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Insights from a Digital Lean Startup: Co-creating Digital Tools for Cognitive Augmentation of the Worker

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Abstract

Lean Startup is described as the application of lean thinking to the process of innovation, where a process of validated learning allows entrepreneurs to develop and test their products through frequent experiments. Such learning capabilities remain critical as we progress into an era of digitalization, where an abundance of data promises to advance the way in which many organizations develop problem-solving capabilities to learn to do better business. Thus, the aim of this paper is to provide insight into how the lean startup methodology can be used to develop digital solutions which enable manufacturers to better solve their problem-solving problems in the digital era. We present insights from an innovative new startup company that has adopted the lean startup methodology to develop an augmented reality solution that promises to support and enhance the problem-solving capabilities of the operators of the future. The insights have relevance for both practitioners and researchers.

Keywords: Digital Lean Manufacturing, Augmented Reality, Problem-solving, Learning

1. Introduction

Lean Startup has been described as the application of lean thinking to the process of innovation [1]. At the heart of lean startup is *validated learning* – the process of running frequent experiments that allow entrepreneurs to test each element of their vision. However, this type of learning is not unique to the lean startup – and has more recently been identified as the core of lean thinking and practice [2]. As such, Toyota Motor Co. can be considered as the original, lean startup.

Toyota leaders recognized early on that as the company grew, it risked becoming fat, slow and inflexible – a natural consequence of organizing activities for repeatable results. They called this phenomenon "big company disease" [3]. Short of everything, from capital to technology, Toyota leaders responded by developing, through trial and error, several unique learning systems, including the Toyota Production System (TPS) and the Toyota Product and Process Development System (TPPDS). Learning is at the heart of lean.

Learning capabilities remain critical as we progress into an era of digitalization, where an abundance of data promises to advance the way in which many organizations develop problem-solving capabilities to learn to do better business. Therefore, the aim of this paper is to provide insight into how lean thinking and practice (as the foundation to the lean startup methodology) can be used to develop digital solutions which enable manufacturers to better solve their problem-solving problems in the digital era. We present practical insights from the validated learning of KIT-AR, a digital lean start-up that provides an advanced augmented reality (AR) system that enables improved problem-solving in smart manufacturing.

In the following section, we present an overview of relevant theory before we describe our research design in chapter 3. In section 4 we provide an overview of KIT-AR and share insights

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from developing the AR system, before drawing relevant conclusions in section 5.

2. Theoretical Background

[1] discovered that applying the ideas from lean manufacturing to entrepreneurial challenges provides a framework for making sense of them. Therefore, in this section, we provide an overview of relevant theory from lean manufacturing.

2.1. The birth of lean thinking and practice

Lean manufacturing become popular in the 1990s following the publication of *The Machine that Changed the World* [4], in which it was described as a complete organizational approach to business management – from dealing with customers to designing the [product], running the factory, coordinating the supply chain and managing the enterprise. However, many adopters tend to limit applications of lean to the factory floor, in the form of tools and best practices as a means of realizing *operational excellence*. [5] reframes the role of such lean best practices, and presents them as frames for learning and value creation. [6] also suggests that lean is a learning system with four distinct sub-systems, each addressing specific questions:

- Product Planning (PP) system – how can we learn what products to improve or introduce next to make each customer a life-time customer?
- Toyota Product Development System (TPDS) – how do we keep in touch with customers and their evolving needs to better understand what to keep and what to develop or discard in each product?
- Toyota Production System (TPS) – How can we continuously look for the next step of the productivity frontier?
- Total Quality Management (TQM) – How do we develop the management and back-office practices that are needed to support the other three learning systems?

We suggest that each of these questions has relevance for building problem-solving capabilities in people, both as small firms as well as in large multinational organizations, such as Toyota.

2.2. Lean startup

Exploring key scientific, academic, and professional concepts and theories behind the lean startup, [7] positions it as a practical and up-to-date implementation of strategy based on the learning school of strategy making [8]. Thus, given its practical-oriented nature, the Build-Measure-Learn (BML) feedback loop serves as a critical element of the lean startup model. Similar to Deming's [9] Plan-Do-Check-Act (PDCA) cycle, BML involves building experiments to test the business model hypotheses, measuring the results of these experiments through data analysis and insight, and finally learning – by confirming or annulling the hypotheses. The result of such validated learning is either pivoting or persevering, often through iteration towards a more superior offering.

2.3. Digital Lean Manufacturing

Digital lean manufacturing builds on new data acquisition, data integration, data processing, and data visualization capabilities to create different descriptive, predictive, and prescriptive analytics applications to detect, repair, predict and prevent unstable process parameters and / or avoid quality issues that might otherwise lead to waste in the cyber- and physical worlds [10]. As such, it can be considered an enabler of Zero-Defect Manufacturing (ZDM). Although ZDM is not a new concept, it promises to reshape the manufacturing ideology, given advances in digital technology.

Manufacturers are in the midst of a fourth industrial revolution, otherwise known as Industry 4.0 [11]. Though there have been many discussions as to whether lean and digitalization are complementary or contradictory [12, 13], we suggest that there is a synergetic effect to be realized – in which lean paves the way for effective digital transformation and digitalization enhances lean thinking and practice. In this context, we emphasize augmented reality (AR) solutions in particular, as there is clear evidence that such solutions positively impact problem-solving capabilities in people [14].

As such, in this paper, we intend to illustrate how lean thinking and practice, with learning at its core, can be used to develop innovative products for customers that help solve the customers' *problem-solving* problems. We suggest, in a digital lean context, that generating insights from data in a user-friendly manner promises to significantly advance the fields of Lean and Zero-Defect Manufacturing in the digital era.

3. Research Design

Given the practical nature of the lean startup and its BML development cycle, we adopt action learning research (ALR) as our research approach to explore how the lean startup methodology can be used to guide the development of an augmented reality (AR) system for the cognitive augmentation of workers in digital lean manufacturing. We provide insights from the lean startup of KIT-AR, a small digital startup with 12 employees operating out of the UK, Norway, and Portugal. One of the authors (as the founder and CEO of the organization), has been responsible for the process from concept to launch and assumes the role of insider action-learning researcher.

ALR can be considered a form of action research [15] and is a related but different form of activity to action learning. [16] suggests that the key to understanding this difference is in making the distinction between learning (through action) and actionable knowledge [17]. When engaging in action learning, two commitments are relevant: a commitment to action and a commitment to learning [18]. There is no expectation, however, that on realization of these commitments, there will be a redeployment of that learning beyond the group, through creation and sharing of the emerging *actionable knowledge*. As such, ALR requires one further, related commitment – a commitment to adding to existing actionable knowledge. For the action-learning researcher, reflecting on the story of the action (from a theoretical perspective) aims to identify emergent theory so as to contribute to actionable knowledge. In ALR, data is both collected and generated (created) in action.

4. Developing KIT-AR

In Industry 4.0, augmented reality (AR) is a key enabling technology that is set to revolutionize manufacturing. Several early adopters have already gained an edge over their competition, by empowering workers with AR to improve quality and reduce costly errors. As such, KIT-AR was established with the vision of facilitating symbiosis between physical plant and human operators in smart factories.

KIT-AR's core technology consists of four interactive system modules:

- KIT-BUILD - provides the means for engineers to capture the knowledge of people and processes in the form of smart instruction sets that are anchored in 3D product and process information.
- KIT-ASSIST - resides in each AR device on the shop floor, whether it be a Head Mounted Device (HMD) or a mobile device. Once the worker is authenticated, KIT-ASSIST retrieves the correct instruction set along with the corresponding 3D models. The knowledge embedded in each step of the instructions is delivered at the point of need for the worker, tailored to their individual needs and personalizing the delivery. The navigation of the instruction sets is via voice recognition, thus enabling the worker to use the device hands-free, with minimal impact on their work.
- KIT-SMART - aims to leverage the signals captured from the environment via wearables, internet of things (IoT) sensors, information systems, (e.g. Manufacturing Execution Systems (MES)), and cameras to enable the platform to perceive the work context and reason on whether the desired quality criteria is being met, triggering an intervention if necessary. The reasoning is based on the use of multiple sub-modules, each using Machine Learning (ML) to tackle a well-defined problem, such as deviation from the current standard or quality verification of an assembly step.
- KIT-INSIGHT - all the data from the KIT-ASSIST and KIT-SMART modules are captured while the worker is carrying out their job. Using both process mining and analytics, the engineer or manager is able to determine how the work was carried out on the shop floor, checking for potential performance bottlenecks, execution variants and verifying compliance, all with the aim of product and process optimization. This module closes the knowledge cycles by connecting the digitalization of the shop floor back to the engineering department, enabling continuous process improvement as both engineers and managers gain better decision-making capabilities.

The KIT-AR solution is the result of lean product development, complemented with lean startup principles and an emphasis on Gemba-based learning (Gemba is the Japanese word for *the real place*, and in lean jargon refers to the place where the problem can be seen in situ). The inception was based on the identification and understanding of the needs of relevant stakeholders within an industrial manufacturing company, namely the operators, managers, and engineers. In the following section, we describe how each of the four modules were developed using the lean startup methodology and BML cycle.

4.1. Learning cycle – KIT-Build

During the first learning cycle, experiments were formed to test the validity of the intended KIT-BUILD module. We can refer to this cycle as *understanding the customer's real problem.* A combination of workshops (Fig. 1). with in-depth interviews resulted in a set of storylines that established the baseline functionality of the system.

Fig. 1. KIT-Build learning workshops

These activities were subsequently followed by workshops where the developers would characterize the needs and design the solution. The use of story maps (the second picture in Fig. 1) was the means of capturing the knowledge generated within the development team, and it was also used to communicate with the stakeholders from the manufacturing companies, who would contribute to the refinement of the design of the solution. Through this iterative learning process, the companies developed a deeper understanding of their needs, which in some cases led to the identification of possible solutions by adapting their processes or adopting existing technical solutions in the marketplace. For the cognitive augmentation of the operators based on the delivery of the right knowledge at the right time, personalized to the operator and coupled with quality assurance data, a new solution was required, and KIT-AR was born.

4.2. Learning cycle – KIT-ASSIST & KIT-SMART

Once the knowledge garnered allowed for the initial design of the solution, the use of the storyline was gradually replaced with interactive prototypes of increased sophistication as all stakeholders shaped the solution through Gemba-based learning. The two images below captured the very first prototype that was developed – tailor-made to support the delivery of knowledge to a worker in the maintenance and assembly of server racks. The task was chosen as representative of other assembly tasks of interest to three specific end-user use cases.

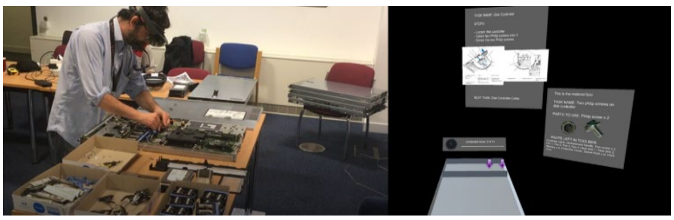

Fig. 2. Initial KIT-AR prototype

The company stakeholders experienced the early prototype, which led to the validation of the principle of cognitive augmentation and allowed to experiment different interface paradigms, thus establishing the specifications of the next prototype. The sole purpose of the early prototype was to validate principles and define the best approach towards solving the different needs associated to cognitive augmentation. In actual fact, the early prototype was discarded.

There were three use cases driving the development of the KIT-AR solution, all with the same underlying needs, but with very different requirements. Consequently, the approach taken was to start with the use case involving less product complexity to determine the functional baseline of the solution and gradually evolve into the solution supporting products of greater complexity.

In addition to multiple visits to the shopfloor of the different manufacturing companies, the development team also setup a laboratory environment to support the development, either using an instance of the real product or using 3D-printed product samples.

4.3. Learning cycle – KIT-INSIGHT

This third learning cycle was different from the previous two cycles in that it emerged as an otherwise unknown need from the collaborative development and learning cycles with the customers. In fact, the KIT-INSIGHT module is the result of one of the customer representatives uttering the words "*wouldn't it be great if the data captured from KIT-AR could be used for traceability – documenting the manufacturing process and enabling product and process improvement in hindsight*". Where KIT-BUILD, KIT-ASSIST and KIT-SMART were specifically designed based on the familiar requirements of the Gemba, KIT-INSIGHT came as a real discovery following the Gemba-based learning interventions.

4.4. Evaluation Activities

The approach taken in the development of KIT-AR was based on the lean startup with an emphasis on the co-creation of value, thus the evaluation of the solution was done regularly throughout the development phase. Different hypotheses were tested, validated, or disproved, thereby informing the next stage of the development cycle. Evaluation activities were often consolidated into subsequent stages of the development cycle.

- Data collection: For training the reasoning of the KIT-SMART modules, data was gathered from multiple sensors (e.g.: head orientation, video, images, etc.) in addition to the KIT-AR hardware. This data gathering happens on the shopfloor level with the operators. It usually occurs together with the technical testing.
- Technical testing: Each particular instance of the KIT-AR solution is tested with operators performing their everyday tasks. Preliminary tuning of KIT-AR occurs during all interactions with initial feedback being obtained from operators. Normally, technical testing goes together with data collection in the same visit.
- UX testing: Specific sessions to assess the UX of the KIT-AR solution, using a mix of quantitative and qualitative methods and tools, were also utilized. The aim was to iteratively improve the user interface until one can comfortably focus on the utility of the solution.
- Formative evaluation study: at this stage, the KIT-AR service was evaluated from all aspects, including the perception of utility. In-depth discussion to expand the initial responses was carried out to understand the underlying motivation and explore potential alternatives to inform the subsequent development cycle. At this stage, the key assumptions of the final study were validated, namely the KPIs.
- Summative study: The final stage of evaluation corresponds to the assessment of utility of the KIT-AR solution. The chosen KPIs were measured to determine the impact assessment.

5. Discussion and Conclusion

The aim of this paper was to provide insight into how lean thinking and practice (as the foundation to the lean startup methodology) can be used to develop digital solutions which enable manufacturers to better solve their problem-solving problems in the digital era. AR solutions that enable the cognitive augmentation of workers for improving problem-solving capabilities in contemporary industrial settings emerged as an interesting and important area for development and learning in action. As such, we presented the development process of KIT-AR – a digital lean startup that aims to facilitate symbiosis between physical plant and human operators in smart factories.

The major contribution of this work is that we present and highlight the BML approach to the lean startup as a useful and useable means of expediting learning in rapid product development iterations. We also highlight that this should always emphasize the *genchi genbutsu* principle of lean manufacturing – going physically to Gemba to experience and solve the problems firsthand with those involved – be it operators, engineers, or indeed customers. This is relevant for both practitioners and researchers in the field of digital innovation and entrepreneurship, as the paper shares actionable knowledge from practice, captured during the lean startup process at KIT-AR.

In terms of further work, we suggest that an interesting area of development in AR is the challenge of collaborative visualization in engineering processes. It would be interesting to examine how the KIT-AR solution could be further developed as a collaborative problem-solving tool for the synchronous engagement of multiple workers in real-time.

In terms of limitations, we understand that we present only one case – however, we suggest that the research process has been rigorous, reflective and relevant [19] as the action learning research approach that guided this study engaged with real life issues, was collaborative and reflective in nature and aimed to produce actionable and usable knowledge [20]. To conclude, we suggest that the interpretation and evaluation of the researcher's own involvement in fact underpins the emergent actionable knowledge as a quality research process outcome.

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References

1. Ries, E.: The lean startup. Crown Business, New York (2011).
2. Netland, T.H.,Powell, D.J., *A Lean World*, in *The Routledge Companion to Lean Management*, T.H. Netland and D.J. Powell, Editors. 2017, Routledge: New York. p. 465-473.
3. Ballé, M., Chartier, N., Coignet, P., Olivencia, S., Powell, D., Reke, E.: The Lean Sensei. Go. See. Challenge. Lean Enterprise Institute, Inc., Boston, MA (2019).
4. Womack, J.P., Jones, D.T., Roos, D.: The Machine that Changed the World. Harper Perennial, New York (1990).
5. Powell, D.J.,Coughlan, P.: Rethinking lean supplier development as a learning system. International Journal of Operations & Production Management 40(7/8), 921-943 (2020).
6. Powell, D.,Reke, E., *No Lean Without Learning: Rethinking Lean Production as a Learning System*, in *Advances in Production Management Systems: Production Management for the Factories of the Future*, F. Ameri, et al., Editors. 2019, Springer: Cham, Switzerland. p. 62-68.
7. Bortolini, R.F., Cortimiglia, M.N., Danilevicz, A.d.M.F., Ghezzi, A.: Lean Startup: a comprehensive historical review. Management Decision (2018).
8. Mintzberg, H., Ahlstrand, B., Lampel, J.B.: Strategy safari. Pearson UK (2020).
9. Deming, W.E.: Out of the Crisis. Massachusetts Institute of Technology, Cambridge (1982).
10. Romero, D., Gaiardelli, P., Powell, D., Wuest, T., Thürer, M.: Digital Lean Cyber-Physical Production Systems: the Emergence of Digital Lean Manufacturing and the Significance of Digital Waste. In: IFIP International Conference on Advances in Production Management Systems, pp. 11-20. Springer, Heidelberg (2018).
11. Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., Hoffmann, M.: Industry 4.0. Business & information systems engineering 6(4), 239-242 (2014).
12. Lorenz, R., Buess, P., Macuvele, J., Friedli, T., Netland, T.H.: Lean and Digitalization—Contradictions or complements? In: IFIP International Conference on Advances in Production Management Systems, pp. 77-84. Springer, (2019).
13. Ashrafian, A., Powell, D.J., Ingvaldsen, J.A., Dreyer, H.C., Holtskog, H., Schütz, P., Holmen, E., Pedersen, A.-C., Lodgaard, E.: Sketching the Landscape for Lean Digital Transformation. In: IFIP International Conference on Advances in Production Management Systems, pp. 29-36. Springer, (2019).
14. Deshpande, A.,Kim, I.: The effects of augmented reality on improving spatial problem solving for object assembly. Advanced Engineering Informatics 38 760-775 (2018).
15. Coughlan, P.,Coghlan, D., *Action Research*, in *Research Methods for Operations Management*, C. Karlsson, Editor. 2016, Routledge: Abingdon. p. 233-267.
16. Coughlan, P.,Coghlan, D.: Collaborative strategic improvement through network action learning: The path to sustainability. Edward Elgar Publishing, Cheltenham (2011).
17. Argyris, C.: Knowledge for action: A guide to overcoming barriers to organizational change. Jossey-Bass, San Francisco (1993).
18. Marquardt, M.J.: Optimizing the power of action learning: solving problems and building leaders in real time. Davies-Black Publishing, Palo Alto, CA (2004).
19. Reason, P.,Bradbury, H., eds. *Handbook of Action Research*. Concise Paperback ed. 2006, Sage Publications: London.
20. Willis, V.J.: Inspecting cases against Revans'‘gold standard’of action learning. Action Learning: Research and Practice 1(1), 11-27 (2004).