GPS and other satellite navigation systems in urban transport

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Abstract **– In urban transport the knowledge of the actual position of the car is one of the most important elements, which determines the economic aspect and the safety. At present (April 2003) this position can be obtained by the use of satellite navigation systems, in particular GPS system. In urban area the possibility of fix position and its accuracy depend on the number of satellite visible above masking elevation angle, the geometry of the system, the dimensions and location of the obstacles, like the heights of the buildings (B), the width of the street (L) and the angle between the North and street axis (α). The calculations were made for the observer situated in the middle of the street for different values of B, L and α at different latitudes for two systems – GPS and Galileo, new system under construction in Europe. The resulting of position fix and overall accuracy are greater for Galileo than for GPS system.**

1. Introduction

The continuous information of the user's position is one of the most important elements, which determines the economic aspect and the safety of the user in the sea transport and rail & road transport. Accuracy requirements of the user's position depend upon various factors which include three different levels of coverage (global, regional and local) and safety performance:

- – essential use – safety of life,
- – essential use – other applications,
- – non essential use.

The user applications summary is presented in the table 1, the summary of accuracy requirements in the table 2. It is recognized that the categorisation are some what subjectively based on current capabilities and may change, particularly if dependence on satellite navigation systems increases, the applications may move from Non–essential to Essential. Also the distinction between local and regional is not always a clear dividing line [4], [6].

A user's position can be obtained by many different methods [3]. At present (April 2003) the most frequently used methods are based on the global satellite navigation systems (SNS) – American GPS (Global Positioning System – Navstar) and Russian Glonass. The new system – Galileo, sponsored by the European Union, is under construction as the European contribution to the next generation of satellite navigation. Nowadays in urban transport the position with mentioned accuracy requirements can be obtained by only GPS system, which is fully operational. The number of different cars equipped with GPS receiver has been increasing continuously. The calculations were made for GPS system and Galileo system for the most probable configuration.

2. Position accuracy

The receiver of satellite navigation system (SNS) needs to see at least four satellites to calculate latitude, longitude, altitude and time. The geometry of the visible satellites changes

Table 1. User applications summary

Coverage	Safety criticality		
	Essential		Non essential
	Safety of life	Other	
Global	Aviation Marine: Oceanic SAR	Timing and frequency Fisheries – deep sea	Recreational
Regional	Aviation Marine: Coastal phase Road: Safety and security Collision avoidance Rail: Train location and control	Rail: management infor–mation Road: Fleet management Land survey Marine survey	Road: Information servi-ces Navigation Demand manage-ment Rail: Passenger informa-tion
Local	Aviation Marine: Harbours Inland waterways Rail: Train location and Control	Marine: Dredging Hydrography Tracking personnel and containers	Road: Traffic control

Table 2. Summary of accuracy requirements [m]

Coverage	Essential		Non essential
	Safety of life	Other	
Global	10 – 100	10 – 100	10 – 100
Regional	1 – 10	1 –10	1 –10
Local	0,1 – 10	0,001 – 10	–

with time due to the relative motion of the satellites constellation. Position fix can be calculated only from these satellites SO (SO – satellite fully operational), which elevation angle at the moment of measurement in observer's receiver is higher than the masking elevation angle H_{min}. If the number of satellites visible by the observer is less than 4, its 3D (three–dimensional) position cannot be obtained (the position is not available – No fix > 0).

Although SNS has a very high availability, mission planning is important, especially if the location has terrain features, which may block the visibility of satellites. Therefore the typical input parameters used to perform SNS mission planning are:

- – location of the observer; especially its latitude,
- – mask angle H_{min};
- – terrain mask; especially in restricted (urban) area; the azimuth and elevation of terrain (buildings, mountains).

The accuracy of the position solution determined by SNS is ultimately expressed as the product of a geometry factor and a pseudorange error factor [5]:

error in SNS solution = (geometry factor) · (pseudorange error factor) (1)

As the error in mentioned solution can be expressed by σ_ρ – the standard deviation of the positioning accuracy, geometry factor by the dilution of precision (DOP) coefficient and pseudorange error factor by the term UERE (User Equivalent Range Error) σ_{UERE}, the relation (1) can be defined as:

$$\sigma_\rho = DOP \cdot \sigma_{UERE} \quad (2)$$

If we can obtain four coordinates of the user's position (latitude, longitude, altitude, time – φ, λ, h, t), geometry factor DOP is expressed by GDOP (Geometric Dilution of Precision) and the position accuracy with 95% confidence level $M^{95\%}_{\varphi,\lambda,h,t}$ can be approximated by:

$$M^{95\%}_{\varphi,\lambda,h,t} \approx 2\ GDOP \cdot \sigma_{UERE} \quad (3)$$

In urban transport we are interested in horizontal (two–dimensional) position only. Therefore if we can obtain two coordinates of the user's position (latitude, longitude – φ, λ), geometry factor DOP is expressed by HDOP (Horizontal Dilution of Precision) and the position accuracy with 95% confidence level $M^{95\%}_{\varphi,\lambda}$ can be approximated by:

$$M^{95\%}_{\varphi,\lambda} \approx 2\ HDOP \cdot \sigma_{UERE} \quad (4)$$

In the case of GPS system (in April 2003) for a geometry with HDOP = 1.5 and with σ_{UERE} = 7.5 m, estimate for the 95% point for the magnitude of the horizontal error is given as follows:

$$M^{95\%}_{\varphi,\lambda} = 2 \cdot 1.5 \cdot 7.5\ m = 22.5\ m \quad (5)$$

This position accuracy (22.5 m) can be increased by the use of differential mode – DGPS. This mode needs the reference stations and the transmission of the pseudorange corrections, but horizontal error (95%) decreases to few meters. Now we can say, in urban area the accuracy of GPS (DGPS) position is sufficient.

HDOP coefficient value = 1.5, horizontal error $M^{95\%}_{\varphi,\lambda}$ = 22.5 m and mentioned above accuracy of DGPS (few meters) are real on condition that all 27 GPS satellites are fully operational and all satellites visible by the user above horizon can be taken into account in position calculation process. These conditions are satisfied in open area only. Therefore in this area the accuracy of the user's position obtained from GPS and other satellite navigation systems depends on a number of satellites (l_s) visible above masking elevation angle (H_{min}) and the geometry of systems – GDOP coefficient. The distributions (in per cent) of GDOP coefficient values for the observer in open area at different elevation H_{min}, alternatively for GPS and Glonass systems (with configuration 24 satellites) and for different numbers of operational satellites were described by the author in [1] and [2].

In restricted area (coastal navigation, urban area etc.), e.g. in the area where some satellites above horizon cannot be visible by the user, position accuracy depends on the parameters mentioned for open area and additionally the dimensions and location of the obstacles. There is not a direct relation between a number l_s of satellites visible above H_{min} and GDOP coefficient value, but we can realize "when l_s is greater, GDOP is less" and vice versa "when l_s is less, GDOP is greater".

In this situation we can put the following questions:

- – how many satellites are visible by the user in open area at different observer's latitudes and at different masking elevations angles, in particular for the angles 10^O and 15^O ?
- – in which way the number of satellites visible by the observer in urban area depends on the dimensions and the location of the obstacles ?

3. Test Method

The calculations were performed for two systems:

- – Galileo (GAL); 27 satellites SO distributed in three planes with nine satellites on the altitude 23616 km and with the inclination 56 degrees,
- – GPS– Navstar (GPS); 27 satellites SO distributed in three planes with five satellites and three planes with four satellites on the altitude 20 183 km and with the inclination 55 degrees.

The interval of the latitude of the observer between 0^O and 90^O was divided into 9 zones, each 10^O wide. Orbit parameters – right ascension of ascending nodes and arguments of latitude for all 27 GAL satellites and 27 GPS satellites at the referred time were known.

Elevation H_{min} was assumed to be 0^O, 5^O, 10^O, and 15^O. Satellite selection criteria (combination of 4 satellites) were found on the base of minimization of GDOP. All calculations, based on reference ellipsoid WGS–84, were made by using author's simulating program.

For every system, for each zone of latitude and for each masking elevation angle (H_{min}), one thousand (1000) geographic-time coordinates of the observer were generated by random–number generator with uniform distribution:

- – latitude interval 0 – 600 minutes (10^O),
- – longitude interval 0 – 21600 minutes (360^O),
- – time interval 0 – 1440 minutes (24 hours).

For each geographic–time coordinates the satellite elevation (H), the satellite azimuth (Az) and the number of visible satellites (l_s) were calculated. Elevation H was divided in 9 intervals, each 10^O wide: 1st for $0^O<H\leq10^O$, 2nd for $10^O<H\leq20^O$, . . . , 9th for $80^O<H\leq90^O$. Azimuth (Az) was divided in 8 intervals: 1st for $0^O<Az\leq45^O$, 2nd for $45^O<H\leq90^O$, . . . , 8th for $315^O<H\leq360^O$.

The calculations were made in the open area and in urban area for the observer situated in the middle of the street for different buildings heights and different widths of the street. Street parameters were: the angle between the North and street's axis and latitude φ.

4. Satellite visibility in open area

The minimal, maximal and weighed mean numbers of satellites visible for different H_{min} were calculated in all 9 latitude zones for both systems. The results in 4 zones, 0–10^{O} as low latitude, 40–50^{O} and 50–60^{O} as middle latitudes and 80–90^{O} as high latitude are presented in the Table 1. We recapitulate that:

- – the number l_s of satellites visible above the horizon ($H_{min} = 0^{O}$) changes between 6 and 12 for GAL and between 7 and 14 for GPS. The number l_s decreases with H_{min} for both systems, independently of observer's latitude, but for GPS system l_s can be equal 3 for $H_{min} = 20^{O}$ in zone 20–30^{O} and for $H_{min} = 25^{O}$ at latitude 10^{O} to 80^{O}. It means, that the position of the observer in mode "3D" cannot be obtained.

Table 1. Number of satellites visible in open area for different masking elevation angles (H_{min}) for Galileo system and GPS system at different observer's latitudes (φ); l_{min} – minimum value, l_{max} – maximum value, l_m – weighted value

φ [^{O}]	H_{min} [^{O}]	Sys–tem	Number of satellites			φ [^{O}]	H_{min} [^{O}]	Sys–tem	Number of satellites		
			l_{min}	l_{max}	l_m				l_{min}	l_{max}	l_m
0 – 10	0	GAL GPS	9 9	12 13	11.05 10.74	50 – 60	0	GAL GPS	9 8	12 13	10.84 10.53
	5	GAL GPS	8 7	12 13	10.02 9.75		5	GAL GPS	6 6	12 12	9.66 9.31
	10	GAL GPS	7 6	11 12	8.96 8.69		10	GAL GPS	6 5	11 11	8.41 8.16
	15	GAL GPS	6 5	10 10	7.84 7.59		15	GAL GPS	5 4	10 10	7.35 7.07
	20	GAL GPS	4 4	9 9	6.62 6.38		20	GAL GPS	4 3	9 9	6.40 6.19
	25	GAL GPS	4 3	8 8	5.46 5.20		25	GAL GPS	4 3	8 8	5.56 5.36
40 – 50	0	GAL GPS	7 7	12 13	10.25 9.74	80 – 90	0	GAL GPS	10 8	12 14	11.28 10.90
	5	GAL GPS	6 6	12 12	8.95 8.58		5	GAL GPS	9 8	12 12	10.38 9.35
	10	GAL GPS	6 5	11 11	7.87 7.57		10	GAL GPS	9 7	11 12	9.46 9.07
	15	GAL GPS	6 4	10 9	6.98 6.73		15	GAL GPS	7 6	9 11	8.53 8.16
	20	GAL GPS	4 4	9 9	6.18 5.93		20	GAL GPS	6 4	9 10	7.60 7.24
	25	GAL GPS	4 3	8 8	5.41 5.15		25	GAL GPS	5 4	8 9	6.66 6.22

- – the mean number l_m of satellites is greater for GAL than for GPS in all 9 zones and for each H_{min}.

The distributions (in per cent) of satellite elevation angles (H) in all 9 latitude zones for both systems are presented in the Table 2. We recapitulate that:

- – the distributions of angle H values in all 9 zones for both systems are practically the same,
- – for both systems the angles H in latitude zone 70–80^O are less than 80^O and in zone 80–90^O less than 60^O,
- – for both systems in all 9 zones about half of satellites is visible below 30^O, while the percentage of satellites visible above 70^O is less than 10.

Table 2. Distribution (in per cent) of satellite elevation angles (H) in open area for Galileo system and GPS system at different observer's latitudes (φ),

φ [^{O}]	**Sys–tem**	**Elevation angle H [^{O}]**								
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**
0 – 10	GAL GPS	18.8 19.2	21.2 21.5	19.8 20.3	14.8 14.6	9.5 9.2	7.3 6.9	5.0 4.7	2.7 2.6	0.9 1.0
10 – 20	GAL GPS	22.4 22.5	18.6 18.7	15.4 15.9	14.4 14.7	12.1 11.6	7.8 7.7	5.3 4.9	3.0 3.0	1.0 1.0
20 – 30	GAL GPS	21.4 21.2	17.1 16.9	14.5 14.9	12.7 13.2	12.4 12.6	10.7 10.7	6.3 6.2	3.7 3.3	1.2 1.0
30 – 40	GAL GPS	21.0 20.2	16.8 16.8	13.9 14.9	12.5 12.3	11.0 11.2	9.6 10.2	9.1 8.7	4.5 4.4	1.6 1.3
40 – 50	GAL GPS	23.0 22.2	16.7 16.9	14.3 14.9	11.8 12.1	9.9 10.1	8.5 8.7	7.6 7.2	6.1 5.8	2.1 2.1
50 – 60	GAL GPS	23.0 24.1	19.7 19.3	14.5 14.8	11.8 11.3	9.3 10.1	8.2 7.8	6.4 6.1	4.8 4.1	2.3 2.4
60 – 70	GAL GPS	18.2 19.8	21.5 22.4	18.4 17.7	13.1 13.1	10.2 10.0	8.5 7.9	6.5 6.2	3.3 2.7	0.3 0.2
70 – 80	GAL GPS	16.4 18.1	17.5 18.1	20.4 21.9	18.9 18.2	12.8 11.8	9.8 9.0	4.1 2.9	0.1 0	– –
80 – 90	GAL GPS	16.2 16.8	16.5 16.8	16.7 19.0	21.1 23.6	24.2 20.9	5.3 2.9	– –	– –	– –

Distributions (in per cent) of satellite azimuths for angle H_{min} = 0^O and H_{min} = 15^O for both systems at different observer's latitudes (φ) are presented in the Table 3. We can say that:

- – distributions of satellite azimuths for both systems are practically the same at given angle H_{min},
- – at latitudes 0–20^O for H_{min} = 0^O and in zone 0–10^O for H_{min} = 15^O the number of satellites with azimuth from intervals 315–045^O and 135–225^O are for both systems greater than from intervals 045–135^O and 225–315^O considerably,
- – at latitudes 70^O to 90^O the distributions for both systems are practically equal for H_{min} = 0^O and H_{min}=15^O,
- – at latitudes 30^O to 60^O for H_{min} = 0^O and H_{min} = 15^O the number of satellites with azimuth from interval 315–045^O are for both systems less than from intervals 045–090^O and 270–315^O considerably.

5. Satellite visibility in urban area

In urban area the mean number of satellites (l_{ms}) visible above H_{min} and the obstacles blocking the observer situated in the middle of the street for different angles between the North and street axis (angle α) for two systems at different observer's latitudes (φ) are demonstrated in the Tables 4 and 5. The calculations were made for four angles H_{min} (0^O, 5^O, 10^O and 15^O) for two dimensions of the street (1st – width L = 20 m, height of the buildings B = 10 m, 2nd – width L = 70 m, height B = 15 m) for four angles α (0^O, 45^O, 90^O and 135^O) for three selected zones of latitude (two extreme 0–10^O and 80–90^O and zone 50–60^O, latitude interval of Poland). We recapitulate that:

- – the number l_{ms} for Galileo system is always greater than for GPS system,

Table 3. Distribution (in per cent) of satellite azimuths for different masking elevation angles (H_{min}) for Galileo system and GPS system at different observer's latitudes (φ), l_m – weighted mean number of satellites visible

φ [^{O}]	H_{min} [^{O}]	Sys–tem	l_m	Satellite azimuth [^{O}]							
				0 – 45	45 – 90	90–135	135 – 180	180 – 225	225 – 270	270 – 315	315 – 360
0 – 10	0	GAL GPS	11.05 10.73	14.6 14.5	10.2 10.6	10.2 10.0	14.8 15.0	14.8 14.8	10.2 10.0	10.4 10.6	14.8 14.5
	15	GAL GPS	7.84 7.59	16.1 15.9	9.7 10.2	9.7 9.3	14.4 14.3	14.3 14.2	9.7 9.7	10.0 10.3	16.3 16.1
10 – 20	0	GAL GPS	10.84 10.53	14.0 13.4	11.1 11.5	10.2 9.9	14.5 15.0	14.7 14.8	9.8 9.9	11.5 11.9	14.2 13.6
	15	GAL GPS	7.35 7.07	16.8 16.4	11.2 11.7	10.2 9.6	11.8 12.1	11.6 11.5	9.9 10.5	11.7 12.0	17.0 16.2
20 – 30	0	GAL GPS	10.23 9.85	13.1 12.3	13.2 14.0	10.8 10.4	12.7 13.1	12.8 12.8	10.2 10.5	13.6 14.3	13.6 12.6
	15	GAL GPS	7.11 6.90	15.0 14.1	13.2 14.5	10.6 10.0	10.8 11.0	10.8 10.8	10.3 11.0	13.8 14.1	15.5 14.5
30 – 40	0	GAL GPS	9.96 9.51	11.0 9.6	16.4 18.0	11.1 10.6	11.3 11.7	11.6 11.7	11.0 11.3	16.3 17.6	11.1 9.5
	15	GAL GPS	7.01 6.77	10.5 9.1	17.7 19.0	11.1 10.5	10.1 10.9	11.1 10.6	10.9 11.6	17.3 18.9	11.3 9.4
40 – 50	0	GAL GPS	10.25 9.74	8.7 7.1	19.5 20.3	11.1 11.3	10.8 11.0	11.1 11.0	11.1 11.9	19.0 20.0	8.7 7.4
	15	GAL GPS	6.98 6.73	4.6 3.4	22.4 22.7	11.7 12.1	10.7 11.2	11.6 10.8	11.8 12.7	22.2 23.6	5.0 3.5
50 – 60	0	GAL GPS	10.85 10.39	10.0 8.9	17.4 17.6	12.0 12.3	10.4 11.1	11.1 11.1	12.1 12.4	17.1 17.3	9.9 9.3
	15	GAL GPS	7.14 6.80	4.0 2.7	20.7 20.3	13.6 14.6	11.4 12.2	12.2 12.3	14.1 14.3	20.3 20.9	3.7 2.7
60 – 70	0	GAL GPS	11.08 10.74	11.0 10.5	14.1 14.2	13.0 13.3	11.6 11.8	12.0 11.8	12.9 13.4	14.2 14.0	11.2 11.0
	15	GAL GPS	7.95 7.41	8.6 6.9	14.8 14.9	14.1 15.2	12.2 12.7	12.5 12.9	14.2 15.1	15.1 15.2	8.5 7.1
70 – 80	0	GAL GPS	11.20 10.90	11.8 11.5	13.1 12.9	12.6 13.1	12.1 12.3	12.7 12.4	12.7 12.9	12.9 12.8	12.1 12.1

	15	GAL	8.40	10.8	13.1	13.2	13.6	13.2	13.0	12.9	11.2
		GPS	7.96	10.3	12.9	13.8	12.5	13.0	13.8	12.9	10.8
80 – 90	0	GAL	11.28	12.1	12.9	12.3	12.4	12.7	12.4	12.6	12.6
		GSP	10.91	12.1	12.6	12.7	12.5	12.6	12.8	12.3	12.4
	15	GAL	8.53	11.9	12.9	12.6	12.3	12.9	12.4	12.6	12.4
		GPS	8.16	12.1	12.6	12.7	12.5	12.6	12.8	12.3	12.4

- – the number l_{ms} depends on the observer's latitude for each angle H_{min} for each angle α for both systems. This number has maximum in zone 80–90^O and minimum in zone 50–60^O,
- – the number l_{ms} decreases and the relation l_m/l_{ms} increases with angle H_{min} in each zone for each angle α for both systems,
- – in zone 80–90^O the number l_{ms} for different α is practically the same for both systems for each H_{min}, in other zones l_{ms} depends on angle α in each case,
- – the number l_{ms} depends on the dimensions L and B (the detailed results are in the Tables 6 and 7),
- – the number l_{ms} is for both systems less than 4 for L = 20 m and B = 10 m in zone 50–60^O for α = 0^O only.

Table 4. Mean number of satellites l_{ms} visible above H_{min} and the obstacles by the observer situated in the middle of the street (width L = 20 m, height B = 10 m) for different angles H_{min} for different angles between the North and street axis (α) for Galileo system and GPS system at different observer's latitudes φ

φ [^{O}]	H_{min} [^{O}]	System	l_m	Angle α [^{O}] 0		45		90		135	
				l_{ms}	l_m/l_{ms} [%]	l_{ms}	l_m/l_{ms} [%]	l_{ms}	l_m/l_{ms} [%]	l_{ms}	l_m/l_{ms} [%]
0 – 10	0	GAL	11.05	7.77	70.3	7.97	72.1	7.34	66.4	7.99	72.3
		GPS	10.74	7.54	70.2	7.72	71.9	7.04	65.5	7.72	71.9
	5	GAL	10.02	7.77	77.5	7.86	78.4	7.23	72.2	7.87	78.5
		GPS	9.75	7.54	77.3	7.62	78.2	7.00	71.8	7.60	77.9
	10	GAL	8.96	7.74	86.4	7.54	84.2	7.12	79.5	7.53	84.0
		GPS	8.69	7.51	86.4	7.26	83.5	6.85	78.8	7.30	84.0
	15	GAL	7.84	7.35	93.8	7.07	90.2	6.83	87.1	7.07	90.2
		GPS	7.59	7.09	93.4	6.82	89.9	6.57	86.6	6.84	90.1
50 – 60	0	GAL	10.85	7.62	70.2	7.33	67.6	7.23	66.6	7.28	67.1
		GPS	10.40	7.00	67.3	6.99	67.2	6.89	66.3	6.94	66.7
	5	GAL	9.67	7.51	77.7	7.25	75.0	7.17	74.1	7.23	74.8
		GPS	9.15	6.86	75.0	6.91	75.5	6.84	74.8	6.88	75.2
	10	GAL	8.35	7.12	85.3	7.01	84.0	6.99	83.7	6.97	83.5
		GPS	7.90	6.56	83.0	6.66	84.3	6.66	84.3	6.64	84.1
	15	GAL	7.14	6.62	92.7	6.55	91.7	6.66	93.3	6.54	91.6
		GPS	6.80	6.21	91.3	6.22	91.5	6.36	93.5	6.20	91.2
80 – 90	0	GAL	11.28	8.53	75.6	8.54	75.7	8.50	75.4	8.50	75.4
		GPS	10.90	8.16	74.9	8.16	74.9	8.12	74.5	8.10	74.3
	5	GAL	10.38	8.48	81.7	8.49	81.8	8.44	81.3	8.44	81.3
		GPS	9.35	8.10	86.6	8.08	86.4	8.03	85.9	8.04	86.0

	10	GAL GPS	9.46 9.07	8.28 7.91	87.5 87.2	8.23 7.91	87.0 87.2	8.28 7.87	87.5 86.8	8.25 7.87	87.2 86.8
	15	GAL GPS	8.53 8.16	7.95 7.57	93.2 92.8	7.95 7.59	93.2 93.0	7.96 7.57	93.3 92.8	7.95 7.57	93.2 92.8

l_m – weighted mean number of satellites visible above H_{min} without the obstacles

The additional calculations were made for different width L and different height B in the zone 50–60^O for street's axis in the direction North–South ($\alpha = 0^O$) and in the direction West–East. Mean number of satellites visible above $H_{min} = 5^O$ (a masking elevation angle used in most receivers) and the obstacles for the observer situated in the middle of the street for Galileo system and GPS system are presented in the Tables 6, 7 and 8. The calculations were made for the following parameters:

- – the street width L between 10 and 70 meters (i.e. Champs Elyssee in Paris) with step 5 meters,
- – the obstacles height B between 5 and 25 meters with step 5 meters.

Some additional calculations were also made for L between 10 and 20 meters with step 1 meter and for B between 5 and 10 meters with step 1 meter. We can say that:

Table 5. Mean number of satellites l_{ms} visible above H_{min} and the obstacles by the observer situated in the middle of the street (width L = 70 m, height B = 15 m) for different angles H_{min} for different angles between the North and street axis (α) for Galileo system and GPS system at different observer's latitudes φ

φ [^{O}]	H_{min} [^{O}]	System	l_m	Angle α [^{O}]							
				0		45		90		135	
				l_{ms}	l_{ms}/ l_m [%]	l_{ms}	l_{ms}/ l_m [%]	l_{ms}	l_{ms}/ l_m [%]	l_{ms}	l_{ms}/ l_{ms} [%]
0 – 10	0	GAL GPS	11.05 10.74	7.77 7.54	70.3 70.2	7.97 7.72	72.1 71.9	7.34 7.04	66.4 65.5	7.99 7.72	72.3 71.9
	5	GAL GPS	10.02 9.75	7.77 7.54	77.5 77.3	7.86 7.62	78.4 78.2	7.23 7.00	72.2 71.8	7.87 7.60	78.5 77.9
	10	GAL GPS	8.96 8.69	7.74 7.51	86.4 86.4	7.54 7.26	84.2 83.5	7.12 6.85	79.5 78.8	7.53 7.30	84.0 84.0
	15	GAL GPS	7.84 7.59	7.35 7.09	93.8 93.4	7.07 6.82	90.2 89.9	6.83 6.57	87.1 86.6	7.07 6.84	90.2 90.1
50 – 60	0	GAL GPS	10.85 10.40	7.62 7.00	70.2 67.3	7.33 6.99	67.6 67.2	7.23 6.89	66.6 66.3	7.28 6.94	67.1 66.7
	5	GAL GPS	9.67 9.15	7.51 6.86	77.7 75.0	7.25 6.91	75.0 75.5	7.17 6.84	74.1 74.8	7.23 6.88	74.8 75.2
	10	GAL GPS	8.35 7.90	7.12 6.56	85.3 83.0	7.01 6.66	84.0 84.3	6.99 6.66	83.7 84.3	6.97 6.64	83.5 84.1
	15	GAL GPS	7.14 6.80	6.62 6.21	92.7 91.3	6.55 6.22	91.7 91.5	6.66 6.36	93.3 93.5	6.54 6.20	91.6 91.2
80 – 90	0	GAL GPS	11.28 10.90	8.53 8.16	75.6 74.9	8.54 8.16	75.7 74.9	8.50 8.12	75.4 74.5	8.50 8.10	75.4 74.3

	5	GAL GPS	10.38 9.35	8.48 8.10	81.7 86.6	8.49 8.08	81.8 86.4	8.44 8.03	81.3 85.9	8.44 8.04	81.3 86.0
	10	GAL GPS	9.46 9.07	8.28 7.91	87.5 87.2	8.23 7.91	87.0 87.2	8.28 7.87	87.5 86.8	8.25 7.87	87.2 86.8
	15	GAL GPS	8.53 8.16	7.95 7.57	93.2 92.8	7.95 7.59	93.2 93.0	7.96 7.57	93.3 92.8	7.95 7.57	93.2 92.8

l_m – weighted mean number of satellites visible above H_{min} without the obstacles

- – the number l_{ms} for both systems increases with width L and decreases with height B. For each width L there is critical value when l_{ms} is less than 4 and position fix in mode "3D" cannot be obtained,
- – as the number l_{ms} for Galileo system is always greater than for GPS system, it means that for given values of L and B Galileo "3D" position fix can be obtained while GPS not,
- – the number l_{ms} for both systems depends on the angle α, however this dependence is greater for smaller values of L and B. It means that if the axis of the street runs in direction West–East the position fix can be obtained while in the direction North–South not be (i.e. for L = 25 m and B = 15 m).

Table 6. Mean number of satellites visible above $H_{min} = 5^{O}$ and the obstacles by the observer situated in the middle of the street for different widths L and different heights B in the zone 50–60^{O} for Galileo system and GPS system, street axis in the direction North–South (1^{st} series)

B [m]	**System**	**L [m]**												
		10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
5	GAL GPS	4.04 3.71	5.73 5.11	6.96 6.27	7.71 7.08	8.18 7.63	8.50 8.00	8.73 8.25	8.94 8.44	9.09 8.59	9.22 8.70	9.31 8.79	9.39 8.87	9.46 8.93
10	GAL GPS	2.18 –	3.14 –	4.04 3.71	4.89 4.43	5.73 5.11	6.43 5.73	6.96 6.27	7.37 6.75	7.71 7.08	7.98 7.39	8.18 7.63	8.34 7.83	8.50 8.00
15	GAL GPS	– –	– –	– –	3.48 3.16	4.04 3.71	4.60 4.21	5.16 4.65	5.73 5.11	6.20 5.53	6.61 5.93	6.96 6.27	7.22 6.59	7.51 6.86
20	GAL GPS	– –	– –	– –	– –	– –	3.61 3.30	4.04 3.71	4.48 4.07	4.89 4.43	5.32 4.77	5.73 5.11	6.09 5.42	6.43 5.73
25	GAL GPS	– –	– –	– –	– –	– –	– –	– –	3.70 3.39	4.04 3.71	4.37 4.01	4.72 4.29	5.06 4.55	5.41 4.85

Table 7. Mean number of satellites visible above $H_{min} = 5^{O}$ and the obstacles by the observer situated in the middle of the street for different widths L and different heights B in the zone 50–60^{O} for Galileo system and GPS system, street axis in the direction North–South (2^{nd} series)

B [m]	**System**	**L [m]**										
		10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
5	GAL GPS	4.04 3.71	4.37 4.01	4.72 4.29	5.06 4.55	5.41 4.85	5.73 5.11	6.02 5.36	6.29 5.60	6.54 5.85	6.76 6.09	6.96 6.27

6	GAL	3.48	3.75	4.04	4.32	4.60	4.89	5.16	5.47	5.73	5.97	6.20
	GPS	–	–	3.71	3.97	4.21	4.43	4.65	4.90	5.11	5.32	5.53
7	GAL	–	–	3.55	3.79	4.04	4.28	4.52	4.76	5.01	5.24	5.51
	GPS	–	–	–	–	3.71	3.93	4.14	4.32	4.51	4.73	4.92
8	GAL	–	–	–	–	3.61	3.83	4.04	4.25	4.48	4.67	4.89
	GPS	–	–	–	–	–	–	3.71	3.90	4.07	4.27	4.43
9	GAL	–	–	–	–	–	–	3.66	3.85	4.04	4.23	4.43
	GPS	–	–	–	–	–	–	–	–	3.71	3.88	4.04
10	GAL	–	–	–	–	–	–	–	–	3.70	3.87	4.04
	GPS	–	–	–	–	–	–	–	–	–	–	3.71

6. Conclusions

- – in urban area the satellite position cannot be obtained, if the number of satellites visible by the observer above masking elevation angle H_{min} and the buildings is less than 4; No Fix is greater than 0;

Table 8. Mean number of satellites visible above $H_{min} = 5^O$ and the obstacles by the observer situated in the middle of the street for different widths L and different heights B in the zone 50–60^O for Galileo system and GPS system, street axis in the direction West–East

B [m]	System	L [m]												
		10	15	20	25	30	35	40	45	50	55	60	65	70
5	GAL	5.13	6.14	6.82	7.32	7.73	8.03	8.29	8.54	8.74	8.91	9.06	9.16	9.27
	GPS	4.90	5.85	6.27	7.00	7.40	7.69	7.95	8.13	8.30	8.44	8.57	8.67	8.75
10	GAL	3.49	4.40	5.13	5.69	6.14	6.50	6.82	7.08	7.32	7.53	7.73	7.88	8.03
	GPS	3.35	4.22	4.90	5.46	5.85	6.20	6.51	6.76	7.00	7.22	7.40	7.56	7.69
15	GAL	–	3.49	4.12	4.68	5.13	5.53	5.85	6.14	6.39	6.61	6.82	6.99	7.17
	GPS	–	3.35	3.97	4.49	4.90	5.31	5.60	5.85	6.10	6.31	6.51	6.68	6.84
20	GAL	–	–	–	3.96	4.40	4.79	5.13	5.43	5.69	5.92	6.14	6.33	6.50
	GPS	–	–	–	3.82	4.22	4.62	4.90	5.21	5.46	5.67	5.85	6.03	6.20
25	GAL	–	–	–	–	3.87	4.24	4.56	4.86	5.13	5.38	5.60	5.79	5.96
	GPS	–	–	–	–	3.73	4.07	4.39	4.68	4.90	5.15	5.37	5.55	5.71

- – in urban area the position accuracy is less than in open area considerably for GPS system and Galileo system. This accuracy depends on the height of the buildings, the width L of the street and the angle between the North and street axis;
- – as the distribution of satellite azimuths depends on observer's latitude, the position accuracy in the town depends on its geographic location. It means that the accuracy in the street with the same widths and the height of the buildings is in Oslo, Lisbon and Dakar different;
- – in urban area for the observer situated in the middle of the street (with given width and height of the buildings) the dependence of position accuracy on angle between the North and street axis is for Galileo system less than for GPS system;
- – nowadays only GPS is fully operational, the exploitation of the second system, as Glonass or Galileo (in 2008), will assure in urban area the possibility of fix position in almost all cases and will increase its accuracy. That's why the question GPS or Galileo doesn't exist already, now the goal is GPS and Galileo!

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