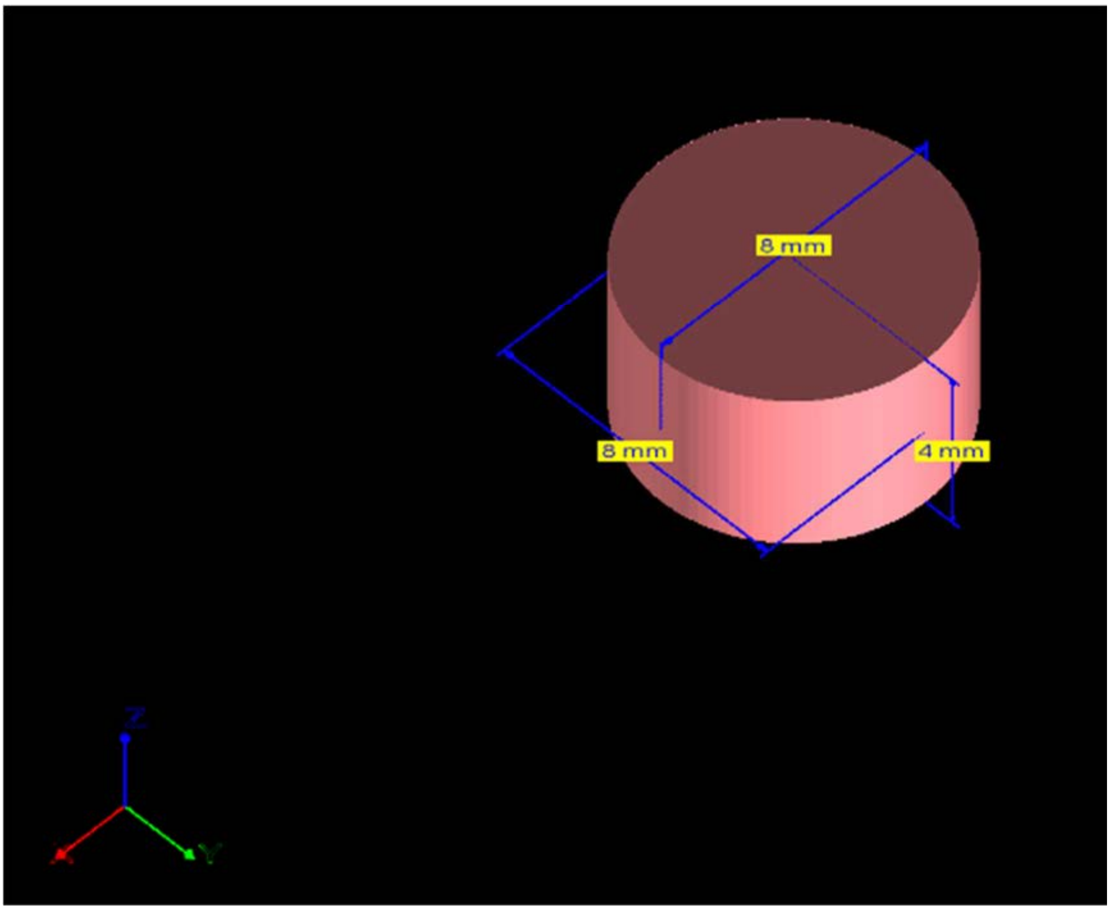

Figure 2 PLA/PHB sample design

Table 1 3D printing settings

Infill	**50%**
Nozzle	0,4mm
Printing temperature	175°C
Plate temperature	80°C
Filament diameter	1,75mm
Material feeding speed	25mm/s
Offset	-2,2mm

Before 3D printing, we put each type of mixed material in the form of granules weighing approximately 10 g into a Radwag MA50/1 moisture analyzer (RADWAG, Radom, Poland) where they were dried for 60 minutes at 80°C. Drying was aimed at removing excess water molecules from the material. We performed drying due to the hydrophilic properties of the PHB component [10-13]. We designed both types of samples, porous and solid, in a cylindrical shape with a diameter of 6 mm and a height of 2 mm. The layer thickness represented 80% of the nozzle diameter (600 µm), i.e. 480 µm. In both types of samples, the individual layers were rotated by 90° with respect to the lower layer. The distance between the centers of the individual fibers that formed the internal fillings was 1.2 mm in the porous samples. In the 3D bioplotter EnvisionTEC (EnvisionTEC, Dearborn, MI, USA) we used the EBB (Extrusion-Based Bioprinting) principle, i.e. the material is pneumatically pushed out by the print head.

The printing itself took place on a Trilab Deltiq 2 printer. This printer is based on the principle of FFF (Fused Filament Fabrication). The filament produced at the TUKE Department of Biomedical Engineering and Measurement was used as input material. This material, based on PLA/PHB, is biodegradable and biocompatible.

The process of printing one sample took 120 seconds. This printer uses a heated nozzle and a heated pad with a cooling system.

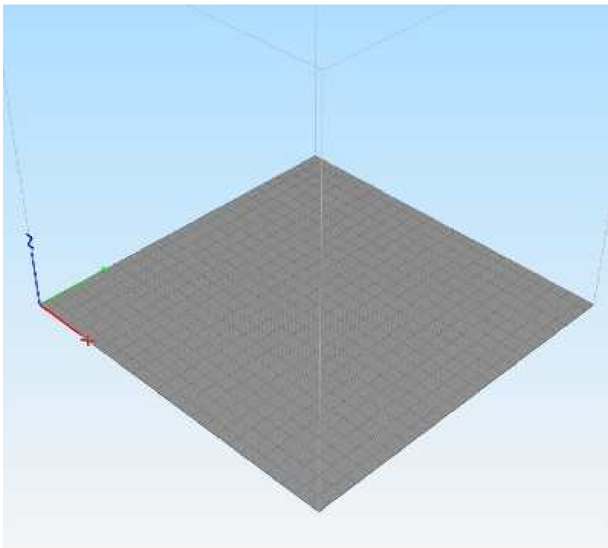

Figure 3 Interface of the Simplif program environment

2.2 Determination of cytotoxicity and biocompatibility

The proliferation of MSCs was measured using a standard MTT colorimetric assay. Cell suspensions containing 15 x 103 viable cells were cultured in 96-well tissue culture plates in a final volume of 200 µl in duplicate. A plate of cells on PLA/PHB scaffolds was treated as a sample, and a plate of cells without a PLA/PHB scaffold was treated as a control. A pure PLA/PHB scaffold served as a negative control. We measured the sample, positive and negative control in parallel. We performed the first experiment approximately 24 hours after deployment. The optical density of each well was measured at 490 nm in a TriStar device LB 941. We used the obtained values to calculate the percentage of metabolic activity compared to controls. Cells were stained with trypan blue. Cells were counted in a Bürker counting chamber under the light of a microscope. We evaluated dark blue cells as dead. We made growth curves for both samples. We evaluated MSCs on PLA/PHB scaffolds. The whole experiment lasted 12 days. We observed proliferation on the first, fifth, ninth and twelfth days.

2.3 Cultivation of mesenchymal stem cells in vitro

Chorionic mesenchymal stromal cells (CMSCs) were isolated and cultured *in vitro* from part of the chorionic fetal membrane from term placenta. We processed the biological tissue in the sterile environment of the PCR box. A part of the chorion measuring 15 x 15 cm was washed in Dulbecco's modified eagle medium (DMEM) (Biochrom AG, Berlin, Germany) with antibiotics 100 IU penicillin/mL, 100 µg streptomycin/mL and 0.25 µg amphotericin B/mL (Lonza, USA)). The cell suspension was obtained after exposure (90 minutes) to the enzyme collagenase II with (1 mg/ml) (Invitrogen, Thermo Fisher, Scientific, USA) at 37°C. We obtained a suspension of cells from the digested tissue after filtering through a cell strainer with a pore size of 40 µm (BD, Falcon, USA). We cultured isolated cells in vitro in culture medium Minimum essential medium, alpha modification (alpha MEM) (Invitrogen, Thermo Fisher, Scientific, USA) with 10% fetal bovine serum (FBS) (Invitrogen, Thermo Fisher, Scientific, USA) with antibiotics 100 IU penicillin/mL, 100 µg streptomycin/mL and 0.25 µg amphotericin B/mL (Lonza, USA) in a 5% CO_2 atmosphere at 37ºC. Cell growth was monitored microscopically (Zeiss Axiovert 200, Zeiss, Germany). Cells that did not adhere to the surface of the culture bottle after 24 hours were removed by replacing part of the culture medium (2 ml). We changed the culture medium three times a week. We cultured the cells until reaching 80% confluence, a single cell layer. Passage, cell separation was performed after reaching cell confluence. We added 4 ml of trypsin EDTA (Invitrogen, Thermo Fisher, Scientific, USA) to the culture bottle, which we left to act for 1-2 minutes at 37ºC. We monitored the gradual release of adhered cells microscopically.

2.4 Cell survival on PLA/PHB biomaterials

We used MSCs to monitor cell survival on PLA/PHB biomaterials. We added 100,000 MSCs cells per well to the biomaterials in the test culture plate. We cultured the cells in combination with PLA/PHB in culture medium DMEM with 10% FBS with antibiotics 100 IU penicillin/mL, 100 µg streptomycin/mL and 0.25 µg amphotericin B/mL at 37°C in a 5% CO_2 incubator. As a control, we used MSCs cells cultured in a culture plate without the presence of biomaterial. After 5 days of culture, 0.5% gentian violet (Thermo Fisher Scientific) was added to each well and cell staining was observed and MTT assay was performed.

3 Results

3.1 Isolation and in vitro cultivation of chorionic MSCs

The main goal of the experimental work was to monitor and test the biocompatible properties of the PHB/PLA composite material tested using CMSCs cells. In this work, we started from the isolation of mesenchymal stem cells, followed by MSC cultivation and biocompatibility testing of the polymeric material. We isolated a population of MSCs from the fetal membrane, its part of the chorion (Figure 4). We observed the adhesion of isolated MSCs cells within 48 hours after isolation in *in vitro* culture of MSCs in DMEM culture medium with bovine fetal serum and antibiotics. At the first exchange of the culture medium, we removed non-adherent hematopoietic cells, erythrocytes and damaged cells. After a week of MSCs culture, we observed the growth of fibroblastic cells, with a characteristic elongated shape (Figure 5). After reaching a complete cell layer, we separated the MSCs by trypsinization and used the suspension for the biocompatibility test.

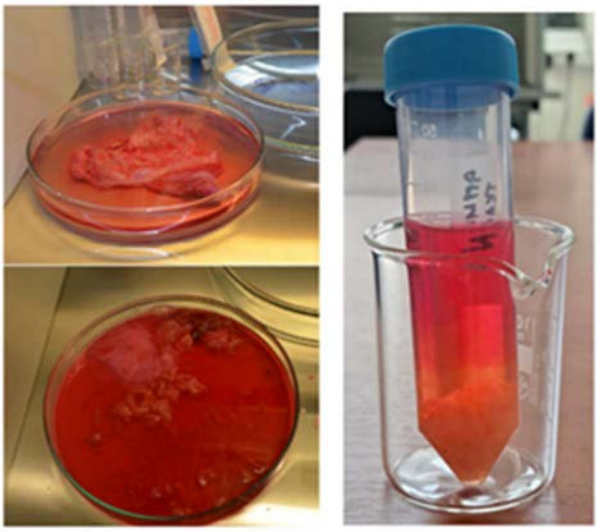

Figure 4 Perinatal tissue, the chorion membrane

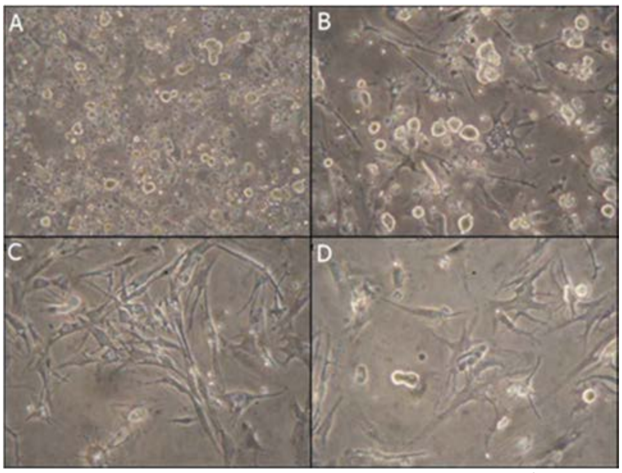

Figure 5 (A) Mesenchymal stem cells in vitro, day 1 of culture. Suspension of non-adherent cells (B) 5th day of culture, (D) Day 9 of culture. Day 12 of culture (C), Adherence of MSCs present (magnification 200x)

We monitored the survival of mesenchymal stem cells during their growth on PLA/PHB-based biomaterials. In vitro, we tested the biocompatibility of the material based on the PLA/PHB polymer. We used mesenchymal stem cells, which are capable of adhering to a suitable material. MSCs are morphologically characterized by a fibroblastic, elongated shape and adherence to a plastic surface during *in vitro* culture. We monitored the ability of MSCs to survive in the presence of PLA/PHB-based biomaterials by culturing them on a plate. 100,000 cells per well were seeded on the PLA/PHB biomaterial. Immediately after seeding MSCs on individual PLA/PHB biomaterials, we observed a typical round shape of the cells in a density that should be sufficient to populate the biomaterials.

The advantage of using MSCs is their proliferation potential and ability to differentiate. We washed the tested PLA/PHB scaffolds with DMEM medium and coated them with a layer of collagen to create an optimal adherent surface. PLA/PHB scaffolds with seeded MSCs [10^5/ml] were cultured on a plate in alpha MEM medium with 10% fetal bovine serum and 1% antibiotics (Penicillin-Streptomycin-Amphotericin B). In *in vitro* culture, we cultured MSCs for 5 days and then stained for the presence of vital cells with 0.5% gentian violet. We observed the proliferation of MSCs cells on PLA/PHB materials. In this work, we confirmed the properties of PLA/PHB as a biologically biocompatible matrix suitable for the adhesion and proliferation of human cells. *In vitro*, MSCs adhered to the 3D matrix and retained the ability to proliferate (Figure 6).

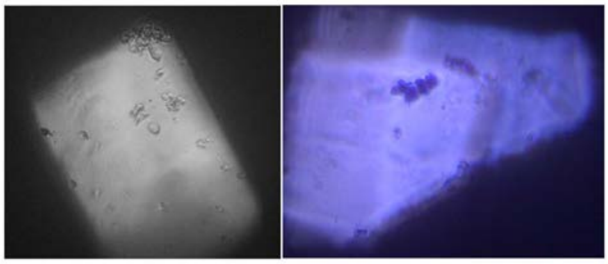

Figure 6 left: PHB/PLA seeded with CMSC, day 5 of culture, right: PHB/PLA seeded with CMSC, gentian violet staining, day 5 of culture

The cytotoxic effect of the scaffold was evaluated by the MTT test and visually microscopically. We were observing the ability of the cells to adhere by the shape of the cells compared to the control and any change in the morphology of the cells. At 24 hours after seeding, we observed cell adherence on a transparent plate of a 24-well culture plate in contact with a visible opaque scaffold. During 12 days, we observed visual proliferation in the monitored group (both solid and porous samples). Cells were morphologically typically spindle-shaped in all monitored wells and were visually compared to control CMSCs without the presence of a scaffold. The percentage degree of compatibility and minimal cytotoxicity effect of PLA/PHB scaffolds were observed by MTT test. Proliferation and longevity of cells were visually confirmed in all samples. The percentage values of the individual groups ranged from 60% to 85%, while the percentage of service life was higher in the group of porous samples.

4 Discussion and conclusion

3D printing and the associated optimization of scaffolds from variable biocompatible materials is a key issue in medical bioengineering. The current challenge of tissue engineering is therefore the testing of biodegradable material suitable for the production of implants. To improve the properties of PLA with other polymers, they use biopolymers with similar ones, where melting point, degree of crystallinity and morphology are monitored. For the final and improved structure and properties of polymers, it is possible to create their PHB/PLA mixture.

The disadvantage of PHB is poor formability and workability, therefore its mixture with PLA is a possible solution. Effective mixing of two polymers requires their mutual affinity, which is based on the solubility parameters of the mixture components. PLA and PHB polymers have a similar melting point, which is a requirement when mixing materials. According to the authors of Arietta et al., PLA and PHB have values in the range of mutual miscibility [14]. Actual miscibility depends on processing temperature as well as molecular weights.

In the experimental work, the topic of assessing the biocompatibility of the PHB/PLA matrix printed by the process of additive 3D printing, which is tolerated in the biological environment, was addressed. The conclusion follows that the used biomaterial is able to provide an environment for the adherence and proliferation of mesenchymal stem cells. The proposed biocompatible 3D scaffold in combination with stem cells could be used in clinical practice in the future.

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Effect of the auxiliary cathode on the thickness of the HiPIMS TiAlN coating deposited on the inner surface of the tube
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Effect of the auxiliary cathode on the thickness of the HiPIMS TiAlN coating deposited on the inner surface of the tube

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Keywords: TiAlN layer, HiPIMS technique, thickness, adhession.
Abstract: The paper is focused on influencing the thickness of the TiAlN layer deposited using the high power pulse magnetron sputtering (HiPIMS) method on the inner surface of the tube. The HiPIMS method makes it possible to deposit layers at temperatures up to 400°C. An auxiliary cathode placed in the axis of the coated tube was used. The auxiliary cathode made it possible to deposit an AlTiN layer with a thickness in the center of the coated tube up to 45% higher compared to the thickness of the layer deposited without an auxiliary cathode.The layer thickness was measured to be from 1.5 µm to 2.2 µm for the layer deposited without an auxiliary cathode and 1.05 µm to 1.95 µm for the layer deposited with the wire as the cathode in the axis of the coated tube. Adhesion of the evaluated layers showed the degree of HF2 at the measured thickness points.

1 Introduction

Coatings deposited on the functional surface of the component enable the desired properties of the functional surface to be achieved. Currently, the HiPIMS (High Power Impulse Magnetron Sputtering) method belongs to the improved MS (Magnetron Sputtering) methods. The HiPIMS method uses very short pulses with a power density on the target surface (during the pulse) that exceeds the typical DC power density by approximately two orders of magnitude (on the order of kW/cm2). This increases the ionization of the sputtered material and creates a metal-based plasma as opposed to a gas plasma for conventional sputtering. The duty cycle is small (<10%), the heating of the target can be regulated. The initially high negative bias that is used leads to an increase in the kinetic energy of the charged particles that bombard the surface of the deposited TV [1,2]. TVs deposited by the HiPIMS method have a denser, less columnar structure, where renucleation usually occurs [1-3]. Compared to the MS method, the HiPIMS method allows the target material to be dedusted in short pulses ranging from 50 µs to 200 µs.

TiN layers are among the basic coatings for improving the wear resistance of FP. By adding Al to the dedusted target, TV TiAlN is created, which additionally has a higher resistance to oxidation and good tribological properties, such as, above all, a low coefficient of friction and wear [4].

Coating the inner surface of the tube, where the tube rotates around an axis passing through the center of the tube perpendicular to its axis - (see Fig. 2), with vacuum methods also has a disadvantage: the thickness of the deposited TV is not constant but decreases from the edge of the tube to the center, where it is the thinnest [5].

In the article, the authors focused on influencing the thickness unevenness of the TiAlN coating deposited by the progressive HiPIMS method into a tube with a diameter of 70 mm and a length of 100 mm using the above-mentioned auxiliary cathode. The adhesion and chemical composition of the TiAlN coating at the point of thickness measurement was also evaluated.

2 Methodology

The TiAlN coating was deposited from a magnetron target in the ratio Ti/Al=50:50 (dimensions approx. 180x500 mm) on samples of C45 steel also steel 12050 (STN 412050) in the shape of a disc with a diameter of 22 mm and a thickness of 4 mm. The chemical composition of steel (wt.%) is 0.42 ÷ 0.50% C, 0.40% Si, 0.50 ÷ 0.80%

Mn, 0.40% Cr, 0.10% Mo, 0.40 % Ni and 0.035% P [6]. The functional surfaces of the samples were gradually polished using diamond pastes with a grain size of 15 µm, 9 µm, 3 µm and 1 µm. A surface roughness (Ra) of approx. 12 nm. After that, the samples were cleaned in acetone by ultrasound for 10 minutes and later dried with warm air for 5 minutes. Finally, the samples were placed using magnets on the inner surface of the tube located in the vacuum chamber on the cathode (Figure 1,2). The dimensions of the tube were length 100 mm and diameter 100 mm. Because the fixing magnets had a length of approx. 25 mm and the thickness of the coated samples was approx. 4 mm, the pipe diameter can be reduced to 70 mm. The bombardment of the surface of the Ar samples (99.999%) took place in the DC (direct current) mode using two magnetrons located opposite each other around the perimeter at a pressure of 1.6 mPa, where the bias voltage of the holder (bias Ub) was -200 V, the magneton power was 1.6 kW and the cleaning time of the tube surface before the deposition process by Ar ion bombardment (etching) was 60 minutes. The Ar flow rate in the vacuum chamber was 300 cm3×min-1.

The deposition process was performed without and with the cathode located in the axis of the coated tube (Figure 1,2). The deposition lasted 210 minutes with the following parameters: 4 magnetrons placed opposite each other around the perimeter of the vacuum chamber were used, each magnetron having a power of 12.5 kW, cathode bias voltage -60 V, N2 flow rate (99.999%) 230 cm3xmin-1, Ar flow rate (99.999 %) 300 cm^3xmin^{-1} and the pressure in the vacuum chamber 4.7 mPa. The temperature of the coated samples did not exceed 300°C. The sample table rotated at a speed of 0.5 revolutions per minute. A CEMECON CC800 HiPIMS device was used.

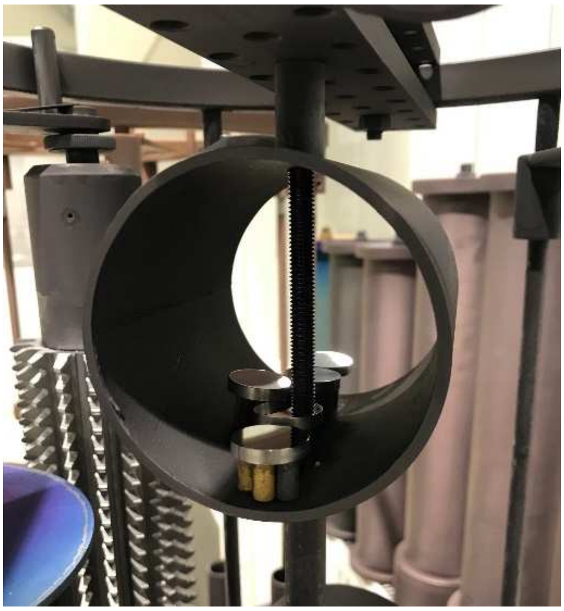

Figure 1 Placement of samples in a tube-shaped fixture (L=100) without a cathode in the tube axis in a vacuum chamber

The thickness of the TiAlN layer was evaluated by the Kalotest method with CSM Instruments. In order not to cut the coated pipe, the steel samples described above were used, placed in five places on the inner surface of the tube (Figure 1,2). A steel ball with a diameter of 15 mm and an abrasive paste with a diamond grain size from 0.5 to 1.0 µm were used for 300 s at a ball speed of 900 per minute. Figure 3 shows the dome from a thickness measurement at a point 10 mm from the edge of the tube with a TiAlN coating deposited by a wire as the cathode in the axis of the coated tube (Figure 2).

Adhesion was evaluated using the Mercedes test method, where the indentation of the edge of a diamond cone (Rockwell indenter) into the surface of the coated sample with a loading force of 1500 N was evaluated. The scale for evaluating adhesion is shown in Figure 3. The indentation edge was observed and evaluated with an Olympus 5000 optical microscope.

Figure 2 Placement of samples in a tube-shaped fixture (L=100 mm) with the cathode in the axis of the tube in a vacuum chamber

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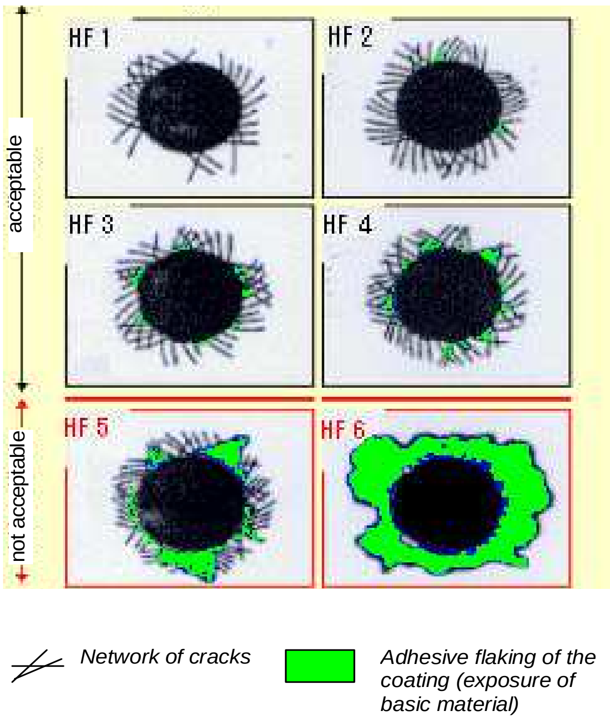

Figure 3 Mercedes test scale" HF1-HF 4 - satisfactory, HF4-HF6 - unsatisfactory adhesion [7]

The surface of the TiAlN layer was observed using the VEGA 3 TESCAN thermal emission electron scanning microscope scanning device. The chemical composition was evaluated using an EDX analyzer x-act Oxford Instruments as an area analysis of the surface of the evaluated coating.

3 Results and discussion

A view of the surface and chemical composition of the TiAlN layer deposited without an auxiliary cathode from the edge of a 100 mm long tube is in Figures 4 and 5. The surface of the evaluated coating deposited with an auxiliary cathode is in Figure 6, the chemical composition is in Figure 7. Area chemical analysis showed that at by using an auxiliary cathode, the nitrogen content in the layer decreased and, on the other hand, the content of Al and Ti slightly increased (Figure 5 and 7). This may be due to the auxiliary cathode, which caused a denser field of dedusted Ti and Al particles in the inner space of the tube.

A view at the surface of AlTiN layers (Figs. 4 and 6) shows the occurrence of voids (surface without layer) with a diameter of approx. 20 nm to 50 nm. This indicates a similar structure and mechanical properties of the evaluated coatings.

Other properties of AlTiN coatings were not evaluated.

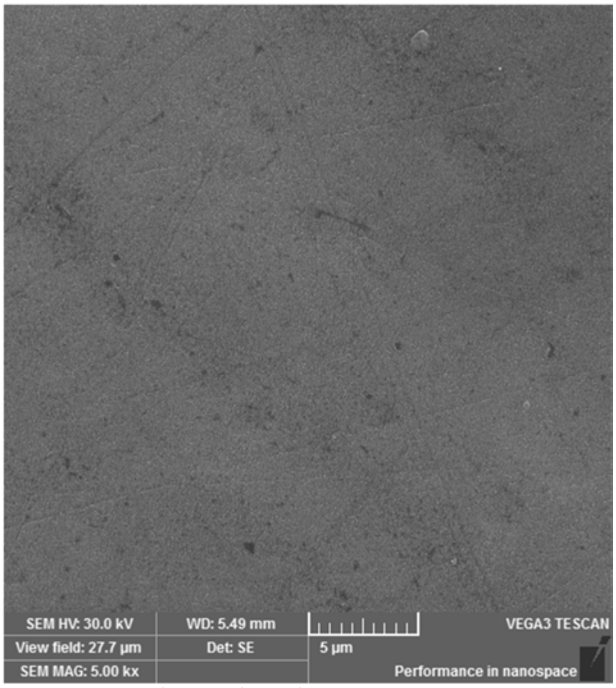

Figure 4 View of the surface of the AlTiN layer (tube length 100 mm) deposited without an auxiliary cathode, SEM

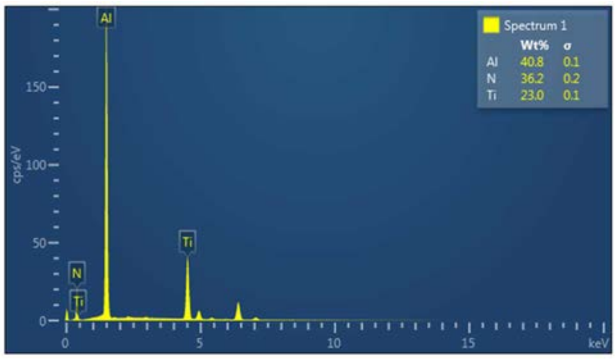

Figure 5 Chemical composition of the AlTiN layer (tube length 100 mm) deposited without an auxiliary cathode, EDX

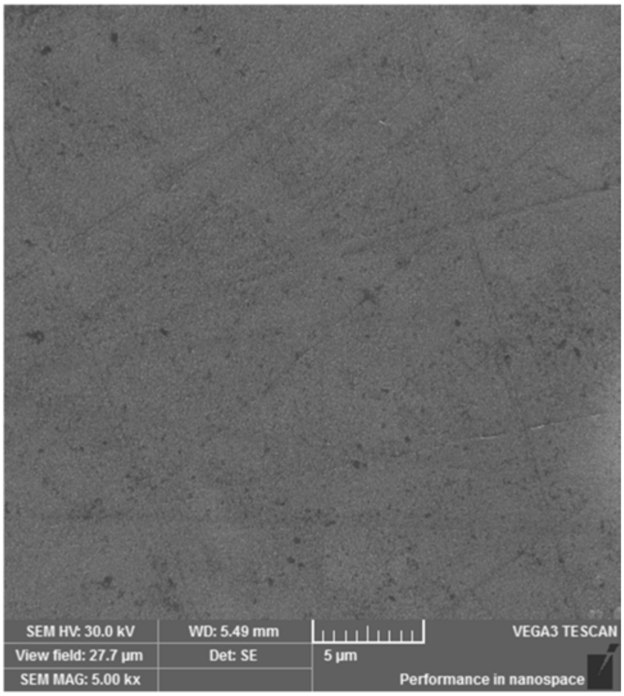

Figure 6 View of the surface of the AlTiN layer (tube length 100 mm) deposited with an auxiliary cathode, SEM

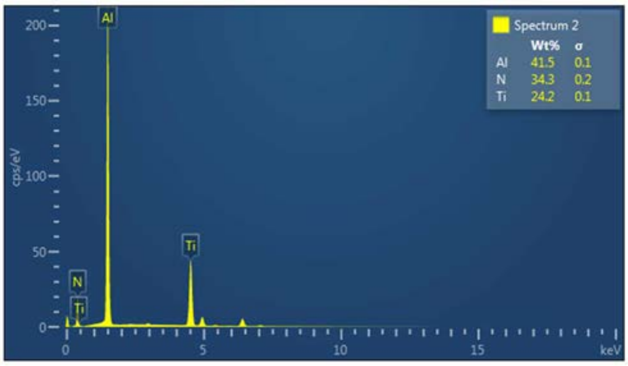

Figure 7 Chemical composition of the AlTiN layer (tube length 100 mm) deposited with an auxiliary cathode, EDX

The thickness of the coating deposited on the inner surface of a tube with a diameter of 70 mm and a length of 100 mm was evaluated.

In the case of a tube L=100 mm, the measured values were 1.5 to 2.2 µm in the case of a coating deposited with a wire as a cathode in the axis of the coated pipe (Figure 8). The thickness of the layer is one third lower in the middle of the tube compared to the thickness value at the ends of the tube (Figure 4). The diameter of the thickness measured at the edge of the tube (L=100mm) is shown in Figure 9.

In the case of the measured values of the thickness of TiAlN layers deposited without wire (L=100 mm) as an auxiliary cathode in the axis of the tube, the measured values were from 1.05 µm (in the center) to 1.95 µm (10 mm from the edge), which is approximately 10% less compared to the thickness of the layer deposited with the wire measured at a point 10 mm from the edge of the tube. The thickness of the evaluated layer measured in the center of the tube wall is up to 30% lower compared to the layer deposited with the wire in the tube axis (Figure 8). It can also be stated that the thickness in the center of the tube has decreased to 55%, which is significantly more than in the case of the deposited layer without wire in the axis of the tube. This may be due to the lower plasma density in the tube space [2,8].

The adhesion of the evaluated coatings showed a grade of HF 2 (Figure 10).

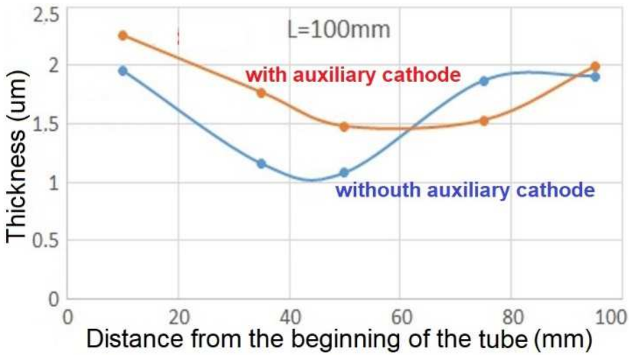

Figure 8 Dependence of the TiAlN layer thickness on the measurement position in the tube, L=100 mm

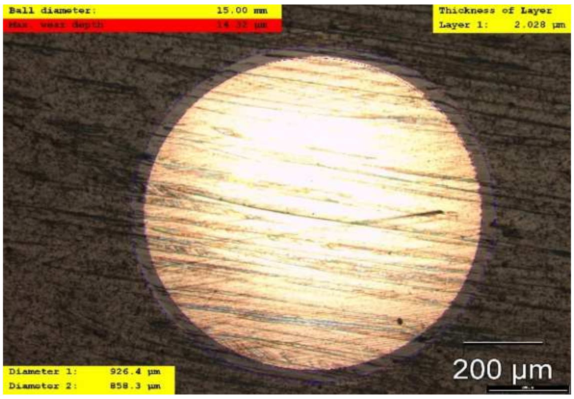

Figure 9 TiAlN layer calote, measured thickness 2.028 µm

Figure 10 Puncture after Mercedes test HF level 2

4 Conclusions

A TiAlN layer was deposited on the inner surface of the tube with and without an auxiliary cathode located in the axis of the tube, where:

• thicknesses of the assessed layer from 1.05 µm to 2.2 µm (tube L=100 mm).

• a significantly lower decrease in thickness was measured in the case of using an auxiliary cathode in the pipe axis L=100 mm (approx. 30%) compared to the deposition of a layer without an auxiliary cathode (45%). This was caused by a better distribution of the plasma in the space of the tube, achieved by placing the auxiliary cathode in the axis of the tube.

• adhesion of the TiAlN layer in all property's evaluation points was satisfactory, HF 2.

Further research will focus on the influence of technological parameters on the growth of the thickness of the AlTiN layer deposited on the inner surface of the tube by the HiPIMS method.

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Review on PCB assembly line balancing – glance

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Keywords: assembly line balancing, workstation and PCB manufacturing, precedence constraints and balancing efficiency, algorithm, mathematical model and simulation.

Abstract: The industrial technique known as assembly line balancing is used to increase the efficiency of balancing in production lines. By increasing line efficiency, the assembly line balance problem reduces the number of workstations. The assembly line balancing technique improves line production by utilizing the priority limits for task assignment in the workstation. By distributing the tasks among the workstations according to priority constraints, assembly line balancing improves the efficiency of the line. Line balance issues are observed to fall under the category of sequence-dependent issues while deciding which part numbers to allocate in the workstation. When choosing which part numbers to allocate in the workstation, line balancing concerns are seen to fall under the category of sequence-dependent issues. Mathematical models, algorithms, and simulation software are just a few of the techniques that have been used in the past to handle assembly line balancing concerns. In order to decrease workstation loads and boost assembly line productivity, an effort has been made to review the PCB manufacturing assembly line balancing problem in the current research study. The goal of the study is to cut down on the workloads and waiting times for each task on a manufacturing line. In order to reduce job waiting times and maximize station workloads, U Type Assembly Line is preferred in this study.

1 Introduction

In order to balance the workload across the workstations within the constraints of the cycle time, a procedure known as "line balancing" is used. The fundamental difficulty in an assembly line is assigning a set of duties to each workstation without going against the order of assembly. By increasing line efficiency, a good assembly line will attempt to balance all workloads. Line balancing is a flow-oriented manufacturing approach for boosting productivity and cost-effectiveness in mass production processes. A certain amount of time is allotted for the production of a particular product. Tasks are then evenly distributed across staff and workstations to ensure that every activity in the queue is finished within the allowed time limit.

Production line balancing is the process of simply allocating the correct quantity of workers and machinery to each area of the assembly line. This helps to achieve production rate targets by cutting down on idle time.

1.1 *Why production line balancing is beneficial?*

In order to increase production process efficiency, production line balancing is a great model to use. Here are a few of its advantages:

- Reduces the amount of idle time at workstations.
- Helps the production process to flow more efficiently.
- It aids in establishing the ideal assortment of workstations and the quantity of tasks to be performed at each one.
- By streamlining processes, one may increase teamwork and staff morale.
- enhances both the output quality and pace of manufacturing of the generated goods.
- Increases production capacity and labor utilization cuts down on waste.

1.2 *Guidelines for line balancing:*

To take advantage of the aforementioned benefits, your production line must be configured in a way that makes it easy for materials and components to move freely from one workstation to another.

A workstation is any place in the assembly line where employees execute a task on the final product. The cycle time is the length of time required to complete each workstation task. Production is at its peak when every product is made within the allotted time frame. The vast majority of specialists concur that achieving optimal scheduling is practically unattainable. Manual calculations can frequently be challenging and time-consuming. Each task at each workstation ought to be processed in an equal amount of time.

1.3 *Assembly line balancing procedures*

A. Create a precedence chart and outline the order of your workstations.

The entire production process is divided into a series of steps in this method. The task at a specific workstation must be finished before a product can go on to the next section.

A precedence diagram is a table-based depiction of the tasks that must be completed during a production project. The project can be displayed as a whole or in part using general or partial precedence diagrams. Your diagram should include information on the activities involved in production as well as their interdependencies.

B. Determine how much cycle time is required at each workstation.

You must conduct time studies to find out how long it takes to complete each task on the production line. The maximum amount of time a task can conceivably take to complete at each workstation is known as the cycle time.

You can determine the precise amount by dividing the quantity of the intended product by the number of manufacturing hours in a day. The time between each workstation and the workforce at the current machine pace will then be known to you.

The daily production volume of one line is used when determining cycle time. When the same product is produced on several lines, composite cycle time estimations using digital line balancing equipment would be necessary for accuracy.

C. Determine the estimated number of workstations you'll require.

This computation, which is based on cycle times, will help distribute the workloads across the workstations fairly. You can figure out how many workstations you need by dividing the overall task times by the desired actual times.

D. Assign work to the workstations and continue doing so until the process times are equal.

Continue to reorganize the duties to lessen overproduction and production bottlenecks. This entails moving a certain number of employees from stations with light workloads to stations with heavy workloads. This method aids in shortening wait times in overcrowded stations.To maximize machine utilization; make an effort to intelligently distribute the workload among the operators in a queue. For synchronicity, it is intended for each activity to take the same amount of time. Be aware that Takt time calculations will be necessary to guide your job distribution if you want to efficiently satisfy consumer demand. The Takt time is a measurement of how long a skilled individual or an automated system needs to complete a task. You incur the danger of overproduction and waste if you undertake keg line balancing until production exceeds takt time.

1.4 Assembly line significant importance

The process of making items or products is time-consuming since various tiny elements must be put together. The finished product is formed by connecting or assembling smaller elements in a specific order of phases. The use of an assembly line guarantees that the manufacturing process is divided into several steps, with smaller parts being attached at each level.

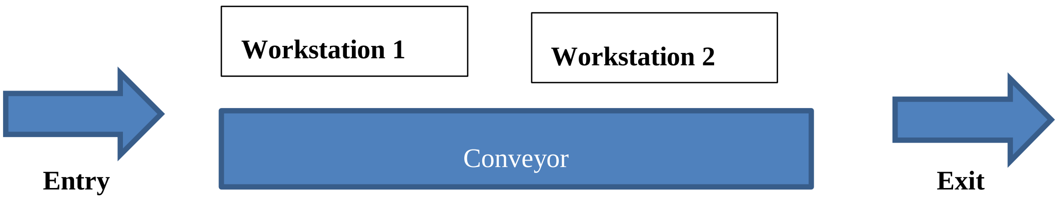

Figure 1 Assembly line systems in production

Workers can work side by side at their various phases of a streamlined manufacturing process, and the utilization of a conveyor belt or line guarantees that the product is sent to each stage after it for the assembly of the next smaller item. A key strategy for increasing productivity and maximizing the effectiveness of the product being created is assembly line production.

1.5 Types of assembly line

There are various assembly line manufacturing procedures, depending on the set up, design, stages, production needs, etc. Among them are:

1. A modular approach

In this method, numerous smaller goods are produced simultaneously on parallel assembly lines.

All lines or smaller items are combined to create the finished product at the end of each assembly line.

2. Manufacturing of cells

Instead of using separate stages for each step that needs to be completed, this assembly line method uses machines that can complete numerous tasks at once.

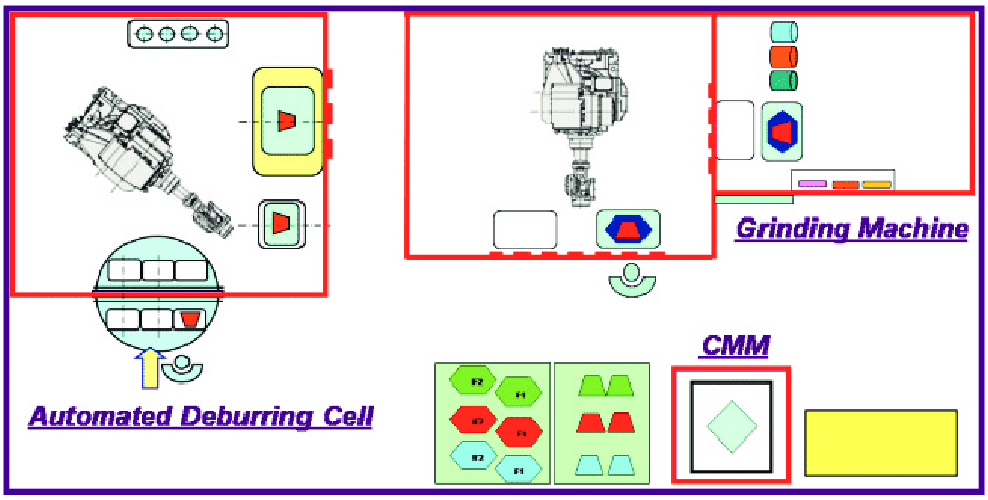

Figure 2 Manufacturing cells

3. Group effort

Teams had to participate in each stage and the final quality check in order for the technique to guarantee a high-quality final output. The several teams each have their own set of tasks to complete inside a stage, which they then turn over to the following team.

4. U-shaped assembly line

Workers in this method stand between the curves of a U-shaped or curved production line, which replaces the traditional straight production line. Better communication between related production phases is ensured as a result.

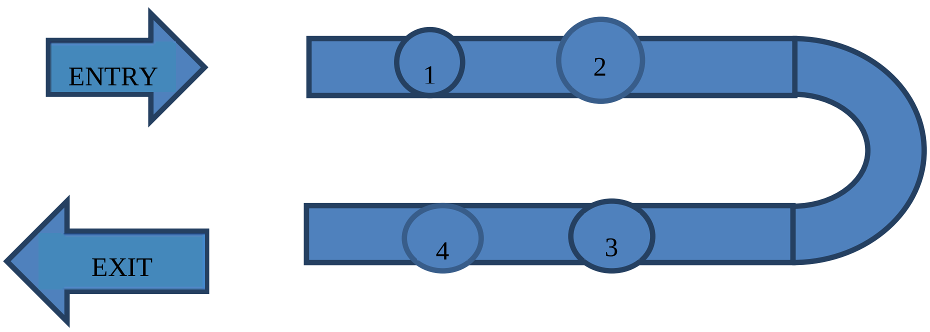

Figure 3 U type assembly line

2 Literature on asssembly line for PCB manufacturing

Assembly line balancing for PCB manufacturing is the subject of a thorough analysis of the literature in this part, which is listed below.

Classification of Assembly line balancing after 2007, 2013 and beyond 2015:

Onc¨u Hazır & Alexandre Dolgui [2019] This article reviews the difficulties, solutions, models, and algorithms associated with resilient assembly line balancing problems and offers potential attractive future research directions. Applications for single- and multi-criteria optimisation issues include precise and heuristic solution methods. Included are decision support systems (DSS), cutting-edge modelling techniques, simulation models, and their application to business decision-making and product life cycle management. Finding unresolved problems and research areas with immediate industrial relevance may be made easier with the help of the analysis and debate.

Naveen Kumar & Dalgobind Mahto [2013] Achieving the stated goal on an assembly line requires understanding how to balance tasks among workstations. The most frequent goals are to reduce the number of workstations and boost output. This paper reviews a number of works in the area of assembly line balancing in an effort to lower the cost of all the equipment and the number of workstations. Additionally, it looks for current market trends and technological advancements.

Nils Boysena, Philipp Schulze & Armin Scholl [2021] Mass-producers in many industrial branches have prioritized flow-oriented assembly processes, in which work parts are moved from workstation to workstation on an assembly line, since the time of Henry Ford up until the industry 4.0 period. One of the most fundamental optimization challenges in this situation is the assembly line balancing problem, which determines how to distribute labor throughout an assembly line's stations. This study examines the body of scholarly literature that has been produced since the most recent substantial review publications on assembly line balancing, which were published in 2006 and 2007, respectively.

Kheirabad M., Keivanpour S., Chinniah. Y & Frayret, J.M. [2022] The problems with assembly line balancing have been studied for a long time. The integration of collaborative robots into assembly processes and recent advancements in Industry 4.0 technology have created problems with task distribution, workload balance, and scheduling. This essay contrasts the salient features of the collaborative assembly line balancing issues that have been discussed in the literature to date and offers some suggestions for further study.

Mohamed Abdelkhak, Shady Salama & Amr B. Eltawil [2018] Discrete event simulation was utilized in this study to better understand the behavior of a TV PCB production line in one of the leading companies in the Middle East and Africa. The outcome of the simulation demonstrates an imbalance in workload between workstations that precludes any opportunity for improvement. In order to break up bottlenecks and enhance resource utilization, a range of scenarios for resource rearranging were presented. These scenarios involved transferring technicians from idle to active workstations. Throughput and workload balancing over the entire line have been considerably improved by the suggested configurations, demonstrating their superiority. Finally, a cost analysis was performed to assess the return on investment of each scenario separately in order to confirm the validity of these recommendations.

Fansuri, A.F.H, Rose, A.N.M, Ab Rashid, M.F.F, Nik Mohamed, N.M.Z, Ahmad, H [2018] Discrete event simulation was utilized in this study to better understand the behaviour of a TV PCB production line in one of the leading companies in the Middle East and Africa. The outcome of the simulation demonstrates an imbalance in workload between workstations that precludes any opportunity for improvement. In order to break up bottlenecks and enhance resource utilization, a range of scenarios for resource rearranging were presented. These scenarios involved transferring technicians from idle to active workstations. Throughput and workload balancing over the entire line have been considerably improved by the suggested configurations, demonstrating their superiority. Finally, a cost analysis was performed to assess the return on investment of each scenario separately in order to confirm the validity of these recommendations.

Yiyo Kuo, Taho Yang & Tzu-Lin Huang [2022] This paper suggests applying two restrictions to address the U-shaped production line balance problem. First, tasks can be performed in different places as long as they respect the order of priority between any two activities. Second, every piece of work is intended to be finished in a particular setting. When an operator is given two or more jobs, the cycle time must account for the time spent walking between the tasks' locations. The proposed problem is first presented using an integer programming formulation and is then resolved by commercial software named LINGO in order to decrease the cycle time and performance of the U-shaped production line. The empirical results show that U-shaped manufacturing lines function more effectively than traditional straight production lines.

Marcello Fera, Alessandro Greco, Mario Caterino, Salvatore Gerbino, Francesco Caputo, Roberto Macchiaroli & Egidio D'Amato [2019] The optimization of production processes, which strives to increase productivity while reducing associated costs, has historically been one of the foundations of manufacturing businesses. Thanks to Industry 4.0, some cutting-edge technologies that were believed to be out of reach just a few years ago are now available to everyone. The widespread use of these technologies in manufacturing facilities enables the interconnection of the resources (people and machines) and the control of the entire production chain through the collection and analysis of real-time production data to support decision-making. In order to examine production line performance metrics, this article will give a methodological framework that supports the analysis of both experimental and numerical data.

R. Gupta [2023] The goal of this study is to identify the essential components that will maximize printed circuit board (PCB) performance by increasing manufacturing process efficiency. A low scrap rate and optimised PCB design leads are the results of using the Failure Modes and Effects Analysis (FMEA) technique to reduce the percentage of finished goods that are discovered to be defective during the manufacturing process and final inspection. The entire quality process to obtain excellent performance in PCB design is introduced in this article. The study is set in the electronics manufacturing sector, where printed circuit boards are first accepted as raw materials and fed into the stamping and assembly processes using surface mount technology (SMT).

A.G. Gudsoorkar [2015] The study examines the procedures employed in a sizable electronics industry for the manufacture and assembly of electronic components and gadgets. The initial introduction to the industry details its goals as well as the rapid developments it has made in the 17 years since its founding in the fields of consumer electronics, computers, communications, and control systems. It also discusses the rise in sales turnover over the previous five years.

Carlos Alexandre X. Silva, Les Foulds & Humberto J. Longo [2019] In a common variation of the Simple Assembly Line Balancing Problem (SALBP-1), tasks are assigned to stations along an assembly line with a predetermined cycle period in order to decrease the required number of stations. It has long been held that the total quantity of labour necessary to produce each product unit is broken down into discrete tasks that are economically unassignable. However, it is often feasible to divide particular jobs in a certain way at a time penalty cost. Despite the consequences, task division occasionally reduces the required minimum of stations when it is feasible. The task division assembly line balancing issue, or TDALBP for short, is created when deciding which permissible jobs to split. We offer a precise solution method, a mathematical model of the TDALBP, and encouraging computational findings for the adaption of various traditional SALBP examples from the research literature. The outcomes show that the TDALBP sometimes has the ability to dramatically raise assembly line productivity.

Sivasankaran P. & P. Shahabudeen [2014] The productivity of an organisation depends on the architecture of its mass production system. Production lines that assemble goods and those that machine components are the two different kinds of mass production systems. The system of assembling products on an assembly line, also referred to as a production line, is the subject of this study. In this method, balancing the assembly line to get the right amount of production per shift is challenging. Reduce the number of workstations for a given cycle time (type 1), reduce the time for a given number of workstations operating at maximum capacity (type 2), and so forth are the main objectives of the assembly line design.

Sivasankaran P. & P. Shahabudeen [2016] The intensifying global competitions force organisations to use a number of productivity growth strategies. By assisting in the design of the assembly line to maximise balancing efficiency, assembly line balancing helps a company achieve this. When more than one model is assembled on the same line, the aim of the mixed model assembly line balancing problem is to maximise the average balancing efficiency of the models. By maximising the average balancing effectiveness of the models and minimising the makes pan of the sequencing models, a multi-objective function is created. The intensifying global competition forces organisations to use a number of productivity improvement strategies.

Sivasankaran P. & P. Shahabudeen [2017] This study contrasts assembly line balancing problem type 1 solutions with and without the use of a mixed model. To maximise the assembly line's ability to balance workloads, the ALB problem type 1 aims to distribute the jobs among the fewest number of workstations for a given cycle length. In contrast to the single model assembly line balancing, which involves only one model being assembled, the mixed model assembly line balancing involves numerous models being assembled on the same assembly line. A company must use mixed-model assembly line balancing in order to respond to the needs of its clients.

Jabir Mumtaz, Zailin Guan, Lei Yue, Zhengya Wang, Saif Ullah & Mudassar Rauf [2019] Printed circuit board (PCB) assembly lines are crucial for producing a variety of electrical devices. The PCB manufacturing industries tend to develop towards automated and complex manufacturing processes as a result of an increase in consumer demand for increasingly sophisticated products. The PCB assembly process is impacted by many planning and scheduling problems. Therefore, the current study looks at multiple levels of planning and scheduling for PCB assembly lines, including line assignment to PCB models, component allocation to machines, and component placement sequencing by machines on PCB boards.

Attila Tótha, Timo Knuutilaband Olli S. Nevalainen [2018] A typical gantry-type placement machine is made up of numerous connected, independently operating component placement modules. The machine was designed to allow for the use of several types of interchangeable placement heads and vacuum nozzles in the modules. Many interconnected, independently functioning component placement modules make up a conventional gantry-type placement machine. In order to accommodate several types of interchangeable placement heads and vacuum nozzles in the modules, the machine was constructed. A typical gantry-type placement machine is made up of numerous interconnected, independently operating component placement modules. The machine was built to be able to fit several types of interchangeable placement heads and vacuum nozzles in the modules.

M. Duran Toksar, Selcuk K., Isleyen, Ertan Guner, Omer Faruk Baykoc [2008] In this work, the learning impact of assembly line balancing problems was taken into consideration. By performing the same or similar activities repeatedly in multiple realistic contexts, the produced worker(s) (or machine(s)) evolve. As a result, processing a product later speeds up the production process. We show that for both the simple assembly line balancing problem

(SALBP) and the U-type line balancing problem (ULBP), polynomial solutions may be discovered with the help of learning.

Yu-ling Jiao, Han-qi Jin & Xin-ran Liu [2021] Due to the constant update of the manufacturing system, the research of the assembly line balance issue (ALBP) is continuously deeper in application theory and solution approaches. To determine the research topic and stage of assembly line balancing development, 89 papers are studied and reviewed. We classify ALBPs utilising vertical thinking and horizontal classification to create the research network structure.

Parames Chutima, Panuwat Olanviwatchai [2010] It is practically challenging to solve real-world problems using deterministic algorithms due to the documented NP-hardness of mixed-model U-shaped assembly line balancing problems (MMUALBP). This study uses a just-in-time production system and the combinatorial optimisation with coincidence algorithm (COIN) to solve Type I MMUALBP problems. All three criteria are taken into account at once: the least amount of workstations, the least amount of work-relatedness, and the least amount of workload smoothness.

Amir Nourmohammadia, Hamidreza Eskandarib, Masood Fathic & Mehdi Ranjbar Bouranid [2018] The line balancing and parts feeding (PF) challenges related to assembly line design are examined in this study using supermarkets. These problems occur in actual assembly lines (ALs), when decision-makers try to reduce total installation costs for ALs, which include line balancing and PF costs, by figuring out the appropriate number of stations and stores at the same time. To do this, an integrated mathematical model is proposed, and its performance is assessed by resolving a variety of benchmark problems and a real-world case from industry.

Parames Chutima [2020] The findings of a review of studies on assembly line balance issues (ALBPs) that were released between 2014 and 2018 are presented in this study. Before beginning a detailed literature analysis, the inefficiency of the previous ALBP categorization structures is investigated. A new classification system based on assembly line layout configurations is then offered. The research trend in each manufacturing line architecture is depicted graphically. Additionally emphasised as a technological path for upcoming research studies are the challenges with ALBPs.

Yuchen Li, Xiaofeng Hu, Xiaowen Tang & Ibrahim Kucukkoc [2019] In the written word. The vagueness of the task may lead to overcrowded workstations. Aspects of unpredictable task time were investigated using probability theory's frameworks. In terms of the best answers, we arrive to a few useful theorems. We also develop an algorithm based on the branch and bind remember method to address the proposed issue. To illustrate our model, numerical studies are then performed.

Yuri N. Sotskov [2023] Conventionally, assembly lines (conveyors) are used for large- and mass-scale production. The assembly process can be made more efficient by setting up and establishing an assembly line for the same or similar types of final products. The issue at hand is the layout of the assembly line and how the full burden for creating each unit of the fixed product to be assembled is distributed among the assigned workstations along the established assembly line. The assembly line balancing study focuses on simple assembly line balancing problems, which are limited by a number of elements that make a particular assembly line interesting for investigation.

Nuchsara Kriengkorakot and Nalin Pianthong [2007] The classic line balancing problem, commonly referred to as the straight line assembly line balancing problem, considers a production line with stations arranged in a line sequentially. A balance is produced by dividing work into stations and moving through a precedence diagram. However, the just-in-time (JIT) manufacturing approach has demonstrated that the U-line configuration of the stations has a number of advantages over the traditional setup. This paper introduces the U-line assembly line balance challenge. It is more challenging than the balance problem for a straight assembly line since tasks can be given by moving ahead, backward, or simultaneously in both directions through the precedence diagram.

Mustafa Fatih Yegul, Kursad Agpak & Mustafa Yavuz [2010] This study provides a new hybrid design for a certain type of assembly line and suggests a multi-pass random assignment method to identify the bare minimum number of stations required. The given tasks' timetable and sequence are also decided by the algorithm. The new design mixes U-shaped and two-sided lines, gaining the advantages of both at once. One side of the line is configured in a U form to accommodate stations with crossings, while the other side is balanced like a typical straight flow. Depending on the orientation of the product, the line's left or right side may be shaped like a U. The method was applied to fix both small and significant two-sided assembly line test-bed issues.

Ronnachai Sirovetnukul and Parames Chutima [2010] In most cases, the one-piece flow production line is set up as a U-shaped assembly configuration for both standard and customized goods. The properties of a single U-line are discussed and modelled in this paper. The job assignment into a U-line and assigning tasks to workers in order are both hierarchically important aspects of the worker allocation problem. Seven-task to 297-task challenges that require the assembly of several products are completed in a particular cycle time. Finding the effects of walking time on symmetrical and rectangular U-shaped assembly layouts is the main goal. Comparing the number of workers between two fixed layouts is the minor goal.

Zixiang Li, Mukund Janardhanan, Qiuhua Tang & Zikai Zhang [2022] Due to the development in robotic technology and the rise in labour expenses, collaborative robots (cobots) are being used more and more in many sectors. The cobots in the assembly line can be used to finish the jobs autonomously or with the help of the people. The U-shaped assembly line balancing problem involving cobots is examined in this study. Several cobots with various purchasing costs are chosen in accordance with the budgetary restrictions. To reduce cycle time, three mixed-integer programming models are developed, and the resulting models are effective in finding the best solutions for small-scale problems.

Krit Chantarasamai [2021] For the purpose of resolving Type 2 U-shaped Assembly Line Balancing Problems (UALBP-2), we outline a Differential Evolution (DE) algorithm. By creating solution techniques and conducting testing on 15 problem sets (101 occurrences), it was possible to determine the minimal cycle time in a just-in-time production line for producing a single product with a specific number of workstations. Ten sets of medium-scale issues (50 instances each) and five sets of large difficulties (51 instances each) were created from the problems. The DE method could produce 14 better solutions (28%) in the medium-scale problems and 3 better solutions (approximately 6%) in the large-scale problems when compared to the results of the rule-based heuristic; three rules and two rules.

Yuling Jiao, Xue Deng, Mingjuan Li, Xiaocui Xing, and Binjie Xu [2022] A parallel U-shaped assembly line system balancing approach is developed with the goal of increasing assembly line flexibility and efficiency. It is possible to get the bidirectional priority value formula from the improved product priority diagram. Workstation definition follows the z-q partitioning of assembly lines. The parallel U-shaped assembly line balance problem is then given a mathematical formulation. Explanatory examples and test examples are resolved using a heuristic process based on bidirectional priority values. The heuristic algorithm is suitable for big balancing problems, as can be seen from the outcomes and effect indicators of the assembly line balancing problem.

Mohammad Zakaraia, Hegazy Zaher [2021] A parallel U-shaped assembly line system balancing approach is developed with the goal of increasing assembly line flexibility and efficiency. It is possible to get the bidirectional priority value formula from the improved product priority diagram. Workstation definition follows the z-q partitioning of assembly lines. The parallel U-shaped assembly line balance problem is then given a mathematical formulation. Explanatory examples and test examples are resolved using a heuristic process based on bidirectional priority values. The heuristic algorithm is suitable for big balancing problems, as can be seen from the outcomes and effect indicators of the assembly line balancing problem. The suggested approach provides a faster calculation time and greater calculation accuracy.

Ihsan Sabuncuoglu, Erdal Erel & Arda Alp [2009] A production line where items move continually through a series of stations is called an assembly line. The assignment of work to an ordered series of stations subject to priority restrictions with the aim of optimizing a performance metric is known as the "assembly line balancing problem." In this study, we suggest ant colony algorithms to address the issue of balancing a single-model U-type manufacturing line. We carry out a thorough experimental research in which the performance of the suggested algorithm is evaluated in comparison to best-known algorithms described in the literature. The outcomes show that the proposed algorithms outperform them in a very competitive manner.

Adarsh Adeppa, M. S. Uppin [2018] Balancing in the assembly line is one of the often employed production methods. Assembly line balancing involves reducing the number of workstations, reducing cycle time, and increasing the smoothness of the workload. an increase in work-relatedness It is utilized to quickly assemble huge quantities of a consistent product. Assembly lines were initially created for the mass manufacturing of standardized products at a low cost in order to take advantage of the high specialization of labor and the resulting learning effects.

Aadarsh Adeppa [2015] One of the most common production methods is the assembly line. Assembly line balancing involves reducing the number of workstations, reducing cycle time, and increasing the smoothness of the workload. an increase in work-relatedness It is utilized to quickly assemble huge quantities of a consistent product. Assembly lines were initially created for the mass manufacturing of standardized products at a low cost in order to take advantage of the high specialization of manpower and the resulting learning effects.

Guangyue Jia, Honghui Zhan and Yunfang Peng [2023] Just-in-time manufacturing is frequently implemented using U-shaped assembly lines. To increase production, the U-shaped assembly line balancing problem must be solved. The majority of research disregard variables like operating times. In order to solve the type-II U-shaped assembly line balancing issue (UALBP-2) under uncertainty, this work employs robust optimisation techniques. A genetic algorithm is created to handle a mathematical programming model that has interval task operation timings. The most frequent option that falls within a predetermined percentage of the ideal solution for several sets of scenarios is referred to as a robust solution. To confirm the viability and efficacy of the robust approach, the experimental findings are compared with the anticipated outcome.

Mohammad Zakaraia The U-shaped assembly line balancing problem with stochastic processing time is covered in this article. Chance-constrained programming is utilized to formulate the issue, and the greedy randomized adaptive search method is employed to resolve it. 71 issues from well-known benchmarks are solved and compared with the theoretical lower bound in order to demonstrate the effectiveness of the suggested algorithm. Of these, 13 were compared with beam search, another method that was employed to tackle the identical problem in a different work. The findings reveal that 59 issues match the theoretical aspiration lower bound. In addition, 11 out of 13 issues' outcomes compared to beam search are same, and two problems' results are superior to beam search.

Salah Eddine Ayoub El Ahmadi, Laila El Abbadi & Moulay Taib Belghiti [2019] A technique used in mass production, particularly in the automotive sector, is the assembly line. It comprises of numerous workstations arranged along a belt transport system or other handling equipment. The Assembly Line Balancing Problem (ALBP), which has a direct impact on the productivity of the entire production system, is a key issue. This study provides an up-to-date review of the subject and discusses the evolution of the classification of assembly line balancing issues (ALBP), as well as the procedures and algorithms that, in our particular example, suggest solutions to the ALBP.

Belassiria Imad, Mazouzi Mohamed, ELfezazi Said, Cherrafi Anass & ELMaskaoui Zakaria [2017] In order to solve the challenge of balancing an assembly line, we suggest a hybrid genetic algorithm in this study. We concurrently maximise assembly line productivity and reduce overall idle time in the optimization framework. The model can handle more realistic assembly line balancing situations, like zoning restrictions. By sequentially combining the well-known assignment rules heuristics with the genetic algorithm, we seek to give the genetic algorithm with the ability to explore the solution space effectively.

N.H. Kamarudin, M.F.F. Ab. Rashid [2017] This article presents a mathematical model for the Simple Assembly Line Problem Type 1 (SALBP-1) with constraints on both human and mechanical resources. The present SALBP-1 model assumes that each workstation has a similar capability, but in reality, due to technological and human skill limits, each workstation has a unique capability. The proposed model seeks to mathematically represent the SALBP-1 with resource constraints. Three objective functions are also provided with the intention of reducing the number of personnel, machines, and workstations. Different machine types are assumed to be needed in an assembly line to produce diverse items, while the workers are thought to have a variety of skills and aptitudes. The concept is then demonstrated and validated using a few instances.

M. Bagher & M. Zandieh & H. Farsijani [2011] In order to improve efficiency and flexibility, U-shaped assembly lines are increasingly being examined in the industry as a replacement for traditional straight assembly lines. Due to their complexity in terms of mathematics and computation, assembly line balance problems are known to be NP-hard in nature. Many meta-heuristics have been proposed in order to find the optimal solution to these problems. This research offers a new hybrid evolutionary algorithm to balance stochastic U-type assembly lines with the aim of lowering the number of workstations, idle time at each station, and non-completion probabilities of each station (probability of the station duration exceeding cycle time).

Olcay Polat, Özcan Mutlu and Elif Özgormus [2018] One of the crucial components of production systems that affects the overall cost and efficiency is the assembly line. The effectiveness of assembly lines in actual use is directly impacted by the productivity of the human resource on the lines.

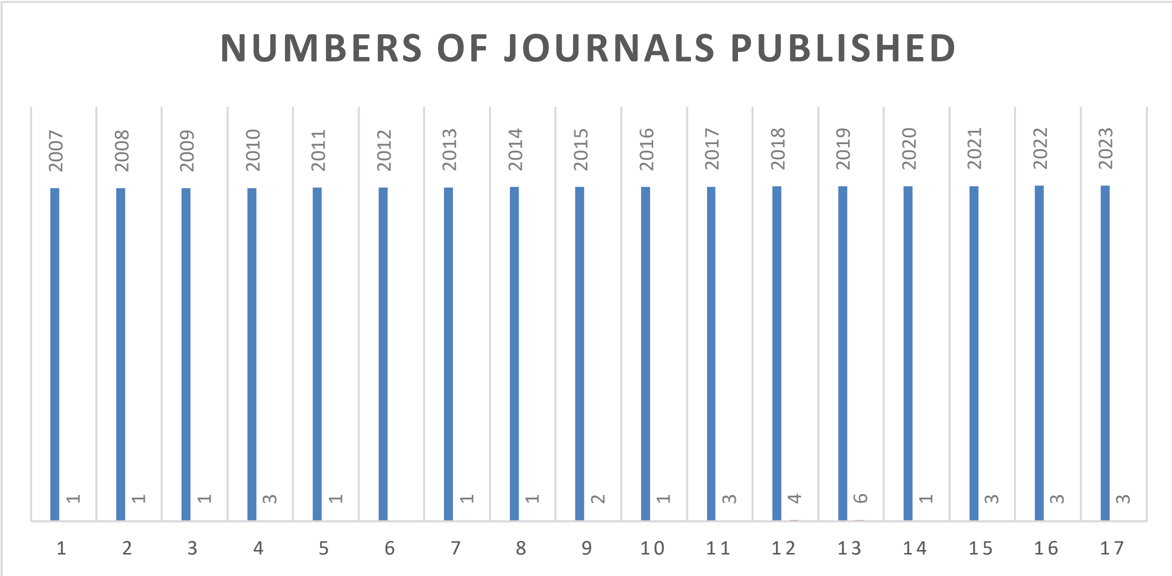

Figure 4 Nubers of journals published

From Figure 4, it is observed that number of journals published in 2019 is higher compared to other years in line balancing concepts. Line balancing is one of the modern concepts in operation management system. Hence attempt has been made to conduct survey on U type line balancing problem.

3 Methodology

In this section detailed methodology of solving assembly line balancing problems is illustrated here. Among various types of line layout, U Type Assembly line balancing is considered in this research. The general description of layout is given below in the following illustration (Figure 5).

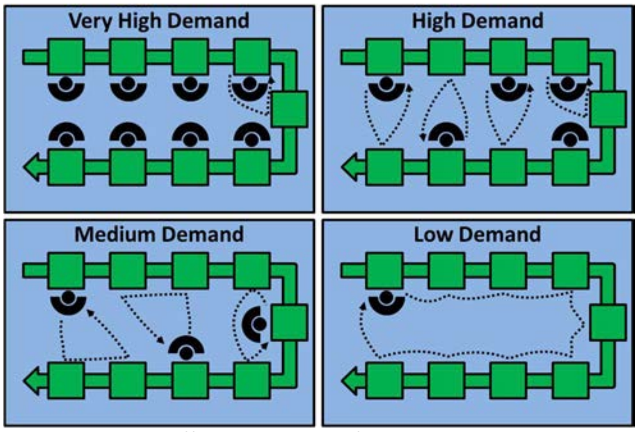

Figure 5 Different demands of U type Assembly line

For optimizing the Various station workloads U Type assembly line is most preferred one in common use.

3.1 Benefits of using U type line balancing in assembly process

- Product should always be moved anticlockwise in the same direction.
- To increase accountability, quality, and traceability, cross-train staff so they can handle all or the majority of the tasks within the cell.
- To reduce the distance between the start and finish of the process, if possible, use U-shaped assembly cells.
- Use First in First out (FIFO) to decrease errors, speed up lead times, and enhance order accuracy.
- Workstations should be placed as near together as feasible to reduce wasted space, but not too close that maintenance is hampered or workers are uncomfortable.
- Design a mechanism that will allow sub-parts to enter the system in the best possible way while taking ergonomic principles into account.
- Keep the cell's flow channel open and unobstructed.

3.2 Case study on U type assembly line balancing problem

In this section detailed case study on U type Assembly line balancing problem in PCB assembly line is discussed here in this phase of research. Consider Assembly line with seven workstations as illustrated below.

Table 1 Precedence relationship table

S.NO	Task	Description	Duration	Predecessors
1	1	Preparing the Box	3	-
2	2	PCB with Bluetooth module	6	1
3	3	PCB with amplifier	7	1
4	4	Battery	6	2
5	5	Connecting circuit	4	2
6	6	Connecting The PCB s	8	2,3
7	7	Integrated circuit of the speaker	9	3
8	8	Adjusting the Connections	11	6
9	9	Charging & Command Panel	2	4,5,8
10	10	Protective grid	13	8,11
11	11	Speaker	4	7
12	12	Closing the box	3	9,1

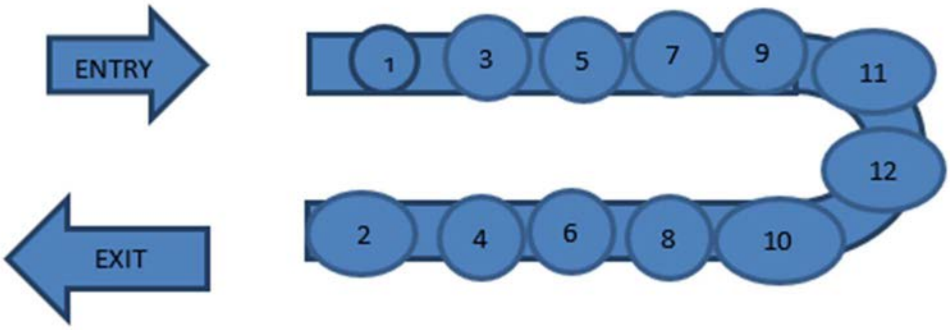

Figure 6 U type layout

From Figure 6 the various activities of PCB assembly line are arranged as per the precedence network constraints as illustrated above. In the precedence network tasks times also scheduled for each activity respectively as shown in Figure 6. The cycle time in the assembly is said to be 15 minutes.

3.3 Workstation formation

From Figure 7 Workstation design of assembly line is illustrated with various workstations say seven workstations in assembly line with cycle time as 15 minutes.

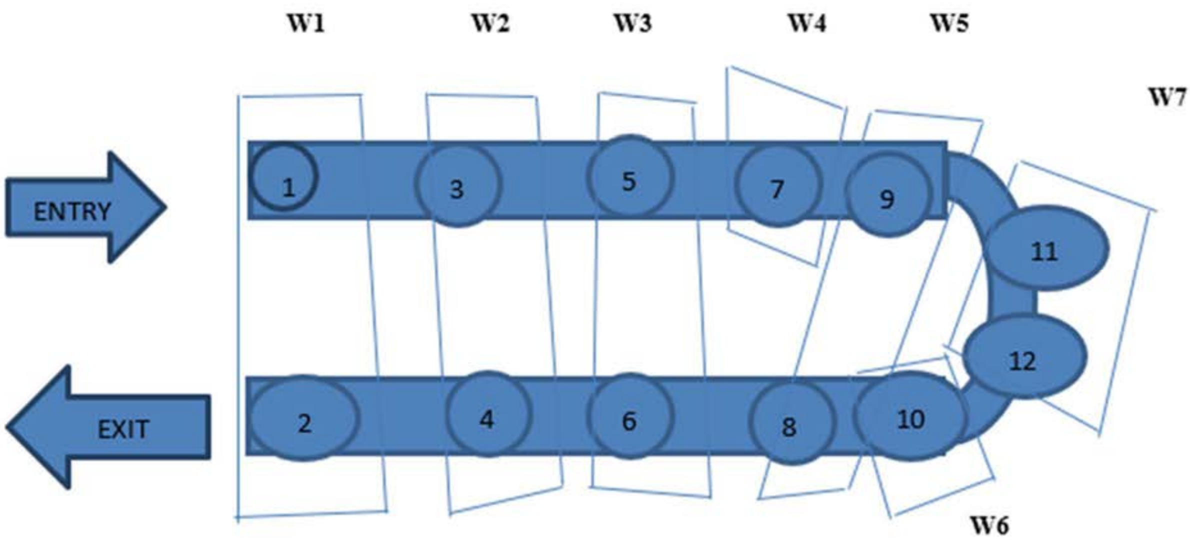

Figure 7 Workstation design of assembly line

In each stations the workload is assigned within the given cycle time constraints as listed below shown in the following table (Table 2).

Table 2 Computation of idle time for assembly station

Assembly Station	Tasks	Station Time (Minutes)	Idle time (Minutes)
1	1,2	09	06
2	3,4	13	02
3	5,6	12	03
4	7	09	06
5	8,9	13	02
6	10	13	02
7	11,12	07	08

From Table 2 station time and idle time are calculated by using the following expressions as listed below.

$$A = I + J \quad (1)$$

$$B = K - A \quad (2)$$

where:
A - station time,
B - idle time,
I - process time of activity,
J - process activity,
K - cycle time.

For task (1) and (2):
Station time *A* = 6 +3 = 09 minutes
Idle time *B* = 15-9 = 06 minutes

Computation of line efficiency (3):

$$L = M / (N*K) * 100 \, (\%) \quad (3)$$

where:
L - balancing efficiency (%),
M - sum of process times of all activities,
N - number of stations.

Balancing efficiency *L* = 76 / (7*15) * 100 = 72.38%

Thus, the balancing efficiency for U type assembly line is evaluated based on the number of workstations and cycle time respectively.

Outcome of case study:

In this case study attempt has been made to solve U type assembly line balancing for electronic PCB manufacturing system. The line efficiency was 72.38% which is considered to be average in nature. The maximum idle time in the assembly station occurs in the following station such as workstation 1, workstation 4 and workstation 7 respectively. Due to that line efficiency gives moderate percentage yield.

4 Conclusion

Line balancing is the production technique which is used to balance the workstation constraints for given cycle time. The main idea of line balancing concept is to adjust the station workloads as per cycle time constraints. Line balancing helps to maximize the line efficiency by assigning the workload in the assembly station. In this paper attempt has been made to solve line balancing problem under U Type model configuration for electronic manufacturing systems say PCB manufacturing Applications. Case study on U type line balancing problem is illustrated with precedence ray diagram with process time for various tasks elements.

In the case study description, the various workstation along with station time and idle time was discussed in the case study illustration shown in precedence graph. In addition to that balancing efficiency is computed as per cycle time constraints.

Future scope:

Mathematical model can be developed to solve line balancing problems then the solution is compared with algorithm in terms of solving time.

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The mechanism parts of mechanical motion rectifier to produce energy from third pedal in automotive

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Keywords: energy harvesting, break and throttle pedal, mechanical parts, connecting rod, shaft and bearing.
Abstract: Energy harvesting architectures, such as wind turbines and solar panels, have become a necessity as renewable energy sources have grown in popularity. The most promising source of electric energy appears to be electromechanical energy harvesting, as it generates significant amounts of electricity that can be utilized in numerous ways. This research supports and supplements the automotive, regardless of how much and how effectively power is generated. Essentially, when the driver touches the throttle or brake pedal, the energy-harvesting pedal receives motion from them through a mechanical connection rod. Considering its utility in charging electric cars, it is considered one of the most useful sources of electricity.

1 Introduction

The harvesting of energy refers to the capture of electricity from the environment and using it for energy production. There are several methods of harvesting energy, including piezoelectricity, thermoelectricity, and electromagnetic energy [1]. There are numerous ways to utilize electromagnetic energy harvesting, which has the potential to provide a significant amount of electricity. Research on roads has been conducted by a few independent companies and researchers. The first, we must understand the design of HPE.

2 Conceptualization of design

Pedal energy harvesting refers to capturing the potential and kinetic energy produced by the driver's foot when the pedal is pressed. In Figure 1. the concept development stages are illustrated.

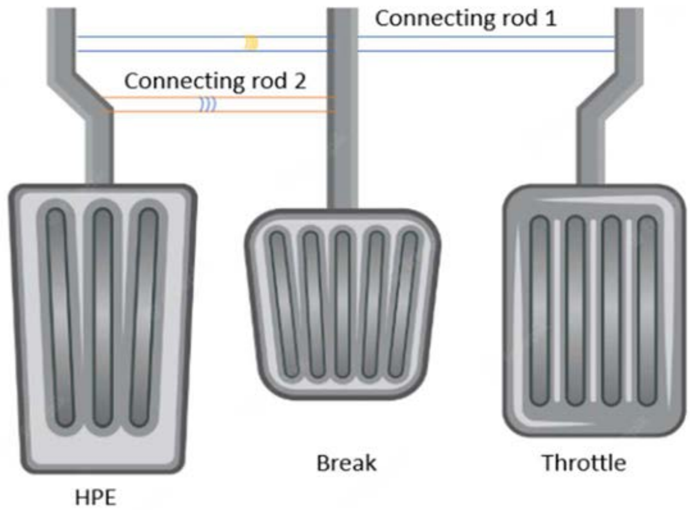

Figure 1 Concept development stages for HPE

Pedal energy harvesters (HPE) capture the kinetic and potential energy that is emitted by contact between the feet of the driver and the pedal [2]. The main components for the pedal energy harvester are included in Figure 2.

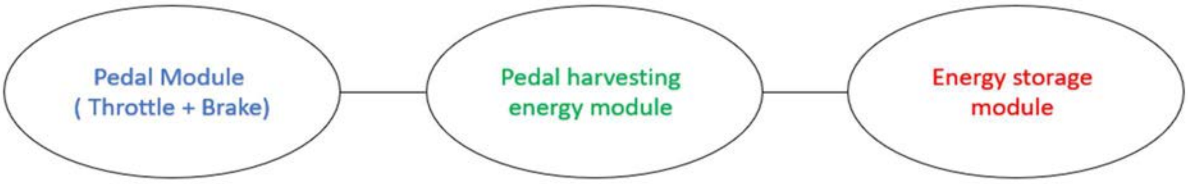

Figure 2 The main components for the harvester pedal energy

In order to understand each model, we must first learn about its characteristics and features.

1. Pedal (throttle + break) module: As mentioned previously, a connecting rod connects the throttle and brake pedals to the HPE module [3].

1.1. Connecting plate: it is made from stainless steel type 440 because the reason for this is so that the load can withstand shocks and be carried effectively. It delivers the load from the driver to the harvesting module.

1.2. Springs and Bearings: there are springs connected to the pedal from the bottom and linear bearings connected with shafts, as shown in Figure 3.

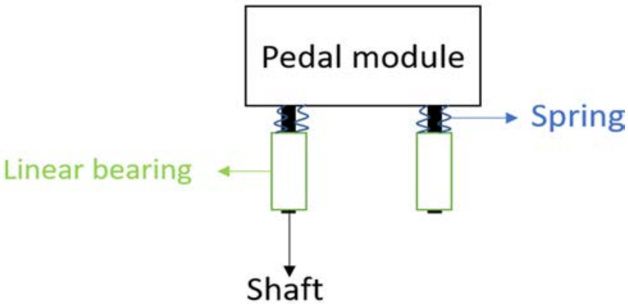

Figure 3 A schematic of the (throttle & brake) module

How do we choose the springs?

As part of the design process for pedal energy harvesters, spring selection plays a vital role since it determines the energy harvester's performance and load ability. In order for the spring to be chosen correctly, it is important to note that the time required for it to rebound to its natural or original position should be roughly one-quarter of the time it takes for one complete cycle of oscillation, which corresponds to the natural frequency of the system. Another important consideration in spring selection is the time between each pedal press and the next. This time interval, also known as the pedal cadence, should be taken into account when selecting the spring, as it affects the energy storage and release characteristics of the system. The spring must be able to store and release energy quickly enough to keep up with the pedal cadence, while also providing sufficient energy storage capacity to meet the system's overall requirements.

2. Pedal harvesting energy module: it contains the following.

2.1 Pinion gear (1 and 2) and rack system: it acts to convert linear motion into rotational motion. as seen in Figure 4.1 and Figure 4.2. The specification for its L=340 m, 2F, LAM, DDF= 9-14.

Figure 4.1 Rack system

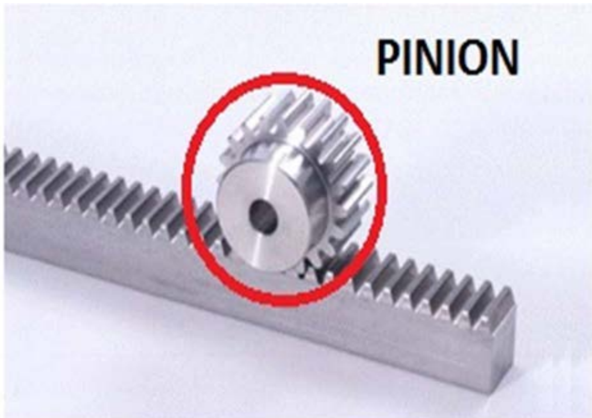

Figure 4.2 Normal pinion gear 1 and 2

The specification for the toothed wheel is Z = 25 M2 LR = 20 IF DF = 25 CLLR = 8.

2.2. Gearbox (Figure 5): A harvesting unit's gearbox plays an important role. it is used. Because normal pinion gear speeds are insufficient to drive the motor and achieve its rated speed [4]. The planetary gearbox made from Nanotec Company.

Figure 5 Gearbox

2.3. Guide & bearing: it forms the part of the connection between the connecting rod and rack system by bearing pin which can see in Figure 6.1. There are two different types of bearings, linear bearing guide FRN 32EI and FRNR 32 EI as shown in Figure 6.2 and Figure 6.3 [5].

Figure 6.1 Guide, FS32TT, L=460mm, 9F, DF9

Figure 6.2 Bearing FRN and bearing FRNR

2.4. Support: The purpose of shaft supports is to clamp and place parts that are used in linear motion applications. There is a tendency for the support blocks to deflect between the supports when the weight is somewhat light. Support blocks are most likely to be used for applications with a low load in order to minimize deflection between the supports. the type we used is UCPA 206 as in Figure 7.

Figure 7 Support UCPA 206 of shaft

2.5. Coupling (Figure 8): it is a mechanical device that connects two rotating components, such as shafts or gears, while providing flexibility to accommodate minor misalignments or movements [6]. This flexibility enables the two components to remain connected and transmit power, even if they are not perfectly aligned or if there is some movement or vibration in the system.

Figure 8 Coupling of the shaft

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3. Energy storage module: It is consisting of a generator motor that there are no brushes in brushless DC motors (Figure 9), so friction cannot occur. As a result, brushless motors are more efficient. Additionally, BLDC motors can be used as generators, so the prototype uses a three-phase, single-shaft BLDC motor. Also, this model has an electrical load.

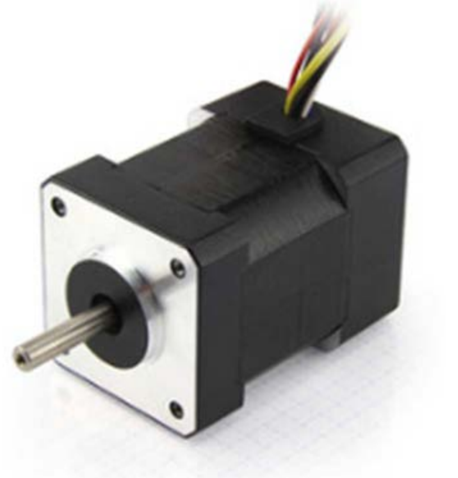

Figure 9 Brushless DC motor NEMA 17

3 Mechanism of motion

For all three modules, we can collect the previous parts and draw them as follows (Figure 10, Figure 11).

From the previous schematic, it can be seen that the device responsible for converting energy from linear motion to rotational motion is known as a mechanical motion rectifier (MMR). The MMR accomplishes this by converting the linear motion from racks into rotational motion by interlocking the pinions gear 1 and 2 in a system [7]. With the help of a connector rod, the rack is attached to the pedal module. As the driver presses the pedal module vertically, the rack will move, the pinion gear will rotate as well as the shaft will spin also. When the shaft rotates, causing the gearbox spins, and thus the DC motor thereby rotates which then generates electric power. A gearbox will be used to speed up the power generation and to improve the efficiency of the conversion since the linear rotation of the rack cannot achieve high rotational speeds. These generated energies are stored in a battery, which is used to recharge the vehicle later.

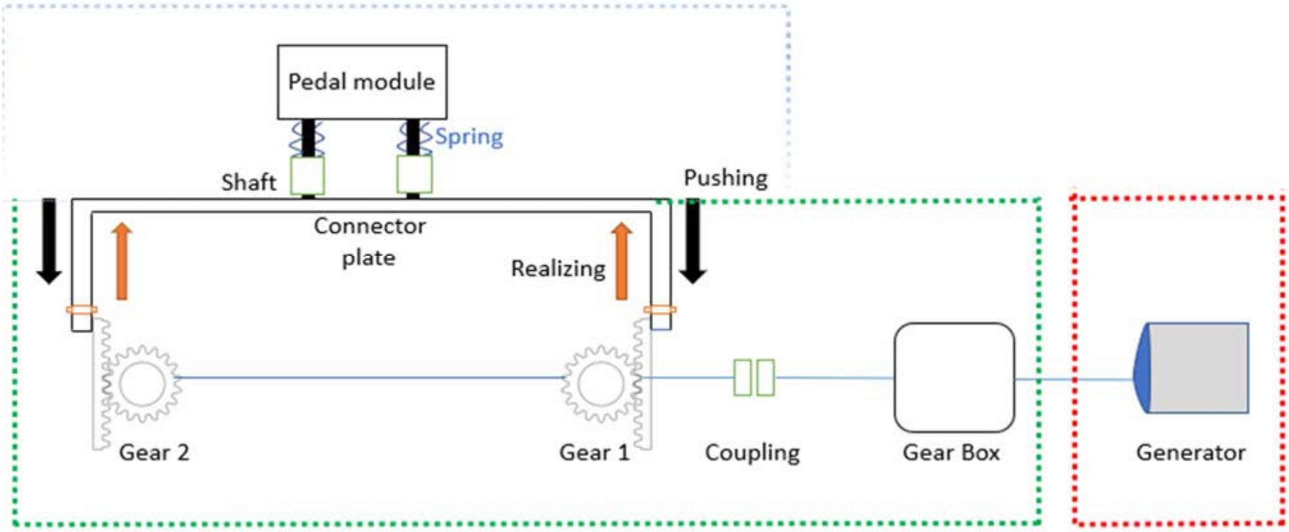

Figure 10 A schematic of the mechanical motion transformation for the harvester pedal energy (HPE)

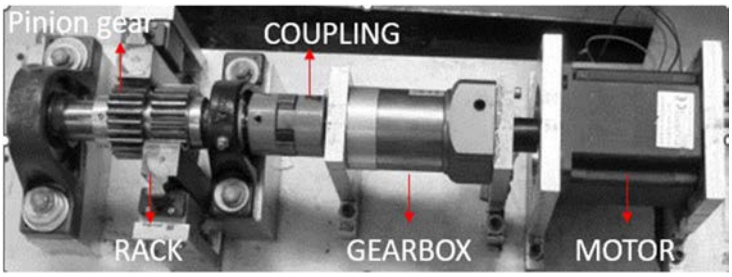

Figure 11 Mechanical motion transformation of the harvester pedal energy (HPE)

4 Conclusions

It was found that whatever the amount and effectiveness of power generated, this mechanism of motion for pedal harvester energy supports the automotive industry by supplying electricity much like pressing this pedal and then converting the motion to rotate the DC motor by MMR. The prototype represents the forerunner of future concepts of similar PHE and creates other ideas for researchers.

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