

DATA ANALYSIS FOR RACE STRATEGY

USING MATLAB AND VI GRADE

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1. ABSTRACT

In this research proposal, the use of data analysis for race strategy decisions is discussed. It is discussed how softwares such as VI CarRealTime and MATLAB can be used to achieve this goal. Initially, previous research done in this topic area is talked about and the research gap that can be seen in the same is discussed along with the objectives of this research. VI CarRealTime allows one to build complete models of vehicles where each and every component and parameter of the vehicle can be varied. In this proposal, how these parameters are varied to create different setups is explained in detail. Design of experiment is used to achieve the same. Next, how the results from the simulations in VI CarRealTime can be exported to MATLAB and how these can be filtered out using signal and data processing tools in MATLAB are discussed. Along with signal and data processing, MATLAB will also be used to build a code that could be used to predict lap times based on fuel load, tyre degradations and other factors affecting the overall race pace of the vehicle. End the end, the expected outcomes of this research and the expected timeline to complete each task in the process is discussed.

2. INTRODUCTION

University of Wales Trinity Saint David has a student led race team that competes in a racing series called Sports 2000, which is an amateur racing series. Here, the university team uses the MCR race car. The team enters two cars in every event, one driven by one of the university professors, Tim Tudor and the other car is driven by John Iley, former Head of Aerodynamics for various Formula One teams. A picture of one of the cars can be seen below in Fig. 1.



Fig. 1: UWTSD MCR Team Car 40 Driven by Tim Tudor (UWTSD Motorsport, no date)

The Sports 2000 championship consists of multiple rounds every season, competing in different circuits around United Kingdom and sometimes in Europe. For all the different circuits, the race cars need to be setup to suit the specific requirements to go fast. But setting up the car to achieve the fastest lap time possible might not always be beneficial. Over a full race distance, the fuel loads and tyre degradation continuously changes. This requires the car to be setup in such a way that it can achieve quick lap times for a wide operating window.

A simulator is a tool that enables to simulate and replicate real world conditions. In case of a driving simulators, it simulates the real world driving conditions where a driver can replicate the experience of driving a real car with only the aid of computers, without actually having to go out and drive in the real world. This is especially beneficial in cases where the race competition regulations limit the amount of testing or in cases where the racing budget of a team is low and they cannot afford to go out and drive the real car to gather vital information. These simulators are also very useful in deciding setups for the cars.

The university has a driver in-loop simulator (Bruck et al., 2021) that is based on the racing platform Automobilista. This simulator has a model of the MCR race car. But the problem with using this simulator is that the accuracy of the built model is unknown. So, it cannot be guaranteed that the results achieved by changing vehicle setup in the simulator would replicate how the car behaves when making the changes in the real world. This is a huge problem since the UWTSD MCR Team operates on a very tight budget and cannot afford to go for multiple test sessions. So, there is a need for the development of a tool that can be used to test and assess vehicle setups so that the team could use them on the race weekends.

Along with setting up the vehicle using the simulator, gaining and identifying the desirable data from it is equally important as well. Only then the data achieved will be helpful in usefully identifying which setups are the best for the race car and for the overall strategy of the race. So, it is important to process this data successfully.

Hence, in this project, the aim will be to use the different tools available to identifying the best strategies for the race based on the set ups of the race cars and lap times achieved.

3. THEORY

3.1 VI CarRealTime

For the development of a vehicle, it is very important to know how the smallest of changes to the vehicle affects its overall physics. A vehicle can only be developed in the correct direction if the engineers completely understand the dynamics of the vehicle. There are multiple simulation tools and applications that allow to simulate a vehicle in order to understand its vehicle dynamics. One such tool that we are going to use in this project is VI CarRealTime. VI CarRealTime is a real time vehicle simulation environment that uses a single simplified vehicle model. It allows the user to modify every detail of the vehicle, starting from major things like spring rates, damper rates, centre of gravity, aerodynamic loads, engine parameters etc to minute things such as positions of every suspension component down to the exact millimetre. This is a very useful tool that can be used by engineers to assess how a vehicle would behave under different manoeuvres and different driving circumstances. A picture of the basic VI CarRealTime interface can be seen in Fig. 2.

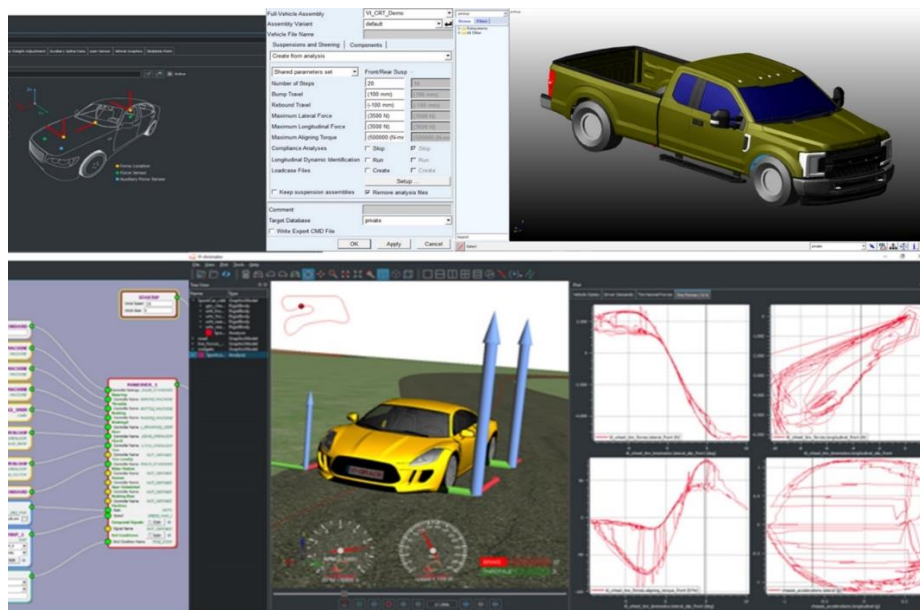


Fig. 2: VI CarRealTime (VI-GRADE, no date)

In VI CarRealTime, in addition to being able to build vehicle models, it also has the option to add different racing circuits and roads. Here, the exact path or driving line that the vehicle takes can be added as well. This is very helpful in determining how quickly a vehicle can complete a lap of a particular circuit while following a certain path, enabling the engineers to modify certain parameters of the vehicle to examine if the changes make the vehicle go quicker or slower as a result.

At the end of the simulation, the telemetry data from the runs can be viewed. Telemetry is the data that is extracted from a vehicle. This data can be from multiple parameters such as lateral acceleration, longitudinal acceleration, amount of spring movement, throttle percentage, brake pressures, gears etc. If the engineers want the vehicle to improve in a certain parameter, they can make the appropriate changes required by simply looking at the telemetry.

One major benefit of using VI CarRealTime is that it enables the user of transfer files easily between different applications. For example, all the telemetry that is generated from running the simulations can be exported in the form of .mat files, i.e., as MATLAB file and these files can be imported seamlessly into MATLAB.

3.2 Design of Experiment (DOE)

Design of experiment (Cavazzuti, 2013) is a tool that is used for data collection and analysis. It can be defined as a branch of applied statistics that deals with planning, conducting, analyzing, interpreting controlled tests to evaluate the factors that control the value of a parameter or a group of parameters. DOE usually requires multiple input factors, where the

values of these factors are changed in order to determine their effect on the output response.

By changing the input factors, DOE is able to identify which factors are the most important factors and effect the output response the most. There are various ways of carrying out DOE approaches such as one factor at a time (OFAT), two factorial, three factorial, Box-Behnken design, full factorial etc.

4. LITERATURE REVIEW

Goyal et al. (no date) discuss the application of MATLAB in signals and systems and digital signal processing. Here, MATLAB was applied at three different levels to a problem to assess it at three different levels to completely understand the theory and some of the mathematical processing and physical meaning involved in the problem.

This is not the first time VI CarRealTime has been used in conjunction with MATLAB. Ferraris et al. (2019) developed a model of an electric car with all wheel drive where they developed control systems to control the torque of the vehicle using MATLAB along with a vehicle dynamics model in MATLAB Simulink. They then tested the effectiveness of their model in a co-simulation environment in VI CarRealTime. Here they tested the effectiveness of torque vectoring and its influence on lap times along with the effective decrease in energy consumption. They discovered that the vehicle could achieve better lap times with a 1% improvement while decreasing the overall energy consumption by around 20%, by send the power to the wheel that would most effectively help the vehicle rotate instead of sending the power to all the four wheels.

Wu and Pan (2021) built a model of the E22 pure electric formula racing car in VI CarRealTime using multi-body dynamics as the theoretical basis in order to optimize the suspension system of the vehicle. They analysed the steady state steering characteristics of the car to improve its handling stability. This was done by changing the four wheel alignment parameters of the car and was done so in order to identify the best combination of front beam angle and wheel camber.

Heilmeier et al. (2020) discuss using strategy based on the tyre wear of a Formula One car. They developed a so called virtual strategy engineer which based on two artificial neural

networks. One of the networks decided every lap if the car should be called in for a pitstop based on the time required to complete laps while the other was programmed to decide the which tyre should be put on the car based on available tyre allocation data. Python was used for the same. In order to achieve this, the two neural networks were fed with Formula One timing data from 2014 to 2019.

Law (2017) provides a tutorial on how design of experiment can be used for simulation models. They discuss how changing only one factor at a time in a simulation environment is highly statistically inefficient as changing one factor of a model often has an impact on the other responses. They also discuss different classical design of experiment methods such as full factorial and fraction factorial. Lastly, Latin hypercube design is talked about, which are designed for complex, nonlinear responses that are usually associated to simulation models.

Castrounis (2009) determined the mean pitch response of a race car using optimization methods while varying various factors, to see their effects and interactions with the mean pitch response. The factors used in this case were low and high speedbump and rebound damper settings for both the front and rear along with the front and rear tyre stiffnesses. These factors were varied using fractional factorial DOE for different damper and tyre stiffness settings. In the end, the most important factor to control the pitch response was determined to be the rear damper settings.

The main paper which will be taken as a reference for this project is by Byam et al. (2003). Here, they applied DOE approaches on a Formula SAE car to improve its dynamics and overall performance over four events: skid pad, acceleration, autocross and endurance. They used seven factors to optimize the vehicle over these events namely, the factors being rear tyre pressure, final drive ratio, ride height, rear spring rate, front and rear compression damping

and front and rear rebound damping. The authors used full factorial DOE for the same. The most effective results were seen when the tyre pressures were between 15 to 20 psi and with front and rear toe in for the endurance and autocross events, the fastest accelerations were observed with increased ride height and the fastest lap times were achieved when damping coefficients were set to at or around critical damping.

5. RESEARCH GAP

From the literature review, it was revealed that the research done previously in this particular topic area had some major gaps in it. After thorough examination of the research papers, it was discovered that MATLAB is one of the most useful tools in terms of mathematically modelling race cars. It is extensively used to assess the vehicle dynamic models of the vehicles. It is also majorly used for developing algorithms for the different control systems within the race cars. But, in the racing industry, MATLAB is not used for digital signal processing and there has been no research done on how it could be used to assess and filter the signals for use in racing and developing strategies based on them for the races.

Another major gap that has been discovered is in relation to the use of Design of Experiment (DOE) in motor racing. It is well known that DOE is a very useful tool and that it is used extensively in motor racing, be it to determine the direction of vehicle development, allocation of resources or to decide vehicle setups. But the racing teams do not like to disclose how they use DOE and what are the key areas they discover for the development of their vehicles. So, details on how DOE approaches are used for vehicle setup and performance are not publicly available.

Lastly, there are no MATLAB models to assess how fuel load and tyre degradation affect the performance and lap times of a race car.

6. OBJECTIVES

The objective of this project is to use data analysis to develop and improve race strategies of the UWTSD MCR Team to use during the race weekends in the Sports 2000 racing series. But this is the overall object of this project. In order to achieve this main objective, there are multiple minor objectives that are needed to be completed first. If any of the minor objectives are not met, then there is a huge risk of not achieving the overall major objective of this project.

These minor objectives are below:

- Develop a model of the UWTSD MCR race car in VI CarRealTime for the team to test setups.
- Validate the model against actual race data from the team.
- Apply Design of Experiment approaches for testing setups and assess its effectiveness and efficiency.
- Extract telemetry to carry out data analysis of the different setups.
- Build up a MATLAB model to assess the effects of fuel loads and tyre degradation on lap time based on which race setups and strategy decisions could be made.

7. METHODOLOGY

The methodology that has been proposed for this project is majorly based on computation and simulation aided by computers. It involves building up models of the MCR race car and simulate its operation around different racing circuits using VI CarRealTime. This will be done in conjuncture with testing different setups for each circuit and extracting the output results in the end. These results will then be processed using MATLAB signal processing and data processing along with the code for fuel loads and tyre degradation. A detailed flow chart of the same can be seen below in Fig. 3.

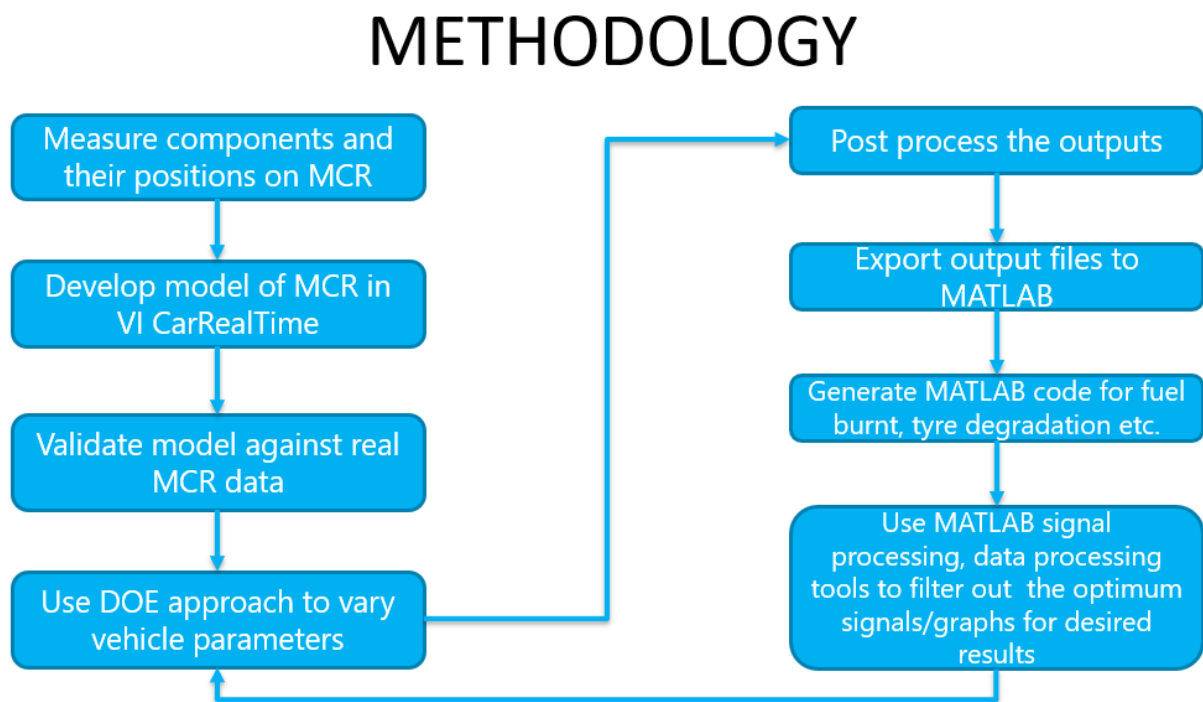


Fig. 3: Proposed Methodology

7.1 Measure the components and their positions on the MCR race car

This would begin with creating a reference coordinate point that would be considered as the origin. Based on the point of origin, the location of each component of the race car can be easily measured. Measuring the basic things like the wheelbase, front and rear track, width of the car etc. would not be much difficult. The main area that would be hard to measure would be the suspension components of the car. Since there will be multiple points of linkages and the geometries of each of these components will be very different, it would be essential to get every measurement correct. This will also be the most important part of the vehicle during the measuring process because majority of the setup changes that would be made during this project would be directly related to the suspension components and their linkages to the wheels of the vehicle, for example spring rates, damper rates, camber and toe of the wheels etc. It would be of utmost priority to get this part right because if the components or their locations are measured incorrectly, the whole response of the vehicle during the simulations would be very different compared to that of its real world response.

7.2 Develop the model of the MCR race car in VI CarRealTime

The next step would be to use VI CarRealTime to develop the model of the MCR race car. This step has to be done as meticulously as measuring the components and their locations because if the modelling of the vehicle is done inaccurately then the previous step of measuring the components precisely would be of no use. It would only be possible to get the correct response from the vehicle if both these steps are done almost zero to minimum error.

7.3 Validate the model against the real MCR race car data

After developing the model of the car, the model would be set up to replicate the setups from one of the race weekends that the UWTSD MCR Team participated in in the previous season. There is a data logbook that the team uses to keep records of all the things related to the cars on the race weekends. There is also a device known as a V-box that logs all the data such as lap times, lateral and longitudinal accelerations, steering angle, speed, throttle and brake maps etc. when the car is on the track. The output data from the V-box is similar to that of the output one gets from VI CarRealTime. So, with the previous data available on setups along with the V-box, it would be easy to compare these to the output from VI CarRealTime for validation.

7.4 Use DOE approaches to vary vehicle parameters

This is the part where design of experiment comes in. the plan here is to use full factorial DOE, in which all the vehicle parameters such as spring rates, damper rate, toe and camber of the wheels, ride height, tyre pressures etc. are changed simultaneously to look at the overall outcome of the changes made instead of changing two or three parameters at a time. The issue with doing a full factorial DOE is that it would take more time to simulate the run. But, at the same time, it is better than two or three factorial approaches because it would optimize all the parameters at once and one would not have to worry about how changing a certain parameter would affect the rest of the parameters, like in two or three factorial DOE. Also, since the UWTSD MCR Team already has the data from previous runs on the tracks, it would give a general idea of what the optimum operating settings would be for each parameter. With this knowledge, the parameters could be

changed by about 10 to 20 percent and the differences in the performance of the race cars could be observed.

7.5 Post process the output data

After completing the simulations using DOE approaches, the results of the simulations can be seen in the post processor. This is the section where all the output graphs from the run are visible. It can be determined from here if the simulations have produced the expected results. It also gives the optimum lap time that the vehicle can achieve for the particular track and path assigned to it.

7.6 Export output files to MATLAB

The advantage of using VI CarRealTime is that this software is compatible with many other softwares. It allows cross platform file and data sharing. This is greatly advantageous when VI CarRealTime is used simultaneously along with other softwares. One such software tool is MATLAB. The output telemetry and data files that are produced after post processing in VI CarRealTime can be saved in the form of .mat files, i.e., as MATLAB files. This is especially helpful for this project because the next part of this project will be done using MATLAB.

7.7 Generating MATLAB code for fuel load and tyre degradation

During a race, the amount of fuel in the car constantly changes. As the car moves, it is burning more and more fuel every metre it travels. This means that as the car travels

more, the amount of the fuel remaining in the fuel tank decreases, i.e., the mass of fuel in the car decreases. In motorsports, lower overall mass of the vehicle means faster lap times. A drawback of using VI CarRealTime is that it considers the mass of the vehicle to be constant. It is also designed to give the best lap time for a particular setup over a single lap and it does not simulate the model for an entire race distance. Similarly, since it does not simulate an entire race distance, VI CarRealTime does not take tyre degradation into account. Hence, in order to make strategy decisions, these factors must be taken into account. For this reason, a MATLAB code has to be generated so that the fuel load and tyre degradation are considered. Since the amount of fuel needed for every track and the amount of tyre degradation varies, the code has to be generated in such a way that the fuel burn rate and the rate of tyre degradation could be taken into factor and varied. It is also important to account for some amount of time that will be lost during the race while fighting with other cars, not taking the optimum driving lines and also time lost due to driver fatigue.

7.8 Using MATLAB to filter optimum signals and graphs

In MATLAB, there are tools to filter and optimize data and signals so that the most optimum signals and graphs can be identified and the rest can be eliminated. This would be useful because when the simulation is done in VI CarRealTime, the vehicle simulates around the given circuit multiple times. The number of times the vehicle goes around the circuit can be set by the user in the form of number of iterations. The more iterations there are, the higher the changes are for the vehicle to achieve better lap times. But with the higher number of iterations, it would be necessary to filter out the best results. Hence,

this will be done in MATLAB using signal processing and data processing. This would also be helpful because VI CarRealTime assumes that the vehicle is driven to hundred percent of its capability, while the truth of the matter is that in real world, more often than not the race cars are driven just under their limit in order to keep full control. This is also done to reduce tyre degradation and increase the longevity of the components of the car. So, signal and data processing would be helpful in identifying those signals that are just under the optimum results.

Once the most optimum signals are identified in the end, the process would have to be repeated again to see if there are other setups that could improve on the results achieved. Hence, this would be an iterative process and the entire process has to be repeated after reapplying DOE approaches to decide the next set of parameters.

8. ERROR ESTIMATES AND LIMITATIONS

Even with the best efforts made to minimise error, there is always a chance of getting some error, be it due to human error or because of the limitations of the available equipment. In the case of this project, the error that is most likely to happen is while measuring the components of the race car. Since the geometry of the car has a direct correlation to its performance, it is very important get every single measurement correctly down to the millimetre. Similarly, even if the components of the race car are measured accurately, there might be some error while building the vehicle in VI CarRealTime. If any value is put incorrectly, there is a possibility of having a huge difference in the end result.

A limitation of the using VI CarRealTime is that it always considers the track conditions to be ideal. In the real world, the conditions can be far from ideal. VI CarRealTime does not account for things like changing track temperatures, amount and direction of wind, amount of marbles on track, track evolution etc., which are just a couple of things that can affect the dynamics of the car and can cause a huge difference in the performance of the car.

Another limitation of VI CarRealTime is that it only gives the fastest and most optimum lap time. This is great to assess the fastest lap time a vehicle can achieve. But, it does not take into account the longer runs of the race where the car is driven for multiple laps at once. Also, over a race distance, the mass of the vehicle decreases as the fuel load in the vehicle decreases. VI CarRealTime considers the mass of the car to be constant all the time. It also does not account for tyre degradation.

Lastly, another error that could be happen is while identifying the correct signals while signal processing.

9. EXPECTED OUTCOME

At the end of this project, the outcomes that could be expected are as follows:

- Build a VI CarRealTime model for the UWTSD MCR Team to test setups.
- Use DOE to focus on the most important parameters of setup for the desired outcomes.
- Develop a MATLAB code that could predict lap times based on fuel load and tyre degradation for optimizing strategy on race weekends.
- Use signal and data processing to filter and identify the best setups for the races.

10. TIMELINE

TASK	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
PROJECT PLANNING						
RESEARCH						
MEASURING COMPONENTS						
DEVELOPING VI CARREALTIME MODEL						
VALIDATION						
APPLY DOE APPROACHES						
POST PROCESS						
GENERATE MATLAB MODEL						
WRITE UP						

Fig. 4: Proposed Timeline

Fig. 4 above shows the Gantt chart for the proposed timeline of the project. As the project topic had to be decided for this research proposal, there was some research and planning going on in the month of March. But since the project cannot be started prior to completing all module, there will only be research on the topic until the month of May. Once the project can be started in May, it would begin with measuring the components of the car. While this is being done, the plan is to start building the VI CarRealTime model simultaneously, which would go on until the month of June. Towards the end of June, the validation of the model will be carried out and the DOE approaches would be applied. Also, at a similar time or toward the beginning of July, the MATLAB model will be generated. Applying DOE approaches, post processing and using MATLAB for signal processing would go hand in hand until early to mid-August because this would be an iterative process and has to be repeated multiple times. While the main work in the project would going on, the write up would begin simultaneously from May and would go on until the end of August.

11.CONCLUSIONS

In this research proposal report, how data analysis could be used for lap time simulation and race strategy decisions was discussed. It was discussed why there is a need for such a tool after going through published research papers and finding the research gaps in them. It was then discussed how this tool could be used by the UWTSD MCR Team to use in order to build and test race car setups for their race weekends. The step by step methodology to build the same is talked about. The plan is to build a model of the MCR race car in VI CarRealTime after measuring all its components accurately and validate the model against actual race data available. It also discusses how design of experiment could be used to change certain parameter of the car to improve its performance. The results achieved from the simulations will then be exported to MATLAB where data and signal processing would be used to analyse the best setups and filter out the unwanted ones. It also discusses building a MATLAB model that could be used to predict lap times not only based on the setup of the vehicle but also the fuel loads and tyre degradation. In the end, the expected outcomes of this project were talked about along the expected timeline to complete all the tasks.

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