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Contents

The new age of autonomous driving – built tough but smart enough?

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1 Abstract

Automotive engineering is used to serve the consumer in a way as it has been done for ages so far. A plethora of new exterior lighting features, enabled with new technologies and light sources, have entered the market within the last decade, the engineering focus remained on building vehicles that would allow occupants to travel safe and relaxed. Historically new exterior lighting features and technologies have not gone along with a substitution of the old ones, but a greater selection of different kinds of functionalities as well as appearance execution possibilities. In particular exterior lighting has become a key contributor of the vehicle's first impression. The features and technologies that provide as much light as possible on the road to improve the driver's visibility have become more relevant.

Today the automotive industry will use innovation to create advanced new vehicles and solve tomorrow's transportation challenges. Considering recent trends, exterior lighting innovations have to be part of the next level of connectivity, mobility, customer experience and autonomous driving to support the future transportation solutions.

Driving safety will always be a key attribute. However, providing a sufficient amount of light on the road for the driver will no longer be sufficient when there is no longer a driver. What will the focus for exterior lighting features be for autonomous vehicles? This paper will discuss the impact on exterior lighting features as well as further attributes to consider for full autonomous vehicles.

2 Introduction

Automotive engineering is used to serve the consumer in a way as it has been done for ages until now. The footrace of technology and feature development in exterior lighting to support the customer and vehicle driver has been increased significantly after the introduction of light technologies like HID, AFS and especially LED. The engineering focus so far has remained on developing and building vehicles that ensure safe and comfortable

travel depending on specific customer needs and expectations for all kind of vehicles. Against this backdrop, the focus of the exterior lighting demand varies from case to case depending on the vehicle segment and attribute target. Whereas environmental influencing factors stay the same, different vehicles attributes of the great selection of vehicles in the fleet have always an impact on the attribute emphasis of the lighting system to provide the best experiences for the customers (see Figures 1 to 4.). The development of a sports car, like the Ford GT, is basically driven by innovative design to be super light but super strong. The devil is in the details for trucks, such as the Ford Raptor, to be lean and tough from headlamp to tailgate and from suspension to drivetrain. For luxury vehicles unique features have to work in perfect unison to punctuate elegance through design as demonstrated with the latest Lincoln vehicles.

Figure 1: Ford GT;

Figure 2: Ford Raptor

Figure 3: Lincoln Continental;

Figure 4: Lincoln Navigator

Within a driver-free autonomous environment the attribute targets of each lighting system have to focus on the vehicle connectivity and communication instead of providing a better

light for the driver when driving at night. A relocation of the customer experience is essential to meet the new mobility requirements. To provide an optimal autonomous driving environment for the car passengers, as well as for all other road users, it is crucial to consider car to car and car to human communication in the future with the same level of attention as to car passenger needs, or even higher. Where to put the key priorities in detail for exterior lighting is the guiding question of this paper.

3 Feature importance

In general features together with attributes support the brand perception and customer experience, as shown in Figure 5. Features provide customers with advanced functionality and shape the overall vehicle perception, facilitating its attributes. Today's key exterior lighting attributes are on the one hand lighting performance and on the other hand intelligent lighting.

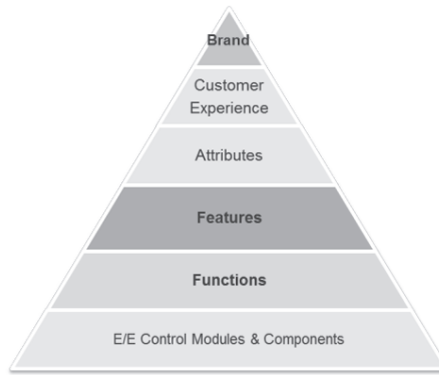

Figure 5: Feature development approach considering the brand and user experience

Considering the age of autonomous driving the attribute lighting performance for related features is no longer the primary goal to achieve for exterior lighting systems in future. Providing a sufficient amount of light on the road for the driver will no longer be required when there is no driver anymore. Additionally, the definition of what intelligent lighting is about will completely change in the future as the vehicle intelligence changes significantly as well. However, driving safety will always be the top attribute to achieve.

Until today exterior lighting was meant to provide light to see better while driving at night. Lately, it was also realized that lamps are a means to identify with the brand driven by the

user experience as a safety and appearance feature. In addition to that, exterior lighting is experienced by the user as a tool to communicate with the environment (C2X). This leads to the age of an autonomous automotive environment where exterior lighting will lose its light providing functions for the driver completely and will shift to a personalized experience of exterior lighting as a communication and identification tool. The overall target at that stage is a new level of mobility and connectivity for future transportation solutions.

Every feature needs to be assessed regarding the impact of the higher level attribute requirements in order to identify and differentiate the main exterior lighting features for autonomous vehicles. This analysis is targeted to achieve an exterior lighting feature set importance for autonomous vehicle. The table below shows an example of feature sets categorized into their attributes and assessed in terms of the importance per attribute for autonomous and non-autonomous vehicles to accomplish a safe mobility environment.

Table 1: Feature importance per attribute for autonomous and non-autonomous vehicles

Feature importance per attribute	**Attribute**	**Feature example**	**Importance for non-autonomous vehicles**	**Importance for autonomous vehicles**
Car2-Driver	Attribute describing exterior lighting attributes to driver	Low beam Map Based AFS; Speed Dependent Light Modes; Dynamic Bending Light; Dynamic Spot Light) High Beam Dynamic Bending Light; Automatic High Beam; Glare-Free High Beam; Traffic-Sign De-glare; High Beam Boost)	9	2
Car2-Pestrian	Attribute describing the lighting attributes to pedestrians	All signal lighting features; Rear/Front Light Symbols	5	10

Car2-Machine	Attributes describing the lighting attributes to the machine/ virtual driver	Light color supporting sensors; Beam pattern increasing sensor detection quality and range	1	10
Car2Car	Attribute describing the lighting attributes to other vehicles using data from surrounding vehicles	Rear/Front Light Symbols; Exterior lighting might be functions only, but no features	0	10

The results of the current assessment show a clear trend in the importance of exterior lighting features in respect to the different attributes. With the focus on enhancing the driver's visibility while driving at night under challenging environmental conditions the car2driver features are extremely important for non-autonomous vehicles. Whereas they do not play any significant role for autonomous vehicles when there is no driver anymore. However, these kinds of features will not completely disappear in future. For sure, autonomous vehicles will play an important role in the upcoming global mobility infrastructure but not with a total market share. Therefore, features which are required to provide an exterior lighting baseline as a legal minimum will remain in the future for autonomous vehicles.

Features that belong in the category of car2pedestrian are already part of the vehicle communication today. Signal lighting features indicate driving directions or the overall vehicle activation already today. With new technologies more ways of how to communicate with pedestrians become possible. With that background, the communication with humans can evolve in certain situations from a driver dependent activation to an activation driven by certain sensors, the virtual driver or machine. Finally, car2machine and car2car supportive features are not that relevant for today's vehicle excellence in exterior lighting. Nevertheless, for fully autonomous driving vehicles lighting and its light color is needed to support sensors and to increase sensor detection range and quality. Additionally, new technologies and the creation of communication symbols, flashing lights or projections among others can increase the interaction between vehicles and machines.

4 From lighting for drivers to lighting for machines

The feature and functional requirements in exterior lighting change in their execution and importance with the megatrend of autonomous vehicles in future. The feature execution, meaning its function, will be a significant part of vehicle price segment differentiation as the offered level of safety must not be compromised. Additionally, the relation of exterior lighting features to certain components as of today will change fundamentally in future. To support the complete range of car2pedestrian, car2machine and car2car features the primary location of exterior lighting features within headlamps, rear lamps, front fog lamps and center high mounted stop lamps are no longer crucial to provide an optimal feature execution.

The given feature assessment indicates that the new age of autonomous driving is more determined by different use cases for exterior lighting features. Lighting features for autonomous vehicles have to support the car passenger and not the car driver with the specific need of different use cases in terms of future communication and mobility as well as the whole environment to facilitate driving safety for all mobility users.

According to the analysis specific use cases of autonomous driving have to be further investigated and defined in order to meet the lighting attribute requirements. The orientation of exterior lighting might be fully dependent on the mobility environment needs whereas the interior lighting might be completely reliant upon the customer needs of the car passenger. Specific use cases have to be further investigated to determine boundaries of the environment impact, driving situation and the scope of what and whom to carry.

5 All features for all cars?

On the basis of having different use cases defining different autonomous vehicle categories it has to be considered that the vehicles are safe within defined driving situations. With that approach another interesting aspect comes into account: use cases dictate the feature deployment as well as defining how intelligent exterior lighting has to be, to meet the attribute requirements. Different vehicle categories are for example, people mover, heavy trucks or even road trains carrying goods. Those vehicles can drive autonomously for instance within defined areas such as business premises, airports or even on separated, closed lanes within a city or only outside of the city on freeways.

As driving safety for all mobility participants is the key goal to achieve, the feature count of an autonomous vehicle is identified by its use case and neither by a specific vehicle segment nor its value proposition. Therefore, the feature set of a B-car people mover has

to be the same as of an E-car people mover in regards to be safely for all mobility participants in an autonomous environment. The more autonomous driving boundaries are defined the better attribute targets for certain lighting features and specific use cases of vehicles can be given. The prediction of uncertainties under challenging driving conditions is a key work stream to further focus on. Indeed, vehicle personalization and customer differentiation can still be achieved in terms of different comfort and appearance feature executions whereas the safety feature set is pre-defined and given for every autonomous vehicle.

6 Conclusion

Autonomous vehicles require a new mindset and development direction for exterior lighting features as well as further attributes. As driving safety is the key attribute to meet for each vehicle, the safety-relevant features highly depend on different use cases of each vehicle. Possible feature count reductions can only be driven by very precisely specified use cases but never based on different vehicle classifications only. Differentiation, personalization and segmentation are achieved by comfort and appearance feature sets and executions. A well-defined level of legislative standards can help to ensure safe driving conditions for autonomous vehicles, creating a baseline for the automotive industry with further potential individual add-ons.

7 Summary and Outlook

In the new age of autonomous driving still remain the industry target to build safe and robust vehicle to fully solve the transportation challenges of the future's high demand of mobility flexibility. The target of building smart vehicle gets more significant in particular for exterior lighting feature and function executions. The demand for next level connectivity, mobility and customer experience will also set the exterior lighting business with autonomous driving vehicles to a completely new level of customer expectations, needs and driving safety. The definition of smart exterior lighting changes significantly compared to todays direction. Autonomous vehicles require from exterior lighting the full concentration on individual mobility use cases to enable driving safety within all driving situations instead of providing a sufficient amount of light on the road combined with a certain feature set depending on the market position and value proposition.