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A Learning Factory concept for skills enhancement in rail car manufacturing industries

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Abstract

Rail manufacturing industries plays a key role in various countries by developing cost effective transportation solutions that could be used more efficiently to provide movement of freight and passengers. To date, the sector has experienced an increase in technological investments that are fundamental in driving efficiencies, better managed operations as well as offer passenger-focused-services (PFS) through industry 4.0 initiatives. Despite this wave of innovative technologies, the rail industry is struggling to bring them into full fruition due to a significant skills shortage. While various learning factories have been established both in industry and academia in the last decades, there is a need to interlink the activities within these various learning factories in order to address skill shortages. This paper aims at developing that link which will bridge the gap by establishing a state of the art learning factory (LF) concept that incorporates strategic initiatives such as customised training programmes and hands on experience to benefit graduates from various engineering disciplines in order to be ready for industry. Various concepts were developed and selected using decision matrix processes through the allocation of certain scores and ratings on each criterion as well as of synthesis of this rating using the standard procedures obtained through the application of Pugh Matrix, in order to select the most optimum LF design concept. In addition, a systematic layout planning (SLP) approach was used to analyse the sequence of operation performed within the proposed LF concept as well as understanding the relationship between the various workstations. The results reveal the chosen concept which the most suitable characteristics in LF design for the rail manufacturing industry. Lastly various projects were proposed in order to determine the performance of student group within the proposed LF concept.

Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.

Keywords: *Learning factory; Industry 4.0; Skills development; Rail manufacturing*

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1. Introduction

Bright scholars withdraw of major modules in engineering due to the lack of practical prospects to satisfy creativity, lack communications and teamwork skills. This problem is also evident in a number of graduates who have the opportunity to completed their programme. They are crying out for hands-on experiences to complement the classroom lecture experience. Students need a place (analogous to a child's sandbox) away from the lecture hall, where they can get their hands dirty [1]. Many engineering students are "visual learners", much better served by active, visual and tactile teaching methods [2]. The cause of a failed knowledge transfer in Education is often the missing practical application [3]. The acquisition of competence goes beyond the purely theoretical knowledge. It also includes the ability to apply knowledge to solve practical problems. Only when the connection is guaranteed between knowledge and ability for its application, we can speak of competence [4]. The specific objectives of LF concepts in an academic environment are to offer a practice-based engineering curriculum as shown in Figure 1, which balances analytical and theoretical knowledge with manufacturing skills as well as hands-on experience in the design of manufacturing systems and product realization [5]. LF laboratories differ from the traditional, highly focused, disciplinary laboratories that are tied to specific courses such as fluid mechanics, electronics, or controls. In learning factories, students are experiencing a product and the related manufacturing and/or assembly process [6].

Fig. 1. Proposed schematic layout of the learning factory.

According to the problems described above in terms of pure frontal teaching in the classroom, the Department of Industrial Engineering at the Tshwane University of Technology (TUT) decided in 2018 to establish rapid incubator that will be designed using the similar LF ideas proposed in this manuscript. The aim was to integrate the research activities centred around rail manufacturing within the department with the technology business ideas generated through theoretical investigations an practical lessons. In practical lessons, the students should have the opportunity to apply their theoretical knowledge in a real manufacturing situation and environment. The focus of the LF is to simulate a flexible, changeable and reconfigurable assembly line on which a product, multiple products or product variants can be produced. At the same time, there was a concern to represent manual, semi-automated and automated assembly situations in the laboratory. The elaborated training concept therefore provides both, the design and planning of layout and assembly process as well as the integration of automated assembly elements. In addition to lessons for students, the LF will be also used in future for the implementation of training for small and medium-sized companies, which today often have a certain fear of automation and methods of lean production, as these have their origins mainly in large companies. This paper describes the LF concept and gives an overview of the applied and successfully proven training concept of a manual and semi-automated assembly process of the various reconfigurable technologies. The next section of the manuscript presents the various related works on LF design concept in a manufacturing environment.

2. Related works on various learning factory design concepts

Due to the rapid changes in products and production systems, students need to be much more rapidly introduced to existing and future methods. In the future, a more practice oriented teaching is required. Therefore, an adaptation in teaching and of the training content and its delivery mechanisms to the new requirements of manufacturing is needed [7]. LF is an advanced approach that has been used lately for the education of engineers and participants in the production process. Its main goal is to allow the application of the theoretical concepts in order to give the learners bigger room for experimentation to be able to reach the optimized state for the processes and activities involved in the process as well as the methodological approach for design the LF concept.

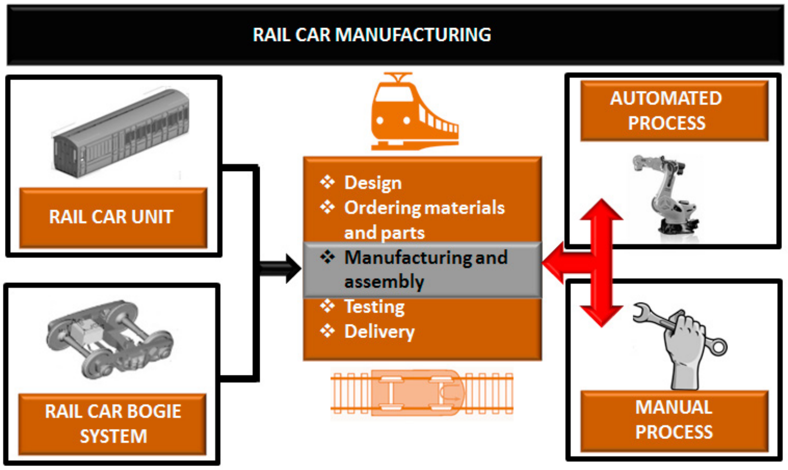


Fig. 2. Detailed manufacturing and assembly activities that will embed in the Learning Factory concept.

The Institute for Machine Tools and Industrial Management (iwb) at the Technical University of Munich developed and installed a new LF called LOZ (Learning Factory for Optimized Machining) that introduces these approaches to machine users as well as production managers in order to close the gap between research and industry [8]. Mattsson *et al.* [9] designed a LF environment concept using human-centered approach: studying the introduction of advanced automation, managing product variety, supporting operators in finding information and supporting existing human-automation interactions. Schallock *et al.* [10] proposed the design of a learning factory for Industry 4.0 that addresses the growing demand for future skills of production staff. Ogorodnyk *et al.* [11] describes the process of creating a LF based on an assembly line of roller skis used in order to enhance students' practical and theoretical knowledge on topics of kaizen, waste types, efficiency, push/pull production systems. Abele *et al.* [12] presents a training concept for transferring the multidisciplinary technical and methodical know-how about the proposed energy efficiency measures to industry and engineering students with an adapted didactical concept. Gräßler *et al.* [13] upgraded an existing centralized production laboratory to a cyber-physical production systems (CPPS) LF which enables the realization of manufacturing various products at the same time, mass customization aspects and automatic production of new products. Tisch *et al.* [14] proposed a systematic approach for the competency-oriented development of learning factories integrating the conceptual design levels 'LF, 'teaching module' and 'learning situation'. Shariatzadeh *et al.* [15] investigated approaches and principles when integrating the digital factory, IT tools and IoT in manufacturing in a heterogeneous IT environment to ensure data consistency. The presented approaches enable an effective competency development in learning factories by addressing problems of intuitively designed learning systems.

3. Methodological approach for rail car Learning Factory design

3.1. Need assessment

A methodical approach was developed to identify the requirements of different stakeholders on learning factories, namely operators, trainers and employees. In doing so, it will allow the connection of learning outcomes and learning activities in a LF, which then provides opportunities to explore the three pillars i.e. learning activities, learning outcomes and assessment in learning factories according to the theory of constructive alignment [16].

3.2. Concept generation

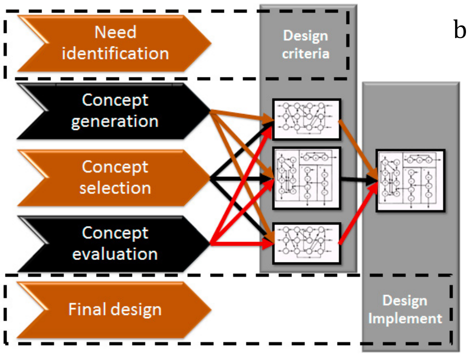
Concept generation is a procedure that begins with a set of customer needs and target specifications and results in an array of product concept design alternatives from which a final design will be selected. In this manuscript, various

LF for the rail car manufacturing industry has been generated based on the various requirements of the users. The next sub-section describes the process followed in selecting the optimal LF concept for the rail industry.

3.3. Concept selection

The design concepts for LF are evaluated using the concept scoring via Pugh matrix based on the selection criteria as shown in Figure 4(a). In order to minimize bias, several designers/graduate students have evaluated the scoring and axiomatic design approaches for the designs. In this paper a skill based LF concept was developed that specifically focused on the various activities applicable to rail car manufacturing industry.

a



b

	Section	Area SF
1	Storage/Warehouse	88.4m^2
2	Railcar Centre	74m^2
3	Bogie Centre	88.4m^2
4	Research Centre	139m^2
5	Operations Centre	88.4m^2
6	Toilets	28.86m^2
7	Living Area	46.36m^2
8	Bedrooms	493m^2
9	Dining Area	190m^2
10	Flexible Classrooms	51.2m^2
11	Reception	74.97m^2
12	Office Space	371.6m^2
13	Auditorium	557.42m^2
14	Incubator	204.4m^2

Fig. 3. (a) Proposed approach for layout selection and evaluation; (b) Various section of the learning factory and its related areas.

The layout procedure used to develop the learning factory for this study is the SLP method by Muther [17]. The activity relationship chart was formulated after analysing the data that was collected on learning factories, the manufacturing industry and training centres. Fourteen different areas were put together and the relationship between them was analysed using the closeness rating symbols. After the activity relationship chart was developed, a relationship diagram was drawn to show the relationship between the different areas within the learning factory as shown in Figure 4(b).

4. Student projects within the Learning Factory

Figure 5 below presents a flow-chart of the process followed by the various engineering students in executing projects within the learning factory environment. The first process takes place is the building of a frame structure for the under frame as depicted in Figure 5. The material used will be either a channel section or a rectangular box type. The material will be cut to size to build the structure. The Braces/support members/ cross beams, will be welded to the frame. A sheet metal cut to size will then be welded on top of the frame. After that the frame will be turned upside down to position a bolster for the bogie. The housing for the bogie pin will be manufactured separately by machining and the battery tray fabricated through cutting and bending, and both subsequently welded to their respective positions on the frame. Cabling/trunking will be done for the drive motor and lighting for the railcar. After cabling is done, the underframe should be turned back to its upright position. The side frames will then be Gas welded to the base to give the general structure of the car. The side panels will then be spot welded (or riveted) to the side frames. The roof frames as well as the roof panels are done separately. Firstly, the frame is constructed, Then the panels to suit the roof frame. Cabling/trunking is now done on the roof. Subsequently, the front and end of the car are also manufactured/ cut to size. The bogie will be manufactured in two ways. One way of making the bogie is through additive manufacturing by printing it (3D printer). Another form of manufacturing the bogie is through fabrication. After all the components have been done they are then assembled. During the assembly process the roof, front and end are fitted to the body and cables are connected. The last stage is fitting the bogie, connecting the feed cables, painting and testing.

a

Selection Criteria		Pugh Concept Selection Matrix	Weight	Concept A	Concept B	Concept C
				Design Concepts		
Selection Criteria	Setting	Changeable Processes (Workflow of production)		S	–	–
		Changeable equipment		S	–	
		changeable building		S	–	–
		Multi-purpose application of equipment for different exercises		S	–	
		changeable layout of equipment		S	–	–
	Process	Different representation of manufacturing processes		S	S	S
		Ability to accommodate different functions		S	–	+
		Application, Development, Improvement and showcase of different technologies		S	S	S
		Planning and application of factory systems		S		
	Product	A functioning product is produced		S	S	S
		Product can be produced in many different ways		S	–	–
		Product is changeable		S	S	S
		capability of different industry cases application during training		S	S	S
		Ability to train on different competencies (soft skills)		S	S	S
	Didactics	Ability to use different training media to impart Knowledge/skills		S	S	S
		Imparted knowledge matches current state of art		S	S	S
		Continuous development of training models and material		S	S	S
		Expert trainers on specialised field		S	S	S
		Wide range of topics to learn from		S	S	–
	Purpose	Offers training on different topics		S	S	–
		Accommodates participants from different companies		S	S	S
		Accommodates participants from the same company		S	S	S
		Clearly defined objectives before training commences		S	S	S
		Development of new technologies and innovation methods		S	S	S
		Research activities available		S	S	S
	Operating Model	Sustainable funding for activities		S	S	S
		Sustainable Model for hiring and developing staff member		S	S	S
		Sustainable model for implementing new learning content		S	S	S
		TOTAL +		0	0	1
		TOTAL -		0	7	6
		TOTAL SCORE		0	-7	-5
		WEIGHTED SCORE				

b

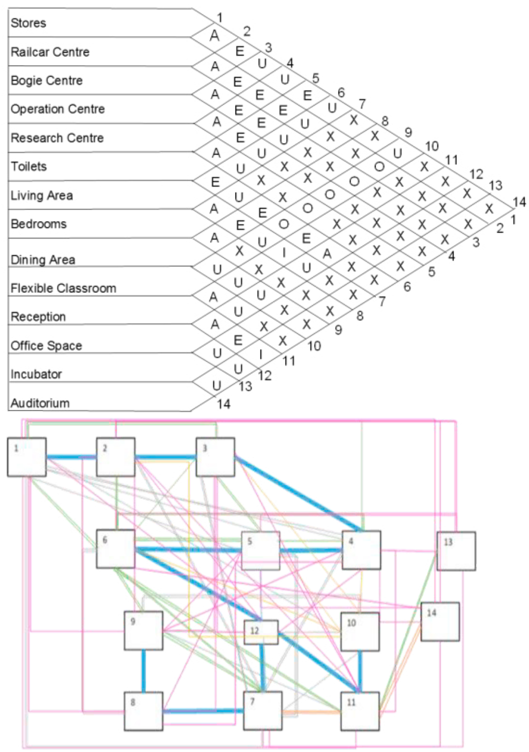


Fig. 4. (a) Concept selection using Pugh matrix; (b) Learning Factory Activity Relationship Chart.

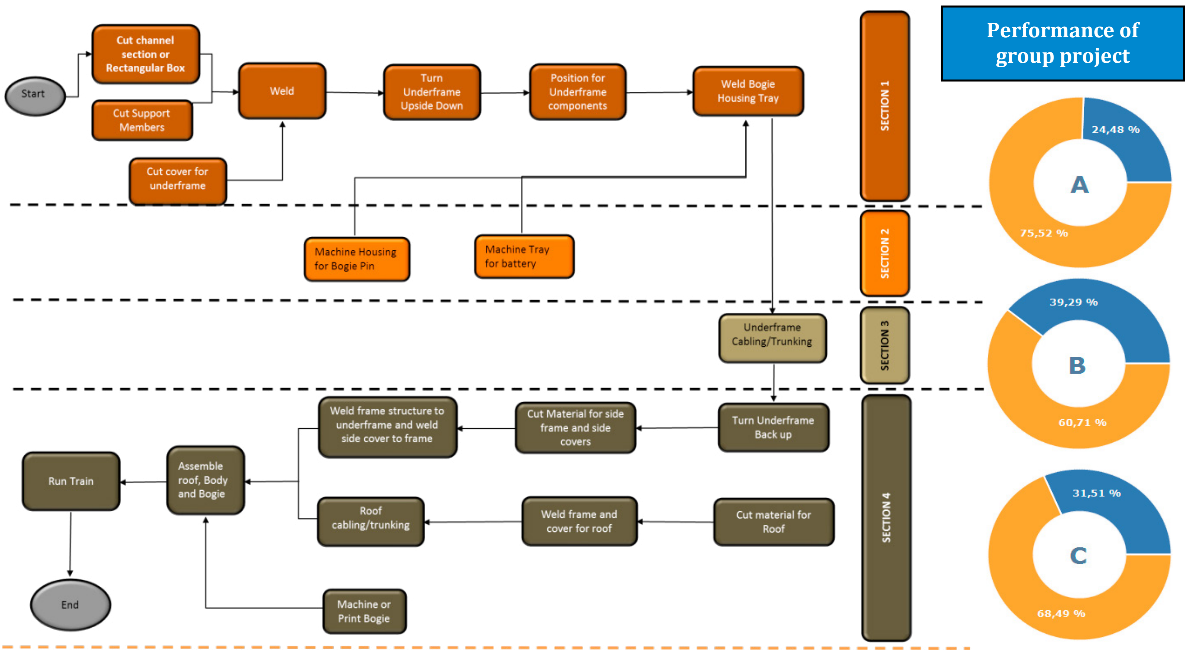


Fig. 5. proposed flow-chart of the rail car manufacturing Learning Factory project.

5. The proposed Learning Factory design

The design of a LF is aimed at providing an inclusive training and learning environment for various skills under one roof. The LF has interlinking workstations with shared material and information flows. Parts of the train will flow through different sections as prescribed by their manufacturing process. Bogies are part of a railcar and only a section of the LF will accommodate their manufacturing process (see Figure 6 (b)). The bogies provide the running gear or the suspension of a rail car. Individual components are manufactured under two main sections, the electrical and mechanical engineering sections. There are mechanically produced parts (on site) as well as purchased parts required for assembling into a bogie. The components are assembled and prepared in a workstation as sub-assemblies, which are eventually assembled into the bogie. The layouts of the schematic and the 3D LF are depicted in Figures 6 (a) and (b). Figure 6 (a) represents the entire learning factory and all the supporting functions required to build a whole unit (railcar) including the reception, stores, lecture room and control centre etc. [18].

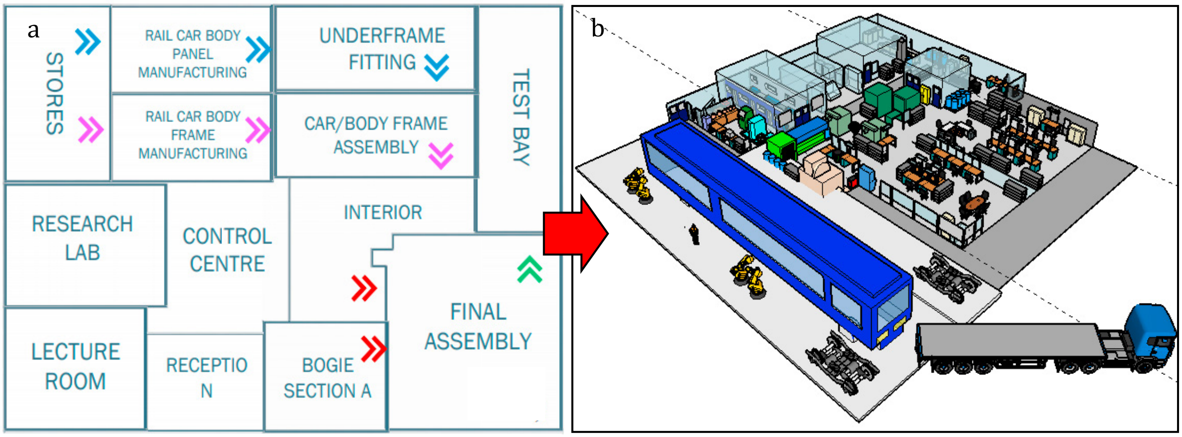


Fig. 6. (a) Proposed layout of the Learning Factory [17]; (b) 3D representation of the Learning Factory using Sketchup Software.

The final 3D layout of the LF was divided into separate blocks and labels where each component was designated in relation to its section in order to be able to determine & draw the process according to the components that are under assembly. This can be seen in Figure 6 (b) above.

6. Conclusions

To optimize the output for future learning factories experiments, it is important to be sure what companies want and need. Since the test environments can be designed to capture many aspects of production work this is crucial in order to produce relevant experiment results. The Learning Factory at TUT is envisaged to be a university-industry partnership established to integrate design, manufacturing and business realities into the engineering curriculum. This will be accomplished by providing real (industry- driven) projects, a curriculum in Product Realization, and a state-of-the-art, hands-on learning laboratory. The learning factory environment provides a good platform to overcome skill related challenges in rail car manufacturing and can also be used for testing new methods and design concepts that can be used for human-centered production.

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References

[1] Lamancusa, J.S. and Simpson, T.W., 2004, October. The learning factory–10 years of impact at penn state. In International Conference on Engineering Education (pp. 16-21).
[2] Jäger, A., Mayrhofer, W., Kuhlang, P., Matyas, K., & Sihn, W. (2012). The "learning factory": An immersive learning environment for comprehensive and lasting education in industrial engineering. In 16th World Multi-Conference on Systemics. Cybernetics and Informatics, 16(2), 237–242.
[3] Matt, D.T., Rauch, E. and Dallasega, P., 2014. Mini-factory–a learning factory concept for students and small and medium sized enterprises. Procedia CiRP, 17, pp.178-183.
[4] Klieme E. To develop national education standards. Research in Education). Berlin: Bundesministerium für Bildung und Forschung: 2007.
[5] Lamancusa JS, Jorgensen JE, Zayas-Castro JL, De Ramirez LM. The Learning Factory-Integrating Design, Manufacturing and Business Realities into Engineering Curricula-a Sixth Year Report Card. In: International Conference on Engineering Education, 2001. p. 6-10.
[6] DeMeter E, Jorgensen J, Rullan A. The Learning Factory Of The Manufacturing Engineering Educational Program. In: Proceedings of the International Conference on Manufacturing Education. San Diego, CA; March 1996.
[7] Chryssolouris, G., Mavrikios, D. and Rentzos, L., 2016. The teaching factory: a manufacturing education paradigm. Procedia CIRP, 57, pp.44-48.
[8] Kleinwort, R., Semm, T., Falger, P.M. and Zaeh, M.F., 2018. Integration of an Android Application into the Learning Factory for Optimized Machining. Procedia Manufacturing, 23, pp.9-14.
[9] Mattsson, S., Salunke, O., Fast-Berglund, Å., Li, D. and Skoogh, A., 2018. Design concept towards a human-centered learning factory. Procedia Manufacturing, 25, pp.526-534.
[10] Schallock, B., Rybski, C., Jochem, R. and Kohl, H., 2018. Learning Factory for Industry 4.0 to provide future skills beyond technical training. Procedia Manufacturing, 23, pp.27-32.
[11] Ogorodnyk, O., Granheim, M., Holtskog, H. and Ogorodnyk, I., 2017. Roller skis assembly line learning factory–development and learning outcomes. Procedia Manufacturing, 9, pp.121-126.
[12] Abele, E., Bauerdick, C.J., Strobel, N. and Panten, N., 2016. ETA Learning Factory: A holistic Concept for teaching Energy Efficiency in Production. Procedia CIRP, 54, pp.83-88.
[13] Gräßler, I., Pöhler, A. and Pottebaum, J., 2016. Creation of a learning factory for cyber physical production systems. Procedia CIRP, 54, pp.107-112.
[14] Tisch, M., Hertle, C., Abele, E., Metternich, J. and Tenberg, R., 2016. Learning factory design: a competency-oriented approach integrating three design levels. International Journal of Computer Integrated Manufacturing, 29(12), pp.1355-1375.
[15] N. Shariatzadeh, T. Lundholm, L. Lindberg, G. Sivard, Integration of digital factory with smart factory based on Internet of Things, Procedia CIRP, 50 (2016) 512-517.
[16] Tvenge, N. and Ogorodnyk, O., 2018. Development of evaluation tools for learning factories in manufacturing education. Procedia Manufacturing, 23, pp.33-38.
[17] Muther, R. (1973), Systematic Layout Planning, 2nd ed., Cahners Books, Boston, MA.
[18] Maheso, M.N., Mpofu, K. and Sibanda, V., 2018. Flexible and Adaptable Learning Factories for the Rail Car Manufacturing industry. Procedia Manufacturing, 23, pp.243-248.