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IRNSS Performance Evaluation of SPS Services on Military Aircraft

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ABSTRACT

The essence of this paper is to study and characterise the performance of Indian Regional Navigation Satellite System (IRNSS), also known as NavIC (Navigation with Indian Constellation), in actual dynamic environment by conducting field trials on military aircraft. The dynamic accuracy of IRNSS receiver in terms of position, velocity and altitude has not yet been tested on any aircraft system i.e. commercial or military applications. These field trials and performance evaluation will help in on-field assessment of IRNSS receiver performance with availability of five, six and seven IRNSS satellites. During conduct of trials, IRNSS receiver and IRNSS antenna were placed inside the aircraft. Results analysis of 18 hours flying data depicts position availability of 99.872% with five satellites and 100% position availability with six and seven satellites.

Keywords: IRNSS performance; Dynamic environment; Military aircraft; Field trials; Position availability

I. INTRODUCTION

Presently all military aircraft of Indian Armed forces are primarily utilising the services of USA based GPS navigation system for flying in absence of any indigenised Navigation system till IRNSS system was recognised as fully operational constellation. However, till date the dynamic accuracy of IRNSS receiver in terms of position, velocity and altitude has not been tested on any aircraft system i.e. commercial or military applications. The Indian Regional Navigation Satellite system (IRNSS)[1-2,12] has been developed by Indian Space Research Organization (ISRO) with the objective to provide positioning, navigation and timing (PNT) services over India for terrestrial, aerial, and space applications[7]. Also known as the Navigation with Indian Constellation (NavIC), the IRNSS constellation consists of three GEO satellites and four GSO satellites, all of which always remain visible over the Indian region. Till date the dynamic accuracy of IRNSS receiver in terms of position, velocity, and altitude has not been tested on any aircraft system i.e., commercial or military applications. Conduct of field trials on aerial platform and performance evaluation of IRNSS will pave way for future use of independent navigation system i.e. IRNSS on military and commercial aircraft especially flying in India and 1500 kms around India with high position accuracy. Performance evaluation of IRNSS receiver using IRNSS satellites for position determination involves collection of navigation data from field trials using IRNSS receiver fitted on aircraft and performance assessment in terms of comparing horizontal and vertical absolute position accuracy with respect to the runway centre line, Position Dilution of Precision (PDOP), Carrier to Noise (C/N0) ratio and number of IRNSS satellites available at any instant for position determination[3-8]. This involves obtaining data in NMEA format[11], data filtering using excel sheets, generation of MATLAB programs[10] to convert receiver logs into Geographical Information System (GIS) readable data format, like .KML. This format can be used on any GIS, like Google Fusion Tables or ISRO's BHUVAN maps for better visualisation and data analysis. Data is recorded with the help of NavIC-'L5' and 'S' band supported right hand circularly polarised active navigational antenna operating at 5 volt DC power. Antenna receives Navigational data from IRNSS satellites constellation. DC Power to antenna is supplied through IRNSS receiver via connecting RF cable. This data containing latitude, longitude and altitude information is transmitted through RF coaxial cable to the navigation IRNSS receiver using a TNC connector. The purpose of receiver is to convert the incoming data stream from IRNSS satellites into protocol NMEA messages. From these messages relevant data in terms of latitude, longitude, and altitude is extracted. DC power of 12 volt and 5 Ampere to the IRNSS receiver is provided with the help of independent battery bank connected via power cable to receiver. IRNSS receiver is connected to computer/Laptop for data visualisation and analysis. Further absolute accuracy of NavIC receiver can be determined by comparing latitude, longitude and altitude information received using IRNSS receiver at the sampling rate of 1Hz/sec and elevation mask of zero degree with respect to well defined coordinates of runway centre line.

2. FIELD TRIALS & RESULT ANALYSIS

This section defines the methodology for data analysis during takeoff and landing phase of aircraft for correct evaluation of improvement in the performance of NavIC receiver with five, six and seven IRNSS satellites as maximum

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change in speed, altitude and attitude of transport military aircraft is experienced in these flying profiles. Performance assessment of IRNSS system has been carried out in terms of measuring absolute position accuracy as mentioned in preceding paragraph centerline of airfield where trials were conducted, PDOP, C/N0 value and number of satellites availability for position calculation. To achieve this mostly the same route/ aircraft profile was followed. Results obtained are presented in the form of maps and graphs with the help of various software programs as mentioned in preceding paragraph[13].

2.1. Runway Dimension Details and Associated Markings: Marking details are mentioned in Fig. 1 and dimensions of runway are shown in Table 1. The horizontal and vertical position accuracy with respect to runway centre line during takeoff and landing is calculated on following data.

Horizontal accuracy= Difference between coordinates (LAT& LON) of take-off and landing point obtained from ATC of operating airfield and IRNSS receiver coordinates obtained during takeoff and landing) - 0.25 m.

Table 1. Runway marking details

Total Runway width	46 m
'Centre Navigation Line' Marking	23 m
'Side Navigation Line' Marking with reference to 'Centre Navigation Line'	11.5 m (each side)
Height of IRNSS receiver mounting with reference to runway	3.05 m
IRNSS receiver offset (towards left) with reference to aircraft Longitudinal axis	1.25 m

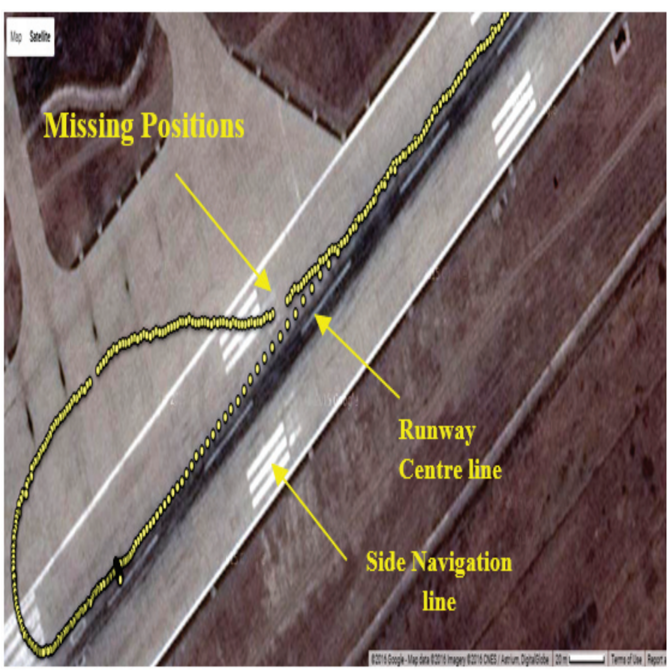

Figure 1. Takeoff profile with five satellites.

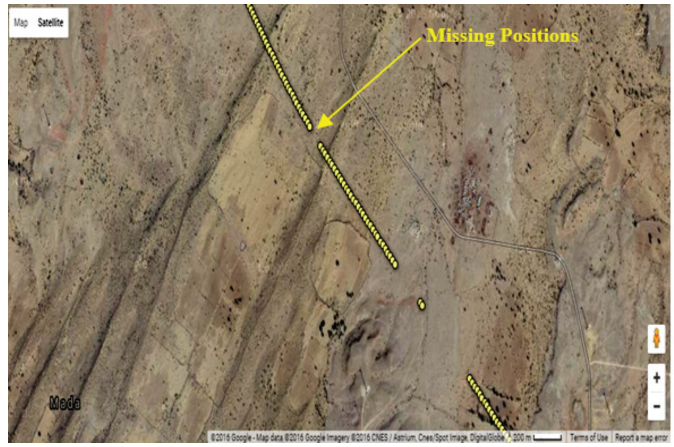

Figure 2. Prior to landing profile with five satellites.

Vertical accuracy= (Difference between coordinate (ALT) of take-off and landingpoint obtained from ATC of operating airfield and IRNSS receiver coordinates during takeoff and landing)-3.05m.

3. DATA ANALYSIS WITH FIVE SATELLITES

In this section results obtained during air trials and data analysis with availability of five IRNSS satellites during takeoff, aircraft approach prior to landing and post landing carried out using IRNSS receiver in stringent *'Pure Dual'* mode[3, 8] i.e. if the signal from any of the IRNSS satellites falls below the required threshold in either L/S band it will reject that particular satellite. Data is assessed in terms of horizontal and vertical position accuracy, PDOP, C/N0 and the number of IRNSS satellites available. In subsequent paragraphs data analysis with six and seven satellites are also commented upon (without figures).

3.1 Horizontal and Vertical Position Accuracy Estimation

Map visualisation has been shown in Fig. 1 for aircraft takeoff and aircraft approach prior to landing (Fig. 2) and post landing (Fig. 3) for calculating horizontal and vertical position accuracy with respect to defined runway centre line.

Figure 3. Landing profile.

3.2 Graphs showing the DOP, C/N0 and satellites availability for Figs. 1, 2 and 3 are depicted in the Figs. 4, 5, 6, 7, 8, 9 and 10 respectively

3.3 Analysis/Observations

3.3.1 Maps Analysis

During takeoff and landing, the horizontal and vertical absolute position accuracy[3,7-8] of IRNSS was found within 2-3 m with reference to runway centre line.

Prior to takeoff position, fix found missing for short instances (Fig. 1). This is attributed to signals loss from three satellites (PRN-3, PRN-4 & PRN-5) in S-band falling momentarily. During this phase of flying, receiver was operated in *'Pure Dual'* mode i.e., if the signal from any of the IRNSS satellites falls below the required threshold in either L/S band it will reject that particular satellite. At this instance, there was loss of signal observed from satellites assessed in terms of DOP, C/N0 and number of IRNSS satellites in view at that particular time duration is as shown in takeoff profile of Figs. 4, 6, and 9 thereby resulting in loss of position. This loss of signal from satellites is attributed to blockage of signals due to continuous change in the aircraft attitude prior to takeoff which may result in the decrease of elevation angle of respective satellites momentarily to '0' value.

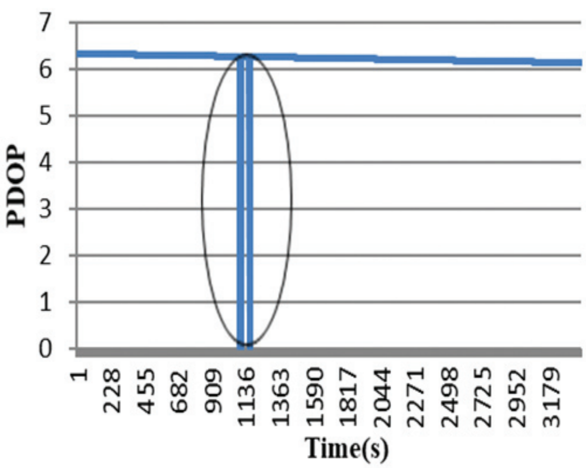

Figure 4. Takeoff profile.

Prior to landing (15-20 miles before) Fig. 2 again momentarily loss of position fix was observed at three instances. This is attributed to loss of signals from three satellites (PRN-4 & PRN-5) in 'L' band and one satellite (PRN-1) in 'S' band as shown in 'prior and post landing' profile of Figs. 5,7,8 and 10. During this phase of flying receiver was again operated in *'Pure Dual'* mode i.e. if the signal from any of the IRNSS satellites falls below the required threshold in either L/S band it will reject that particular satellite. Fall in signal strength from satellites primarily attributed to blockage of signals due to rapid change in the aircraft attitude prior to landing therefore resulting in the decrease of elevation angle of respective satellites momentarily to '0' value.

3.3.2 PDOP Values

Average PDOP value during takeoff and landing period for IRNSS receivers was found to be 6-6.5 with value momentarily dropping to '0' during takeoff (Figs. 4) due to loss of lock from three satellites as mentioned in 'Map Analysis' above and with momentarily drop in PDOP values to '0' (Fig.5) due to blockage of signals due to change in aircraft attitude as mentioned in 'Map Analysis' above prior to aircraft landing. Further, prior to flying expected PDOP values for particular air field were generated in simulator as initially no reference data was available and found to be consonance with field results.

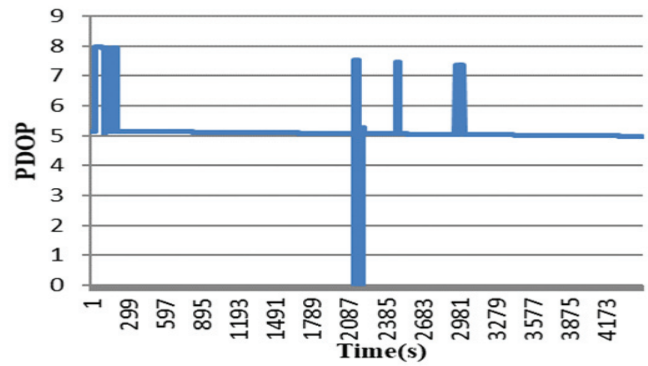

Figure 5. Prior and post landing.

3.3.3 C/N0 Values

Average C/N0 value during take-off and landing greater than 45 dB-Hz which is well above the design threshold of 30 Db-Hz of the receiver was observed in both 'L' and 'S' band (Figs 6,7 and 8) with momentarily loss of signals from three satellites during takeoff due to reasons stated above. Prior to landing complete loss of signal from three satellites at two different instances were observed attributed to change in elevation angle due to rapid change in aircraft attitude.

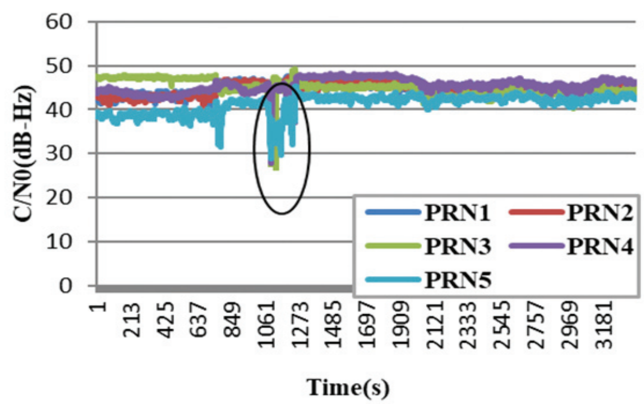

Figure 6. Takeoff profile-S band signal.

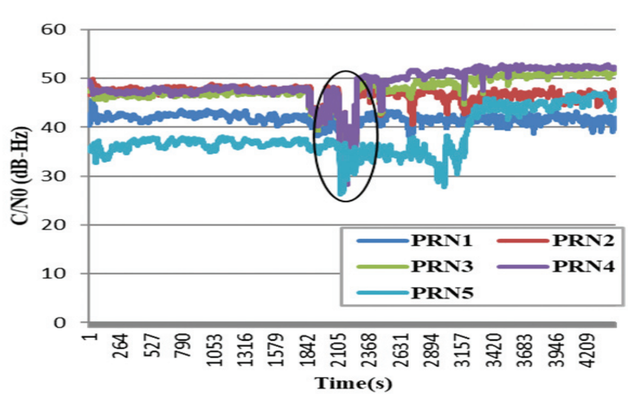

Figure 7. Prior and post landing profile-L band signal.

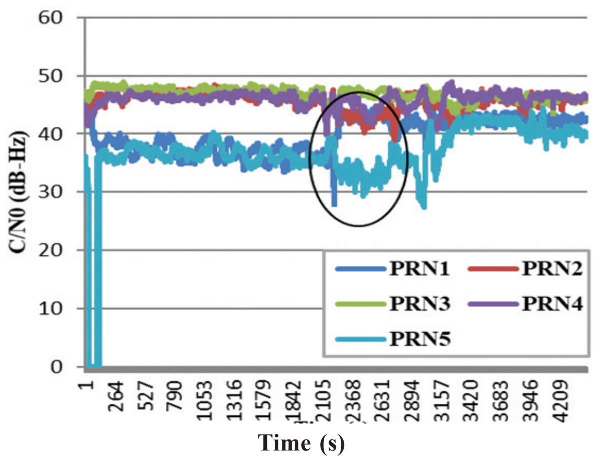

Figure 8. Prior and post landing profile-S band signal.

3.3.4 Satellites Availability

Continuous availability of 5 satellites throughout the period of operation was observed except momentarily drop to '0' (Figs. 9 and 10) at two instances attributed due to reasons stated above.

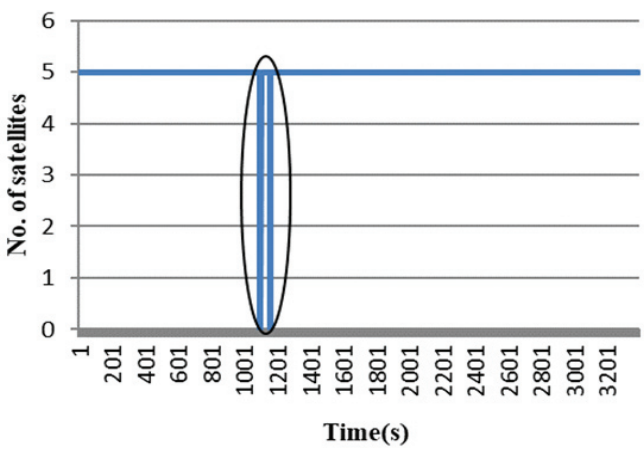

Figure 9. Takeoff profile.

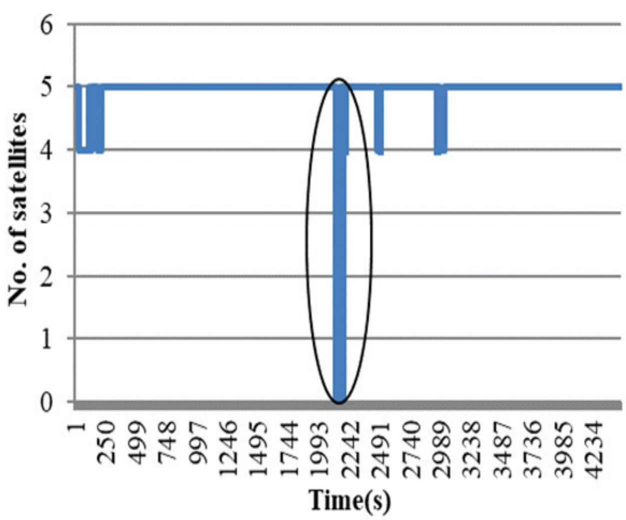

Figure 10. Prior and post landing profile.

4. DATA ANALYSIS WITH SIX SATELLITES

In this section results obtained during air trials and data analysis with availability of six IRNSS satellites during takeoff and landing carried out using IRNSS receiver in stringent *'Pure Dual'* mode in terms of horizontal & vertical position accuracy, PDOP, C/N0 and numbers of IRNSS satellites available are discussed.

4.1 Analysis/Observations

- *Map Analysis:* During take-off and landing horizontal and vertical absolute position accuracy of IRNSS was found within 2 and 2.5 m respectively with reference to runway centre line
- 100% position availability was obtained during entire route of flying
- *PDOP Values:* 3.4 to 3.9 during entire period of operation
- *C/N0 Values:* Value of greater than 40 dB-Hz was observed in both 'L' and 'S' band during entire period of operation.
- *Satellites Availability:* Continuous availability of 06 satellites throughout the period of operation with a momentarily drop to 05 satellites attributed to change in aircraft attitude during landing. However, no position loss was observed due to this as observed in case of operations with 05 satellites.

5. DATA ANALYSIS WITH SEVEN SATELLITES

In this section, results obtained during air trials and data analysis with availability of seven IRNSS satellites during takeoff and landing carried out in terms of horizontal and vertical position accuracy, PDOP, C/N0 and numbers of IRNSS satellites available are discussed with *IRNSS receiver in operation in 'L5' band.*

5.1 Analysis/Observations

- *Map Analysis:* During takeoff and landing horizontal and vertical absolute position accuracy of IRNSS was found within 1.2 and 2.0 m respectively with reference to runway centre line
- 100% position availability was obtained during entire route of flying
- *PDOP Values:* Average value of 3.2 was observed during continuous change in aircraft attitude for entire period of operation. Momentarily increase to 4.8 was observed due to sudden change in aircraft attitude
- *Satellites Availability:* Continuous availability of seven satellites throughout the period of flying was observed
- *C/N0 Values:* Value of greater than 32 dB-Hz was observed in 'L5' band during entire period of operation

6. DATA ANALYSIS SUMMARY

Based on the aircraft sorties flown performance of IRNSS receiver was assessed with availability of five, six and seven satellites as shown in Table 2. It is observed that with increase in number of satellites position availability, position accuracy, and PDOP values improved[3,6-8]. Further comparison between PDOP data obtained during field trials and expected data generated from GNSS simulator do not show any major variation between field and simulated value with field values of PDOP found better than expected value as shown in Table

3 with six and seven satellites. During conduction of trials IRNSS receiver was also operated in Hybrid 'L1+L5' mode[3,6-8] i.e., combination of GPS and IRNSS satellites which resulted in increased availability of number of satellites between 14-16 and average availability of 15 thereby resulting in better PDOP (average value of 1.1) and therefore better position accuracy as compared to the system when used alone i.e. either GPS or IRNSS. Results obtained during combined operation of GPS and IRNSS are depicted in Table 2. This observation is valuable input for future Global Navigation Satellite System (GNSS) operation of GPS and IRNSS in the field of aviation as aircraft frequently operates in varied geographical locations.

7. IRNSS PERFORMANCE IN HIGH DYNAMIC CONDITIONS

Due to the infant stage of IRNSS as compared to the GPS[9] and other global and regional navigation systems additional performance parameters i.e., velocity and altitude performance assessment[3] of aircraft in which IRNSS receiver performed in dynamic conditions has been brought out in this section. IRNSS receiver fitted on military transport aircraft was subjected to an altitude of 8.4 km above mean sea level in 'L5' band as shown in Fig. 11. Receiver performance was also tested up to speed of 311 knots (575 km/h) as shown in Fig. 12 and found satisfactory. Speed and Altitude performance testing was restricted to these values due to design limitation of aircraft.

8. CONCLUSIONS & FUTURE SCOPE

Field trials are conducted for the first time on aircraft to access the performance of IRNSS receiver for position determination and data analysis with various aircraft profiles and different operation bands of IRNSS with five, six and seven satellites. Data shows improvement in PDOP values and position accuracy in vertical and horizontal directions with increase in number of satellites. During these trials application of position determination was explored and these field trials can be further extended in future for position determination with seven satellites for fighter class of aircraft and real time aircraft tracking application[1] of NavIC for transport and fighter aircrafts.

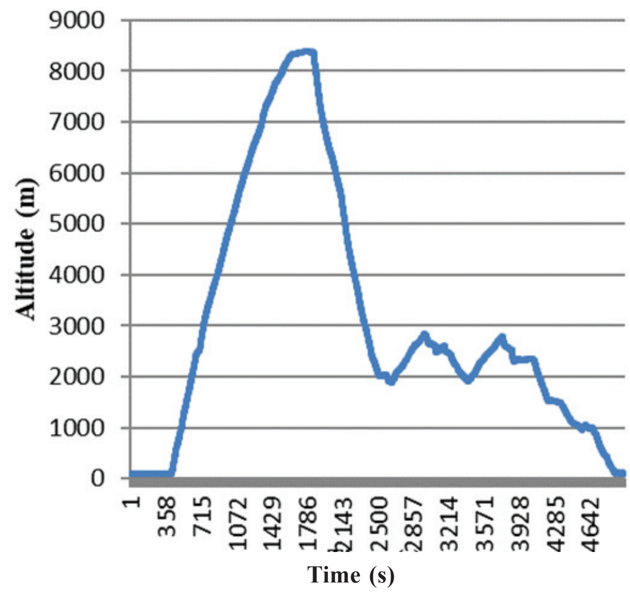

Figure 11. Altitude performance.

Table 2. Data summary with five, six and seven satellites

Operation band	Number of IRNSS satellites available	Position availability percentage	Horizontal position accuracy (m)	Vertical position accuracy (m)	PDOP value	C/N0 value (dB-Hz)
'L5+S'-(Pure Dual Mode)	05	99.872%	2-3	2-3	5-6.5	45
'L5+S'-(Pure Dual Mode)	06	100%	2-2.5	2-2.5	3.4-3.9	40
'L5'	07	100%	1.2-2.0	1.2-2.0	3.2	32
'L1+L5'	14-16	100%	0.9-1.0	0.9-1.0	1.16	40

Table 3. Expected Vs Obtained PDOP values with five, six and seven satellites

Number of IRNSS satellites	Expected PDOP (GNSS simulator value)	PDOP value obtained during field trials
5	4.9-9.5	5.0-6.5
6	4.0-5.4	3.4-3.9
7	3.6-3.7	3.1-3.2

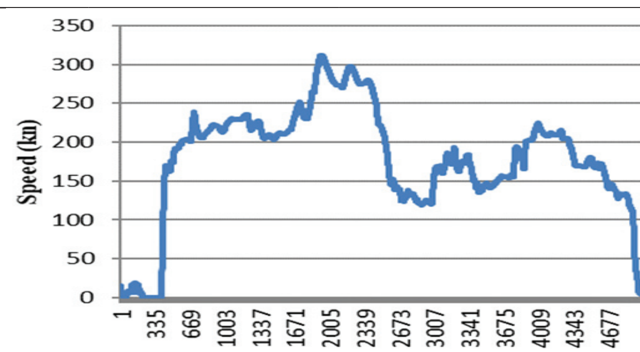

Figure 12. Speed performance.

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