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1. Introduction

This report forms part of the deliverables for Work Package 2 (WP2) of the ProSFeT project. The objective is to provide a summative overview of the literature on Decision Support Systems (DSS) being employed in the field of Sustainable Urban Logistics, as well as some preliminary findings from empirical work as part of the project.

Urban logistics remains inherently complex with conflicting objectives and externalities for different stakeholders. The literature suggests that most urban authorities still struggle to balance multi-stakeholder objectives and this often places limitations on the effectiveness of policy and operational outcomes (Ballantyne and Lindholm, 2014).

Decision support systems (DSS) can offer mechanisms and metrics that can provide useful basis for informed decision-making at an organisational level. They rely on an extensive use of operational research and data analytics techniques in order to predict and create scenario outcomes that can ease the decision-making process, provide comparisons of alternative courses of action and optimise a variety of objectives.

Although potentially positively impacting, the adoption, on a systematic basis, of Decision Support Systems in urban logistics practice has been limited, so far, by a variety of reasons. Indeed, despite an increasing number of advanced models and powerful algorithms presented in the literature for optimizing Urban Logistics, planning-oriented Decision Support Systems (DSSs) are seldom considered by private and public agents as software tools to be adopted for practical purposes. This is partly due to the fact that these models and methods rarely incorporate a multi-stakeholder perspective in their analysis, often resulting in centralised and hierarchical decision-making procedures that might be of little help in contexts where a more participatory approach is required. However, advancements in the scientific and technological development of DSSs, designed and implemented in strict cooperation with potential beneficiaries such as local authorities, transport planners and private sector logistics operators, have the potential to increase the adoption of innovative model-driven DSS approaches in real-world urban logistics.

The ProSFeT project is contributing towards addressing this challenge by evolving multi-stakeholder constructs to support the development of DSS tools that support transferability and integration across the European region.

This report highlights some critical gaps, potential outcomes and recommendations for improving sustainable urban logistics (SUL) initiatives at multi-city authority levels within the EU.

The review of the literature starts from building blocks of DSSs, such as: the adaptation of classical logistical decision-making problems to the urban context; the development of key performance indicators for evaluating logistical systems within multi-criteria decision-making frameworks; the promotion of integrated decision support tools for advancing the practical application of approaches developed in the academic literature to everyday scenarios.

It is important to emphasize that the current report does not aim to provide an extensive review of the literature on the topic (since several papers have been developed to this aim) but rather advancing some preliminary recommendations that will support the final deliverables for WP1, 2 and 4 of the ProSFeT project.

2. Emerging and Consolidated Themes

Within this section, a discussion of some of the themes currently being dealt with in the urban logistics literature is presented; in particular, this brief review will analyse typical activities within urban logistics that require the development of decision support systems.

2.1 Freight Movement Optimisation

Studies from this category seek to optimise goods movements between the consigner and consignee in SUL networks. Vehicle Routing Problems (VRPs) are the primary research area in this topic. VRP can be described as *"the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints"* (Laporte, 1992). Compared to traditional VRPs, urban logistics variants include further issues, such as the respect of traffic regulations, road congestion considerations, the modelling of road conditions, parking space, air pollution, noise, and emergencies (Ehmke et al., 2012). All these aspects contribute to a further increase in the computational complexity of considered problems.

Furthermore, Stakeholders' specific requirements can also result in new problems for city VRPs, such as ensuring optimal levels of profit to carriers or minimising nuisance levels for the citizenship (Kim et al., 2015). Table 1 below lists typical VRP types in urban environments, along with specific constraints.

VRP Types	Key Features
CVRP (Capacitated Vehicle Routing Problem)	Restrictions on vehicle loading capacities
Dial-a-Ride Problems (DARP)	Problems with dynamic demand, with application to freight movement
Distance-Constrained Capacitated Vehicle Routing Problem (DCVRP)	Restrictions on the maximum amount of travel miles for considered vehicles
Emissions Minimisation Vehicle Routing problem (EMVRP)	Restrictions on emission and pollution levels within certain areas
Vehicle Routing Problem with Time Windows (VRPTW)	Restictions on the fact that vehicles have to visit customers within a certain time frame

Table 1 – Vehicle Routing Problems and Key Features

2.2 Planning and Design

Papers in this category focus on the process to be followed in order to formulate reasonable overall plans for the implementation of sustainable urban logistics measures. Russo and Comi (2016) illustrate the complete planning process cycle, commencing from the ex-ante assessment of potential practices to be implemented and ending with the ex-post assessment of actual results.

Urban Logistics networks are very complex systems and include a plethora of factors to be taken into consideration during planning. As such, the design of the road capacity and logistical facilities should also incorporate the future freight demand and goods movement in the city, as well as the connection of the city freight transportation with the inter-city transportation to avoid the congestion (Dablanc, 2007). Also, when preparing delivery plans, all constraints (e.g. road accidents, traffic congestion, unexpected events) should be considered (Zeimpekis and Giaglis, 2006).

There is no standard methodology for analysing planning processes in the context of city logistics (Lindholm and Behrends, 2012). The *light transferability approach* is a popular method in the planning practice. This method consists of identifying and adapting good practices from successfully implemented urban logistics strategies to new scenarios. Such a method can reduce the cost and investment required at the planning stage; however, this method has a high failure rate, owing to the complexity of urban logistics networks (Timms, 2014): each city has its own characteristics, and solutions adopted in typical successful cases may not return the same results in other cases.

For example, from a sustainability point of view, the selection of the most suitable location for an urban consolidation centre (UCC) facility is one of the most complicated issues in the design of an urban logistics network. Urban population and the quantity of freight demand determine the size of the UCC; there are however, other factors such as the geographical characteristics of environment, land use costs, density of urban buildings, presence of public facilities, road sizes, traffic conditions, the distance to urban areas, and residents' reactions, all of which can significantly influence locational choices, all of which differ from city to city and inhibit the development of general purposes approaches (Tánczos and Rónai, 2000; Jaller et al., 2015).

2.3 Alternative delivery methods

Muñuzuri et al. (2010) Muñuzuri et al. (2013) and use trip generation models to simulate traffic congestion in Seville, showing that off-hours delivery can efficiently reduce pollution and congestion issues, as, in this way, freight flows are less affected by the high volume of traffic which characterises daytime operations. However, Silas et al. (2012) argue that off-hours delivery could significantly increase total delivery costs due to additional labour expense.

Meanwhile, night traffic will also lead to social issues, such as safety and noise problems (Sathaye et al., 2010). Holguín-Veras (2012) stress that in order to conduct off-hours operation, the attitude of nearby residents and employees, along with support from the government, have become the main factors influencing the profitability of delivery activities.

Muñuzuri et al. (2012) suggest using mini-hubs in the city centre to improve delivery activities and reduce total emissions. However, they identify barriers to this in the capability of mini-hubs in dealing with different goods categories. Furthermore, there may not be sufficient facilities to support the operation of mini-hubs in cities characterised by large historical centres. Li et al. (2014) propose using taxis for goods deliveries, using their spare capacity. They formulate the so-called *share-a-ride problem*, which is solved through a *greedy insertion algorithm*.

Wang and Zhou (2015) propose a resident-driven delivery model to replace the traditional *door-to-door* delivery method. In this model, carriers leave goods in a storage hub in the residential area, and customers collect the goods themselves. This model helps companies reduce costs and travel distance. However, they note that acceptance of this model is hugely variable, depending on residents' education background.

Another kind of research investigates the possibility of non-road delivery models. For example, in Amsterdam, deliveries by electric ships through the water canal networks significantly reduce waiting times and fuel consumption in the city (Van Duin et al., 2014).

Van Binsbergen and Bovy (2010) also propose the use of metro railways systems for goods deliveries; this has advantages in terms of capacity, fuel consumption and ground space occupation. However, some constraints do exist: a lack of support facilities and activities; the inflexibility of the routes; the difficulties in gaining the cooperation of delivery companies and underground operators. Similar studies have been developed for investigating the feasibility of usage of tram networks for freight purposes in urban environments (Arvidsson and Browne, 2013).

2.4 Alternative Vehicles

A substantive strand of literature has been looking at the usage of alternative vehicles for evaluating their impact on urban logistics operations, mainly developing cost considerations. Davis and Figliozzi (2013) focussed exclusively on Internal Combustion Engines (ICEs) and Battery Electric Vehicles (BEVs) delivery trucks operating in urban environments (focussing, specifically, on the last-mile scenario). They noted that electric trucks are the more expensive option for almost all cases but the possibility of rising energy costs and development of battery technology and subsequent reduction in costs would lead to a situation where electric trucks would be competitive in most cases. Wu et al. (2015) produced a probabilistic model to simulate the Total Cost of Ownership of both BEVs and ICE vehicles. Their findings show no distinction as to which is the most the cost-efficient. However, they could conclude that BEVs have a "good probability" of becoming the most cost-efficient for smaller vehicles operating at medium distances, characteristics typical of urban usage. Diao et al. (2016) constructed a cost model that took into consideration the "intangible costs of traffic policies" such as purchase restrictions or licensing laws. They also considered the economic effects of policy, subsidies, and taxes. They conclude that currently BEVs are uncompetitive even considering the current levels of national subsidy and that additional investment is necessary.

2.5 Urban Consolidation Centres (UDCs)

UCC projects encourage private companies to build shared distribution centres in the outskirts or industrial areas of a city. All participants share the facilities and equipment of the UCCs; here, goods are sorted and loaded onto smaller vehicles for last-mile delivery to customers. When well-orchestrated, this cooperating strategy could help participants to reduce operation costs, vehicle numbers, and travel distance (Battaia et al., 2014). At UCCs, careful planning should be undertaken in order to consolidate volumes and arrange the right types routes and schedules in order to reduce the negative environmental impact on the city (Olsson and Woxenius, 2014). The UCC model has performed well in some small-scale cooperative exploratory programmes (Jacyna, 2013). However, despite the fact that significant benefits can be achieved by using UDCs, not many private companies are willing to participate in these schemes. As many UCC projects are more aimed at solving environmental problems, this objective does not always match the core interests of private companies (Holguín-Veras and Sánchez-Díaz, 2016).

Results arising from real-world implementation show that distribution costs and travel miles can be successfully reduced by employing UCCs. UCCs are also used as a platform for testing new technologies for research and evaluation purposes, which leads to strong forward-looking features.

Marcucci and Danielis (2008) stress that UCCs can reduce truck traffic on urban roads through the common delivery model; this alleviates congestion in city centres. UCCs can provide advantages in terms of reducing the numbers of truck and vehicle journeys (Roca-Riu and Estrada, 2012). Furthermore, quality of life for residents is improved by the reduction of emissions and noise. As UCCs allow shorter distances in order to reach consumers, UCC can also be seen as a platform for employing Electric Vehicles for urban deliveries (Allen et al., 2014). Jacyna's (2013) study illustrates that the other significant results provided by UDC implementation are reductions in: traffic congestion in intercity movement; road infrastructure damages; transport congestion in city centres. However, Leonardi et al. (2014) illustrate that there is no sufficient quantifiable data related to the performance of UCC systems across these key indicators; this is a serious barrier to the evaluation of the performance of UCCs.

Van Duin et al. (2016) argue that success chances and financial performances of UCCs can be significantly improved when such facilities provide additional value-added logistical services.

It must be highlighted that, within free-market contexts, the adoption of UCCs is ultimately based on users' preferences and conflicting stakeholders pressures Browne et al. (2011); de Oliveira et al., (2012) and de Assis Correia et al. (2012) develop an adoption theory model in order to analyse the propensity of retailers to join UCC-schemes, which turns out to be a critical factor in the successful implementation of UCCs.

3. Methods

Several critical components of DSS frameworks that can be utilised for dealing with mentioned urban logistics decision-making problems can be identified. These include: indicators and constructs for the development of multi-criteria decision-making (MCDM) tools aimed at evaluating the performances of urban logistics systems; algorithms and procedures oriented to the solution of mentioned problems. The combination of these components determines the functionality and scope of the DSS application in sustainable urban logistics; this section of the report covers these two critical components.

3.1 Performance Evaluation and Multi-Criteria Decision-Making

Last-mile delivery activities account for significant proportions of Emissions and energy consumption deriving from distribution systems (Wygonik and Goodchild, 2014). The implications of this have resulted in increased focus on environmental indicators for measuring the performances of urban logistics systems from a sustainability point of view.

Environmental indicators (e.g. CO_2, NO_x, SO_x, fuel consumption, PM2.5, PM10) are part of the core indicators usually used to evaluate the performance of urban logistics. These indicators are deemed measureable, since they can be verifiable by documented relationships to vehicle travel miles, road conditions, traffic congestion. Different methods have been employed to evaluate utilise such indicators and conduct evaluation exercises, stemming on energy conservation and mathematical functionality models (Gonzalez-Feliu et al., 2012, Veličković et al., 2014; Yang et al., 2016).

These indicators, also referred to as environmental key performance indicators (KPIs) are utilised to track the influence of urban logistical systems on other phenomena (e.g., public health). For example, Lee et al.'s (2012) study selected levels of carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter as KPIs for keeping track of public health, comparing values across time before and after the implementation of a city logistics programme.

Table 2 below summarises indicators that have been utilised in the DSS literature in order to keep track of performances of urban logistics systems from a triple bottom line (3BL) perspective (Gonzalez-Feliu and Morana, 2014; Morana and Gonzalez-Feliu, 2015).

Economic Indicators (Cost, Quality, Punctuality)	
Distance Traveled	Investment costs
Average vehicle load factor	Operational costs
Warehouse load factor	Return on investment
Vehicle load path	Total travel time
Number of parcels at warehouses	Service rates
Number of delivery points	Delay rates
Number of collection points	Customer satisfaction rates
Environmental Indicators	
Greenhouse gas emission rates	Noise rates
Pollutant gas emission rates	Road occupancy rates
Solid particles emission rates	Reverse flows rates
Social Indicators	
Absenteeism rates	Employment creation rates
Stress management rates	Employment conversion rates
Users' acceptability	Training rates
Inhabitants satisfaction rates	City image improvement

Table 2 - Main indicators for evaluating the performance of Urban Logistics systems

From the table above, there is some sense of the potential conflicts that may arise in the prioritisation of indicators by relevant authorities. In some cases, indicators may have greater relevance for some stakeholders compared to others, e.g. parking decisions may conflict with acoustic preferences of particular groups, leading to resistance in some instances.

This conflict among indicators (and among multiple stakeholders involved) can make the decision making process for the implementation of sustainable urban logistics solutions (or for the evaluation of their performances) more complex; this has informed the deployment of MCDM tools to support decision making in the implementation of urban logistics solutions.

Multi-criteria Decision-Making (MCDM) methods are used to evaluate multiple conflicting criteria for either supporting or effecting a decision. They are effectively, problem solving tools and are often ranked based on ranking, rating, screening, and sorting problems.

Methodologies such as Fuzzy Set Theory, TOPSIS, Analytic Hierarchy Process, and Affinity Diagrams are commonly used to assess the performance of SUL initiatives. Awasthi et al. (2011) and Awasthi and Chauhan (2012) list the four steps for using MCDM methods in the context of SUL:

(i) identifying criteria for assessing the performance of urban logistics initiatives;

(ii) establishing a decision-making committee comprising of representatives of urban logistics stakeholders to select the criteria and viable alternatives;

(iii) providing a rating for all alternatives against selected criteria, and aggregating these ratings through the selected methodology;

(iv) performing a sensitivity analysis for evaluating the robustness of the results.

According to this framework, several authors have proposed the usage of different MCDM methods for dealing with the evaluation of SUL initiatives. Notably, Radoman and Tadić (2014) developed an approach that integrated AHP and TOPSIS methods for evaluating the performances of several logistics scenarios in order to serve a central business district in a European city. Tadić et al. (2014) integrate Fuzzy-AHP, DEMATEL and VIKOR approaches in order to evaluate several logistical options (decentralised road systems, centralised cargo tram systems, intermodal transport networks, and a unified freight systems with trams and electric vehicles) across three criteria further articulated in ten sub-criteria. Awasthi et al. (2016) merged a Fuzzy-BOCR (Benefit, Opportunities, Cost and Risk) analysis and a GRA (Grey Relational

Analysis) approach in order to select logistical partners in order to run a distribution facility in a urban context.

As well as the listed indicators, Janjevic et al. (2016) identify several critical success factors (number of UCCs, geographic location, size volume, fleet, regulations, market conditions, operational framework) as the main variables influencing performances of UDCs.

3.2 Modelling and Algorithmic Developments

Jacobsen and Madsen (1980) firstly define the delivery mode which uses a transfer station (transit point) between the sender and the receiver in the introduction to two-level routing-location problems. In mathematics, senders, receivers, and the transit point are represented through 'nodes', and the route between them is referred to as an 'edge' (Ahuja et al., 1993). The route between senders and the transfer station is defined as the primary route, and the following route between the transfer station and the receivers are secondary routes. As such, the principle of a two-tier city delivery network is to transfer goods from long-distance vehicles to smaller ones through mentioned Urban Consolidation Centres, increasing loading rates for both types of vehicles, and therefore reducing fuel consumption and emissions per parcel. It has to be mentioned that further enhancements to these frameworks have been developed. A similar two-tier framework is employed by Crainic and Sgalambro (2014). Hamidi et al. (2012) propose a three-tier VRP network, which adds another transfer point to the route between UDCs and consumers in order to reduce waiting times and congestion issues (Figure 1).

Within this context, a relevant number of papers focus on the development of algorithms and solution methodologies for mathematical models. Most of these developments deal with the above-mentioned routing problems in urban contexts.

For instance, Hemmelmayr et al. (2012) use an adaptive large neighbourhood search heuristic for dealing with a location routing problem (LRP) in a two-echelon city logistics system, in which location decisions need to be made about the location of distribution centres and distribution points. Van Duin et al. (2013) use a heuristic algorithm for solving the MILP formulation of the Fleet Size and Mix Vehicle Routing Problem (FSMVRP), which helps carriers to design routes that are compatible with maximum travel distances of electric vehicles.

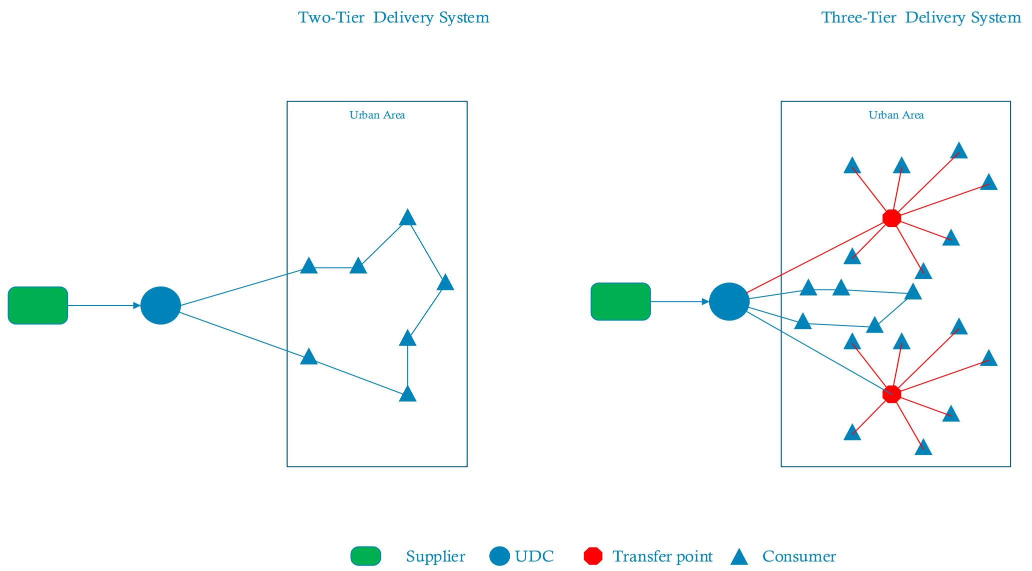

Figure **1** -Structure of UDC Networks

Cattaruzza et al. (2014) propose a hybrid genetic algorithm to resolve the multi-trip vehicle routing problem. Boschetti and Maniezzo (2015) use an extended set covering model (SCC) and a randomised constructive heuristic algorithm for the multi-trip vehicle routing problem with time windows. Breunig et al. (2016) propose a hybrid meta-heuristic to optimise the selections of intermediate facilities in a two-echelon system.

Besides the above approaches, MCDM tools can also be used for the optimisation of freight movement. Smirlis et al. (2012) develop a combination of Data Envelopment Analysis (DEA) and a Geographic Information System in order to select the best vehicle routing. The role of the DEA component is to transform the qualitative information into measurable quantitative data, when dealing with insufficient data input. Similarly, Wichapa and Khokhajaikiat (2017), combine fuzzy analytic hierarchy process and goal programming (FAHP-GP) for choosing a suitable new location for a reverse logistics facility in a urban context. The proposed method is a multi-objective facility location problem, which combines the. Priority weights for the candidate locations are generated by using FAHP, then feeding the input of the GP model in order to include additional criteria in the evaluation process. Such method is used in a case study to identify suitable locations for an infectious waste disposal facility in sub-Northeastern Thailand, considering simultaneously quantitative and qualitative factors.

3.3 Holistic Modelling Approaches

A few studies have been attempting to deal with whole-systems approaches to urban logistic challenges. These are mostly utilising Agent-Based Models (ABMs) methodologies, which have been experimented to investigate the configuration of priorities in urban logistics systems (Piotte and Jourquin, 2011).

A remarkable feature of ABM methodologies is their capability to simulate the impact of multiple objective dimensions such as private interventions in urban logistics planning, behavioural tendencies of groups, market factors, freight channel flows and performance of delivery channels between different agents in the system (Taniguchi et al., 2003; Baindur and Viegas, 2011; Boussier et al., 2011; Teo et al., 2014; Maggi and Vallino, 2016). Gatta and Marcucci (2014) developed an ABM framework representing different SUL stakeholders as autonomous agents; the objective of the framework is to optimise freight movement performance across a variety of dimensions (e.g., congestion, pollution, safety issues).

Despite the usefulness of ABMs in representing multi-objective and multi-stakeholder environments, such models face validation challenges as inconsistent output can limit the implementation of their recommendations in real world scenarios (Maggi and Vallino, 2016).

Similarly, Bouhana et al. (2015) build an intelligent decision-making system through a Case-Based Reasoning (CBR) approach. The information input of this model is based on semantic web rule languages. This system optimises delivery routing for the carriers, considering the different requirements (environmental impact, time windows) from several stakeholders simultaneously.

At a more conceptual level, Ambrosini et al. (2013) propose a method for policy scenario analysis in urban logistics.

4. Key Findings - A dichotomy between theory and practice

Alternative delivery modes, time-based strategies and urban consolidation centres are some of the main solutions being utilised by local authorities for addressing freight mobility challenges in urban spaces. Some of these solutions (such as UCCs) are becoming increasingly attractive options within Europe and one that is being embraced by local authorities across board. However, a significant drawback to the implementation of such solutions is represented by the high set-up costs and the subsequent operations priority assignments once running (Browne et al., 2005). Additionally, the implementation of urban logistics solutions can create stakeholders conflicts as carriers' operations might be significantly disrupted (Van Duin et al., 2016).

Given the relatively low success rate of urban logistics initiatives (for instance, UCCs) especially in mainland Europe, contemporary and future initiatives have to be based on careful planning, and on the usage of appropriate DSSs for maximising success rates.

The successful case studies suggest that these elements of implementation are critical and the successful application of appropriate decision support systems is crucial to the implementation. Unfortunately, at the moment, approaches developed in the academic literature (mainly tested on numerical examples or on ad-hoc case studies) exhibit a low degree of transferability to real-world situations; at the same time, the lack of general-purpose systems aimed at decision-aiding in the field of urban logistics means that local authorities need, in most of the cases, invest significant resources in the creation of ad-hoc tools that might not be reutilised for future projects. Also, such investments might be problematic in an era of austerity, cuts to public expenditure and limited budgets.

Based on initial conversations with public sector stakeholders involved in the ProSFeT project, it emerges that a critical area for impact would be the possibility of turning *common operational tools* (designed, for instance, for the management of existing systems, such as UCCs) into strategic decision support systems (that could be utilised also by other stakeholders in the industry).

In particular, scenario planning functionalities would be very useful in the phase of strategic design of urban logistics solutions.

As such, the development of core strategic tools that offer decision support beyond operational levels is critical to advancement in the field of sustainable urban logistics. Such strategy-based tools with capacity for scenario planning and optimal resource and stakeholder prioritisation can effectively move local authorities beyond the complexities of the many operations tools into single user friendly and optimal decision frameworks.

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