TRENDY EKONOMIKY A MANAGEMENTU
TRENDS ECONOMICS AND MANAGEMENT
ISSN 1802-8527 (Print) / ISSN 2336-6508 (Online)

2021 37(1): 73–84
DOI: http://dx.doi.org/10.13164/trends.2021.37.73

Operative Production Controlling as Entrance into Controlling 4.0

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Abstract

Purpose of the article: The paper focuses on the potentials and benefits which controlling provides to companies in the transition period towards Industry 4.0. Operative production controlling provides data that will be used in the future to apply the concept of smart factories. This article proposes a controlling architecture based on computer-aided standardization.
Methodology/methods: The paper develops an architecture on operational production controlling based on an international literature review. The literature on Controlling 4.0 is found mostly in publications in the German language. While this literature has its focus on controlling as a whole or on strategic controlling, the paper has a look on operational controlling and its further usage and development towards smart factories.
Scientific aim: The aim of this article is to develop a model of an operational production controlling architecture that is able to suit the requirements of smart factories by using computer-aided standardization.
Findings: Research is working on concepts for Industry 4.0 and its way towards real implementation. Competitive advantage in Industry 4.0 is created through digitisation and robotisation. An architecture that fully complies with Industry 4.0 is expected to be developed in real companies due to technical limitation in data storing, retrieval and processing, as well as storage capacities.
Conclusions: The paper discussed the development of a controlling architecture suitable for Industry 4.0. Already today controlling is making use of data. Smart factories will need to make use of production data. Together with the CAS, which is able to provide standardized data on all manufacturing, maintenance, and auxiliary processes, production controlling systems are able to make a step forward towards smart factories. The concept of production controlling combined with the strengths of the CAS may be seen as the basis from which to target smart factories and Industry 4.0. This research contributes to developing a data-driven framework for future research in the field of smart factories and the transition towards Industry 4.0.

Keywords: production controlling, computer-aided standardisation, case, Industry 4.0, smart factories, machine-learning

JEL Classification: L11, L16, L60, M11

Introduction

In the recent decades, controlling has become of rising importance in companies. Being a discipline to support the company management by supplying compact information from various field of the company, the standing of controlling tasks changed from an initial auxiliary task to a task with the strategic character. As such, controlling is a field that provides information to the management in the form of logically- or artificially-created indicators, often Key Performance Indicators (KPI) (Pfeifer, 2019b). These KPIs represent data from all fields in the company. These fields might be supported by an aggregated or separate controlling, such as the purchase controlling, the sales controlling, and the production controlling. While the controlling tasks might differ to some extent between the different fields of application, all of those play their role in the company to provide valuable data for the management's decision-making.

Production controlling is a discipline of controlling that support managing, planning, and controlling of production processes. The target of production controlling is the effective production based on technical and economic indicators. These indicators are developed by the controlling department or may be gathered directly from the company's information system (Bauer, 2009; Sejdić, 2019). Production controlling allows for a basic overview on machines, equipment, and lines, on inputs and outputs, and might also be used for information on quality and maintenance.

Today, controlling is a strategic tool to support the company's competitiveness by systematically displaying strengths and weaknesses. While management has to deal with the outcome of the pre-defined controlling analysis, controlling is also able to gather data and to monitor these data over time. For production companies, the focus of controlling may be put on production controlling.

With the trend striving for Industry 4.0, the digitisation comes also into the area of production and its controlling. While Industry 4.0 has been referred to in various research papers, these research papers have not yet come up with implemented solutions for the production. As research shows, many production companies are still struggling with the third industrial revolution, having issues with the acquisition and usage of data in the company. Production controlling may therefore be a preliminary stage for industry 4.0 in production companies.

1. Literature review

Literature on production and production support systems may be found in several languages all over the world and in all categories. Articles for related terms, such as "production controlling" are not present in the Web of Science (WoS) database, only one article gives a hit based on the keywords. For the term "Controlling 4.0", there was no hit, while lower-ranked databases, such as Google Scholar have several articles for Controlling 4.0 available. For articles on Controlling 4.0, articles in the German language prevail. However, articles in the English language are available for several alternative approaches to enhance production control and management (Schuh *et al.*, 2011; Brecher, Klocke, 2011; Reuter *et al.*, 2016; Reichmann *et al.*, 2017).

Production controlling is an auxiliary controlling field that belongs to the logistic controlling. Within the logistic controlling, it has interfaces with the purchase controlling and the sales controlling. The information generated by the production controlling consists in input values for the purchase and for the purchase controlling. At the same time, it means asking for information from the sales controlling (Figure 1).

It is the objective to have the production following the real sales. Individual plans,

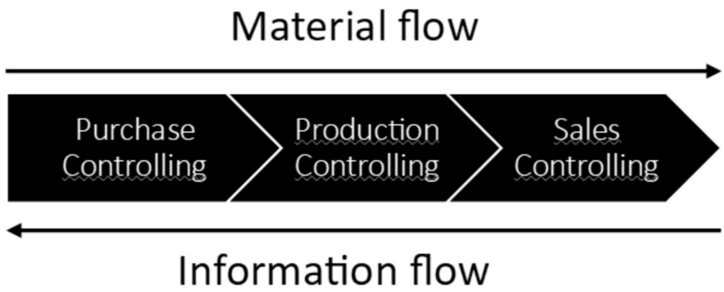

Figure 1. Placement of production controlling inside the logistic chain. Source: Bauer, 2009.

production range, *etc.* are required information needed in production, as well as for its controlling activities. Standard indicators for production controlling are production delay, quality, number of workers and work hours, material consumption, productivity, and production. These indicators can be divided according to their relation into input (relation with input indicators) and output (relation with output indicators) (Pfeifer, 2019b).

A better and more complete picture on the production and its indicators may lead to an increase in compatibility. Schuh *et al.* developed High Resolution Production Management in 2011 which asks for a support of production controlling through computer technology (Schuh *et al.*, 2011). Computer technology should be used to mainly automatically retrieve data more frequently (Brecher, Klocke, 2011). In addition, other approaches, such as the ICT-enabled real-time production planning and control approach developed in 2014 by Arica *et al.* (2014) confirms the requirement for frequent production data feedback in order to establish a more efficient controlling. Reuter *et al.* (2016) stated that there are several theoretical approaches on how to apply a more efficient production management and control. These approaches lacked practical examples on their implementation. However, Arica *et al.* (2014) understood the need of the existing IT infrastructure, such as Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and Advanced Planning and Scheduling (APS). A similar approach, as far as the proposed components are concerned, is the Computer-aided Standardization (CAS) architecture that relies on the ERP, APS, and data processing through the CAS. A crucial requirement and benefit of this architecture is the usage of standardized data. While all of these approaches work with a faster retrieval and feedback of data, none of these approaches is able to show a way of how to speed-up the concerning actions. Reuter *et al.* (2016) also developed their approach on the ERP and APS system, including the Aachen PPC model. This model relies on triggers based on throughput and inventory levels, hence on quantities of products. Due to Reuter *et al.* (2016) RFID is the fastest and in non-metallic environments most reliable technology to trace products. While this approach tries to implement a differentiated view on production and the strategies how things should be targeted, depending on the production size and the degree of differentiation of products.

Striving for higher efficiency in production led to the development of the CAS. The CAS provides a database for standardized data for all kind of processes. It was developed as a tool to support maintenance processes in the company. The CAS combined with the ERP and APS is able to provide an architecture of currently available components that allows for standardized data input for planning purposes. In this approach, the system is able to operatively plan and re-schedule plans based on standardized plan data and machine production data. In this, these systems act as the Intelligent Management Systems (IMS) that have the task to support management decisions on maintenance (Lee *et al.*, 2020). As the CAS is working in an autonomous environment of M2M-communication, it may also provide an approach to exclude manual shocks through management decision.

Further production controlling and its tasks were not considered in the CAS approach. With the research aiming towards Industry 4.0, it has to be anticipated that also production management and production controlling move towards machine learning and further automation (Abele *et al.*, 2019). This is mostly valid for the operative part of controlling where smart factories should be able to work autonomously while human beings only get a digital copy of the factory and all its sensors and measured values on computer monitors.

In order to prepare production for smart factories, companies are in need to have valid planned data available. This data has to allow for comparisons between plan and reality. As Heimel, Müller (2019) stated, a requirement for all data in the system is its standardization. While Heimel and Müller had their focus on the strategic controlling data derived from external sources through text-mining technologies, also operative controlling data has to underlie a certain level of standardization. For the planned data, the CAS or other storage systems are available on the market.

As a smart factory requires online data, which have to be available at the right time at the right place, it has to retrieve any such data from the shop floor. In doing this, it has the same target as the production controlling acquiring data to assess them, *e.g.* to determine efficiency and productivity. Thus, it may be anticipated that smart technologies will be built on the principles of today's production controlling.

Production controlling today has the task to assess data, to combine them and to give a compressed overview to the company's management. For smart companies, the overview will have to be presented to computers and machines. The potential to assess a far wider range of data is an advantage coming into play with estimated future technologies. The faster distribution and processing of data allow for elimination of the data compressing. Instead, machines shall be able to assess each piece separately. The limitation brought into the process by a human-created and human-needed interface vanishes.

Industry 4.0 and smart companies move towards a data- and IT-based environment. The system that in today's companies resembles the tasks that should be required by future companies is the controlling. While there are theoretical concepts to enhance capabilities in the system and in the production by quantities, the approach to prepare a system that is moving nearer towards smart companies may also bring benefits in today's companies. The centre of this approach is still a production controlling with its principles and patterns.

2. Methodology

The main goal of this research study is to show a theoretical approach for the development of the operational controlling in the conception of Industry 4.0 with reference to production. Based on the provided literature review, there are publications available on Industry 4.0 and some also on Controlling 4.0. These publications do not directly target production controlling 4.0.

With reference to the existing literature, some patterns and topics were already mentioned and discussed. Controlling 4.0 was mostly discussed from the view of strategic controlling while operative controlling was barely considered. The following theoretical approach is presented as a potential approach moving towards operative production controlling in an Industry 4.0 environment.

The research aims to show the relationship of today's understanding of controlling and the requirements arising from Industry 4.0 and smart factories in the future. Controlling will gain importance not only in the strategic understanding of the company, but also in the operative production management. As smart manufacturing is seen as the source for competitive advantage in the near future, the relationship and the further development of operation controlling will be of rising importance.

As also recent theoretical approaches on production development show, production companies rely on quantities and on the final outcome for the controlling and management of production lines. Taking into consideration that process stability is a target *e.g.* in automotive and pharmaceutical industries, future conception have to be able to cover the monitoring of process stability in full. Using controlling logic and assessing a higher amount of data may lead to this target (Zheng *et al.*, 2020). Hence, it is estimated that today's operative production controlling may be a predecessor or the entrance into Controlling 4.0 as this paper aims to show based on a sample architecture with the CAS usage.

3. Results

3.1 Industry 4.0 and smart factories

The CAS represents a system that is able to provide full work procedures. These full work procedures contain all required materials and information, as well as documents, for all main, supporting, and auxiliary activities. Information from this system may be used during standardisation, rationalisation and for controlling functions.

The CAS was developed as a system for maintenance purposes. Research showed that the underlying approach could also be used for production processes in an integrated environment (Nguyen, 2014). The system architecture (Figure 2) requires cooperation with other already existing systems in the company, *e.g.* the ERP or a planning system, where the CAS may be used as a database for information on work procedures of all kind (Bieker, 2019).

While most of the recommended structures already exist in today's international and

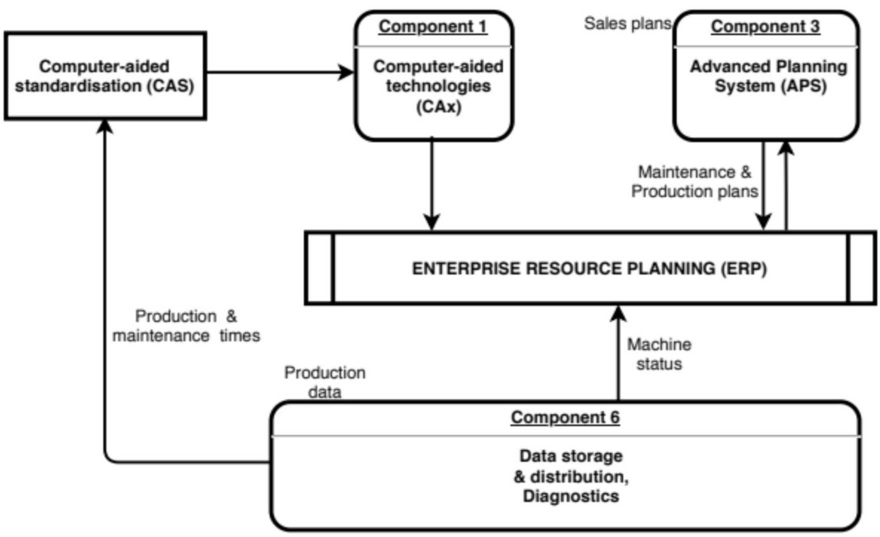

Figure 2. Integrated CAS architecture (simplified). Source: Modified from Pfeifer, 2019b.

transnational companies, the usage of CAS systems is only weakly developed. This system was initially developed for maintenance activities and requires complex algorithmic logic. This complexity limits the willingness of the companies to implement these systems in reality. A further issue for the system is the non-existing documentation for a financial benefit that can only be estimated for the particualr system.

A purposeful usage of the system requires several complex data interfaces and data transformation process, as well as a full integration into the company's information system. The system requires data in the right time. The advantage of this system is the provision of required data of all work activities. The assessment of planned versus actual status, consumption, and further parameters on activities are hidden in the logic of the whole basic information system.

The conception of Industry 4.0 is linked with a change in the fundamental nature of works and activities in the company. Learning machines are required to organise their learning working, managing, and controlling themselves. The whole concept is based on a database and further auxiliary system, such as the CAS, which is able to provide data for assessing the production status with the help of defined indicators.

Within the framework of Industry 4.0, all these operations and activities have to be handled automatically and systematically. A stable system of individual machines allows for a stable planning and a control through a stable feedback function, including the assessment of the related indicators. A further step into Industry 4.0 is the conducting of corrective actions that have to be defined already beforehand by a programming algorithm. As an essence of this, not only main activities, but also all auxiliary activities are conducted automatically and systematically.

Smart factories are to a certain extent a step leading to the conception of Industry 4.0. Smart factories serve as a tool visualising the whole factory on monitors as a full digital copy of the real world. The monitors show numbers of production indicators on the screen within real time directly from the shop floor. Smart factories therefore have to be able to provide and assess the actual ongoing in production. Already today companies try to have the possibility of a detailed tracking system. Often these companies are already on the edge of their possibilities due to the vast data volume and the limited possibilities to save and distribute data in the system (Schnell, 2016b).

A vital point is an effective data collection and distribution system. This system may work centralised or decentralized (Wolf, Holvoet, 2007). A form of these decentralized systems are multi-agent systems (MAS) (Novák *et al.*, 2019). Through the time, information systems have proved to lack the ability to meet the requirements of the companies, being it time-wise, infrastructure-wise, or technology-wise. With a joined database, such as modern business intelligence software may provide, the whole architecture has to rely on the capacity of this database. The shortcoming or limited flows will immediately hinder the production from working and will stop the ongoing assessment of production, maintenance and further activities in the company. Smart companies relying on and working with data require input in order to be able to process it. The database and the processor capacities likewise have to be able to process and distribute the data in real time.

A further increased data volume is required in the even further developing concept of Industry 4.0, which requires to constantly retrieve, process, and compare data. According to the actual values of the indicators and the result of its comparison to the required values, the system starts an automatic operative management process for the production (Canetta *et al.*, 2011). Controlling is the fundamental cornerstone of this conception in which the corrective actions and the permanent improvement process work simultaneously, while the system assesses the actual values of all defined indicators. Today's controlling function will then be substituted by the automatic and systematic communication between machines (M2M) (Lu, Ashgar, 2020).

As this inhibits a systematic working of all sensors, computers, and further devices in the company under a joined intelligence, it is necessary to ensure that all of these elements work correctly. While the subsystems within a machine or process step may be easily digitalised, the implementation of a whole virtual network respecting all influences and interdependencies is another step forward. Production companies are struggling with this step due to the complexity of the matter. In the case of a hidden bug, the whole system might be taken out of service and it might take a longer time to identify where the error originated.

For such cases, it is important to be able to rely on a controlling structure. This controlling structure should have the possibility to identify where the bug is hidden. While today's controlling functions have the target to assess all circumstances and to derive KPIs to support management decisions, Industry 4.0 requires all data and is not able to aggregate or to neglect any of them. This means, that the function of a controlling database has to be taken over by the production engine itself. The processing and preparation of data, including also its transfer, may be based on today's controlling principles but goes far beyond them. Industry 4.0 requires more data, those to be always available, and it requires the technological environment to be able to do it (Schnell, 2016a).

3.2 Development towards Operative Production Controlling 4.0

The CAS system provides data on all production activities. This refers to the data showing the plan and the standards. These data may be used to compare planned values in the controlling system. These data is compared with the actual data from production. The result of this comparison may be given as the percentage of fulfilment of planned indicators. This case describes a system with an ex-post assessment of the parameters from production, maintenance, and further activities (Pfeifer, 2019b).

The requirements on controlling in Industry 4.0 concept are changing with the development of the industry itself. Already today, saving time and increasing speed represent a competitive advantage. Within Industry 4.0, the elimination of the interface between man and machine and its substitution with an interface between two machines represents the competitive advantage. These machines are able to process data and orders with a higher speed than human beings can do with a standard procedure.

The result is that the whole system permanently requires data from the database from all production and further activities (Pfeifer, 2019a). The data will be compared with the data from the controlling module. The controlling may therefore be divided into several controlling functions depending on the time frame taken into account. The operative controlling is responsible for tracking the slightest deviations in the processes and activities and triggering corrective actions based on the result of the data comparison. ERP systems and their subsystems, which also include the CAS, play an important role in the operative controlling with the highest importance in the production controlling subsystem.

For strategic controlling activities already today controlling systems assess parameters according to the specific requirements of the particular company. The difference in Industry 4.0 consists in the processing speed of the data assessment, as well as the realisation speed for corrective actions. Both actions will happen in almost real time (Pfeifer, 2019a). What is uncertain is the time until Industry 4.0 is introduced and where the system is still without a viable database, which also implies missing data for the assessment that will trigger corrective actions. The system has to be a learning system that is taken the data from production itself over time, if these should not be set manually.

4. Results

Research papers in various languages deal with the potentials and possible expectations related to Industry 4.0. While the industry is claimed to be in the transition phase from Industry 3.0 to Industry 4.0, a full application of these concepts does not yet exist. The discussion is therefore more on a theoretical level. In German and other European publications, new trends, such as Controlling 4.0, are branded with the suffix 4.0 to indicate the conformity with Industry 4.0 concepts.

While several authors in the last years have claimed the needs and benefits of enhanced controlling systems, these concepts are just a step towards Industry 4.0. The developed theoretical approaches are based on the tracking of products with the RFID technology. This technology seems at the very moment to be one of the most promising as far as reliability of traceability is concerned. These approaches focus on traceability of production and quantities, rather than on process qualities and stabilities based on sensor networks.

The presented approach focuses on the usage of production controlling and standardised data from the CAS. This approach understands smart factories as the outcome of the digitisation requiring the extensive usage of data. In order to be able to compare planned and actual values of parameters, standardised values shall be available for any activity conducted in the company, on production, maintenance, and auxiliary activities.

Besides the benefits for planning itself, the CAS together with an APS system is able to provide information on the deviation in production processes as far as process times are concerned. This information may also be displayed on monitors of smart factories. As these smart factories should work autonomously based on the acquired and planned data, a proper data management and processing is the centre of such a factory.

Data retrieval, processing, and compression are one of the main tasks of controlling, already in today's understanding. Smart factories require a faster data processing and need to assess a higher amount of data at the same time (Gargalo *et al.*, 2020). This simultaneous processing has to lead to a real-time (right-time) assessment. Instabilities in processes shall be detected that fast that monitors are able to highlight them before the next processes start (Guo *et al.*, 2021).

Even though companies still struggle with technical limitations, making it difficult to assess such quantities of data in real time, Industry 4.0 and smart factories ask for it. An intense relation of controlling, production, and logistics are mandatory to bring companies into the position to benefit from the further trends. The controlling principles and functions will lead towards smart factories. The architecture based on the ERP, CAS and controlling allows for the extensive usage of data and enables companies to make their way closer to smart factories.

Production controlling is the field that should already have all information on production. For the future and the better stability of processes, it makes sense to apply production controlling principles in a more extensive range, as well. The efficient acquisition and proceeding of data will be a competitive advantage in the future; the principles of Industry 4.0 anticipate this. Production controlling today may therefore be seen as the entrance into Controlling 4.0 being a precondition for Industry 4.0 implementation.

5. Discussion

As Industry 4.0 strives for a data-driven environment, companies have to find a way to master the transition towards this concept. The approach in this paper deducted from the literature available focuses on making use of the potentials of current controlling. As controlling is predicted to evolve towards Controlling 4.0 using the internet of things and further advanced technologies, the architecture has to be able to handle the vast amount of data in the system. This has to be done simultaneously to the computing effort in order to assess the actual state of production.

While controlling is currently working with KPIs to provide a fast overview of information for a decision-making process, these KPIs represent aggregated and only for this purpose created numbers (Pfeifer, 2019a). Minor deviations in the underlying parameters and characteristics may not be taken into consideration for the management decision. Further shortcomings may be found, as smart factories will be able to control all required parameters in the factory, taking also the stability of the parameter and the reliability of production into consideration.

Being a pending issue, international authors have been aware on the up-to-date nature and need of frameworks to conquer Industry 4.0 by facilitating production management and production control (Schuh *et al.*, 2011; Brecher, Klocke, 2011; Reuter *et al.*, 2016; Reichmann *et al.*, 2017). However, while being theoretically consistent and robust, these approaches lacked practical feasibility. Furthermore, these approaches also include limitations due to the initial framework, such as the company size and IT infrastructure.

The provided approach (Figure 2) assumes a simplified architecture that allows for a fast data processing, assessing, and feedback. Based on the fundamental controlling structure of a company, the suggested approach makes use of the existing and available components. However, the CAS is taking the role of a downsized BI-tool, enabling to provide all vital information on standard processes. Hence, this system is able to compare the actual state with standard data. It does not allow for dynamic assessments on real time basis. The limited complexity of the system is bought with limitation in its application. Additional requirements that will be raised by companies will require additional amounts of data to be processed by additional algorithms making the system more complex.

As in other approaches, the system builds around the company's central ERP system. This system is able to provide the fundamental computational logic. Despite the amount of data, these systems do not treat data differently whether they are gathered directly through M2M communication (Lu, Ashgar, 2020) or whether the system still requires people to gather and transmit the data. In both cases, the architecture is able to provide a logic circle to make decisions on planning and production management based on gathered data.

Even though the provided architecture does not allow to be understood as Controlling 4.0 with advanced technologies from the internet of things, the approach provides companies with the possibility to assess a higher amount of data than they are doing today. This may be done with standardised data. Standardised data serve as an asset companies may have available. Hence, despite Industry 4.0 being assumed to be on the edge of realisation, there are still gaps in the approach of production management and control during the transition. While alternative approaches focus on the IT-structure as a basis for the architecture, this paper assumes controlling to provide the basis for the architecture for transition. This architecture builds on simple and available components, bringing standardized data back into focus.

6. Conclusion

Industry 4.0 requires fast and effective production controlling. This production controlling has to influence the operative management and has to have close relations to the production, maintenance, and further activities. Strategic controlling is required for the transition period to determine the boundaries of the particular system. For the introduction of smart companies with an automatic production, the assessment and comparison of complex parameter sets has to happen in real time.

The concept of smart factories represents a concept for the transition period and can be seen as a temporary preliminary stage. This system relies on measured data and its comparison with the planned indicators from the system. All decisions are still made by human beings based on highlighted parameters on the monitors showing abnormal or unwanted production parameters. The operative management and the company strategy as such are still subject to managers' control and decision-making, the same as the task of the production controlling is today.

Controlling and CAS systems therefore represent the fundamentals for smart companies and their further development towards autonomic companies, where the communication is solely handled M2M. This autonomic and self-deciding system is only based on the comparison of the underlying plan with the actual production parameters. The present controlling and its principles are therefore one of the keys for a successful transformation of today's companies into autonomic companies and thus represent a basis for further development of Industry 4.0.

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Received: 5. 12. 2020
Reviewed: 17. 6. 2021
Accepted: 30. 6. 2021

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