

# ALGORITHM FOR OPTIMIZING TRUCK UTILIZATION USING RESIDUAL CAPACITIES

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## ABSTRACT

**Purpose:** Average truck utilization is only 50-55 percent based on distance travelled. Furthermore, 25 percent of current truck trips are empty runs. These facts lead to increased emissions, more traffic and a waste of time and financial resources. The aim of this paper is to develop an algorithm for logistics service providers to optimize truck capacity utilization and to increase supply chain resilience by identifying, visualizing, and optimizing routes with available residual capacity.

**Design/methodology/approach:** The development is focused on a logic able to identify tours from a transport network, in which open transport orders can be integrated optimally. Available residual capacities in trucks are calculated based on master data, initial loaded and already delivered orders. Additionally, the distances between the stations of the initial tours and the pick-up/delivery point of the open transport order are calculated and integrated optimally into the existing tours to minimize the total distances travelled and maximize the truck utilization.

**Findings:** The developed optimization algorithm creates transparency and resilience in supply chain networks by merging customer and freight forwarding data in real time. This results in an integrated route optimization that allocates residual capacities of currently executed truck transports with suitable open transport orders to avoid empty runs and increase truck utilization.

**Research limitations/implications (if applicable):** Future research includes integrating real-time data sources into the algorithm to make prescriptive decisions. In addition, a suitable decision support system for truck dispatching is to be developed.

**Practical implications (if applicable):** The algorithm is evaluated by applying it to the transport network of a freight forwarder. It is shown that a significant contribution to the optimization of truck utilization can be made.

**Originality/value:** The novelty of this contribution is that the developed algorithm combines already running and distributed trucks and their real-time utilization with open transport orders, thereby making optimal use of residual capacities of the already running trucks.

**Keywords:** residual capacities, truck utilization, optimization algorithm, forwarder

## Introduction

In recent years, companies in various industries have tried to cut costs by steadily reducing their storage capacity and relying on short-term deliveries. Therefore, the risk of supply chain ruptures increased. To counteract this, transport logistics and the associated planning of logistical distribution systems have moved into the centre of attention in supply chain planning again (Meier and Portmann, 2016; ten Hompel et al., 2020). With the increasing digitalization of modern logistics chains, the planning systems used to operational planning and scheduling are becoming more information-intensive and technology dependent. Depending on the scenario, companies need high transparency of deliveries for making decisions on short-term to increase the quality of their service level and reduce overall process costs. For this purpose, they are introducing supply chain event management (SCEM) systems (Heinbach et al., 2020; Feng et al., 2017). For these systems to work, the exchange of information between forwarders and shippers is a crucial factor. The current problem is that there are no harmonised interfaces and communication standards that shippers can use to transmit transport orders to their forwarder's dispatching system at short notice. As a result, the potential of data-driven value creation along the supply chain is not used comprehensively and forwarders have to use different systems, interfaces, and databases. In addition to the lack of linkage between existing

systems, the lack of process documentation and the insufficient transparency of the transport chain pose further problems. This is intensified by the fact that participating transport companies often do not want to make confidential and internal company data available. As a result, there is no or only weakly developed cooperation between forwarders and shippers, which is necessary for optimal utilization of transport capacities (Heinbach et al., 2020; Gansterer et al., 2020).

The resulting consequences are an average utilization of loaded trucks of only about 50 to 55 percent. Furthermore, 25 percent of the distance driven is made as empty runs. (Daudi and Thoben, 2020) This increases truck emissions, wasting time and financial resources (Schlott, 2017). Efficiently utilizing transportation assets while ensuring supply chain resilience is further complicated by the following issues (Allaoui et al., 2019; He et al., 2019):

- The number of short-term delivery orders for general cargo is rising continuously. The capacity utilization of the means of transport used for these orders is lower than for long-term delivery orders (Grazia Speranza, 2018).
- Means of transport are limited in terms of maximum transport volume and maximum transport weight. Heavy transport goods often do not use the available space, and large-volume transport goods do not use the available maximum weight (Rizet et al., 2012).
- The ability of combining transports is often not given due to time discrepancies between the receipt of goods and the dispatch of goods, which leads to empty runs. Sustainable and efficient return transports are rare in current transport networks. (Schulte et al., 2017).

This paper aims to develop a concept for logistics service providers to optimize truck capacity utilization and increase supply chain resilience by identifying, visualizing, and optimizing routes with available residual capacity of already dispatched trucks. This concept is to contribute to increase the use of residual truck capacities and to optimize the dispatching process of forwarders regarding time resources. Furthermore, emissions are to be reduced by reducing empty runs. A visualization of the results in a dashboard will be developed to serve dispatchers as a qualitative decision-support tool.

The following structure is chosen in this paper. The following chapter provides an overview of intelligent transport windows and their contribution to improving cooperation in transport networks. Based on this, the development of the concept is done in the steps of data preparation, matching algorithm, tour optimization, and visualization. The validation of the results is carried out in a case study with an Austrian freight forwarder. Finally, the results are concluded, and an outlook for future research is given.

### **Collaboration through Smart Transport Windows**

Due to the increasing pressure to act economically and ecologically, the need for efficient use of available transport capacities is steadily growing. This challenge is to be achieved through improved cooperation and the sharing of resources. An example of this kind of collaboration in logistics is a group of freight forwarders who exchange transport requests (Gansterer et al., 2020; Daudi and Thoben, 2020).

By collaborating and sharing resources, the goal is to reduce truck idle time, logistics costs, and harmful greenhouse gas emissions. In addition, the utilization of all logistics assets is to be improved. Freight forwarding cooperations are usually realized via online portals and auction-based bilateral exchange systems. Matching cargo information with truck information is the key to establishing logistics information-sharing platforms (Feng and Cheng, 2021; Gansterer et al., 2020; Daudi and Thoben, 2020). Smart transport windows represent one possibility for implementing this approach. With them internal and external data of the carriers are to be combined uniformly using a central cloud platform with a collaborative, data-driven transport management model (Heinbach et al., 2020).

In current smart transport windows, weaknesses like incomprehensive tour optimization appear. In most cases, there is no possibility to optimally integrate and visualize the loading and unloading locations of the cargo into existing transport tours (Wang et al., 2021). Selecting the best-fitting transport with the corresponding remaining capacities within a transport network to increase truck utilization is necessary (Park et al., 2021; Aloui et al., 2021).

### **Developed Concept**

In order to close the research gap regarding the automatic dispatching of short-term transport orders in the current state of the art, this chapter describes a developed concept that optimally integrates short-term transport orders into already dispatched truck tours by using their residual capacities. To this end, the requirements for a successful tour allocation and optimization are first defined:

- **Dispatching data:** The dispatching data must include the date and the pick-up and delivery addresses of the current tour as well as the available loading space capacities in terms of area (m<sup>2</sup>), volume (m<sup>3</sup>) and weight (kg) at each station of the tour.
- **Cargo data:** New transport orders must contain information about the dimensions of the cargo in terms of length (m), width (m) and height (m) as well as the weight (kg). In addition, the exact addresses of the loading and unloading points and information on the desired pick-up and delivery date of the cargo are required.
- **Order confirmation:** As soon as a shipper feeds the data of new loads into the software, its contact details are to be displayed in the dashboard, including telephone number and e-mail address. The forwarder can thus contact the shipper and let him know whether he accepts the order.
- **Tour optimization:** For tour optimization, a developed algorithm must select the optimal route based on the truck and cargo data. Both the required loading space capacities and the distance to the location of the cargo are to be taken into account. Together with the loading and unloading points of the cargo of the new transport order, the tour is then to be optimized so that all stations are approached in the optimal order and the total distance is minimised.
- **Visualization:** The final visualization of the results must be structured in such a way that important information is immediately recognisable. The routes of the respective truck tours and the individual stations must be clearly recognisable on the map. Furthermore, the loading and unloading points of the new transport order must be clearly distinguished from other stations so that any arising detours are clearly visible.

Based on these requirements, the procedure of the concept is shown in Figure 1. First, the relevant data of the forwarder is prepared so that it can be passed to a matching algorithm without further processing. Then, the optimal tour for picking up additional loads is determined and passed on to the tour optimization process. For these steps, Alteryx Designer [1] is used. Finally, the visualization of results is done with Tableau Desktop [2] to support the decision-making of dispatchers. These steps are explained in the following subchapters.

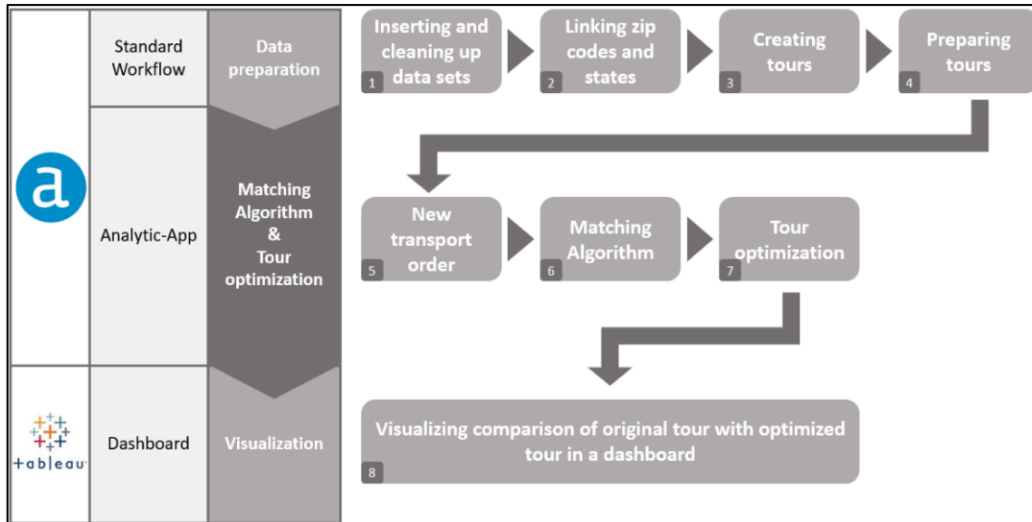


Figure 1: Procedure of the developed concept

## Data Preparation

The task of data preparation is to integrate the raw data of the forwarder into the algorithm. Furthermore, this data has to be prepared to provide the matching algorithm and tour optimization with all the information needed about the currently dispatched tours. To fulfil these tasks, data preparation consists of four steps according to Figure 1:

- Inserting and cleaning up data sets
- Linking zip codes and states
- Creating tours
- Preparing tours

First, all open and already scheduled transport orders are read in from the forwarder's master data. These data are provided with unique postal codes, city, and state designations. This step is necessary for the subsequent geocoding. Incomplete data records are cleaned up. The remaining data records are grouped according to their delivery relations and day. Afterwards, the transport orders are assigned to occurring tours. In addition, the individual stations of the respective tours are determined, and their recipient addresses are geocoded. Subsequently, the prepared data records are passed to a batch macro to solve the traveling salesman problem. The casaGeoTSP-Tool [3] is used to determine an optimal tour sequence according to the minimum distance travelled for the entire tour. Furthermore, the deliveries are grouped according to the addresses, and the loads of the respective stations are added. Thus, the available free space, volume, and weight capacity are calculated for each station, considering the tour sequence. Based on these steps discussed, all necessary information for the matching algorithm and the tour optimization could be inserted and prepared.

## Matching Algorithm and Tour Optimization

The matching algorithm and tour optimization consist of three steps as shown in Figure 1:

- New transport order
- Matching algorithm
- Tour optimization

A graphical user interface has been created for dispatching new transport orders. This interface is used for entering transport logistic key data by the shipper. Specifically, general contact details, the pickup and delivery address, and freight metrics such as weight, dimension, and load carrier are submitted through this interface.

Subsequently, this new input data is integrated into a matching algorithm. First, the pickup and delivery addresses are geocoded to capture the latitude and longitude coordinates. The freight parameters desired pickup and delivery date, required weight, volume, and space requirements are linked to these coordinates. The actual and already prepared tours of the forwarder are then transferred from the data preparation. This tour data is then compared with the new transport order to evaluate the optimal route for this transport order. This matching procedure is based on the following restrictions to identify the optimal tour, which have to be fulfilled by at least one station  $i$  for pick up and at least one station  $j$  for delivery of a truck tour  $k$  of the forwarders transport network:

- (1)  $DIS_{\overline{P}U_i} \leq FWD \ \wedge \ DIS_{\overline{D}j} \leq FWD$
- (2)  $TO_{DD} \geq TO_{PUD} = TD_k$
- (3)  $TO_V \leq AV_i \ \wedge \ TO_F \leq AF_i \ \wedge \ TO_W \leq AW_i$
- (4)  $S_j > S_i$

$DIS_{\overline{P}U_i}$	Driving Distance between pick up point of transport order and station $i$ of tour $k$ in km
$DIS_{\overline{D}j}$	Driving Distance between delivery point of transport order and station $j$ of tour $k$ in km
$FWD$	Forwarder's threshold of maximal permitted driving distance from Pick up point to $i$ or delivery point to $j$ of tour $k$ in km
$TO_{PUD}$	Pick up date and time of transport order
$TO_{DD}$	Delivery date and time of transport order
$TD_k$	Execution date and time of tour $k$
$TO_V$	Volume of transport order in $m^3$
$TO_F$	Floor area of transport order $m^2$
$TO_W$	Weight of transport order kg
$AV_i$	Available volume at station $i$ of tour $k$ in $m^3$
$AF_i$	Available floor area at station $i$ of tour $k$ in $m^2$
$AW_i$	Available weight at station $i$ of tour $k$ in kg
$S_i$	Sequence number of station $i$ of tour $k$
$S_j$	Sequence number of station $j$ of tour $k$

Based on these constraints the optimal tour for the new transport order is selected. In case of more than one possible tour, the tour with the lowest Distances to pick up and delivery points is chosen. The next step is to optimally integrate the loading and unloading points into the existing tour to minimize the transport distance on the entire tour. This is done with the casaGeoTSP-Tool [3] considering additionally the restrictions defined above. The results of this tour optimization are passed on to the subsequent visualization of the results. The entire implementation of the described algorithm is done via an Analytic App in Alteryx Designer [1].

## Visualization

Finally, the visualization of the tours is provided to the forwarder in a Tableau [3] dashboard. Its structure is shown in Figure 2. The original tour selected by the matching algorithm to include additional loads is plotted left. The optimized tour with integrated new loading and unloading locations is visualized in the right plot. In addition, the locations to be approached are shown in coloured legends. In the upper bar, the contact details of the shipper are displayed. This information supports the dispatcher to accept or reject the order and to contact the shipper.

## Case Study

The developed algorithm was applied in a nationally operating, medium-sized, Austrian freight forwarding company. The company's core business is less than truckload and full truckload transports. Due to the challenging competitive situation and the increasing pressure to achieve sustainability goals, the company is increasingly facing challenges in truck distribution:

- (1) **Lack of transparency** - The dispatching software does not automatically display free capacities and the routes and tour sequence of the tours already dispatched.
- (2) **Lack of data interface** - Dispatchers take pick-up orders by phone and must manually transfer the information into the dispatching software.
- (3) **Incorrect and time-consuming creation of tours** - Short-term orders are processed manually, which leads to errors in scheduling. Often the optimal tour is not selected from the transport network, and the new stations are not optimally inserted into the existing tour sequence.

To eliminate these challenges, the developed concept and the associated dashboard will be evaluated as a decision-support tool in the company. To this end, limitations of the scope of the case study should be noted. The scope of the evaluation was limited to one depot of the forwarding company. The Austrian regions Vienna, Lower Austria, and northern Burgenland are supplied from this depot. The validation is based on anonymized customer data in which a shipper requests the transport of goods.

### **Application of the Concept**

During data preparation, the transport orders for the current and the next two days are inserted into the system. After data cleaning, the needed zip codes and states are added to the data sets. The data preparation is completed by creating and preparing the current transport routes. Then, the creation of new transport orders is carried out. The validation is based on three new transport orders. These are summarized in Table 1. The data of each order consists of a loading and an unloading location, the weight of the freight, the needed space, and volume. Based on this information, the matching algorithm selects the optimal tour of the forwarder's transport network.

<b>Transport order</b>	<b>Loading location</b>	<b>Unloading location</b>	<b>Weight [kg]</b>	<b>Floor area [m<sup>2</sup>]</b>	<b>Volume [m<sup>3</sup>]</b>
1	A	B	6,000	10	10
2	C	D	5,000	8	10
3	C	E	2,000	2.5	2.5

Table 1: Transport orders of the case study

Then, the loading and unloading locations of the transport order must be integrated into the existing tour. This procedure includes meeting the previously defined boundary conditions. Therefore, this paper will focus on transport order 2 from Table 1. For this order, a delivery route in the form of a ring structure has been selected as the optimal transport route by the matching algorithm based on formula 1. The details of this route in terms of the order of the delivery stations, the available weight, the floor area, the volume, the distance to the next station and the utilization rate for each station are shown in Table 2.

<b>Station</b>	<b>Free weight [kg]</b>	<b>Free floor area [m<sup>2</sup>]</b>	<b>Free volume [m<sup>3</sup>]</b>	<b>Distance to next station [km]</b>	<b>Utilization rate in regard to the free floor area [%]</b>
0	4,313	7.42	32.62	40.5	66.3
1	4,621	9.18	33.03	2.9	58.3
2	4,701	10.89	35.57	12.7	50.5

3	4,861	12.33	36.63	10.6	44
4	5,011	13.29	37.40	11	39.5
5	5,361	13.78	38.20	12.8	37.4
6	7,376	19.60	42.44	7.1	10.9
7	7,946	21.04	43.20	18	4.4
8	8,000	22.00	45.00	57	0

Table 2: Information about the original transport tour

Subsequently, the free capacities are analysed regarding the available weight, space, and volume requirements. In this specific case, the route optimization shows that sufficient free capacities are available from station 4 and that the loading point of the transport order can be approached. In the second step, the loading and unloading locations are optimally integrated into the existing route regarding distances covered. In the concrete use case of transport order 2, the pick-up station is approached after station 5. The delivery station of transport order 2 is situated as the last station to guarantee minimum distances. Figure 2 shows the visualization of the results of this use case using the developed dashboard. The left plot shows the original tour. The right plot shows the optimized tour with the loading point (green ring) and unloading point (red ring).

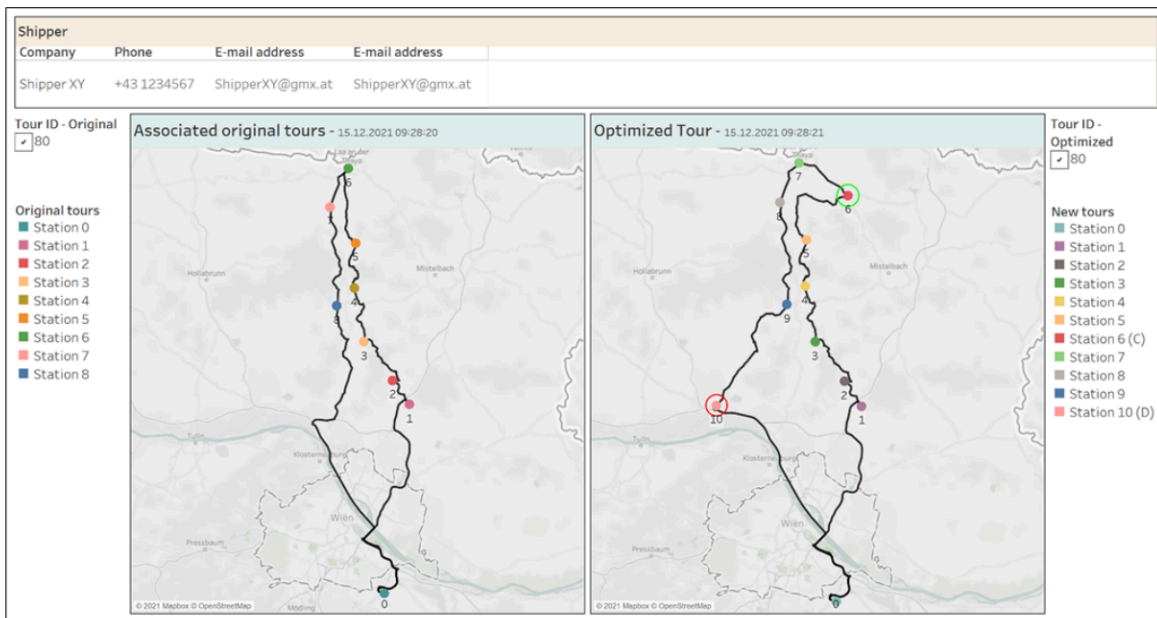


Figure 2: Comparison of the optimized tour (right) with the original tour (left)

The details of the optimized route in terms of the order of the delivery stations, the available weight, the floor area, the volume, the distance to the next station and the utilization rate for each station are shown in Table 3.

Station	Free weight [kg]	Free floor area [m <sup>2</sup> ]	Free volume [m <sup>3</sup> ]	Distance to next station [km]	Utilisation rate in regard to the free floor area [%]
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5	5,361	13.78	38.20	14.4	37.4
6	361	5.78	28.2	10	73.7
7	2,376	11.60	32.44	7.1	47.3
8	2,946	13.04	33.20	18	40.7
9	3,000	14.00	35.00	22.3	36.4
10	8,000	22.00	45.00	41	0

Table 3: Information about the optimized transport tour

According to table 2 and 3 for this specific tour, the application of the developed concept increased the weighted utilization rate according to formula 1 of the truck by 21,2% (6,2 pp.) compared to the original tour.

$$\text{Weighted utilization rate} [\%] = \frac{\sum_{i=0}^n U_i * D_i}{\sum_{i=0}^n D_i}$$

$U_i$  Utilization rate for each station [%]

$D_i$  Distance to the next station for each station [km]

Formula 1: Weighted utilization rate

## Results and Discussion

The results of the application of the developed concept and the visualization of its results in a dashboard are positive for the user. The automatic creation and correct mapping of the tours increased the transparency of the transport network. Furthermore, the determination of the optimal route sequence was automated, and the time required for this was reduced by 15% in average compared to manual execution. Furthermore, the data acquisition could be simplified. After inputting the data into the user interface and starting the Analytic App, additional orders could be imported within just 5 seconds and suitable original tours could be selected and visualized. The dispatchers only have to contact the client as a final task.

The automatic integration of the loading and unloading points into the already existing tours after an order has been imported via the Analytic App was noted as a particularly positive impact. This means that the dispatchers no longer have to manually search for suitable tours that have enough free loading space capacity. Furthermore, the error rate when assigning orders to tours is reduced by 10%. Tours that were ideal for pick-up transport of a certain load, for example, were automatically displayed in the dashboard. The loads are thus no longer assigned to an additional or incorrect tour. In summary, the use of the dashboard provided a qualitative decision support tool that contributed to a significant increase in the utilization rate of the trucks by 13.4% (4.8pp) in average.

Furthermore, the automated allocation and optimization of existing truck tours avoided bottlenecks and increased the resilience of the transport network. Stacking capabilities and information on dangerous goods are not yet taken into account in this concept. Furthermore, it is assumed that shippers provide correct information on cargo data. Incorrect information or indiscreet cargo cubage leads to errors in the calculation of the matching algorithm and are considered as further limitations.

## **Conclusions**

For the optimal use of residual capacities, the matching of loads and free residual capacities by itself is not sufficient. Challenges such as the lack of transparency in the transport network, the poor integration of data, and the inefficient cooperation of the shipping industry require a more comprehensive solution.

The main contribution of this paper is a comprehensive concept for the optimised use of residual capacities by supporting dispatchers in the allocation of transport orders. In the course of this, an optimization algorithm was developed. This algorithm consists of four steps. The data preparation integrates the current tour data of the forwarder. After the shipper enters a new transport order, the matching algorithm analyses the tour data to identify the optimal tour for the new order. During tour optimisation, the order is integrated into the selected existing tour while minimising the total distance. Finally, the results are prepared graphically for the dispatcher.

The concept creates transparency and resilience in supply chain networks by merging customer and freight forwarding data. The novelty of this contribution is that the developed algorithm combines already dispatched trucks and their current utilization with open transport orders, thereby making optimal use of the residual capacities of trucks. This could also be confirmed in a case study with an Austrian forwarder.

Since qualitatively deficient or missing data often appear, the next step is to develop a sensor system for trucks to close these data gaps. In the future, the algorithm presented will access these real-time data to perform the calculation logic and route optimization discussed. In addition, the collection and integration of weather, traffic, and transport order data in real time will be integrated to increase the dynamics of the tour optimization. Text mining, web scraping, and social media analysis should be used for automatically extracting the relevant content of websites and social networks. Finally, this extended algorithm should be integrated into a suitable decision support system for truck dispatching.

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