The Impact of Starting Amber Traffic Signal on Traffic Flow and Safety: a Driving Simulator Study

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ABSTRACT

Due to the growing demand for efficient transportation and limited capacity, the performance of the existing infrastructure and traffic control systems need to be optimized in order to control the growing saturation of roads and intersections. This study gives a first indication of the traffic safety and traffic flow implications of the starting amber phase on Belgian traffic signals. Non-Belgian studies reported an increased capacity of intersections after the implementation of the starting amber, but warned for an increase of early departures and violations. During the experiments of this study, forty four participants completed four experimental drives by which a comparison between the conventional traffic light scheme and the starting amber phase was made.

This study concludes that a starting amber of 2 seconds has a positive impact on the traffic flow as the driver gains a time advantage of 1.1 seconds compared to the traditional traffic light scheme. Drivers could prepare themselves for the oncoming green phase and started accelerating earlier. Traffic Safety effects were tested by including conflict situations with pedestrians and crossing vehicles, but due to the usage of a driving simulator, no valid results were found. This immediately forms the foundation of further investigation.

Keywords: Starting amber; Intersection capacity; Start-up lost time; Conflicts; Early departures; Traffic safety.

INTRODUCTION

For many years, several urbanized parts of Belgium suffer from the increasing travel demand and the need for improved infrastructure. Based on assumptions of the Federal Bureau of Planning the amount of kilometers travelled in Flanders will increase by 20% by 2030 (*16*). This will result in an increased travel time of 1.9% for motorized traffic on regional roads by 2020, which will have a significant impact on the environment and economic sectors of cities (*9*). To deal with this issue, the mobility plan of Flanders tries to minimize this negative impact by promoting alternative means of transport, decreasing the need to travel and to optimize and increase the intelligence of the existing infrastructure (*5*). Part of the latter category of countermeasures is the optimization of the traffic lights at intersections. Several studies focus on the fine-tuning of traffic lights in order to increase the traffic flow or concentrate on the stopping amber and the optimization of the stopping process involved. For example, a recent study researched the impact of a countdown timer on Belgian driving behavior. (*15)*

This study focuses on the starting amber, which announces the activation of the upcoming green phase. Most of the studies related to this scheme are conducted in countries like Germany and the UK where the starting amber is already in practice. Due to legal constraints that prohibit the use of starting amber, no such studies have been conducted in Belgium.

The main advantage of the starting amber is on the reduction of the start-up lost time. This parameter describes the time that is lost due to the delayed response (perception – reaction time) of humans on the transition of the traffic signal. Values for this start-up lost time are around three to four seconds (*1*). By implementing a starting amber phase of one second, Maxwell & York (2006) found a reduction of 0.7 to 0.8 seconds in the start-up lost time. A starting amber of two seconds reduces the start-up lost time even further by 1.2 to 1.6 seconds. The reduction of the start-up lost time by implementing a starting amber of two seconds results in an increased capacity of the intersection by 6% *(12*). However, a distinction should be made between young and elder drivers. Young drivers indicate that the starting amber is a better configuration since it increases the capacity of the intersection due to a better preparation for the green phase, which also results in a reduction of the stress level. Elder drivers, however, found this additional phase rather confusing *(10*). Furthermore, studies also indicate that the average perception – reaction time of the elder drivers was longer compared with the one of younger drivers (*10*).

The legal context of the starting amber is the same as the legal context of the conventional phase, which means that it is prohibited to cross the stopping line before the light turns to green. However, an increase in the amount of early crossing was found, indicating that the starting amber does not correspond to a lower perception – reaction time but to a departure before the traffic light turned green. Many drivers already start accelerating during the starting amber in which 36 % of the drivers crossed the stop line before the traffic light had turned into green (*10) (12) (13*). It was found that bicycles and motorcycles crossed the stop line more frequently during the starting amber compared with other motorized vehicles, possibly due to their lighter weight and faster acceleration (*10*) .These earlier crossings do not necessarily result in more conflicts and accidents. During a practical investigation, none of the conflicts were caused by the starting amber. They found a kind of communication between the road users. In the presence of a potential conflict with another vehicle or pedestrian, the drivers delayed their departure or reduced their acceleration till the conflicting road user left the conflict zone (*10).*

To summarize, it can be stated that starting amber decreases the start-up lost time. This increases the capacity of the intersection but might also induce a potential safety risk due to an increased amount of early departures (i.e. prohibited crossings of the stop line). The main objective of this study is to give a first indication of the impact of the starting amber on the traffic safety and traffic flow on Belgian intersections.

METHODOLOGY

Driving simulator

Due to the fact that this signal scheme is not yet implemented in Belgium, we opted for a driving simulator study. The experiment was conducted on a medium fidelity driving simulator (STISIM M400; Systems Technology Incorporated). It is a fixed based driving simulator (drivers do not get kinesthetic feedback) with a force feedback steering wheel, brake pedal, and accelerator. The simulation includes vehicle dynamics, visual and auditory feedback and a performance measurement system. The virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side view mirror images and depiction of the speedometer. Three projectors offer a resolution of 4200 x 1050 pixels and a 60 Hz refresh rate. The sounds of traffic in the environment and of the participant's car were presented. Data were collected at a 60Hz frame rate.

Figure 1: Driving simulator

Participants

Forty seven volunteers with a valid driver's license participated in the study, of which three were excluded: two participants could not complete the experimental test due to simulation sickness and one participant was identified as a statistical outlier (a participant's behavior deviated extremely in more than 25% of the conditions). Forty four participants (27 men and 17 women) remained with a mean age of 35 years and a mean driving experience of 15 years.

Procedure

Prior to the experiment, participants were asked for their informed consent and to fill in a questionnaire concerning personal data (e.g. age, gender, driving experience and experience with starting amber). After a general introduction, a practice session was given in order to let participants get acquainted with the driving simulator. During this practice session, the participant encountered five intersections of which two intersections were equipped with the starting amber configuration. Afterwards, participants drove four experimental drives of around five kilometers each in a low density suburban environment and unsaturated traffic conditions. The first two experimental drives, indicated as the reference scenario, included ten intersections, equipped with conventional traffic light schemes. The last two experimental drives, known as the starting amber scenario comprised of ten intersections, equipped with the starting amber scheme of 2 seconds. In order to verify the potential negative traffic safety impacts, participants were confronted with different conflict situations (i.e. a pedestrian or a car crossing the street at the last moment). The occurrence of the conflict situations was randomized in order to mimic the unpredictability of real traffic situations. At the end of the experiment, participants were asked to fill in another questionnaire in which their opinion about the starting amber configuration was gathered.

DATA COLLECTION AND ANALYSES

During the experiment, the following data was collected in order to assess the impact of the starting amber phase on traffic flow and traffic safety levels:

Perception-Reaction Time (PRT)

The perception reaction time is defined as the time interval between the signal change and the moment on which the vehicle starts moving.

Start-up Lost Time of the first driver

The start-up lost time of the first driver is defined as the time interval between the signal change and the moment of passing the stop line.

Time required to leave the intersection

For determining the time gain of the starting amber, the time required to cross the intersection will be used and compared with the start-up lost time (described in the previous point). The comparison would also indicate whether there is a change in acceleration behavior or not. When the time difference between the starting amber scheme and the conventional traffic light scheme is the same for start-up lost time and time required to leave the intersection, it can be concluded that the acceleration behavior is the same in the two scenarios.

Post-Encroachment Time

This parameter indicates the time lapse between the end of encroachment of the crossing vehicle and the time that the through vehicle actually arrives at the potential point of collision. The smaller this value, the higher the risk of crash occurrence. The critical value used in the study is 1 second. This critical value is used to separate the serious conflicts from the less severe conflicts *(3) (4) (8).*

Distance travelled during the red/starting amber phase

This parameter indicates the distance travelled before the traffic light turned into green.

Distance-to-stop-line

The distance to stop line indicates the distance between the stop line and the location where the vehicle has stopped. This parameter is mainly used as an indicator to verify the validity of the driving simulator.

To analyze the dependent variables, a two way analysis of variance (ANOVA) was conducted. A two-way ANOVA informs whether there is an interaction between the two independent variables (the occurrence of a conflict and the type of traffic light configuration) on the dependent variable. Additional post-hoc paired t-tests were performed in order to compare the behavior of the participants when confronted with the different conflicts and traffic light configurations. The p-value was set at 0.05 to determine statistical significance (*7*).

RESULTS

In order to avoid the interference of unknown variables and to increase the unpredictability of the simulated traffic conditions for participants, it was necessary to randomize the sequence of intersections and conflicts, resulting in two scenarios, each with two driving rounds. The encounter of a conditional/starting amber traffic light was not randomized. The participant knew what kind of traffic light he would encounter. Before the analyses of the parameters started, a paired t-test was carried out to compare the results of the first and the second driving rounds of each scenario in order to assess the impact of randomization. The results of this paired t-test showed that there was no significant learning effect between the first and the second driving round of each scenario, indicating that the participants did not change their behavior based on their earlier experiences.

During the analyses of the perception reaction time, it was found that in the scenario with the conventional traffic light (mean = 0.653 seconds), the perception reaction time was found higher than the perception reaction time found in the scenario with the starting amber (mean = -0.894 seconds). This difference was significant and indicates that the starting amber allows the driver to start accelerating before the traffic light turns to green. As there was a significant interaction effect “Type configuration x Conflict”, a post-hoc paired t-test was conducted. This post-hoc test revealed that on average drivers significantly delayed acceleration when there was a potential conflict with the crossing vehicle or pedestrian in the starting amber scenario (see figure 1). In the reference scenario, due to the delayed departure of the drivers, only conflicts with crossing vehicles resulted in a delayed acceleration.

A similar reduction was found for the start-up lost times (Figure 1). In the reference scenario, a mean start-up lost time of 3.477 seconds was observed, which then significantly decreased to 2.409 seconds in the starting amber scenario, resulting in a decrease of around 1.1 seconds. This reduction was found irrespective of the presence of conflict as there was no significant interaction effect between the type of configuration and the presence of a conflict when considering start-up lost time.

In line with the results of the start-up lost time, the time required to leave the intersection also reduced with 1.1 seconds. In the reference scenario, the time required was found to be around 6.249 seconds which reduced significantly to 5.144 seconds in the starting amber scenario. This similar reduction indicates that the acceleration behavior in the reference scenario and in the starting amber scenario is the same. Similar with the start-up lost time, the interaction effect “Type configuration x Conflict” was missing, indicating that a potential conflict does not influence this parameter.

The PET-values, shown in figure 1, in the starting amber scenario (mean = 3.876 seconds) were significantly smaller compared to the PET-values of the reference scenario (mean = 4.575 seconds). None of the participants exceeded the critical value of 1 second, indicating that there were no serious conflicts in both scenarios. As there are no significant results, an interaction effect between the traffic light configuration and the type of conflict does not exist for the PET values.

In the reference scenario, only small distance values were found (mean = 0.004 meters). Even this small distance travelled can be explained by the fact that some participants didn't completely come to a full standstill. This value increased significantly in the starting amber scenario to a covered distance of 0.549 meter. The existing interaction effect "Type configuration x Conflict" indicates that the type of conflict influences the covered distance. Based on the results of the post-hoc paired t-test, it became clear that the drivers covered significantly less distance when a potential conflict with a crossing vehicle occurred. In presence with a potential conflict with a pedestrian, the drivers also covered less distance but this was not significant.

When waiting for a green light, the participants stopped at an average distance of 7.5 meters from the stopping line. This value remained constant in both scenarios and was independent of the type of conflict. Since there were no significant results, an interaction effect between the type of traffic light configuration and the type of conflict did not exist. In general, relative validity is usually achieved in driving simulator studies. However, since proprioceptive self-motion information is missing and due to the relatively low levels of resolution (compared with images perceived from the real world), the absolute validity of distance estimation is affected resulted in misperception of vehicle position *(6)*.

Tables 1 and 2 give an overview of the ANOVA and post-hoc t-test analyses. During this test, the impact of the absence/presence of starting amber (type of traffic light) and the absence/presence of a conflict (type of conflict) were tested. The post-hoc t-test afterwards could only be conducted for two variables, as this test tries to reveal patterns when a significant interaction effect exists. The values in bold are those which were found significant.

TABLE 1 ANOVA analyses

Parameter	***Analyses***	***F-measure***	***Significance***
Perception reaction time	Type traffic light	769.365	**0.000**
	Type conflict	20.696	**0.000**
	Traffic light x Conflict	12.100	**0.000**
Start-up lost time	Type traffic light	249.110	**0.000**
	Type conflict	3.478	**0.033**
	Traffic light x Conflict	0.093	0.899
Time needed to leave the intersection	Type traffic light	154.450	**0.000**
	Type conflict	1.248	0.290
	Traffic light x Conflict	0.175	0.830
Post-Encroachment Time	Type traffic light	37.228	**0.000**
	Type conflict	0.435	0.512
	Traffic light x Conflict	0.014	0.906
Distance travelled during red phase	Type traffic light	123.127	**0.000**
	Type conflict	5.696	**0.006**
	Traffic light x Conflict	5.785	**0.006**
Distance to stop line	Type traffic light	0.284	0.596
	Type conflict	1.073	0.344
	Traffic light x Conflict	0.728	0.463

TABLE 2 Post-hoc t-test for parameters with significant interaction

Parameter			***Mean***	***Significance***	***SD***
Perception reaction time	***Reference scenario***				
	No conflict	Pedestrian	-0.036	0.450	0.436
	No conflict	Car	-0.129	**0.001**	0.337
	Pedestrian	Car	-0.082	0.138	0.481
	Starting amber scenario				
	No conflict	Pedestrian	-0.433	**0.000**	0.6198
	No conflict	Car	-0.318	**0.000**	0.5525
	Pedestrian	Car	0.128	0.105	0.7145
Distance travelled during red phase	***Reference scenario***				
	No conflict	Pedestrian	0.00075	0.617	0.014
	No conflict	Car	0.00029	0.864	0.016
	Pedestrian	Car	-0.0007	0.690	0.016
	Starting amber scenario				
	No conflict	Pedestrian	0.152	0.085	0.822
	No conflict	Car	0.228	**0.000**	0.537
	Pedestrian	Car	0.060	0.436	0.705

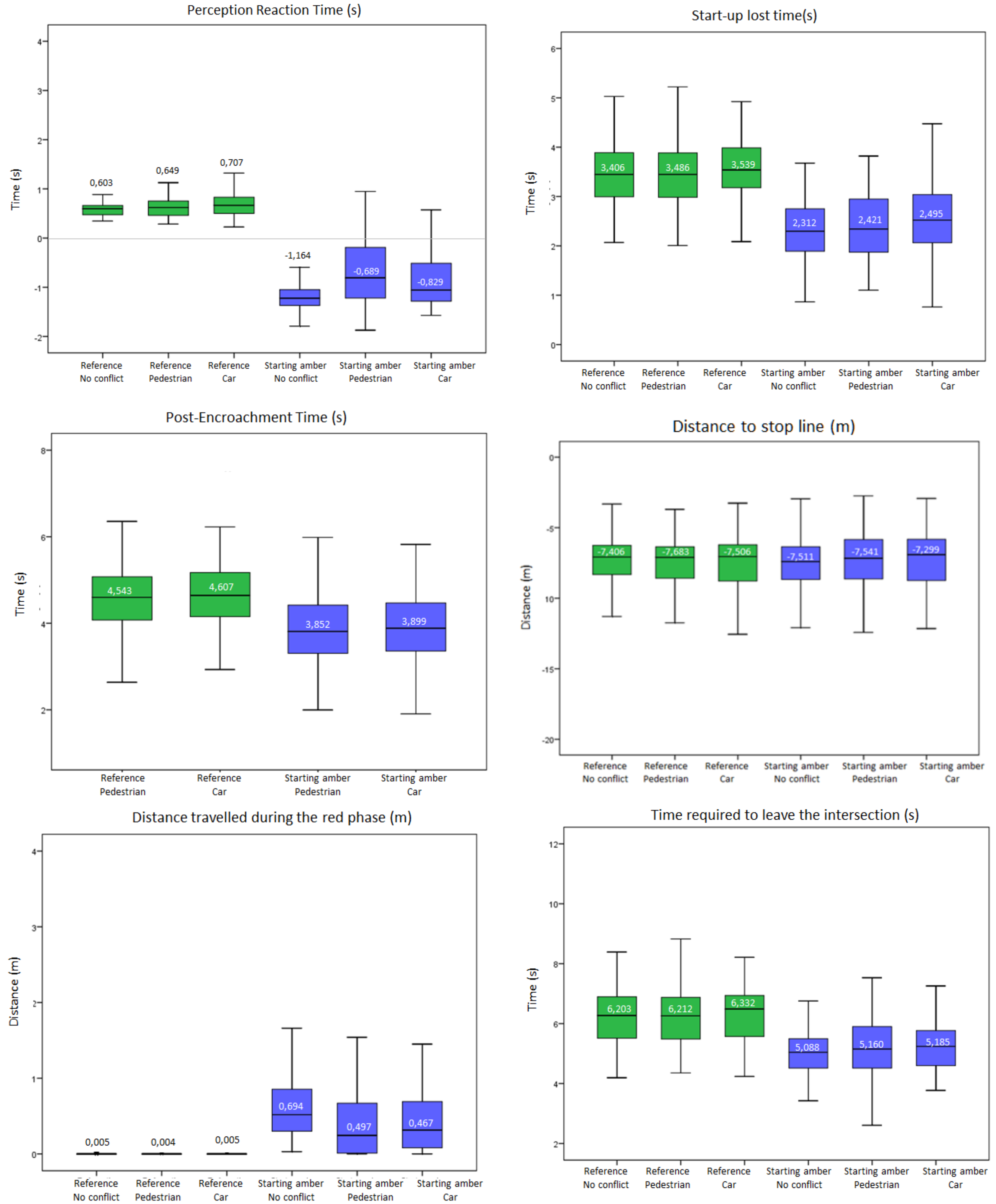

FIGURE 1 Overview of the results of the parameters, divided in type of configuration and type of conflict (retrieved from SPSS)

Based on the responses collected by the final questionnaire and the experience with the starting amber in the driving simulator or in real life, 39 out of 44 participants were in favor of implementing the starting amber phase in Belgium. Being better prepared and increased traffic flows were the main reasons given. However, one participant found the starting amber rather confusing. Moreover, the majority of participants were concerned about the possible negative impact on traffic safety.

DISCUSSION AND RECOMMENDATIONS

As this was the first study conducted in Belgium concerning the starting amber configuration, several limitations were imposed. Due to the missing legal framework, a practical test on terrain was not possible. Using a driving simulator was a suitable replacement, however, it has some disadvantages too. When participating in driving simulator experiments, test subjects might be more inclined to adopt a more sociably accepted driving style. Furthermore, the participants were driving in a simulated environment in which their perception of speed and distance are most likely different from reality.

During the test drives, the environment was kept non-complex as there was no interaction with other road users and the driving simulator was using an automatic gear box. This latter configuration might have resulted in shorter perception reaction times as compared with a previous study where higher perception reaction times were found using a manual gear box (*15*). With a mean age of 35 years old, the participants closely represent the Flemish population. However, none of the participants had an age of 70 or older. Given the nature of the study, this test group was sufficient to give a first indication of the impact. At last, this study only gives the impact of the starting amber on a short term. The question is whether these results are still valid on a longer term or not.

In order to confirm the results that are achieved in this study, it is recommended to conduct an empirical study. This facilitates to collect real data revealing participants' natural behavior and also enables the investigator to draw constructive conclusions of the long term effects and a broader test group. Assessment of the impact on traffic safety will be also more reliable as the absolute validity of the collected data is ensured.

It is also recommended to increase the complexity of the scenarios in the future. An urban environment with more possible conflicts and more distracting factors like vehicles in the same direction can bring the driving environment closer to the reality, which in return might influence the impact of the starting amber configuration. Using a manual gear box might also improve the scenarios as most of the vehicle fleet in Belgium are equipped with manual gearbox.

During this study, a starting amber of 2 seconds was used while some countries use a starting amber duration of 1 or 1.5 seconds. This might influence the traffic flow and the traffic safety, therefore, the sensitivity analysis with respect to the starting amber duration is another direction for future improvement to the current study.

Finally, legislation issues should be taken into account. In Belgium, it is obligated to implement a 2-second all-red phase in order to safely clear the intersection. In the UK however, this all-phase is only used at complex intersections and is replaced by the starting amber phase as it has the same juridical value as the red phase. The question raised is whether this replacement might decrease the traffic safety due to early starters.

CONCLUSIONS

In line with the results found in the literature, this study found a positive impact of the starting amber phase on traffic flow performance. The drivers were better prepared to respond to the oncoming green phase which resulted in a reduction of the start-up lost time of around 1.1 seconds. The lower start-up lost time was mainly caused by an earlier departure of the drivers as they already covered around 0.5 meter before the traffic light turned to green. This time gain of 1.1 seconds remained unchanged till the end of the intersection, suggesting that the acceleration behavior did not change compared to the one of conventional traffic lights.

The presence of a potential conflict only postponed the starting moment of acceleration and accordingly the covered distance during the starting amber, however, it did not influence the start-up lost time significantly.

Due to the issue of long distance records from the stop line, the PET-results could not be used to make any valid conclusions about the impact on traffic safety. Driving simulators generally achieve a relative validity but that the absence of proprioceptive self-motion information might lead to invalid results for distance and speed *(6)*. However, the other parameters were not influenced by this deviation as those parameters did not depend on the assessment of distance.

The positive impact on the traffic flow (i.e. quantitative measures derived from the analysis) was further supported by the public perception (i.e. the subjective opinion of participants). The participants indicated that the starting amber gave them more time to prepare themselves for the oncoming green phase, resulting in an increased traffic flow.

It is recommended to extend the scope of this investigation. By moving this experiment to the real world, it is possible to observe the actual behavior of the participants in its natural driving environment. This also allows the experimenter to include all age categories and to assess the impact of the starting amber on traffic safety during the long term.

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