# Demystifying Navigation Systems – User-Centric Perspective Approach

JOSE M. ARIAS
Systems Engineering Technical Assistance
VITROCISET Belgium
Huygenstraat 34, 2201 DK – Noordwijk
THE NETHERLANDS
j.arias@vitrocisetbelgium.com https://www.linkedin.com/in/josé-manuel-arias-calvo-20134917

*Abstract:* - Russia, the United States, European Union, and even China seem to be all of them embarked in highly consuming projects in terms of cost and time. While it seems to be widely accepted that human capital is enriched through interactions between systems engineers and the final product itself, it is questionable whether the system built is good enough for its user. The trend is currently to evolve the systems existing towards better performances but whether the final user device is aware of it or not during the operational timeline of the system is not clear at all.

*Key-Words:* - COMPASS Navigation Satellite System, Galileo, Global Navigation Satellite System, Global Positioning System, systems engineering, & user needs

## 1 Introduction

The Global Positioning System (GPS) is maybe the most realistic example of a navigation system over the whole globe surface. As the rest of existing operational positioning systems - the Global Navigation Satellite System (GLONASS) - it provides final users with accuracies of the order of meters. Regardless of how it works, accuracies achievable range from 2 to 15 meters, and are valid during 1 nanosecond. Higher accuracy can be reached by means of the use of the Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS), and Multi-functional Satellite Augmentation System (MSAS). In fact, improvements of accuracy from 1 to 5 meters are foreseeable as part of the GPS evolution. Time accuracies are in the 100 nanoseconds range [1].

On the other hand, the Global Navigation Satellite System (GLONASS) accuracy restrictions for civilian use are around 30 meters. In spite of this, it is believed receptors that appear in the market allowing to receive signals belonging to both systems make interesting the possibilities of GLONASS in measurements for the support of GPS. In fact, GLONASS originally was conceived to be as accurate as 65 meters, but it really had 20 meters accuracy for civilian use, and 10 meters for military use. The second generation possesses inter-satellite links between and among satellites to perform control online of the system integrity and enhance the duration of autonomous operation of the satellites constellation without loosing navigation accuracy. GLONASS clocks transfer times with a day-to-day stability of 10 nanoseconds [2].

COMPASS is a project carried out by China whose objective is to develop an independent satellite navigation system. Differently from the previous two projects, it is not still operational. The resulting system will consist on a constellation of thirty Medium Earth Orbit (MEO) satellites, and five Geosynchronous Earth Orbit (GEO) satellites. As it is the case with other satellite navigation systems, the system is prepared to give two service levels: free services and military services. Free services will have an accuracy of localization with an error lower than 10 meters distance, 50 nanoseconds clock synchronization, and an accuracy when measuring speed of 0.2 meters per second margin. Time accuracy can reach 100 picoseconds [3].

Finally, Galileo equates GPS, GLONASS, and COMPASS in Europe. The In-Orbit Validation (IOV) phase was completed between 2011 and 2012 with four new satellites. The last phase – Final Operation Capability or FOC – adds 26 satellites to the previous four. Galileo will give position in space and in real time with accuracies of the order of 1 meter. An important concern, however, of satellite radio-navigation current users is related to reliability and vulnerability of the signal. Several cases of service interruption have happened due to causes like failures in the satellites. Prediction errors have been found to remain below +/- 8 nanoseconds [4].

All of the satellite navigation systems described before – either already operational or not – are global, for they offer a whole coverage of the globe. In spite of GLONASS being previously used as an acronym for the Russian Global Navigation Satellite System, from now hereafter, GNSS will be used as an acronym for a generic Global Navigation Satellite System.

## 2 Practical Application

While it seems timing accuracies are sufficient in all cases analyzed above, it does not seem to be clear distance accuracies of the order of meters are valid for every application. Two use cases have been taken from applications in real world situations. The first of them corresponds to air transportation, while the second one is devoted to land.

### 2.1 High Altitude Platforms

High Altitude Platform (HAP) is "a station on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth." [5] A good example of this device is the High Altitude Long Endurance Demonstrator developed by Lockheed Martin, depicted in Fig. 1.

Fig. 1 High Altitude Long Endurance Demonstrator (http://lockheedmartin.com/)

There are a bunch of different high altitude platforms available in the market of which Zephyr, developed by Airbus, is one of the most important. As it was the case with the previous prototype, it also relies on solar power.

#### 2.1.1 Flow Diagram

It recently appeared in the news that a jihadist was killed in a planned airstrike. United Kingdom's Prime Minister argued the dead man was planning barbaric attacks and justified the action as an "act of self-defense." [6] It is not clear what where the means through which the fatal decision was carried out. Fig. 2 shows a possible flow diagram for the way the corresponding mission could be performed.

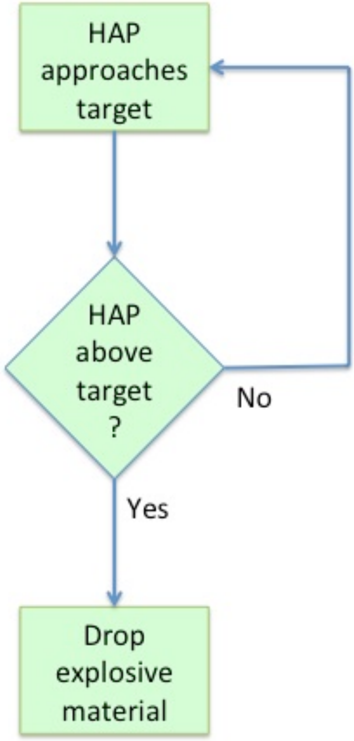


Fig. 2 HAP activity diagram

It is clear the diagram above hides complexity to the point it does not consider aerial obstacles in the way of the HAP towards its destination, and it does not consider signal processing techniques that could definitely help determine the position of the object to be attacked. However, it is a first example – very simple – helping understand how a global navigation system could help address this kind of mission. Another simplification of the analysis lies in the fact no counterattack measurements have been considered – such as electronic was measurements and counter-measurements. Finally, the attacked objective should be sufficiently isolated for an explosion to be not harmful to any other possible friendly object – especially when human lives are involved – around the target. Considering, for example, a 10 meters error (cf. section 1). It has also been considered the detonation effect of the bomb launched from the HAP is as wide as necessary to make sure the before mentioned target is destroyed.

### 2.1.2 Use Case

Information flows establish the need to make sure the final user of the system – maybe the RAF headquarters – is aware of the state of the HAP under operation. It will be necessary, then, to ensure there is an information channel established between the HAP and the RAF headquarters. This is not responsibility of a global navigation system, but it seems to be clear the HAP should be able to know if the position reported to it by means of the navigation service has enough accuracy, and: (1) should accuracy be high enough, then the system commanding attack operations would sound reasonable; (2) on the contrary, al alert message should be reported from the HAP to the operator. This is depicted in Fig. 3 graphically.

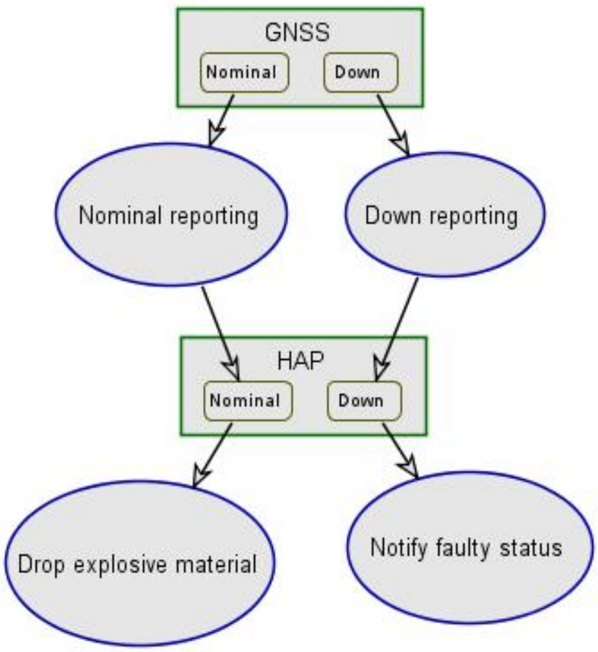


Fig. 3 HAP over target use case

The diagram above is also rather simple, for it is understood the GNSS also has to make the HAP know its position, apart from the fact whether satellites and associated GNSS components are in a nominal state or not. It is clear from it, however, there should be a mechanism to make the HAP device in charge of letting the HAP know its location how many satellites, Ground Sensor Stations, Up Link Stations, Telemetry & Tele Command stations, among other determinant factors, are available at each moment of time.

## 2.2 Highway Driving

Applications of navigation systems can be found both in urban and interurban traffic. While urban driving truly deserves attention, interurban driving will surely receive more benefits from an improved GNSS. It is not now the intention of the current section to provide the reader with an original use of mapping and navigation products. This will surely come later.

### 2.2.1 Flow Diagram

Current use of satellite navigation systems for car drivers just makes use of the GNSS services to locate the position of a vehicle on the road. By knowing roads connected to the road through which the vehicle transitions, an application can tell the driver of a car what is the next movement a driver may perform in order to reach a predetermined final destination. This is depicted in Fig. 4 graphically.

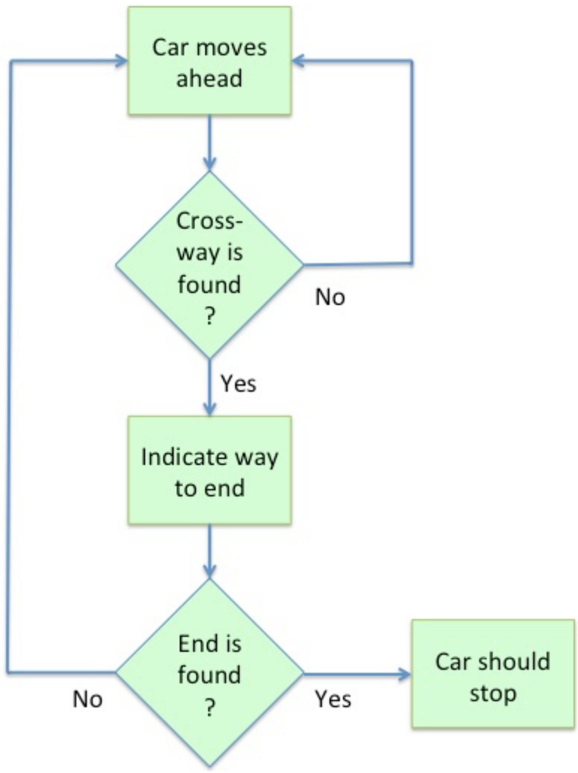


Fig. 4 Driver activity diagram

This activity diagram is very simple and involves the car driver through sentences like "Indicate way to end." It is not foreseen the car itself will perform automatic driving. It would be probably possible through the combination of satellite navigation system technologies with monitoring and control sensors installed along the back, front, and sides of the car. However, current accuracies of the order of meters jeopardize the idea of making a car independent of its driver completely.

### 2.2.2 Use Case

Intelligent vehicle systems are currently under investigation by the international community. A good example of how information and communication technologies can be used for improving car driving and diminishing the amount of car accidents is depicted in Fig. 5.

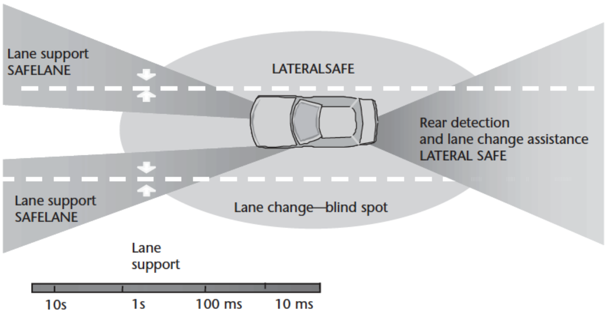


Fig. 5 Lateral Monitoring & Control systems [7]

The project under which this ingenious development is carried out is related to European Commission's i2010's intelligent car initiative [8]. It sounds reasonable that with current existing technologies it is not possible to grant car location reporting at lane level. Therefore, this particular application would be a good reason for an evolution of existing global satellite navigation systems. The purpose of the current section, however, is to focus on the kind of potential applications in line with the activity diagram depicted in Fig. 4. A need exists to make sure the final user of the system – the car driver – is aware of the state of the accuracy of the positioning parameter derived from signals acquired through different satellites. Should accuracy be high enough, then the car driver could follow instructions from its navigation application. On the contrary, al alert message should be reported from the car navigation system terminal to the operator if a lack of accuracy exists. This is depicted in Fig. 6 graphically.

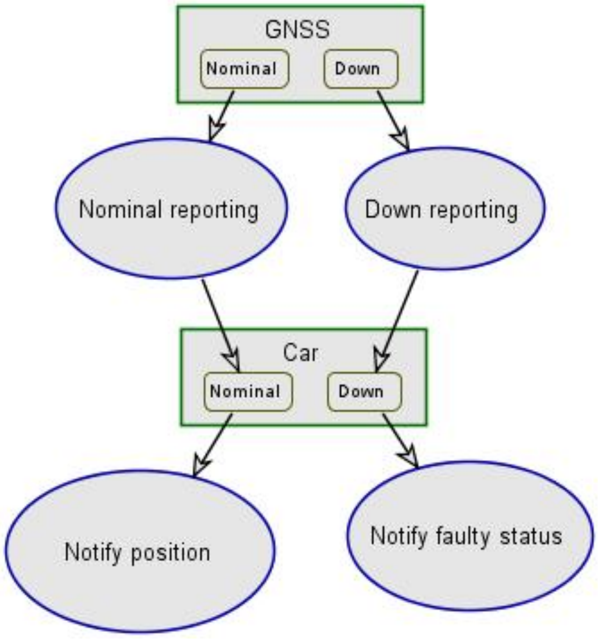


Fig. 6 Driver use case

In practice, errors induced by an incorrect behavior of the satellite navigation system are so negligible when compared to kilometric distances that faulty status will never occur. It will not be the case, however, if greater accuracies are to be required by the kind of applications described in the next section 3.

## 3 Improved Configuration

Distance accuracies of the order of meters allow operators to deal with more complex scenarios. Again, two use cases have been taken from applications in real world situations. The first of them corresponds once again to air transportation, while the second is devoted to land.

### 3.1 High Altitude Platforms

Moving HAPs towards an isolated area in the middle of e.g. a dessert and making the corresponding target explode sounds reasonable when it is clear no further damage is performed, especially human-wise. However, when there is a minimum doubt about accuracy, aborting the dropping of explosive material sounds ethically reasonable. Imagine a scenario like the one depicted in Fig. 7.

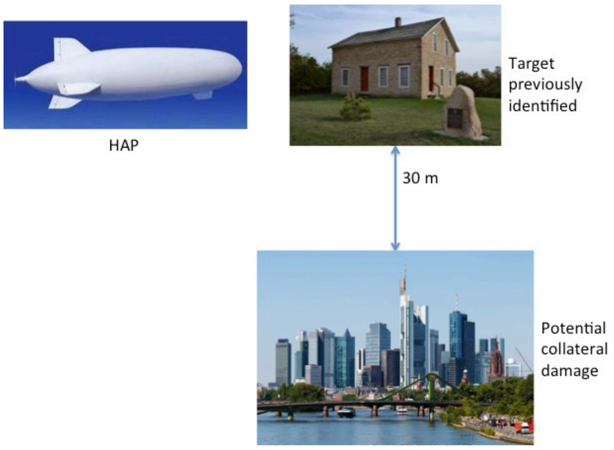


Fig. 7 HAP scenario with stringent requirements

In this case, it is important realizing the accuracy of the attack commanded from the HAP should be of the order of a few meters at maximum, and the detonation radius of the bomb dropped from the HAP not greater than 30 meters. Otherwise, it can happen that potential collateral damages are provoked, with the subsequent loss of human lives and maybe – and less importantly – material damage and moral remorse.

### 3.1.1 Flow Diagram

Further controls are to be added to the original diagram depicted in Fig. 2. A resulting proposal is represented in Fig. 8 graphically.

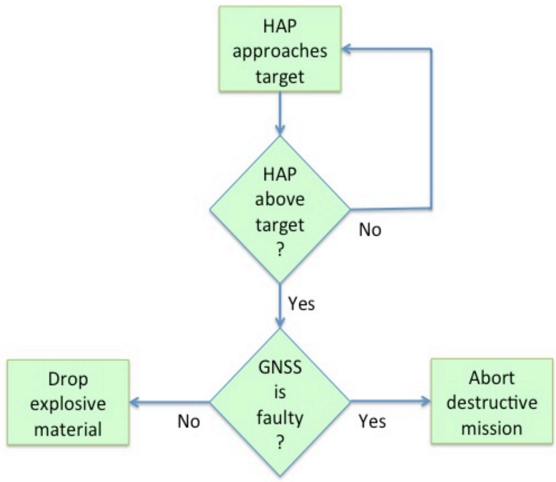


Fig. 8 Enhanced HAP activity diagram

The unintended consequences of neglecting whether the GNSS giving service to the HAP is or not faulty will be analyzed as part of next section 4, dealing with emergent behaviors. This kind of behaviors can be good or bad.

### 3.1.2 Use Case

The fact whether the status reported by the GNSS was taken into account or not by the HAP in charge of performing the destructing action previously described was already taken into account in section 2.1.2 above.

## 3.2 Highway Driving

Highway driving with very accurate positioning reporting – let us take into account it is possible for applications other than open service to reach accuracies of around 1 cm – could allow users to know in what lane of a highway their car travels. Combining this technology with the kind of sensors described in section 2.2.2 could lead to an intelligent overtaking system. But in order to achieve this, the sensors in Fig. 5 are not enough. What is depicted in Fig. 9 would be more appropriate.

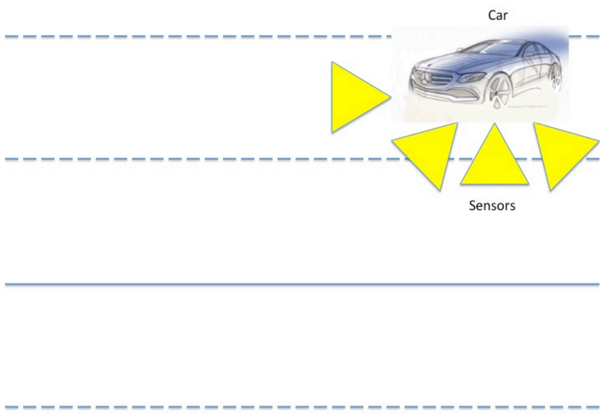


Fig. 9 Lateral Monitoring & Control system for overtaking action

If there is an application generated mapping GNSS positions to the lane in which the car using the system is driving, then it would be possible for the car to know in what lane it is. If the car detects there is another car to be overtaken just in front of it, and there is another lane available in the left, then it should be possible for the original car to perform an automatic overtaking operation, situating itself in the left lane.

#### 3.2.1 Flow Diagram
Further controls are to be added to the original diagram depicted in Fig. 4. A resulting proposal is represented in Fig. 10 graphically.

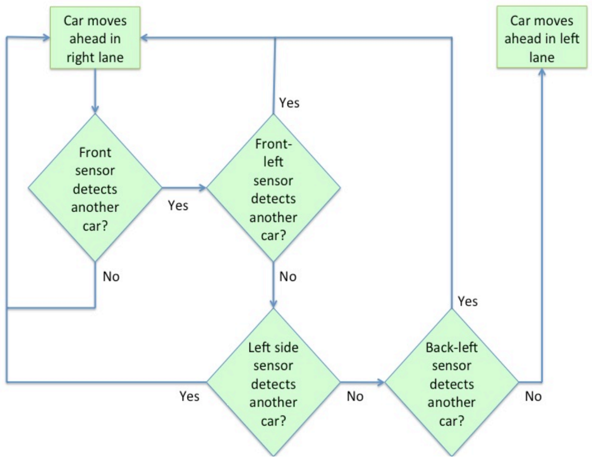


Fig. 10 Automatic overtaking activity diagram

The unintended consequences of neglecting whether the GNSS giving service to the car is or not faulty will be analyzed as part of next section 4, dealing with emergent behaviors. This kind of behaviors can be good or bad.

#### 3.2.2 Use Case
The fact whether the status reported by the GNSS was taken into account or not by the car in charge of performing the automatic overtaking action previously described was already taken into account in section 2.2.2 above.

## 4 Emergent Behavior
Complexity necessarily leads to unexpected behaviors [9]. This is called emergent behavior. Here it will be analyzed why the importance of making the final user aware of the status of the GNSS that supports operations.

### 4.1 High Altitude Platforms
In the case of a High Altitude Platform, if the HAP is moving towards a target identified previously but an error of 60 meters is present in the signal acquired through the GNSS, then it is possible that Fig. 7 is not really representative of the way the system will behave. Instead, the situation represented in Fig. 11 could be the case.

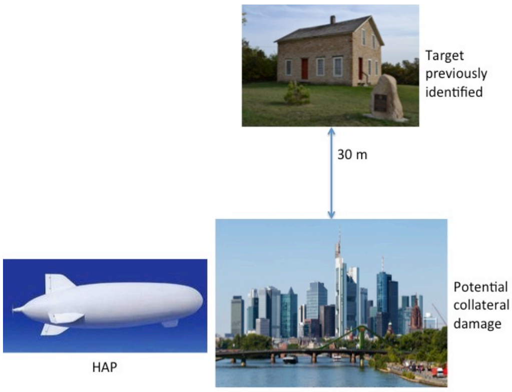


Fig. 11 HAP Welt ein sich

If the user was not aware of a fault status reported by the GNSS, then it could happen that it was bombing a geographical area totally different from the one intended. In this example, Fig. 7 would correspond to the Kantian category Welt für mich – the user – while Fig. 11 would correspond to Welt ein sich.

### 4.2 Highway Driving
In the case of highway driving, if the car willing to carry out an overtaking action has an error lane-wide, then it could happen that even though its vision is the one in Fig. 9, reality seems to be more similar to what is depicted in Fig. 12 below. Fig. 9 is not representative then of the way the system will behave.

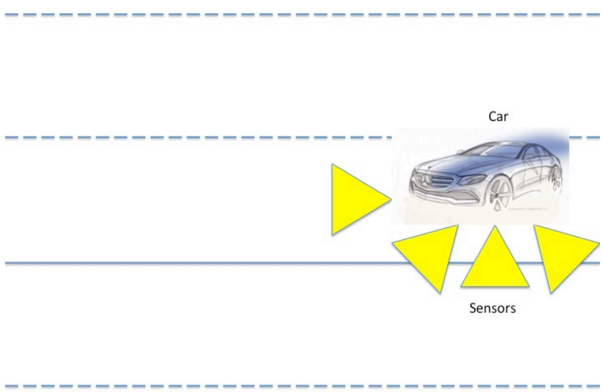


Fig. 12 Car Welt ein sich

If the user car was not aware of a fault status reported by the GNSS, then it could happen that it gets driving in opposite direction, eventually crashing against another car coming against it. In this example, Fig. 9 would correspond to the Kantian category Welt für mich – the user – while Fig. 12 would correspond to Welt ein sich.

## 5 Conclusion

The two previous examples have shown the need to make the user aware of the status of the system – either nominal or down. If the user terminal could know availabilities of satellites, Ground Sensor Stations, Up Link Stations, Telemetry & Tele Command stations, among other determinant factors, it would be possible to internally compute to what extent predictions coming from a GNSS are correct. If would also be gentle if the navigation system was able to provide the final user with an estimate of expected robustness, for a sailor, for example, will think twice before going to the sea when it is not likely he will receive good coverage.

The author wants to acknowledge the set of efforts performed by Nicola de Quattro and Ricard Alegre-Godoy for their patient support in setting the basis for the author of this article to understand the aspects of the system conditioning its Monitoring and Control functionality. These will be crucial through interaction with final users by means of concepts like signal in space flexibility.

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