A KNOWLEDGE BASE FOR STRATEGIC LOGISTICS PLANNING

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Received: August 4, 2023
Received revised: September 14, 2023
Accepted for publishing: September 15, 2023

Abstract

In the paper, a knowledge-based engineering approach to strategic logistics planning is presented. Semantic web technologies for managing a knowledge base of business experiences are used. The proposed knowledge base comprises experiences gained by the SCOR model of logistics planning, according to the Deming's observe, plan, do, study, act cycle. By appropriate structuring of the knowledge base, easy access to the stored experiences for on-line analytic processing is enabled. By the proposed approach an expert system for smart logistics management is founded.

Keywords: predictive analytics, applied industrial technology, artificial intelligence, smart business models, big data and sustainability

1. INTRODUCTION

The Supply-chain operations reference (SCOR) model recognizes six major processes — plan, source, make, deliver, return and enable (AIMS, 2021). The planning processes comprises the activities associated with developing action plans for a company's supply chain management and improvement.

Strategic logistics planning is used to define an approach or a number of activities to follow by an organization in order to achieve its purpose and goals. The strategy is used by its management to define action plans that will enable the organization to always make decisions that are in the organization's best interests. Depending on the time frames and management levels they impact, these plans are classified as operational, tactical and strategic.

In this article knowledge-based engineering is introduced to facilitate strategic logistics planning. Overall, different business intelligence based methods may be applied at different levels of strategic logistics planning, depending on the results one strives to achieve – from business analytics to process optimization, cp. (Gumzej & Rakovska, 2020). In addition, to achieve optimal logistics planning, they should also include total quality management (TQM) (Ciampa, 1992) and just-in-time (JIT) principles (Britannica, 2023).

The main objective of this paper is to provide an overview of methods for strategic logistics planning and investigate a solution for smart logistics management based on knowledge-based engineering. The proposed approach is based on the semantic web and online analytical processing (OLAP) technologies. The research outcomes are summarized by an analysis of the proposed approach, utilizing a knowledge base of business experiences to improve logistics and supply chain management.

2. METHODS

From the methodological point of view, strategic logistics planning is used to define an approach or a number of activities to follow by an organization in order to achieve its purpose and goals. This strategy is used by its management to define action plans that will enable the organization to always make decisions that are in the organization's best interests. They are founded on what is commonly known as institutional knowledge. In combination with business analytics on historic and current data, business decisions are formed in order to maintain or improve the organization's market position.

While institutional knowledge can be based on competent individuals, it is sensible to store it in a knowledge base and make it sustainable. With progression of data storage from data-bases to -warehouses and data migration to the cloud, over time, the next logical step is moving the knowledge base as well. By this research a semantic web approach is proposed to manage a knowledge base of business experiences.

2.1 Six Sigma

Manufacturing and business processes have characteristics that can be defined, measured, analysed, improved, and controlled (DMAIC). Continuous efforts to achieve stable and predictable process results by reducing process variation (6-sigma) are of vital importance to business success (Tennant, 2001). 6-sigma ideas have been combined with lean manufacturing to create a methodology named Lean Six Sigma (Wheat et.al., 2003). Lean manufacturing and 6-sigma originate from Japanese business culture and share similar methods and tools to define best practices.

The lean 6-sigma methodology considers lean manufacturing ("just-in-time" production), which addresses process efficiency, and 6-sigma, with its focus on reducing variation and waste, as complementary disciplines that promote business and operational excellence. Achieving sustained quality improvement requires commitment from the entire organization, particularly from top-level management.

6-sigma projects follow two project methodologies, inspired by W. Edwards Deming's Plan-Do-Study-Act (PDCA) cycle (Tague, 2005), each with five phases:

1. DMAIC is used for projects aimed at improving an existing business process
2. DMADV is used for projects aimed at creating new product or process designs

where individual letters of these abbreviations refer to the aforementioned activities, i.e., define (D), measure (M), analyse (A), improve (I) and control (C) or design (D) and verify (V).

New knowledge usually comes from creating new products or process designs by the phases of the DMADV methodology:

1. Define design goals that are consistent with customer demands and the enterprise strategy.
2. Measure and identify characteristics that are Critical to Quality (CTQ), measure product capabilities, production process capacity, and measure risks.
3. Analyse to develop and design alternatives.
4. Design an improved alternative, best suited per analysis in the previous step.
5. Verify the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

Due to its suitability for progression from design to optimisation, the DMADV methodology is also known as Design for Six Sigma (DFSS) (Chowdhury, 2002).

2.2 Business Intelligence

The methods and technologies used in the process of planning and decision making are commonly termed business intelligence (BI). They are used in

- business analytics (BA), comprising data mining, analysis and decision making, as well as
- knowledge based engineering (KBE), used in production, warehousing and transport planning.

Both are addressing, what is commonly known as *institutional knowledge*[3]. Over time different companies have developed various forms of storing and retrieving this knowledge. In their most rigorous form, they have been included in the Advanced Planning Software (APS) tools (Ueda, 2010). However, in strategic logistics planning

[3] Institutional knowledge is knowledge possessed by a company or other organisation and its employees. It includes all of their skills, processes, data, values, expertise and experience gathered through the history of the organisation, but also gain by new employees in the organisation. Sometimes, it is referred to as „institutional memory“.

they are often considered the last resort for implementing the reached strategic decisions on the tactical and operational levels. Hence, another form of knowledge management and sharing is required – one that will enable retrieving experiences, representing company's best practices, as well as learning from own mistakes, easier and more transparent.

2.2.1 Business Analytics

By definition Business Analytics (BA) is a process, based on BI, enabling new insights into the business process and better strategic decision making for the future.

BA is composed of the following steps (Tableau, 2023):

1. Data Aggregation: prior to analysis, data must first be gathered, organized, and filtered, either through volunteered data or transactional records.
2. Data Mining: data mining sorts through large datasets using databases, statistics, and machine learning to identify trends and establish relationships.
3. Association and Sequence Identification: the identification of predictable actions that are performed in parallel with other actions or sequentially.
4. Text Mining: explores and organizes large, unstructured text datasets for the purpose of qualitative and quantitative analysis.
5. Forecasting: analyses historical data from a specific period in order to make informed estimates that are predictive in determining future events or behaviours.
6. Predictive Analytics: predictive business analytics uses a variety of statistical techniques to create predictive models, which extract information from datasets, identify patterns, and provide a predictive score for an array of organizational outcomes.
7. Optimization: once trends have been identified and predictions have been made, businesses can engage simulation techniques to test out best-case scenarios.
8. Data Visualization: provides visual representations such as charts and graphs for easy and quick data analysis.

BA emerged from data mining (DM), being the process of finding anomalies, patterns, and correlations in larger data sets, to predict the results. Based on the same principles it extends its use to analysing processes and predicting their outcomes.

2.2.2 Knowledge-Based Engineering

Knowledge Based Engineering (KBE) is an engineering methodology that integrates engineering knowledge systematically into the design system (Prasad, 2005). In terms of DFSS it can be considered the introduction of continuous improvement principles to enterprise strategic planning, based on quality-related product or process performance indicators, such as SCOR.

KBE comprises a number of intertwined methods, systematically addressing the common knowledge base, to achieve planned results:

- Computer aided project management (PS),
- Computer aided design (CAD), production (CAM) and robotics (CIM),
- Computer simulation modelling and analysis (SMA),
- Computer aided detailed production planning (MPS / MRP).

The combined use of these methods produces results, whose application leads to controlled changes in the enterprise, which are again analysed to determine possible improvements. These findings enrich the common institutional knowledge and should be included in its knowledge base.

Ultimately, BI is meant to facilitate enterprise decision making using BA and KBE methods as tools. They may form decision support systems (DSS) or expert systems (ES) to be used by experts and decision makers. DSS is an interactive system, which assists the decision makers to use the data and models for solving unstructured or partly structured problems. ES is an application program or environment, which effectively supports problem solving in a specialized problem area, requiring expert knowledge and skills. Although both are serving the same purpose, there is a distinctive difference between the two which narrows down their target audience.

The methods presented above all support strategic logistics planning from different perspectives and levels of decision making. In the sequel an expert system is outlined, which may include results from all previously mentioned methods and is based on the principles of KBE. It combines the gained institutional knowledge in ontologies (Hofweber, 2023) and supports Online Analytic Processing (OLAP) (Codd & Salley, 1993) of the stored knowledge.

3. KNOWLEDGE MANAGEMENT SYSTEM

The lifecycle of knowledge- or experience-based engineering (Andersson et.al., 2011) is founded on the iterative use of the Deming's OPDSA (Observe-Plan-Do-Study-Act) cycle:

1. Identify: a non-conformance with the desired state that appears in the manufacturing process due to an ill-defined product or process.
2. Capture: the experience is captured.
3. Analyse: a root cause analysis of the captured experience is made to identify an appropriate remedy strategy and its re-use to prevent recurring anomalies.
4. Store: insights from the analysis are archived; hereby, the experience is stored.
5. Search & Retrieve: the experience is searched for and retrieved.
6. Use: an element of the experience is used.
7. Re-use: concludes this cycle of knowledge management and starts a new one.

The experts involved in the decision-making process access this information through the enterprise Knowledge Management System (KMS). Hence, the KMS represents an expert system for collecting, cataloguing and retrieving experiences stored in the knowledge base. It may store various kinds of information, however, the most important are the experiences themselves, representing key pieces of information for addressing concrete problem situations (Sowa, 2010).

3.1 Knowledge Base

The knowledge base stores experiences as pieces of information, an organization can utilize in the process of KBE to make better informed and quicker planned decisions. With respect to using the principles of the intelligent Web, the proposed form of knowledge organisation is by an ontology. Here, the collected experiences are stored as entities that can be retrieved and combined in various ways. They have properties, characterizing their nature, and relations, outlining their structure and interconnections.

The proposed form to represent the individual experiences as pieces of information is by using SOAP notes. They contain four distinct pieces of information:

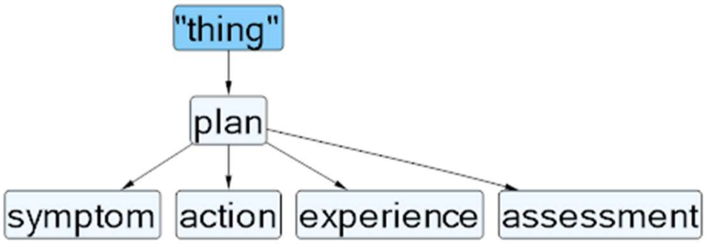
1. Subjective data (S), such as quotes, or paraphrased statements; a few sentences that best capture the most pressing concern.
2. Objective data (O), such as factual, observable values.
3. Assessment (A) of the situation; based on the subjective and objective data, a statement is made about, what they mean; in association with them, here, also planned interventions, goals, and objectives can be included.
4. Plan (P) for interventions.

SOAP notes are the most common type of business experience notes, used here to enable the experts to reason about the problem in an understandable and addressable way. Such notes are commonly used in marketing research, when interviewing clients, to determine customer satisfaction. Hence, they usually lack precision, much needed when making enterprise-level decisions about additions/improvements to the production process. Another kind of business experience notes are DAP notes, which combine the previously mentioned S and O data into D (diagnosis). Such notes are often used in medicine, when treating patients. Diagnosed symptoms are represented by qualitative descriptions and quantitative indicators.

In general, one cannot limit oneself to factual data only. Because of this, concise subjective data also have an important role in the assessment. An assessment comprises the methods used in the analysis of the identified non-conformance with the aspired state. As continuation of the analytic process, plans represent remedy actions that have been identified as beneficial for the improvement of the current state by its assessment.

For simplicity reasons DAP notes have been chosen to represent the enterprise experiences of the proposed KMS. The structure of knowledge in the knowledge base of experiences can thus be presented in the form of an ontology graph, as shown in Figure 1. Here, the planned activities are grouped around experiences formed by analysing the symptoms and assessing the situation to form improvement actions.

Figure 1 KMS ontology



Source: own

3.2 Knowledge Organization

Every piece of experience in the enterprise KMS is catalogued as an entity, having properties and relations to the rest. As mentioned above, every experience has symptoms, an assessment and planed actions. Symptoms are characterised by their descriptions and indicators, listing their specific current as well as target values. Assessments are short descriptions of the methods used in the analysis of the symptoms. Actions are short descriptions of remedy actions taken. Experiences of the same action plan can be grouped to form complex systemic (multi-level) action plans. They are formulated as facts and rules, using Ontorion's controlled natural language (CNL) statements (Kaplanski, et.al., 2015), as presented below.

```
Every experience is something.
Every symptom is-part-of an experience.
Every assessment is-part-of an experience.
Every action is-part-of an experience.

Every symptom that belongs-to an experience has-description nothing-
but (some string value).
Every symptom that belongs-to an experience has-value nothing-but
(some real value).
Every symptom that belongs-to an experience has-target-value
nothing-but (some real value).
Every assessment that belongs-to an experience has-description
nothing-but (some string value).
Every action that belongs-to an experience has-description nothing-
but (some string value).

If X is-part-of Y then X belongs-to Y.
Every-single-thing that is an experience and-or belongs-to something
(that is an experience) is a plan.
```

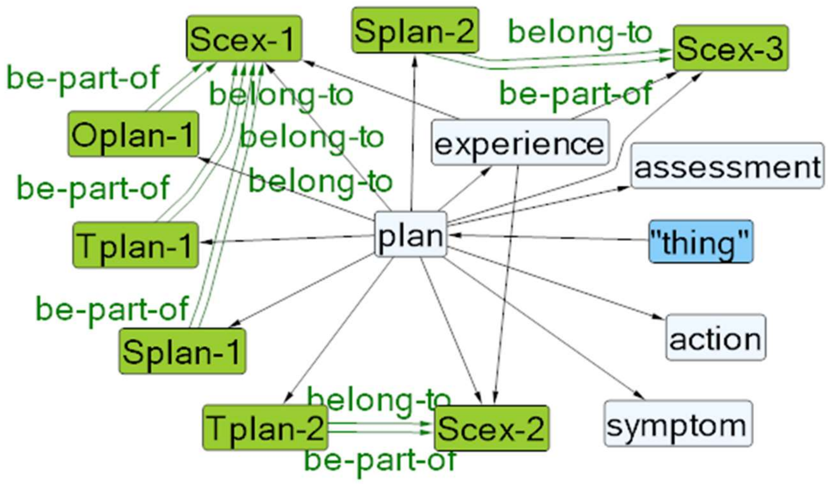
In supply chain management (SCM), experiences may be further characterised by their scope, type and focus. Considering their scope, they may be strategic, tactical or operational. By type, they are classified as network design, strategy formulation and operations planning experiences. Regarding their focus, they may be directed towards capacity planning, performance monitoring or quality assurance. This is expressed by the distinguishing properties of their plans, as outlined below.

```
Every experience has-scope nothing-but (either 'strategic', 'tactical'
or 'operational').
Every experience has-type nothing-but (either 'network-design',
'strategy-formulation' or 'operations-planning').
Every experience has-focus nothing-but (either 'capacity-planning',
'performance-monitoring' or 'quality-assurance').
```

3.3 Knowledge Management

SCM experiences (cp. Figure 2) are formed and maintained as entries in the knowledge database. It can be local (intranet), enterprise wide (extranet) or global (cloud repository). Regardless of its location, the access to the knowledge base is by client-server architecture. The host serves the requests of the clients by a semantic web service using RDF, RDFS, OWL, SPARQL, SKOS or SWRL technologies.

Figure 2 SCM Experiences



Source: own

The Fluent Editor ontology management tool can be used by experts to access, maintain and retrieve information from the knowledge base. Besides Cognitum's Fluent Editor, its Ontorion knowledge base server can also be accessed via similar tools, including Stanford's Protege and W3 interfaces. An additional option is to access the knowledge management tools via the Python and R-language plug-ins.

As an example, a simple knowledge base is outlined below. Three experiences with several action plans are listed, each addressing distinct levels of decision making, usage scenarios as well as performance indicators. The first experience (Scex-1) demonstrates the ability to join experiences in a plan to achieve a complex goal, addressing multiple levels of decision making.

```
Scex-1 is an experience.
Scex-2 is an experience.
Scex-3 is an experience.

Oplan-1 is-part-of Scex-1.
Oplan-1 has-scope equal-to 'operational'.
Oplan-1 has-type equal-to 'operations-planning'.
Oplan-1 has-focus equal-to 'capacity-planning'.
Oplan-1 has-symptom that has-description equal-to 'utilization'.
Oplan-1 has-symptom that has-value equal-to 0.89.
Oplan-1 has-symptom that has-target-value lower-or-equal-to 0.5.
Oplan-1 has-assessment that has-value equal-to 'discrete event simulation'.
Oplan-1 has-action that has-value equal-to 'double capacity'.

Tplan-1 is-part-of Scex-1.
Tplan-1 has-scope equal-to 'tactical'.
Tplan-1 has-type equal-to 'operations-planning'.
Tplan-1 has-focus equal-to 'capacity-planning'.
Tplan-1 has-symptom that has-description equal-to 'cycle-stock'.
Tplan-1 has-symptom that has-value equal-to 260.
Tplan-1 has-symptom that has-target-value lower-or-equal-to 200.
Tplan-1 has-assessment that has-value equal-to 'just-in-time production'.
Tplan-1 has-action that has-value equal-to 'improve operations reliability'.

Splan-1 is-part-of Scex-1.
Splan-1 has-scope equal-to 'strategic'.
Splan-1 has-type equal-to 'strategy-formulation'.
Splan-1 has-focus equal-to 'performance-monitoring'.
Splan-1 has-symptom that has-description equal-to 'out-of-stock'.
Splan-1 has-symptom that has-value equal-to 5.
Splan-1 has-symptom that has-target-value equal-to 0.
Splan-1 has-assessment that has-value equal-to 'lean production'.
Splan-1 has-action that has-value equal-to 'plan safety stock'.

Tplan-2 is-part-of Scex-2.
Tplan-2 has-scope equal-to 'tactical'.
Tplan-2 has-type equal-to 'network-design'.
Tplan-2 has-focus equal-to 'performance-monitoring'.
Tplan-2 has-symptom that has-description equal-to 'bottleneck'.
Tplan-2 has-symptom that has-value equal-to 3.
```

```
Tplan-2 has-symptom that has-target-value equal-to 0.
Tplan-2 has-assessment that has-value equal-to 'systems dynamics'.
Tplan-2 has-action that has-value equal-to 'balance flows'.

Splan-2 is-part-of Scex-3.
Splan-2 has-scope equal-to 'strategic'.
Splan-2 has-type equal-to 'strategy-formulation'.
Splan-2 has-focus equal-to 'quality-assurance'.
Splan-2  has-symptom  that  has-description  equal-to  'quality-of-
service'.
Splan-2 has-symptom that has-value equal-to 0.4.
Splan-2 has-symptom that has-target-value greater-or-equal-to 0.9.
Splan-2  has-assessment  that  has-value  equal-to  'agent  based
simulation'.
Splan-2  has-action  that  has-value  equal-to  'quality-of-service
monitoring'.
```

As outlined in the example each experience in itself is a member of a distinct plan. It is further characterized by its scope, type and focus providing for classification of knowledge. In terms of its content, it comprises the essential DAP components mentioned above, i.e., symptoms (by description, value and target value), assessment (by the description of the methods used to address the symptoms) and action (by the proposed action plan). Depending on the complexity of knowledge, of course the descriptions may be more elaborate, including links to appropriate documentation. Nevertheless, it is important for them to be concise to enable automated decision making (e.g., by artificial intelligence methods).

4. KNOWLEDGE RETRIEVAL

There are various ways to retrieve knowledge from the knowledge base. The simplest is to use the associated knowledge management tools (e.g., Protege, Fluent Editor, etc.) with its knowledge aggregation, classification and representation tools. However, this may prove unpractical to end users, usually being non-experts. ASP tools may use the mentioned programming/statistical language API interfaces provided, by issuing appropriate queries to render the desired results. Below are some SPARQL examples to demonstrate the use of the knowledge base.

To narrow down the search results by scope, one may issue the following query:

```
select * {?x :hasScope "tactical"}
```

lists Tplan1 and Tplan2, since they are both tactical experiences.

To narrow down the search results by application area or focus, one may issue the following query:

```
select * {?x :hasFocus "capacity-planning"}
```

lists Tplan1 and Oplan1, since they both focus on capacity planning, although they have distinct scopes.

To list all experiences which belong to a certain plan, one may issue the following query:

```
select * {?x :isPartOf :Scex1}
```

lists Oplan1, Tplan1 and Splan1, since they belong to the same planned activities group of Scex1.

Of course, one may combine the queries to pinpoint specific experiences. An example of such a combined query is given below:

```
select * {
    ?x :hasType "strategy-formulation".
    ?x :hasFocus "performance-monitoring".
}
```

By the above statement experience Splan1 is rendered, representing the experience with appropriate type *and* focus.

By this mechanism also new experiences may be added to the knowledge base. Once its structure is complete, the aggregation of knowledge is possible by direct input or by results of search queries producing new experiences.

The mentioned knowledge management tools provide interfaces to analytical software packages, like the R-Studio, and programming languages, like the R-language or Python. This extends the application space to the entire range of contemporary OLAP and semantic Web applications.

5. ANALYSIS

The proposed solution has all the properties of an expert system for strategic logistics planning. It contains:

- a knowledge base of improvement solutions to various logistics problems,
- a reasoner to manage this institutional knowledge,
- various tools to access this knowledge and to perform analytic processing and decision making.

The knowledge base is composed of facts and rules, based on the DAP principle. This allows for targeted representation of experiences forming the knowledge base. The experiences are structured according to the SCOR reference model in terms of their management level, scope, type and focus.

The associated knowledge base management tool allows for immediate exploitation of the stored knowledge by managing the structure of knowledge and reasoning based on its key terms. Different types and levels of access to the knowledge base – direct, API and APS – provide for various kinds of reasoning.

The knowledge base is typically stored in a cloud and may be accessed via the Fuseki intelligent Web server (Apache, 2023) directly or via the mentioned interfaces. The various access options enable its private, corporate and even public use. By this, the knowledge base may outgrow the company and even sustain its life in other forms in case its ownership changes or even, if a company seizes to exist and only its brand with its corporate know-how remains.

6. DISCUSSION

Considering the reasons for introducing knowledge bases in the first place, i.e., to store institutional knowledge in a transparent and persistent way, one may claim that ontologies are up to the task. They provide a somewhat less rigorous representation of the knowledge, whilst on the other hand, they provide for their consistent and transparent storage as well as diverse applications.

The simple example presented in the article merely indicates their use and provides a proof-of-concept solution, however a real knowledge base like this may be much more elaborate and complex. For instance, it may provide links to past projects documentation on improvement solutions and similar solutions from corporate partners. Nevertheless, it is a good example to show how a next-generation knowledge base may look like. With its CNL notation it somehow reduces the complexity of ontological knowledge representation and makes it human readable without losing the benefits of the rigorous form of predicate logic behind it.

From the management's perspective, the knowledge base may provide appropriate insights into the prospected solutions for concrete problems, enabling them to reason on their impact, feasibility and cost. Mostly, they represent the management's primary concern. According to the knowledge base organisation, the solutions asked may apply to different levels of decision making and execution environments.

From the expert's perspective the knowledge base provides them with a catalogue of previous experiences for root cause analysis and fine-tuning in case they would need to be applied again in adjusted form. The mentioned documentation from previous projects provides them with the ability to foster targeted improvement solutions faster and more accurately. In its essence the knowledge base reduces the need to investigate everything from scratch. As such, it may well serve as an expert system to provide for strategic logistics planning and decision making.

7. CONCLUSION

In this article the different forms of knowledge representation and management have been discussed with focus on the Deming's improvement cycle in strategic logistics planning.

In the proposed approach smart logistics management (Gumzej, 2021) is supported by semantic Web and online analytical processing (OLAP) technologies. They form a knowledge management system (KMS) based on a logistics knowledge base of experiences, expressed in controlled natural language (CNL). The underlying experiences address the different levels of supply chain management decisions – from strategic, over tactical to operational. They are also structured in way which distinguishes the main supply chain management concerns.

By the proposed approach, logistics knowledge-based engineering (KBE) can be conducted, based on an appropriately structured logistics knowledge base of supply chain improvement experiences.

In future research, a more elaborate example of a knowledge base of supply chain management experiences shall be constructed to provide a first reference point of supply chain management knowledge to practitioners, researchers and students. The main limitations of this research are the use of free and open-source software and the limited knowledge base available.

ACKNOWLEDGEMENT

This research has been supported in part by the Erasmus+ research project "Business Analytics Skills for the Future-proofs Supply Chains" (BAS4SC), project number 2022-1-PL01-KA220-HED-000088856.

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