The Users' Perspective on Autonomous Driving
A Comparative Analysis of Partworth Utilities

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Abstract: Digitisation has brought a major upheaval to the mobility sector, and in the future, self-driving cars will probably be one of the transport modes. This study extends transport and user acceptance research by analysing in greater depth how the new modes of autonomous private cars, autonomous carsharing and autonomous taxis fit into the existing traffic mix from today's perspective. It focuses on accounting for relative added value. For this purpose, user preference theory was used as a base for an online survey (n=172) on the relative added value of the new autonomous traffic modes. Results show that users see advantages in the autonomous modes for driving comfort and time utilization whereas, in comparison to conventional cars, in many other areas – especially in terms of driving pleasure and control – they see no advantages or even relative disadvantages. Compared to public transport, the autonomous modes offer added values in almost all characteristics. This analysis at the partworth level provides a more detailed explanation for user acceptance of automated driving.

1 INTRODUCTION

Self-driving vehicles (SAE International, 2016) represent a technological leap forward that can offer solutions to current traffic problems and dramatically change the way people deal with mobility (Howard and Dai, 2014; Piccinini et al., 2016). For some years, fully automated vehicles have been tested in several pilot projects (Nordhoff, 2014). The leading automotive manufacturers and IT companies in the autonomous driving sector assume that full automation could be ready for series production within the next five to ten years. Experts expect driverless cars to reduce the number of accidents and traffic problems as well as improve the efficiency of traffic flow (Fagnant et al., 2015; Kyriakidis et al., 2015; Krueger et al., 2016). Automated driving technology will also create new, innovative business models such as vehicle-on-demand (Fagnant et al., 2015; Pakusch et al., 2016). Additionally, mobility services such as self-driving taxis or autonomous carsharing could especially benefit from the self-driving technology: lower personnel costs mean that driverless taxis can operate much cheaper (Fagnant et al., 2015), and fully automated carsharing promises improvements in availability as the car comes to the user instead of vice versa (Krueger et al., 2016). In this context, researchers see a strong convergence of taxi and carsharing (Pakusch et al., 2016). Various authors expect a significant reduction in the number of private cars through strengthening usage-based mobility services (Bunghez, 2015; Fagnant et al., 2015; Pakusch et al., 2016). To gain a better understanding of user acceptance and to be able to better predict future changes in mobility behavior due to new autonomous modes of transport, we performed a study that examines autonomous travel modes and compares them to existing modes on the basis of their respective characteristics.

2 THEORETICAL BACKGROUND

2.1 Travel Mode Choice

To satisfy the human need for mobility (Verplanken et al., 1994), various travel modes are available to the user. From the various alternatives, the user chooses the one that has a relative, often subjectively perceived advantage over the others and thus maximizes his or her personal benefit (McFadden, 2000). In addition to user-related and external influencing factors,

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product-related influencing variables play a major role. According to Lancaster (1966), it is not the product as a whole but its special characteristics that provide consumers with a benefit, the so-called partworth utilities. In the past, in addition to demographic, socio-economic, psychographic, geographical, and situational factors, a number of product-specific characteristics could be identified that influence travel mode choice. Those studies come to different conclusions regarding the ranking of those factors, but they show that travel time, travel costs, and reliability play a decisive role (Ponnuswamy and Anantharajan, 1993; Johansson et al., 2004; Ding and Zhang, 2016; Krueger et al., 2016). Further studies such as that by Steg (2003) have analyzed the characteristics of passenger cars and public transport as the most frequently used travel modes from a user's point of view. The ratings reflect the users' usage patterns by clearly showing that the car is rated better than public transport in many respects – e.g. in terms of convenience, independence, flexibility, flexibility, driving comfort, speed and reliability.

2.2 User Acceptance of Autonomous Vehicles

The transformative advantages of the self-driving technology can only be realized if the majority of users accept self-driving cars (Howard and Dai, 2014). Researchers have recently devoted themselves to the topic of user acceptance. Their studies show that most people have a positive attitude towards autonomic driving and can imagine buying and/or using autonomous cars (Payre et al., 2014; Rödel et al., 2014; Schoettle and Sivak, 2014). Thus, many respondents gave a positive opinion on the technology and had optimistic expectations of its benefits (Schoettle and Sivak, 2014). Users see added value in improved road safety, a more efficient traffic flow (Howard and Dai, 2014; Eimler and Geisler, 2015; Zmud et al., 2016), and the convenience of not having to find parking spaces and of better use of time while driving (Howard and Dai, 2014; Pakusch et al., 2016). At the top of the advantages' list, users can imagine autonomous driving for driving on the motorway, in traffic jams, and for automatic parking (Payre et al., 2014). At the same time, the studies report on respondents' concerns: they fear software hacking and abuse and are concerned about legal issues, security and reliability of technology (Schoettle and Sivak, 2014; Kyriakidis et al., 2015). Many respondents think that humans are the better driver (Eimler and Geisler, 2015) and are afraid of handing over control to technology (Howard and Dai, 2014). From the users' point of view, the high acquisition and operating costs (Howard and Dai, 2014; Eimler and Geisler, 2015) one expects from autonomous vehicles and the loss of driving pleasure associated with eliminating the driving task (Nordhoff, 2014; Eimler and Geisler, 2015) speak against their use.

Since new modes of transport such as autonomous private cars, autonomous taxis or autonomous carsharing could extend the options for choosing a travel mode, the question arises as to which travel mode users prefer and how this choice will change mobility behaviour as a whole. Although there are many acceptance studies on autonomous driving, these studies generally view the autonomous car in isolation. To our knowledge, transport mode selection analyses have so far neither included the new modes nor compared these with existing modes of transport. In a previous complete pair comparison study, we have therefore allowed users to choose between the current traffic modes car, public transport, carsharing and the new modes autonomous car and autonomous carsharing (Pakusch et al., 2018). The results showed that, from a user's perspective, the autonomous modes of transport are significantly better than public transport, while they are almost identical or worse than conventional passenger cars. However, the question remained as to what exactly was the reason for the participants' choices – in which factors they see relative advantages or disadvantages of the respective modes of transport. Therefore, this follow-up study analyses the partworth utilities to obtain more precise information on the composition of user acceptance. The central research questions are

1. *How does the decision in favour of or against a travel mode relate to the relative overall benefit?*
2. *What relative partworth utilities do automated travel modes offer?*

3 METHODOLOGY

A two-stage survey was conducted to answer the research questions carried out in Germany. In a qualitative preliminary study, the criteria identified in the literature with regard to their relevance for the new modes of transport were verified and adapted. To this end, ten qualitative interviews were conducted in which the interviewees were asked to assign characteristics to both traditional and new modes of transport and to explain their relevance. Based on this preliminary study, a quantitative questionnaire was created.

The questionnaire began with a comparison of the

traditional car with the autonomous private car, the autonomous carsharing and the autonomous taxi. The participants were asked to identify advantages and disadvantages of the new modes in relation to the conventional car with respect to 13 characteristics: driving time, waiting time, availability, flexibility, driving pleasure, driving comfort, ease of use, control of the vehicle, safety, transport of objects, reliability, costs and time utilization. Similarly, public transport was compared with autonomous travel modes. Subsequently, respondents should indicate which travel mode they would use or own regularly in the future. Traditional and automated travel modes were available. Finally, demographic data and information on current mobility behaviour were collected.

A total of 172 people took part in the survey, 49% of whom were female. The age range was 17 to 79 years (average 35.6). 64.7% lived (rather) urban, the other 35.3% (rather) rural. Almost all participants (95%) had a driving licence and 80% owned a car. Of those surveyed, 71% were employed, 26% were pupils or students and 3% were retired. About 63% of respondents used the car as their main travel mode and 20% used public transport.

4 FINDINGS AND DISCUSSION

4.1 Relative Partworth Utilities Compared to Private Passenger Cars

Figure 1 shows the participants' subjective evaluation of the individual partial utility utilities. From the respondents' perspectives, the automated modes only have advantages over traditional cars in terms of driving comfort and the use of time during driving. In all other characteristics, the participants saw minor advantages for the traditional car in terms of driving pleasure and control. With an (unweighted) average of -0.28 for the autonomous car, -0.52 for autonomous carsharing and-0.49 for autonomous taxis, the direct comparison showed the relative advantage of traditional cars in each case: users would be expected to go for those when having the choice.

In the following, we investigate in more detail some of the prominent characteristics and reflect on why the participants came to their assessments.

Autonomous vehicles offer greater driving comfort and greater time saving than traditional cars. Both benefits are closely linked. Driving comfort is a multidimensional construct under which almost every user understands something different (Gorr, 1997). It includes coziness, comfort, and psychological hygiene. These characteristics are judged negatively if a travel mode must be shared with many others (external people) (especially public transport; Knapp, 2015). Autonomous modes of transport offer not only the private space and comfort of a private car but also the advantages of public transport.

Figure 1: Comparative assessment of autonomous travel modes and the conventional car. (n=172, confidence interval = 95%).

The use of time while driving a traditional car is limited to passive activities such as listening to the radio or making telephone calls. Because the driving task is eliminated, self-driving technology makes it possible to make better use of time in the car (Cyganski et al., 2015). This levels off one of the advantages of public transport because the driver becomes a passenger (Pakusch and Bossauer, 2017). For this reason, the attested added value in the use of time for the autonomous car is in line with expectations.

However, it is surprising that the partial benefits of time utilization for autonomous carsharing and taxis are not as high as for autonomous cars. One explanation could be that the private car seems to be more individualizable so that the time can be used more effectively than e.g. in a non-private taxi.

In terms of driving pleasure and control, the traditional car offers significant relative added value over autonomous modes of transport. This result confirms the results of studies such as those by Nordhoff (2014) or Eimler and Geisler (2015), which show that some respondents fear that automating the car will reduce driving pleasure. Driving pleasure for the user arises from the satisfaction of a personal desire for nerve-racking thrills by risky driving styles when actively driving a vehicle. Due to the necessity of active control, the car does indeed offer users a higher potential for much more driving pleasure than modes where the user does not actively control. The survey confirms this assessment: The participants see a clear added value for driving pleasure in the classic car compared to all driverless modes. Active steering is closely linked to control over the vehicle, which also encompasses the entire physical and organizational power over a travel mode and is of great importance to users (Howard and Dai, 2014; Eimler and Geisler, 2015).

Waiting time, reliability, availability and flexibility are disadvantageous in all autonomous modes compared to the classic car but more so in autonomous vehicle-on-demand services. In the case of autonomous carsharing and taxis, the waiting time is evaluated significantly worse than in the case of car variants. This result is not surprising since, from the moment a user is ready to drive and places an order for autonomous taxi/carsharing, a waiting time can arise until the actual start of the journey if the vehicle has to reach the passenger's location.

The neutral evaluation of the waiting time for the autonomous private car was to be expected. However, an explanation is required as to why the assessment of flexibility/independence and availability is significantly lower for the autonomous version of the car than for the traditional one. Here, the criteria also seem to depend on reliability. The poor evaluation of reliability can probably be attributed to the novelty of the technology that users are still inexperienced with and in which they do not yet trust. Participants in previous studies expressed concerns that the technology could fail (Schoettle and Sivak, 2014; Kyriakidis et al., 2015). These concerns would explain why it is believed that autonomous cars are not equally available and flexible in every situation.

Model simulations assume that data-driven control, automatic relocation and automatic retrieval greatly increase the availability, especially compared to today's carsharing, so that the user has to wait on average less than one minute (Fagnant et al., 2015). Users usually lack such knowledge and thus apparently lack the confidence that quick availability can be guaranteed (e.g. if vehicles are occupied or not in the immediate vicinity), so that the rating is lower than with their own cars. The private car on the doorstep creates a feeling of flexibility and independence, which apparently cannot be achieved in the same way by a mobility service provider – even with full automation. The flexibility also includes free and autonomous time and route planning. The fully automated system actually makes the car even more flexible since autonomous cars can, for example, pick up users directly in front of the door, drop them off at their destination, and then park on their own. However, the survey shows that the traditional car is rated better. One explanation is that flexibility/independence does not only include flexible time and route planning, but also, from the user's point of view, physical control of the vehicle and freedom over driving style and spontaneous decisions (sudden stop or change of direction). Here, the fear that autonomous technology may limit users in their own (ad-hoc) decisions may play a role. Thus, the perceived loss of control (see above) also has a negative effect on independence and flexibility.

In terms of costs, respondents also saw a disadvantage – especially in private autonomous cars. In contrast to the use-based modes, the latter would not only incur usage-dependent variable costs but also fixed costs of ownership. In addition, users also expect higher start-up costs due to the self-driving technology as well as higher operating costs due to the additional technology, which may cause new faults and require more maintenance (Howard and Dai, 2014; Eimler and Geisler 2015).

Due to the fully-automated system, there are improvements especially in carsharing, if the user does not have to carry the luggage to the pick-up station. Although it could be assumed that the transport with similar fully automated vehicles, which always pick up the user at the front door, is equally possible, the interviewees still saw a slight advantage in the classic car. Here, it can only be assumed that users prefer to transport things in their own vehicle or, in particular, rate the services less highly, as they transfer their current image of taxi and carsharing to the automated modes. There were no significant differences between the driving time, ease of use and safety criteria. From an objective point of view, the criterion ease of use requires an explanation since driving a car today is

currently one of the most complex and dangerous cultural skills. Autonomous driving frees the user from this complex task so that, for example, children, the elderly and the disabled can use an autonomous car on their own. However, as almost 95% of the respondents have a driving license, this complexity no longer seems to be decisive once vehicle control has become routine. Rather, users fear that they will have to learn new usage techniques. Although studies of fully-automated vehicles predict a higher safety than for the classic car (Howard and Dai, 2014; Eimler and Geisler, 2015), users are skeptical, have little confidence and often consider themselves to be the better driver than a machine (Eimler and Geisler, 2015). These two contradictory arguments lead to a neutral evaluation in total - this is also supported by the consistently high dispersion in the respondents' response behavior (standard deviation 1.14 to 1.28).

Overall, it can be seen that the autonomous modes of transport have (subjectively perceived) relative disadvantages in almost all characteristics compared to classic passenger cars. Only the driving comfort and the use of time during the journey are considered to be much more positive for autonomic vehicles than for classic cars.

4.2 Relative Partworth Values Compared to Public Transport

When comparing the profile lines (Figures 1 and 2) it is noticeable that the relative added value of the fully automated modes compared to traditional passenger cars is much lower than when the comparison is between fully automatic modes and public transport. While many aspects of the new autonomous travel modes are seen as worse or equivalent to conventional cars, the opposite is true for public transport. This confirms the results of our preliminary study, which showed that users would prefer autonomous modes of transport over public transport but not over today's private car (Pakusch et al. 2018).

Compared to public transport, all three autonomous modes offer a significant relative advantage (of +0.68 for the autonomous car, +0.26 for autonomous carsharing, and +0.38 for autonomous taxis. As Figure 2 shows not only does the autonomous private car perform better in almost every aspect but the autonomous mobility services taxi and carsharing also do except for costs, ease of use (only for carsharing), and time use (for autonomous cars). In all other areas, respondents consistently attest the benefits of autonomous modes. In this context, due to its access at any time, the private autonomous passenger car again outperforms autonomous mobility services as expected

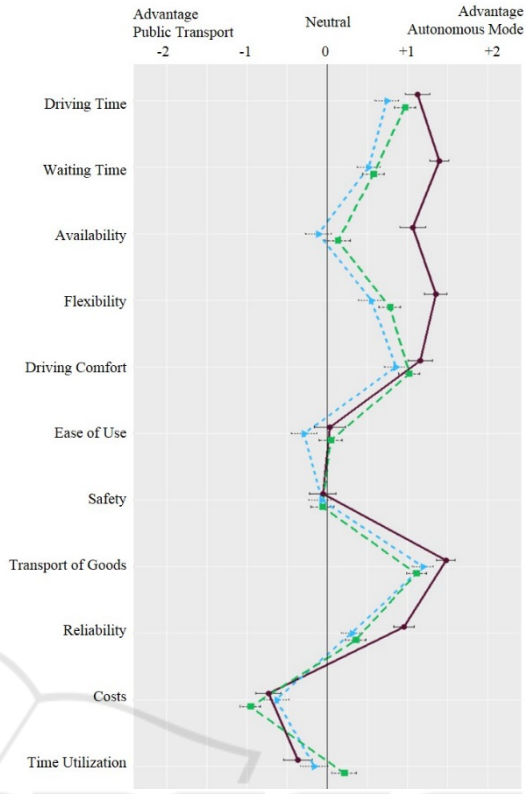

Figure 2: Comparative assessment of autonomous travel modes and public transport.
(n=172, confidence interval = 95%).

in the criteria of waiting time, reliability, availability and flexibility.

4.3 Intention to Use Future Travel Modes

The answer to the question as to which mode of transport the respondents could envisage owning or using regularly in the future shows that private cars will continue to occupy a central position. Almost 90% of the respondents (very) likely would continue using private cars, followed by public transport with about 65%. It is only after these two conventional modes that the autonomous car (37.5%) follows before the classic taxi (27.4%), the autonomous taxi (22%), the autonomous carsharing (16.7%) and the classic carsharing (14.3%). Carsharing is also rejected most strongly – respondents cannot imagine using either the conventional (65.5%) or the autonomous (63.1%) variant in the future.

Although the automation of the car can objectively be expected to bring much added value compared to the conventional car – even more so than to public transport (Howard and Dai, 2014; Pakusch et

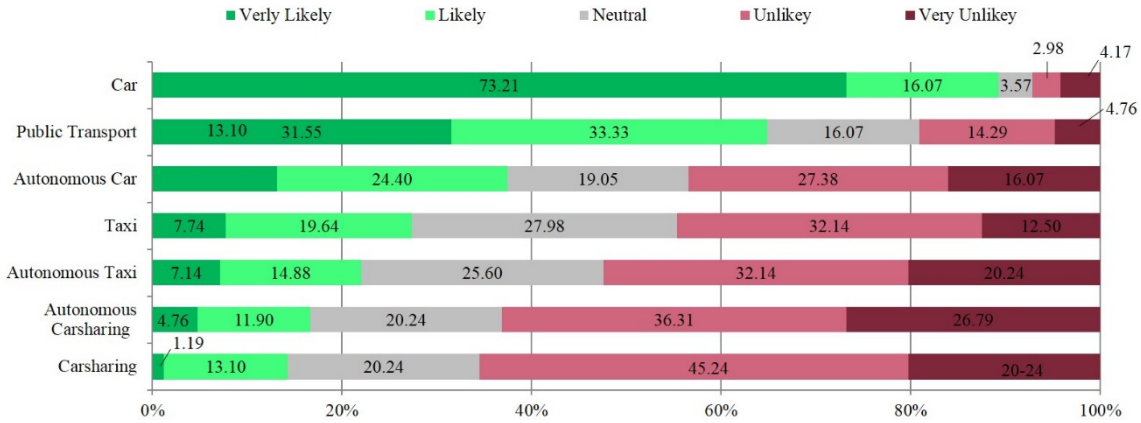

Figure 3: Intention to use/own a travel mode regularly in the future.

al., 2016; 2018) – the participants preferred the traditional travel modes, i.e. passenger car and public transport.

Against the background of the partworth utilities of the conventional car in comparison to the autonomous modes (cf 4.1), it is only reasonable that the private car is assigned the highest intention to use. However, the fact that the intention to use public transport in the future is higher than the intention to use autonomous modes of transport cannot be deduced from the partworth analysis in Section 4.2. After analyzing the partworth values, it would have been expected that the many relative advantages of the autonomous modes would have led to them being given preference over public transport. A high relative advantage – as in the case of those autonomous modes compared to public transportation – of an innovation or alternative product increases the probability of a takeover (Rogers, 2003). However, Figure 3 shows that this is not the case. One explanation is that, for public transport users, costs are a central aspect. Furthermore, this contradiction points to the fact that not all relevant factors have been included in the survey, such as the factor of environmental friendliness or other non-product-related properties such as user-related (custom and mobility socialization (Steg, 2005)) and external influencing factors (Rogers, 2003). The importance of experience and routines in this context particularly points out that the perceived advantage will only slowly assert itself in practice - but in principle there will be latent, serious competition to public transport with the autonomous mobility services.

In the taxi sector, too, respondents placed their trust in the already familiar conventional version; in these fully automatic travel modes, skepticism about innovations and safety prevails over the supposed added value of automation by making use of familiar features. Only when it comes to carsharing could respondents imagine using the autonomous variant rather than the conventional variant. This finding is in line with a previous study (Pakusch et al., 2018). In this mode of transport, the advantages associated with automation (particularly to be picked up and driven instead of having to search for the vehicle) outweigh the disadvantages (uncertainty, complexity of new technology, appropriation). The change in carsharing through automation was thus perceived by the interviewees as greater and more positive than in the case of cars. The evaluation also shows that the traffic modes taxi and carsharing are converging due to the self-driving technology, as predicted by Fagnant et al., (2015) and Krueger et al., (2016) for example.

4.4 Interrelation between Partworth Utilities and Intention to Use

The proponents of autonomous driving rated the autonomous car in all characteristics as being more advantageous compared to the traditional car than the skeptics did. We call those users proponents who could imagine using an autonomous car regularly in the future (Figure 3: regular use is (very) likely) and those skeptics who cannot imagine using an autonomous car regularly in the future (regular use is (very) unlikely). It is not clear in which direction the interdependence works. The proponents could have a generally positive attitude towards autonomous vehicles and assess the partworth benefits accordingly positively. Alternatively (according to the order in which they appear in the survey) they could see relative advantages in the individual characteristics, which consequently lead to their intention to use the future travel modes. In particular, the partworth utilities of waiting time, availability and flexibility are rated higher. There was also a significant difference in driving comfort. This evaluation clearly shows that the

proponents are much more open to the new modes and anticipate the advantages of the self-driving technology. There are not only significant differences in the characteristics of driving time, ease of use, safety, and the transport of goods; while here skeptics see the relative advantage of conventional cars, proponents consider the autonomous car to be generally advantageous.

Figure 4: Partworth assessment of proponents and skeptics in comparing conventional and autonomous car. (n=172, confidence interval = 95%).

4.5 Convergence of Taxi and Carsharing

Although the evaluation of the individual characteristics of the autonomous taxi and the autonomous carsharing indicates a convergence of the two modes, individual partworth utilitiy differences show that users still see differences between the two modes. Overall, there was a slight preference for the autonomous taxi. There are two reasons for this. First, users tend to prefer a well-known alternative. The carsharing business model is generally less well known than the taxi business model. Second, users prefer non-binding offers. In this respect, the two concepts differ in that one makes a regular and longer-term commitment (membership) for the use of carsharing while with a taxi one pays only for the actual use. This insight should be taken into account by practitioners when designing autonomous mobility services.

5 LIMITATIONS

A limit to this study is that the sample is not representative nor can any claim be made to completeness with regard to the selected product characteristics. Other factors such as habits, symbolism, etc. could also influence travel mode choice for autonomous vehicles and services. In addition, the subjective relevance (weighting) of the individual criteria was not included in the evaluation of relative partial and total benefits. However, the study helps to improve the understanding of user acceptance of autonomous driving by taking into account alternative travel modes.

6 CONCLUSIONS

User studies show that the à priori acceptance of autonomous driving is relatively high (Payre et al., 2014; Rödel et al., 2014; Schoettle and Sivak, 2014; Becker and Axhausen, 2017). However, they usually view autonomous driving in isolation so that conclusions about future changes in mobility behavior are difficult to draw. Initial studies have therefore analyzed user preferences for the new traffic modes in comparison with existing traffic modes and have shown that users continue to prefer private cars, regardless of whether they are traditional or fully automated. However, in a direct comparison, carsharing benefits much more from full automation than do individual passenger cars (Pakusch et al., 2018). The present survey showed that users see advantages in the automation of cars, taxis and carsharing in terms of driving comfort and time utilization, but in many other areas they fear no added value or even significant disadvantages compared to the conventional car. The opposite is true for public transport: all three autonomous travel modes offer significant relative added value compared with public transport. From the user's point of view, public transport only retains a competitive advantage in terms of costs and ease of use. The intention to use a travel mode in the future is

still the highest for traditional passenger cars, ahead of public transport, autonomous private cars, conventional taxis, autonomous taxis, autonomous carsharing and conventional carsharing. A closer look at the user ratings shows that the proponents of autonomous vehicles anticipate a higher partworth utility in all properties than the sceptics do.

Overall, the results suggest that autonomous driving will gain acceptance in the short to medium term, especially for private transport, while usage-based (sharing) models can only become established in the long term. It is only through experience and new routines that the relative advantage of autonomous mobility services will prevail, which could then become a serious competition for public transport.

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