Algorithmic Complexity Approach to Study the Safety Factors of Automated Vehicles

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***Abstract*—The advancement of technology has led big companies to develop even more comfort in transportation, automated vehicles. However, there are safety factors that need to be considered before we can see driverless cars driving around our cities. These safety measures have to be incorporated in the algorithms of the automated vehicles, therefore we can use the theory of algorithmic complexity to analyse the plausibility of these automated vehicles.**

***Keywords*—automated, complexity, safety, vehicles.**

I. Introduction

Nowadays, the concept of "Internet of Things" plays a part in the makings of modern machines and widgets, including vehicle industries, spurring the birth of completely automated vehicles. Google took the lead on the development of these vehicles, but now even car companies like Mercedes and BMW have also started developing driverless cars. Many factors compromising safety have to be considered before these cars can be released in the market.

Today, human resources have been replaced by machines in many areas. They have increased efficiency and productivity, even at the cost of some employment. In fact, due to the overwhelming benefits of automatons, many companies have compromised the safety and human factors in order to boost said efficiency and productivity, sometimes comfort. The advancements of automated technologies are indeed helpful but need to be safe so as to not endanger the people using the machines. Automated cars, in the same way, has been developed for production. In fact, if automated cars were safe enough, the figures of traffic accidents could be lowered.

However, before these cars can be said safe to use, they need to be authorised by the regulating official in the area. It is detrimental that the cars are tested and confirmed safe as we do not want any accidents occurring due to the lack of safety in these cars.

The importance of the safety factor cannot be compromised because it may involve efficiency and in fact, possibly the lives of people.

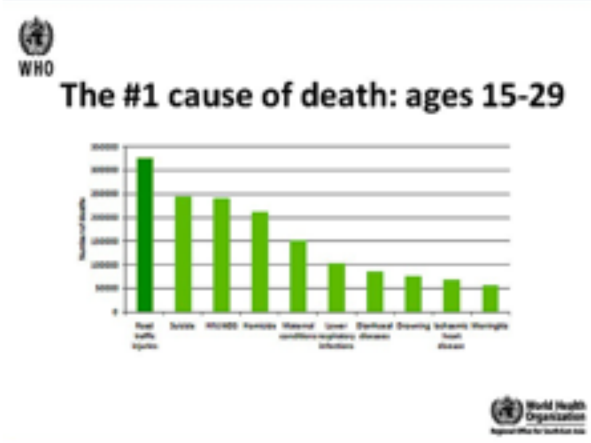


Image 1.1 The number one cause of death in ages 15-29 is traffic accident
source: http://www.thejakartapost.com/news/2017/01/23/as-traffic-death-figures-worsen-what-can-governments-do.html

Therefore, the author feels the need to offer an analysis on the safety of automated vehicles and an overview of an approach using algorithmic complexity to analyse the plausibility of an automated vehicle and the technique to compare the better ways an automated vehicle is handled.

II. Theory

2.1 Algorithmic Complexity

A problem can have a lot of algorithms in order to solve it. However, to determine the most efficient solution, we use a method of analysing the complexity of an algorithm. This complexity is measured by the time taken and memory required for each algorithm.

In analysing Algorithmic Complexity, we use Big-Oh notation to generalise the complexity of time. In Big-Oh notation, we classify each operation into one action. For example, an polynom with a degree of 3 becomes a cubic equation. Thus, the complexity is the same as calculating the number of actions with power of three. Eg. $2x^2 + 5x + 1$ is the same as $2x^2$.

There are several classifications of the operations that we can take as an example:

- Search operation of an array
- Sorting operation
- Addition operation
- Multiplication operation

We can take algorithmic complexity at three different significant values: worst case complexity, best case complexity, and average case.

Sorting Algorithm	Best Case	Average Case	Worst Case
Selection Sort	$O(N^2)$	$O(N^2)$	$O(N^2)$
Insertion Sort	$O(N^2)$	$O(N^2)$	$O(N^2)$
Bubble Sort	$O(N^2)$	$O(N^2)$	$O(N^2)$
Merge Sort	$O(N.\log_2 N)$	$O(N.\log_2 N)$	$O(N.\log_2 N)$
Quick Sort	$O(N.\log_2 N)$	$O(N.\log_2 N)$	$O(N^2)$
Tree Sort	$O(N.\log_2 N)$	$O(N.\log_2 N)$	$O(N^2)$

Image 2.1 An example of Big-Oh notation for several sorting schemes
source: http://informatika.stei.itb.ac.id/~rinaldi.munir/Matdis/2015-2016/Kompleksitas%20Algoritma%20(2015).pdf

The Big-Oh notation is helpful to compare different schemes and to choose one that is most efficient.

2.2 Analysing Automated Vehicle Security

The security control of an automated vehicle needs to be regulated. According to a source on the insurance criteria for automated vehicle in the UK, some factors of safety includes law-abiding, location-specific, clear handover, safe driving, unanticipated handover, safe stop, emergency intervention, backup systems, and accident data.

- Law-abiding: means that an automated vehicle has to abide by the Highway Code, and this means that it has to be able to recognise a Highway sign and the police, or at least has a database on every single Highway Code on the road. When there is an instruction in the name of Law, the vehicle has to be able to comply and override any one of its actions.
- Location-specific: means that in different areas, the vehicle has to be able to react differently and has to be able to adapt in whichever location it is in. For example in a bumpy road, in a highway, etc.
- Clear handover: means that when a driver switches control between manual and automatic, there must be a clear protocol and clear confirmation.
- Safe driving: means that the car is able to anticipate any scenario in order to keep the passengers safe.
- Unanticipated handover: means that there must be appropriate notice when the vehicle needs to unexpectedly return control to the driver.
- Safe stop: means that the vehicle must be able to make a safe stop if it is unable to continue control.
- Emergency intervention: means that the vehicle can identify and respond to an emergency situation. In the events of emergency, the vehicle can make sure that the passengers are safe by deciding what action to take.
- Backup systems: means that when any systems fail, it has an alternative protocol that can take place instead of the initial course of action.
- Accident data: means that in the event of an accident, the vehicle has a blackbox that tells what happens to the vehicle and the reason for the accident.

Only when every condition is satisfied then an automated vehicle can be said safe to use.

III. Studying Safety Factors Using Algorithmic Complexity

A. Law-Abiding

The first condition for automated car safety analysis is that if the vehicle were law-abiding. This means that the car must be able to identify and respond to street signs and to police instructions. In order to be alert, the vehicle must have sensors and are programmed in such a way that they can “see” input and “think” of a response.

However, the way we design these programs can determine the complexity of the problem and can cause a huge difference in the response time. For example, the way we classify states. If we classify street signs as speed limit, instructions, information, etc., our program can more easily determine the nature of a sign system and thus determine the course of action. If we didn't have a proper classification, then the program has to traverse over the possible states to identify and to think up of a response. As a result, with classification, we can skip over unnecessary states and determine the course of action faster.

The problem is, there are a lot of states to choose from because of the variety of sign systems out on the streets. In addition, different regions have different convention for their sign systems. As a result the complexity of algorithms has a very complex nature and thus it could be tedious to measure up the level of complexity.

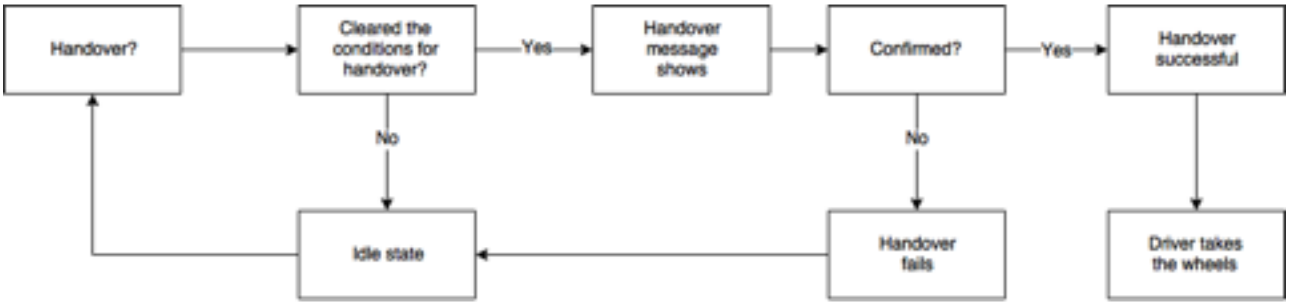
B. Location-Specific

The location-specific nature of automated vehicle can be easily defined by the GPS. However, there needs to be a database of locations that the vehicle needs to access. Otherwise, the vehicles can also use sensors to determine the nature of location it was in real time.

This factor is rather easier to model because it has a less complex algorithm and it can incorporate a pre-existing technology. Thus, it has a rather simple degree of complexity and is easier to realise. However, it do still need to be considered because it may in fact affect other factors as well, such as to determine how quickly it has to take a safe stop, or to determine which precautions to take in case of an emergency.

C. Clear Handover

The clear handover factor may prove to be a factor that demands a lot of considerations. There needs to be a clear protocol set up to switch between manual functions and automated functions. This is to prevent unwanted outcome such as the car being hijacked or being accidentally transferred over manual. This means that there are a lot of accidental scenarios that has to be thought over and to be countered.



The protocol set up means that it may require to go back and forth between states and thus may increase the level of complexity of the algorithm.

Take for example the above image. Before a successful handover can take place, the program has to go through a recursive algorithm to decide whether a handover can be accepted. This means that the complexity increases depending of how many times the algorithm has to be repeated. The more the algorithm repeats, the higher its complexity.

D. Safe Driving

The safe driving factor means that the vehicle must be able to ensure the safety of its passengers. In order to do so, the vehicle must be able to consider many scenarios and be able to respond accordingly. In other words, this factor may have a complex algorithm because there are many scenarios that the program has to think over. Thus, this factor could be said having a very complex algorithm to think over.

E. Unanticipated Handover

The unanticipated handover factor means that the vehicle must be able to switch control from automated to the driver with proper prior notice so that the driver could prepare for the handover. Thus, the program must anticipate scenarios that require it to switch control, whether it is purposefully or accidental.

This factor is important in a sense that if there is an unanticipated event, the vehicle could still safely switch and the driver would be able to be prepared for a take over. However, in the events of emergency, there may be little time to confirm a safe handover. Thus the program needs to have an alternative protocol to override in the events of emergency.

F. Safe Stop

The safe stop factor is rather simple in a sense that it only needs to give a proper slowing down while anticipating and providing a safe stop. However, it also has to consider the speed of the vehicle so that it does not stop too sudden or too slowly, giving room for the driver to prepare for a handover in case it is necessary.

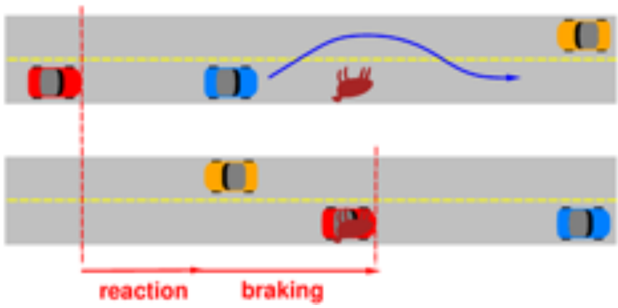


Image 2.2 Illustration of a braking distance and possible threat
source: https://www.av8n.com/physics/car-stopping.htm

As we can see from the image above, the different condition in which a vehicle has to stop can greatly affect the braking distance and braking deceleration of the vehicle. In addition, not only that the vehicle has to consider the obstacles in front of the vehicle, it also has to consider the vehicles behind and around it, so that it can react accordingly if there are anything within it. Which means that this will have to increase the level of complexity of the algorithm of its program.

G. Emergency Intervention

The emergency intervention factor means that the vehicle must be able to anticipate in the events of emergency and react accordingly to an unanticipated events. This means that it has to be able to decide for example whether to slow down or to turn the wheels. This would require the vehicle to analyse many factors and to consider them and choose the suitable response. This could translate to a rather high degree of complexity.

Image 2.3 Illustration of the cases of traffic emergencies
source: https://depositphotos.com/146654903/stock-illustration-car-crash-collision-traffic-insurance.html

An automated vehicle has to have a list of possible scenarios of emergency so that when one of the cases occurs, it can react accordingly, specific to the nature of the emergency. However, for each case, there is a different algorithm to tackle each events, and each derivation may have different algorithms and therefore different levels of complexity. Therefore, the algorithm for emergency intervention may be in fact very complex.

H. Backup Systems

The backup system factor means that the vehicle must be able to keep an alternative action in case that the default action fails. When it does fail, the backup system will propose an alternative plan and would override whatever action that is failing. Thus, even if the default action fails, it would still be safe for the passengers.

I. Accidental Data

The accidental data factor means that the vehicle must be able to keep records of everything that is going on in the vehicle and its surroundings, so that it can troubleshoot itself in the events of emergency. This factor is thus rather simple and has a small degree of complexity.

J. Integrating the Factors

In order to analyse the full credibility of an automated vehicle, we have to look at every single safety factor and weigh each one so that we can rank them. Using the Big-Oh concept, we can compare each factor and see which ones are more significant than the other.

Take for example the factor of Law-Abiding. This clearly is more significant than the Location-Specific factor. Thus, it may be safe to assume that the Location-Specific factor can be overlooked compared to the Law-Abiding factor. Thus, we can ignore the Location-Specific factor to a certain degree when we are analysing both together.

However, when we are analysing similar factor such as the Emergency Intervention factor and the Backup Systems factor, since both are similar compared to each other, we can say that the complexity of both is the sum of both level of complexity. In the Big-Oh notation, we can simply add both together.

IV. Conclusion

In conclusion, each factor has a role to play and thus has to be considered to determine the complexity of a program running an automated vehicle. However, from what we have seen, the complexity is still way too complex before we can see an automated vehicle running. With the current technology, we still have to wait for another few years before automated vehicle technology could be safely used on the streets. Still, the development of such technology would continue and we can expect for one to release in the near future. It comes back to our wisdom to determine whether or not it is safe to use before we get our hands into one of these vehicles.

With the competition of the different companies, there are a lot of possible options of these automated vehicles. However, we need to look at each of their complexities before we can tell which is safer than which. With the competition to become the best out of the best, there will be one that has an advantage over the other in certain fields, but not every fields. It comes back to each of our preference to judge a product and thus its credibility.

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