GUIDELINES FOR SPACING OF PRIORITY CONTROLLED INTERSECTIONS ALONG URBAN COLLECTOR ROADS

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Submitted in fulfillment of the requirements for the degree of

MAGISTER TECHNOLOGIAE:

ENGINEERING: CIVIL

in the

Department of Civil Engineering and Built-Environment

Faculty of Engineering, Information and Communication Technology

at the

CENTRAL UNIVERSITY OF TECHNOLOGY, FREE STATE

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July 2007

DECLARATION

I, SALOMÉ VISSER, hereby declare that this research project submitted for the degree MAGISTER TECHNOLOGIAE: ENGINEERING: CIVIL, is my own independent work that has not been submitted before to any institution by me or anyone else as part of any qualification.

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SIGNATURE OF STUDENT **DATE**

SUMMARY

A vehicular intersection/access is a fundamental element in the geometric design of roads. It can be defined as the location in a road network where two or more road sections cross or intersect. As a result, this location is characterized by conflict between vehicles and/or pedestrians which in turns increase the probability of accidents. The position of intersections relative to one another is of utmost importance to ensure that the minimal interference is experienced by motorists at these conflict points.

A number of geometric design guidelines, pertaining to intersection/access spacing, exist which are used or referred to by the geometric design engineering fraternity. However, uniform guidelines are essential to ensure that intersections/access spacing meet the required standards in geometric design. Current South African guidelines for spacing of intersection/accesses along collector and lower order streets are limited and fragmented and the purpose of the study is therefore to produce a document which can be used as a reference guideline document for the spacing of accesses and intersection along collector roads.

In this dissertation, the aim is to evaluate and compare existing intersection/access spacing standards and guidelines for overseas and local conditions, to perform traffic engineering surveys to use as design parameters to determine intersection/access spacing requirements and to develop a tentative South African guideline for the priority controlled intersection/access spacing along urban collector roads.

Due to the fact that collector roads, in the hierarchy of the road network context, must balance the accessibility and mobility function, the recommendations in this dissertation refer to proposed ideal, preferred and minimum access spacing requirements for the said

road classification. Due to the sharing of accessibility and mobility function of collector roads, this dissertation further recommends the use of **preferred** intersection/access spacing distances for urban collector roads.

The approach and results in this dissertation can also be used as input for further research in establishing uniform national standards for spacing of priority controlled intersection/access along urban collector roads.

OPSOMMING

‘n Voertuig kruising/toegang is ‘n fundamentele element in die geometriese ontwerp van paaie. Dit word gedefineer as die posisie in die padnetwerk waar twee of meer padseksies kruis. Gevolglik word hierdie posisies in die padnetwerk gekaraktiriseer deur konflik tussen voertuie en/of voetgangers wat verder die waarskynlikheid van ‘n toename in ongelukke verhoog. Die posisie van kruisings/toegange relatief tot mekaar is uiters belangrik om te verseker dat motoriste by hierdie konflik punte mekaar minimaal beinvloed .

Daar bestaan ‘n verskeidenheid geometriese ontwerp riglyne, met betrekking tot kruising/toegang spasiëring, wat gebruik of na verwys word deur geometriese ontwerp ingenieurs. Nogtans is uniforme riglyne belangrik om te verseker dat kruisings/toegange spasiëring aan die vereiste geometriese ontwerp standaarde voldoen. Huidige Suid-Afrikaanse riglyne vir die spasiëring van kruising/toegange langs versamel- en laer orde strate is beperk en gefragmenteerd en die doel van hierdie studie is om ‘n dokument daar te stel wat gebruik kan word as ‘n verwysings riglyn vir die spasiëring van prioriteitsbeheerde kruisings langs stedelike versamelstrate.

Die doel van hierdie skripsie is ook om bestaande kruising/toegang spasiëring standaarde en riglyne te evalueer en te vergelyk vir internasionale en plaaslike toestande, om verkeersingenieur opnames uit te voer om as ontwerp parameters te gebruik om kruising/toegang spasiëring vereistes te bepaal en om ‘n tentatiewe Suid-Afrikaanse riglyn vir prioriteitsbeheerde kruisings/toegange langs stedelike versamelstrate te ontwikkel.

Gegewe die feit dat versamelstrate, binne die konteks van padhiërargie, toeganklikheid- en mobiliteitsfunksie moet balanseer, verwys die aanbeveling in hierdie skripsie na die voorgestelde ideale, verkieslike en minimum kruising/toegang spasiëringsvereistes vir die betrokke padklassifikasie. As gevolg van die balans tussen die toeganklikheid- en mobiliteitsfunksie van versamelstrate, word die gebruik van die **verkieslike** kruising/toegang spasiëring afstande vir stedelike versamelstrate in hierdie skripsie aanbeveel.

Die benadering en gevolgtrekkings van hierdie skripsie kan ook gebruik word as basis vir verdere navorsing in die daarstelling van uniforme nasionale standaarde vir die spasiëring van prioriteitsbeheerde kruisings/toegange langs stedelike versamelstrate.

ACKNOWLEDGEMENTS

I wish to express my appreciation to the following organizations and persons who made this thesis possible:

- The Central University of Technology, Free State for assistance in completing this study.
- Mr GD Potgieter, my supervisor, for his guidance and support.
- Dr E Theron, my co-supervisor, for her counseling.
- Ms F Claassens, for her extraordinary effort in locating applicable literature.
- My family and friends for their encouragement.

TABLE OF CONTENTS

Page

3. ACCELERATION AND DECELERATION MODELS

4. EVALUATION AND COMPARISON OF CURRENT INTERSECTION/ACCESS SPACING METHODOLOGY

ANNEXURES

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 BACKGROUND

An intersection/access can be defined as a location on a road network where two or more road sections cross or intersect. Inevitably this results in conflict between vehicles and/or pedestrians which in turn increases the risks of accidents. In order to reduce the probability of traffic accidents it is of utmost importance to design and locate intersections in such a manner as to ensure that the minimal interference is experienced by motorists at these conflict points to negotiate intersections in the safest possible way.

Uniform guidelines are therefore essential to ensure that intersections/ accesses meet the required standards which inter alia include intersection spacing. Current South African guidelines for spacing of intersections/accesses along lower order collector roads and local streets are limited and fragmented and the purpose of the study is to produce a document which can be used as a reference guideline document for the spacing of accesses and intersections along collector roads.

Access spacing requirements for urban roads are defined in the manuals published by the Committee of Urban Transport Authorities (CUTA). Access spacing requirements for collector roads specifically recommended in the Urban Transport Guidelines 5 document (UTG5) are 350m for design speeds of 70km/h and more whilst access spacing requirements for design speeds of less than 70km/h are 80m for four legged intersections (UTG5, 1988:9), 70m for T-type intersections for staggers with right turns from the major road and 50m for T-type intersections for staggers without right turns from the major road (UTG5, 1988:55). However, no indication is given as to how these distances were established or how it should be measured. The document Guidelines for the provision of engineering services and amenities in residential townships (1995), which together with UTG5 (1988), have probably been used by most engineers in South Africa for design of urban collector roads. Both these documents state that 80-90m is the minimum access spacing for Class 4 roads (local distributor) which is equivalent to collector classification. This minimum access spacing is based on a recommended design speed of 50km/h for local distributor roads. Although it is stated in the document that access spacing is measured centre-line to centre-line of intersections, no indication is provided as to how these distances were determined.

American Association of State Highway and Transportation Officials (AASHTO), which is well recognized, respected, accepted and applied by engineers worldwide as an important reference for various road infrastructure design elements (including intersections) provides a number of basic criteria for establishing access spacing, but no specific recommendation pertaining to urban collector roads is mentioned (AASHTO, 2001). The same applies for the Transportation and Land

Development Document (1988) which also discusses some basic factors such as minimum corner clearance, stopping sight distances, queuing etc. which must be considered in access spacing design, without providing any specific recommendation regarding urban collector roads.

Table1 summarises intersection/access spacing distances as indicated in design guideline documents.

Table 1.1: Priority controlled intersection/access spacing: Urban collectors (60 km/h)

Reference	Spacing (in metres)		
	T-Intersections		Four-legged Intersection
	Same side	Opposite side	
Guidelines for the geometric design of urban collector roads, (UTG5, 1988:55)* (no distinction between same and opposite)	50-70†		80
Guidelines on the Planning and Design of Township Roads and Stormwater Drainage. (1981:5.3) & Annexure A**	80	40	100
Guidelines for the Provision of Engineering Services and Amenities in Residential township Development. (1995:5.25)***	80-90	65	80-90

* Reference point for measurement of intersections spacing not given
** Road reserve boundary used as reference point
*** Centre line of intersections used as reference point
† T-type intersections should not be closer than 50 m for staggers without right turns from the major road and 70 m for staggers with right turns from the major road. (UTG5, 1988:55)

1.2 OBJECTIVES OF THE STUDY

The purpose of this study will be to produce a document which can be used nationally, regionally and locally as a reference guideline document for the spacing of priority controlled accesses and intersections along collector roads.

The **specific objectives** of the study are as follows:

(a) Evaluate and compare intersection/access spacing standards and guidelines for overseas and local conditions;

(b) Perform traffic engineering surveys to use as design parameters to determine intersection/access spacing requirements;

(c) Develop a tentative South African guideline for priority controlled intersection/access spacing along urban collector roads;

For the purpose of this study, access spacing will be recommended for **priority controlled, minor collector roads**, i.e. road classification just above local street classification in the normal hierarchy of roads. This corresponds to the class 4 (local distributer) classification as described in the document Guidelines for the Provision of Engineering Services and Amenities in Residential Townships. (1995)

Due to the number of surveys and field observations required in determining a widely acceptable (national and international) standard the study is limited to the above mentioned specific objectives.

1.3 METHODOLOGY

The study involved an investigation and evaluation of access spacing design procedures as applied primarily in UTG5 (CUTA, 1988), Guidelines for the provision of engineering services and amenities in residential townships (1995), AASHTO (2001) and Transportation and Land Development Document (1988). The applications of these procedures were determined through observations of passenger car acceleration performances at intersections. A tentative recommendation pertaining to access spacing distances for priority controlled minor urban collector roads was determined.

1.4 ORGANISATION OF THE REPORT

Chapter 1 serves as an introduction to the report

Chapter 2 serves as a background to intersection/access spacing distances.

Chapter 3 describes the operational characteristics with regard to design vehicles and acceleration- and deceleration models.

Chapter 4 consists of the evaluation of current intersection/access spacing methodology. It also includes the recommendations of fixed points at intersections, from and between which access spacing can be measured.

Chapter 5 provides a recommended procedure for establishing access spacing for priority controlled urban collectors.

Chapter 6 include conclusions and recommendations of the study.

2. INTERSECTION/ACCESS SPACING

2.1 INTRODUCTION

Intersections are areas where conflicting traffic movements occur and are therefore critical locations for potential collisions. The spacing of intersections/accesses therefore plays a significant role in the occurrence of collisions. Table 2.1 below from the document Access Management Manual, Transportation Research Board (TRB) show that the separation of conflict areas can be used as an effective way to improve traffic safety by reducing the probability of conflicting movements intersecting at the same point and time (collisions) (TRB, 2003).

Table 2.1: Relative collision rates for priority controlled intersection/access spacing

Priority controlled intersection/access points per mile[a]	Average spacing[b] (m)	Relative collision rate
10	322	1.0
20	161	1.4
30	107	1.8
40	80	2.1
50	63	2.4
60	54	3.0
70	46	3.5

[a] Total access connections on both sides of the roadway
[b] Average spacing between access connections on the same side of the roadway; one-half of the connections on each side of the roadway

There are a number factors that have to be taken into account when calculating intersection/access spacing. The most important factors include functional area of an intersection/access, stopping sight distance, decision sight distance, left-turn conflict overlap, corner clearance, egress capacity, egress conflict, influence distance, gap acceptance and general safety considerations.

2.2 FACTORS AFFECTING INTERSECTION/ACCESS SPACING

2.2.1 FUNCTIONAL AREA

AASHTO (2001) defines the functional area of an intersection as "the area both upstream and downstream from the physical intersection area and includes any auxiliary lanes and their associated channelization" (AASHTO, 2001:560). Figure 2.1 (AASHTO, 2001) indicates the functional area of an intersection.

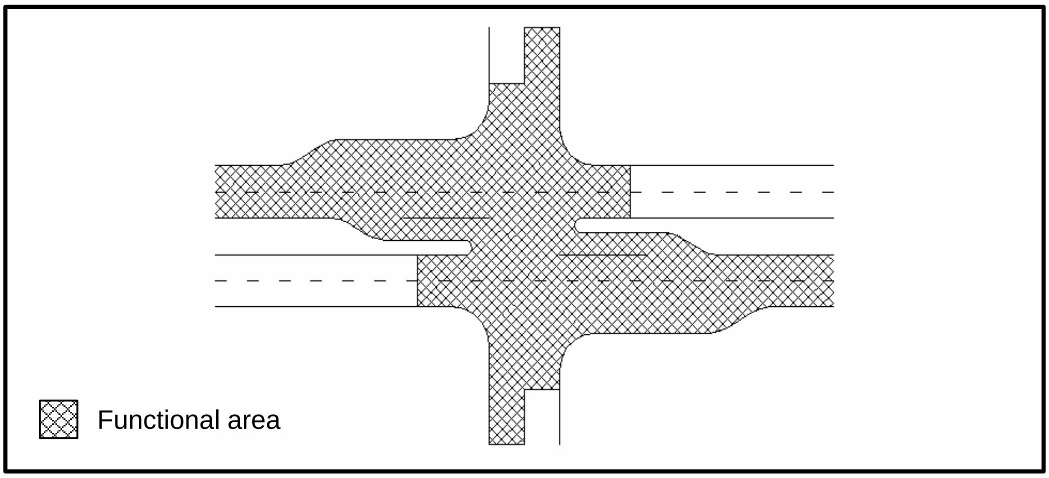


Figure 2.1: Functional area of an intersection (AASHTO, 2001)

Although not indicated in Figure 2.1 (or explicitly stated), based on AASHTO's definition, one has to assume that acceleration lanes, tapers, channelized islands and lanes that fall away or are added are also considered part of the functional area of an intersection.

Figure 2.2 schematically shows the inclusion of these elements in the physical area of an intersection.

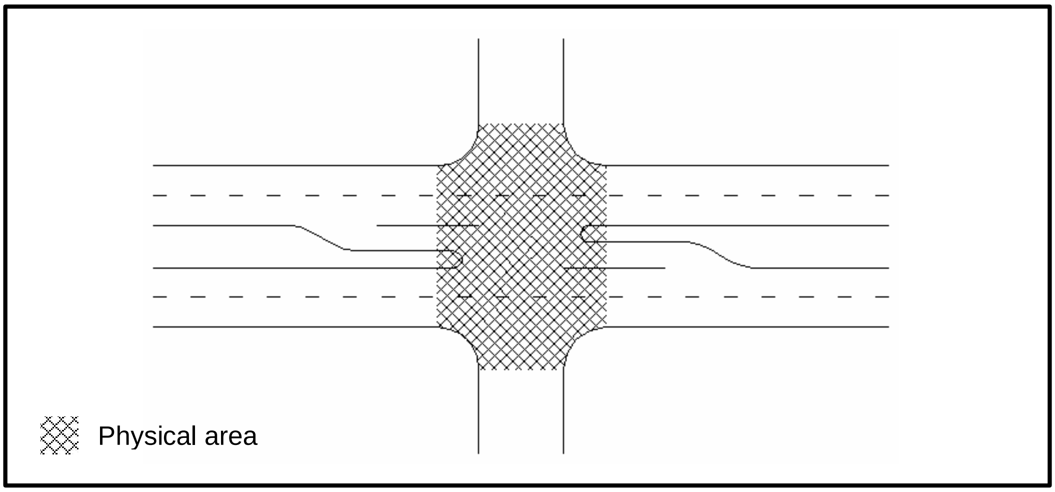


Figure 2.2: Physical area of an intersection

The three basic elements that define the functional area on the approach to an intersection/access are (see Figure 2.3):

- perception-reaction time (d_1);
- maneuver distance (d_2); and
- queue storage distance (d_3).

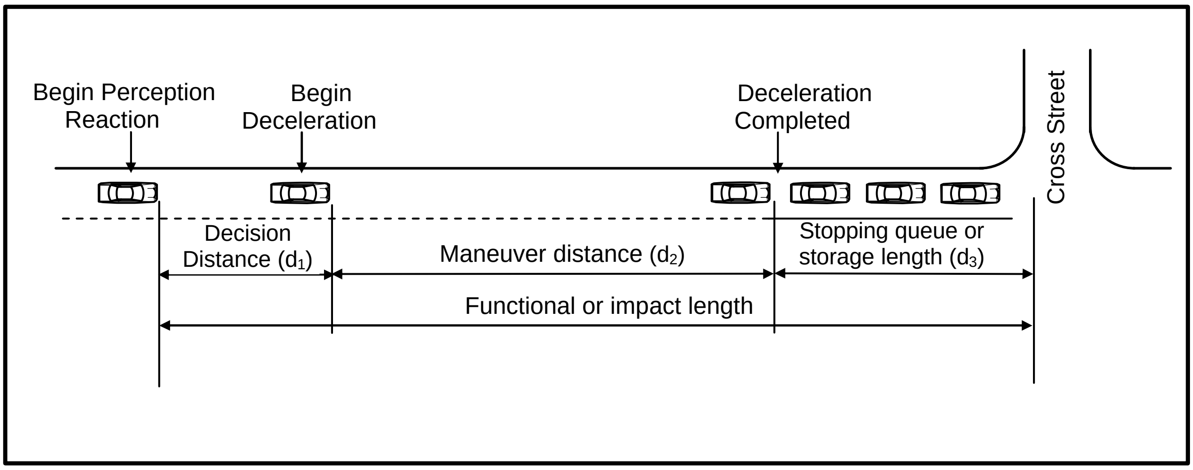


Figure 2.3: Elements of the functional area of an intersection

Vehicle speed, driver alertness and driver familiarity with the location determines the distance travelled during the perception-reaction time.

Where right- or left turn lanes are provided, the maneuver distance includes the length needed for braking and lane changing. If turning lanes are not present, maneuvering distance include braking to a comfortable stop. The storage lane should be sufficient to accommodate the longest expected queue for most of the time. AASHTO recommends that intersections/accesses should ideally not be located within the functional area of another intersection.

2.2.2 STOPPING SIGHT DISTANCE

Stopping sight distance is the distance required for a driver to bring his vehicle to a standstill. The distance is therefore determined by vehicle speed, driver-reaction time and skid resistance. Stopping sight distance is calculated using the following formula (UTG5, 1988) with a recommended perception-reaction time of 2.5 seconds*:*

$$s = 0.7v + \frac{v^2}{254(f \pm G)} \qquad \text{.........(1)}$$

Where:

s = Stopping sight distance (m)

v = Speed (km/h)

f = Brake-force coefficient

G = Grade percentage divided by 100

Table 2.2 indicates stopping sight distances on level roads between 40 and 80km/h calculated from equation 1 for urban collector roads according to UTG5 (1988) for design speeds between 40 and 80km/h for roads with 0% gradient and perception reaction time of 2.5 seconds.

Table 2.2: Stopping sight distances for urban collector roads (UTG5, 1988)

Design speed (km/h)	Brake-force coefficient (a)	Stopping sight distance (b) (m)
40	0.37	45
50	0.34	65
60	0.32	85
70	0.31	110
80	0.30	140

[a] Brake-force coefficients according to Draft UTG 5 (CUTA, 1988)
[b] Rounded to the nearest 5m

According to the Access Management Manual, Transportation Research Board (TRB) intersection/access spacing should ideally be such that a vehicle is able to clear an intersection before the driver is required to respond to vehicles entering, leaving, or crossing the roadway at a downstream access connection (TRB, 2003). Based on this criterion, intersection/access spacing for South African urban collector roads should ideally not be less than the stopping sight distances listed in Table 2.2.

2.2.3 GAP ACCEPTANCE

Gap acceptance can be defined as the procedure used for determining intersection sight distance by using the gap in time accepted by a driver of a vehicle after being presented with a series of "gaps" to cross or merge with a stream of vehicles. The driver accepts the gap only if it is greater than or equal to its minimum acceptable gap or "critical gap". The gap is rejected when it is smaller than the critical gap. The gaps are measured from front-to-front of the following vehicles (Van As, S.C. &. Joubert H.S., 1993). The sight distance is determined by using equation 2:

$$SD = DS * CG \qquad \cdots\cdots (2)$$

Where:

SD = Sight distance in meter

DS = Design speed in m/s

CG = Critical gap accepted in seconds

The AASHTO (2001) model for determining gap acceptance sight distance at Intersections with Stop Control on the Minor Road considers three cases:

- Left turn movements (L)
- Right turn movements (R)
- Crossing the major road from a minor road (T)

AASHTO uses the following model, equation 3, to determine the critical gap size:

$$CG = BG + TF + GF \quad \cdots\cdots(3)$$

Where:

CG = Critical Gap in seconds

BG = Base Gap in seconds

TF = Turning lane factor

GF = Gradient factor

Note: TF = 0 for right and through movements where a maximum of 2 lanes are crossed and for gradients between -3% and 3%

GF = 0 only applicable for gradients between -3% and 3%

According to AASHTO the critical gap Is equal to the base gap of 6.5 seconds for straight- and left turning movements for a two lane road with gradiets between 3% and -3% (as depicted in Figure 2.4) and 7.5 seconds for right turning movements.

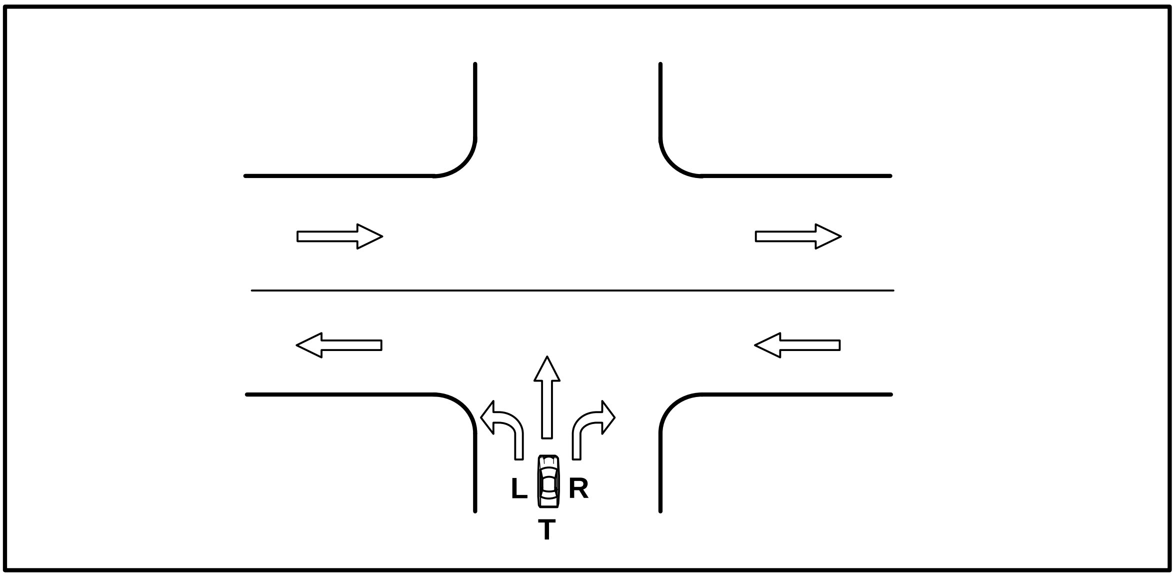


Figure 2.4: Stop control on the minor road with one lane per direction (for all three cases)

Critical gap acceptance sight distances for different design speeds are shown in Table 2.3 for the three different cases.

Table 2.3: Stop control on the minor road with one lane per direction (for all three cases)

Critical gap acceptance sight distances					
Critical gap (seconds)	**Sight distances (m) for design speeds (km/h)**				
	40	**50**	**60**	**70**	**80**
6.5	75	95	110	130	145
7.5	85	105	130	150	170
Note: Table applicable for two lane main road with gradient between 3% and -3%					

2.2.4 CORNER CLEARANCE

The Access Management Manual (TRB, 2003) defines corner clearance as the distance from an upstream intersection/access to a downstream intersections/accesses comprising of distance d1 (distance traversed by vehicle during the perception-reaction time after clearing the upstream intersection), followed by maneuver distance d2 and finally estimated queue length storage distance of the downstream intersection (the longest of either the expected right turn or left turn queue). For all practical purposes, this distance corresponds with the functional area definition according to AASHTO (See Figure 2.3 under paragraph 2.2.1 of this chapter).

Corner clearance can therefore also include the scenario where a vehicle turning left or right from an upstream intersection/access has sufficient time to safely observe a vehicle entering the road from a downstream intersection/access without colliding with it.

2.2.5 LEFT-TURN CONFLICT OVERLAP

Left-turn conflict overlap is the distance required to allow a driver on the main road sufficient time to perceive and react to a vehicle turning left or right from the minor road not to collide with it. The distance depends on a number of variables such as perception reaction-time, deceleration rate of the main road vehicle, acceleration rate of the side road vehicle turning right or left in entering the main road and acceptable speed differential between the main road vehicle and the side road vehicle.

Table 2.4 lists minimum intersection/access spacing distances based on the left-turn conflict overlap criterion as recommended in the Access Management Manual (TRB, 2003) and Access Management Classification and Spacing Standards, (Layton, R.D. & Stover, V., 1996). The distances are measured from centre-line to centre-line of intersections/accesses.

Table 2.4: Minimum distances to reduce collision potential due to overlapping left turn maneuvers

Speed (km/h)	Access Management Manual (Note 1)	Access Management Classification and Spacing Standards (Note 2)
	Minimum Spacing (m)	Minimum Spacing (m)
48	56	31
56	75	46
64	91	61
72	107	91

Note 1: A vehicle entering the traffic stream from a driveway completes the 90-degree left turn and accelerates from a stop at 0.61 m/s². The vehicle in the outside traffic through lane does not change lanes and decelerates at 1.83 m/s² after a 2.0s perception-reaction time. No clearance is provided between the through vehicle and the vehicle entering from the driveway. The resulting speed differentials between the driveway vehicle and the through traffic stream range from about 32 km/h on a roadway having a 48 km/h speed to over 48 km/h where the through traffic speed is 72 km/h. (TRB, 2003)

Note 2: The distance for the left turn conflict is equal to the stopping distance, with 1.0 s perception-reaction time and at 1.83 m/s² average deceleration. Entering vehicles accelerate at an average of 0.64 to 0.94 m/s². The left turn conflict does not require much speed reduction of vehicles in the through lanes, about 16km/h, if one driveway is visible. The table presents the minimum distance to reduce collision potential for left turn conflict with the single left turn conflict condition. (Layton & Stover, 1996)

2.2.6 DECISION SIGHT DISTANCE

Decision sight distance is the distance required in instances where drivers has to make complex or instantaneous decisions, where it is difficult to perceive information or when unexpected or unusual maneuvers are required (UTG5, 1988). Decision sight distances are site specific and for the purpose of this study it will not be alluded to further as a criteria for intersections/access spacing. The assumption is made that the designer will use engineering judgment in instances where decision sight distances are deemed necessary.

2.2.7 INFLUENCE DISTANCE

Influence distance can be defined as the distance at which vehicles turning left into an intersection/access have an influence on the following through traffic.

The National Cooperative Highway Research Program (NCHRP) Report 420 (Gluck J., Levinson, H.S. & Stover, V., 1999) conducted a research project on influence distance. According to this research, the influence distance comprises of the distance from the point up-stream of the intersection/access where the brake lights of the left turning vehicle were activated (impact distance) and the distance travelled during the perception-reaction time before the brakes were activated. This is comparable to the distances d1 and d2 in the functional area of an intersection.

Table 2.5 provides access spacing distance for vehicle speeds between 48km/h and 89km/h using Spill-Back Rate Percentage. Spill-Back occurs when a through vehicle must brake in response to another vehicle making a left turn at an access connection. The spill-back rate represents the percentage of through vehicles experiencing such an event. (For example, from Table 2.5 it can be concluded that for a speed of 80km/h, only 2% of following vehicles are effected with a 189m spacing, whilst 20% will affected with a spacing distance of 105m)

Table 2.5: Access spacing in meter according to allowable spill-back rate percentage

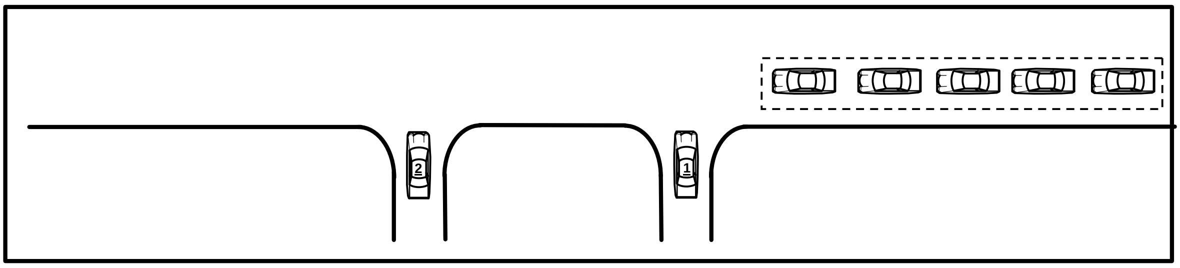
Speed (km/h)	Spill-Back Rate in percentage with corresponding distances in m				
	2%	**5%**	**10%**	**15%**	**20%**
48	116	102	88	79	75
56	123	108	94	85	79
64	140	122	104	93	87
72	162	137	116	104	96
81	189	159	130	116	105
89	221	180	146	128	116

In the Access Management Manual (TRB, 2003) it is stated that the Spill-Back Rate can be used as criteria for establishing connection spacing guidelines. The higher the roadway functional classification is, the lower the acceptable spill-back rate. The distances highlighted in Table 2.5 are for Spill-Back Rates between 5% and 15% for collector roads (used as an example in the NCHRP project).

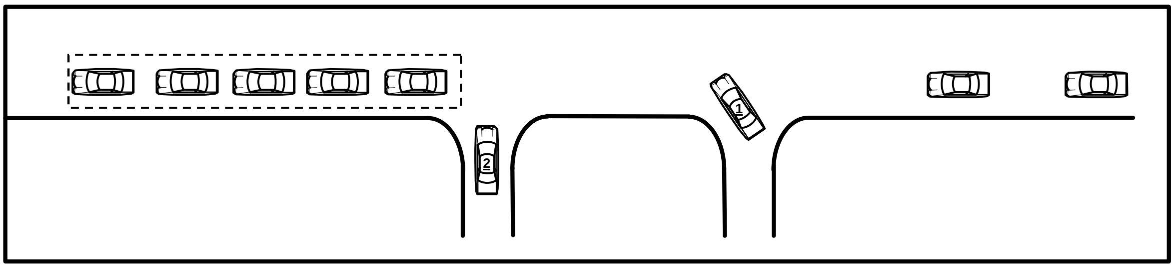
Since spill-back rates can be regarded as a traffic operational rather than a typical geometric design criterion, which will require significant additional research for South-African conditions, it is not considered to fall within the scope of this dissertation. It will therefore not be evaluated further in this document as an intersection/access spacing criterion.

2.2.8 EGRESS CAPACITY

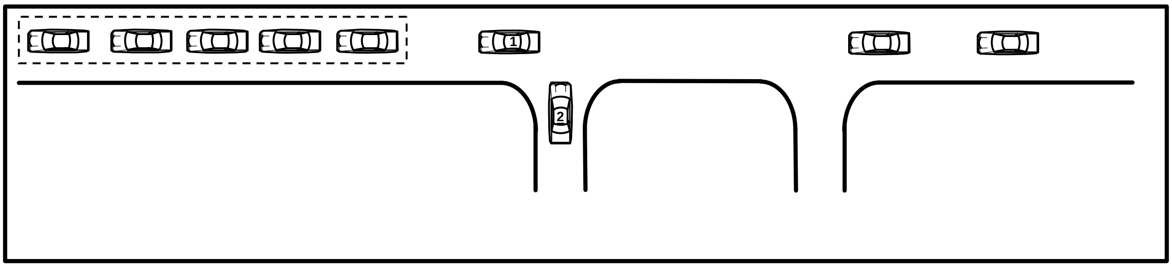
Egress capacity, in intersections/access spacing terms, is the optimum number of vehicles that can exit a priority controlled intersection or access. According to the Access Management Manual (TRB, 2003) closely spaced intersections/accesses interfere with each other and restrict egress capacity. This is especially found where vehicles in adjacent closely spaced priority controlled intersections/accesses attempt to enter the main traffic stream. Figures 2.5 and 2.6 (TRB, 2003) show this phenomenon in more detail. According to Major & Buckley (Proceedings of the Australian Road Research Board, 1962) the capacity of vehicles entering a roadway for abutting properties increases as the spacing between the access connections increases up to point where the spacing is 1.5 times the distance to accelerate from a stop to the average speed of the through traffic.



Time t_1: Insufficient time for drivers in vehicle 1 and 2 to exit ahead of approaching platoon.

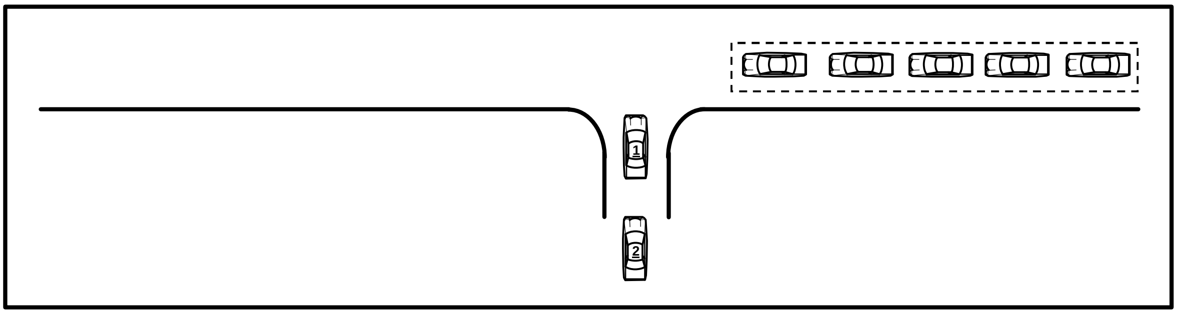


Time t_2: Platoon passes: vehicle 1 exits driveway; vehicle 2 is “blocked” because gap between the end of the platoon and vehicle 1 is not sufficient to make exit maneuver.

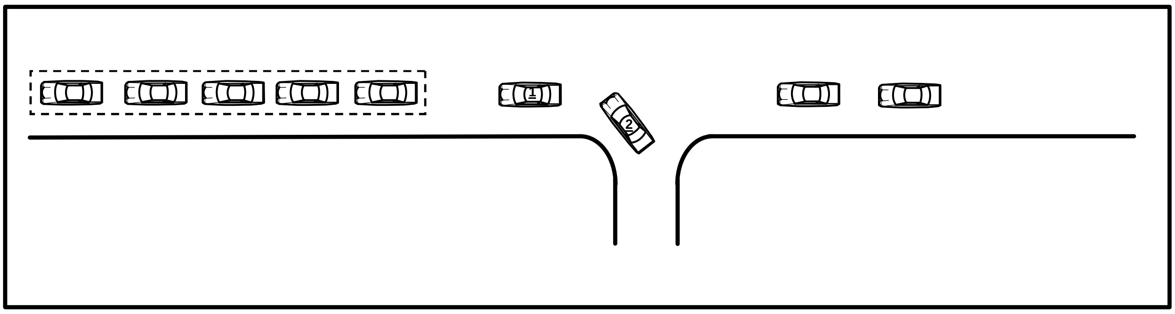


Time t_3: Vehicle 2 is “blocked” because gap between vehicle 1 and approaching stragglers is insufficient to make exit maneuver.

Figure 2.5: Schematic representation of limited egress capacity due to closely spaced (TRB, 2003)



Time t_1: Insufficient time for drivers of vehicle 1 and 2 to exit ahead of approaching platoon.



Time t_2: Platoon passes: both exiting vehicles can enter the gap between the end of the platoon and the approaching stragglers.

Figure 2.6: Schematic representation of improved egress capacity when multiple vehicles exit from the same access drive (TRB, 2003)

Table 2.6 shows the minimum intersection/access spacing distances for various design speeds according to Major & Buckley (Proceedings of the Australian Road Research Board, 1962) to the Access Management Manual (TRB, 2003) to maintain maximum egress capacity.

Table 2.6: Access spacing that maximizes the capacity of passenger cars to re-enter the roadway from priority controlled intersections/accesses

Speed (km/h)	Minimum access spacing (m)
20	30
30	45
40	75
50	115
60	170
70	240

The Access Management Manual (TRB, 2003) further recommends that in selecting and applying access spacing criteria, the following should be considered:

- Roadways with a higher functional classification generally use longer spacing standards.
- Roadways with higher classifications usually have higher speeds than lower classification roadways.
- Roadways with higher classifications tend to carry higher traffic volumes than roadways of a lower classification.
- Interference with through traffic increases when the traffic volumes increase. Especially during peak periods, a large number of through vehicles on high-speed, high-volume suburban/urban roadways can be disturbed through a small number of vehicles that turn. One single vehicle that turn from a through lane can completely interrupt platooned flow and progression.
- Roadways with speeds more than 72 km/h are usually more critical than those with speeds less than 64 km/h.

Since egress capacity, in intersections/access spacing terms, is the optimum number of vehicles that can exit a priority controlled intersection or access, it is regarded more of a traffic operational and capacity related criterion, than a typical geometric and safety design criterion. Consequently, it is not deemed appropriate for further evaluation in terms of access spacing requirements for this dissertation.

2.2.9 SAFETY CONSIDERATIONS

According to AASHTO (2001), safety is an important factor in all roadway elements, but not practical to provide an obstacle-free roadside on low-volume roads or streets in urban areas.

It can therefore be concluded that since collector roads share both an accessibility and mobility function (See Figure 2.7 as depicted in Figure 2.1 of Draft UTG 5), in fact according to Figure 2.7 it leans more toward an accessibility function, access cannot be restricted as rigidly as is the case with arterial roads and freeways. It is, however, important to note that since the number of accesses impact directly on potential collision rates, safety must always be considered as a first priority in the evaluating any new access/intersection along an arterial route.

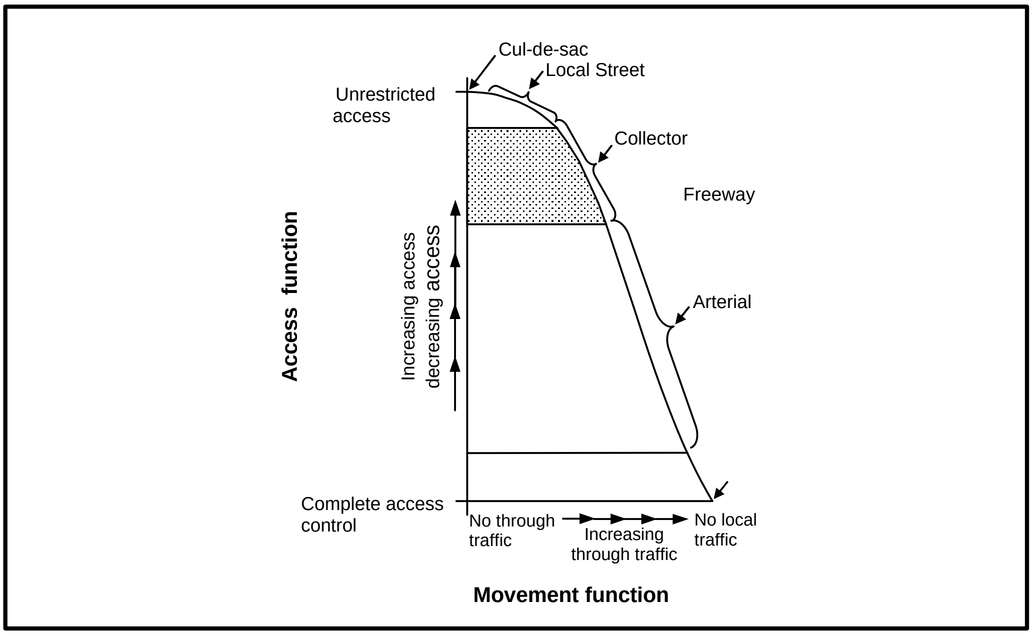


Figure 2.7: Movement – Access functions

3. ACCELERATION AND DECELERATION MODELS

3.1 INTRODUCTION

The operational characteristics of vehicles are those characteristics that describe the manner in which vehicles operate. In geometric design these characteristics are of vital importance as it relates design elements to requirements associated with vehicle operations.

Vehicle operational characteristics include elements such as acceleration and deceleration performance. These characteristics are important because they affect vehicle operations associated with the approach, entering and clearing of intersections (Van As & Joubert, 1993).

3.2 DECELERATION

Deceleration rates of vehicles are applied in the evaluation of vehicles approaching intersections on the side road as well as for vehicles on the main road affected by vehicles entering an intersection either from the main road, or turning from the main road into the side road. For geometric design purposes deceleration rates are normally assumed to be constant and independent of speed (AASHTO, 1990; Bester, C.J.; 1981).

Equations 4, 5 and 6 of movement (motion) applying to such a model are as follows:

$$V_e = V_0 + at \quad \text{..........} (4)$$

$$x = V_0 t + \tfrac{1}{2} a t^2 \quad \text{..........} (5)$$

$$V_e^2 = V_0^2 + at \quad \text{..........} (6)$$

Where:

a = Acceleration (negative deceleration) rate (m/s^2)

V_0 = Initial speed (m/s)

V_e = End speed (m/s)

t = Time interval (second)

x = Distance travelled (m)

The deceleration rates applied in the study are indicated in Table 3.1.

Table 3.1: Constant deceleration rates (m/s^2) on level gradient

Reference		**Deceleration rate (m/s^2)**	**Perception reaction time (s)**
AASHTO, (2001).	Deceleration	-3.40	2.5
Bester, (1981).	Approaching horizontal curves	-1.25	-
	Approaching a stop sign	-1.86	-
Management and control of access to the Pretoria street system, (1998).	Deceleration	-2.25	0.5

3.3 ACCELERATION

As with deceleration, acceleration performance of vehicles plays an important roll in intersection/access spacing design.

3.3.1 ACCELERATION RESISTANCE FORCES

The acceleration rate of vehicles are influenced by forces such as rolling resistance, air resistance, gradient resistance, horizontal curves, inertia resistance and speed fluctuations. Power is necessary to overcome these forces in order to move and accelerate a vehicle. Acceleration resistance forces are illustrates in Figure 3.1.

- <u>Rolling resistance force</u>

  Rolling resistance force is defined as the resistance of the pavement surface to the movement of the vehicle. Various factors such as frictional slippage of wheels, flexing of the tyres, rolling over rough particles, climbing out of potholes, pushing wheel through loose surface materials, etc. contribute to rolling resistance force (Bester, 1981).

- <u>Air resistance force</u>

  Air resistance force is defined as the effect of the air in the path of the vehicle, which resists the movement of a vehicle through it. Air resistance force depends on the shape of the vehicle which affects the aerodynamic drag coefficient, the size of the vehicle which is measured in terms of frontal projected area, the density of the air and speed of the vehicle (Bester, 1981).

- <u>Gradient resistance force</u>

  Gradient resistance force is defined as the component of a vehicle's weight acting parallel to the gradient of the incline on which the vehicle is travelling. It is an additional external force affecting the vehicle's acceleration performance (Bester, 1981).

- <u>Horizontal curve force</u>

  The horizontal curve resistance force is defined as the side forces acting on the wheels due to the centrifugal forces as well as the additional air resistance force because the vehicle is slightly turned sideways on a curve. This only influences the acceleration performance of a vehicle when a horizontal curve is negotiated (Bester, 1981).

- <u>Inertia resistance force</u>

  Inertia resistance force has to be overcome when a vehicle is accelerated. Inertia resistance force is a function of both the mass of a vehicle and its rotating parts. The effect of the rotating parts on the acceleration of the vehicle is calculated to compensate for the additional effective inertia mass of a vehicle (Van As & Joubert, 1993).

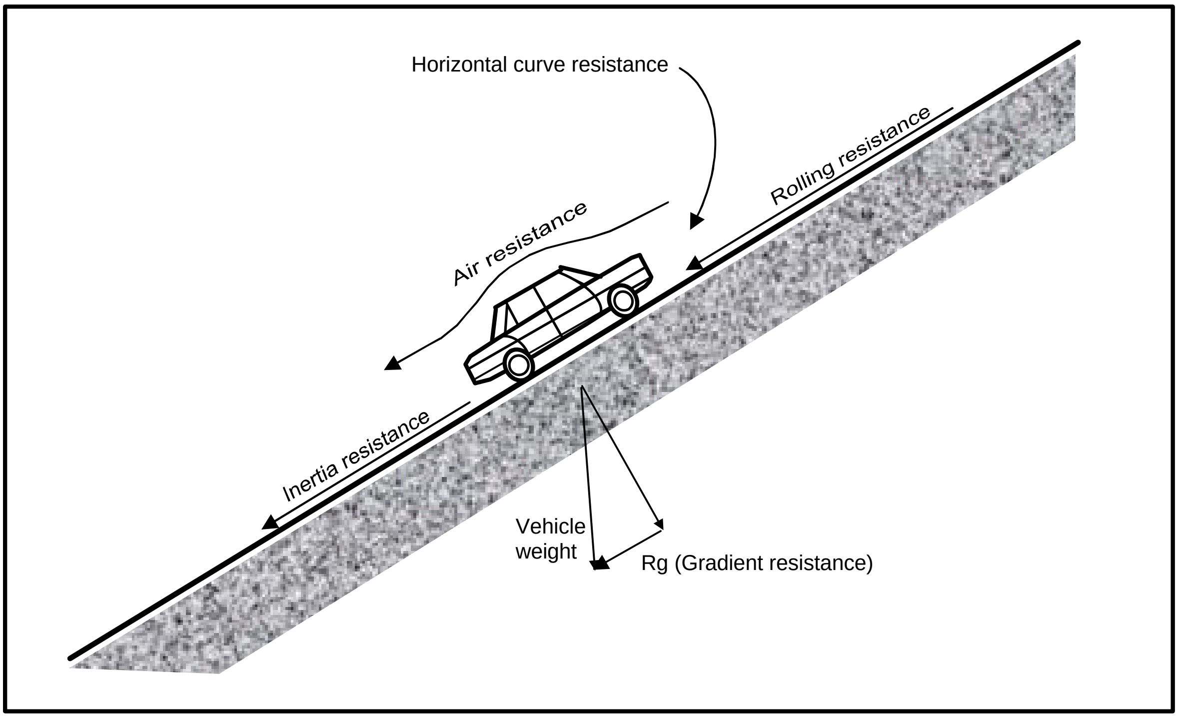


Figure 3.1: Acceleration resistance forces

3.3.2 ACCELERATION MODELS

An acceleration model is used to theoretically simulate the actual acceleration performance of a vehicle. Bester (1981) evaluated two acceleration models which would best describe the acceleration performance of South African vehicles in equation 7 and equation 8:

(a) Acceleration as a linear function of speed (logarithmic model)

$$a = \alpha - \beta * V \quad \text{(7)}$$

Where:

a = Acceleration rate (m/s^2)

a,ß = Constants

V = Speed (m/s)

(b) Acceleration as a parabolic function of speed (parabolic model)

$$a = \frac{(\alpha - \beta * V)^2}{\alpha} \quad \text{(8)}$$

where:

a = Acceleration rate (m/s^2)

a,ß = Constants

V = Speed (m/s)

Bester (1981) applied the logarithmic model in his calibration for South African vehicles because it can allow for negative acceleration on steep grades, a property not incorporated in the parabolic model.

Therefore, the logarithmic acceleration model, equation 9, was also selected for this study:

$$a = \alpha - \beta * V - \frac{M}{Me} * g * G \quad \cdots\cdots (9)$$

Where:

a = Acceleration rate (m/s^2)

a,ß = Constants

V = Speed (m/s)

M/Me = Constants (effective mass ratio)

g = Gravitational constant (9.81 m/s^2)

G = Gradient of road (m/m)

The effective mass ratio allows for the effect of the rotating parts of the vehicle driveline during acceleration. The ratio depends on the gear in use. For traffic engineering purposes it is sufficient to use the following simplified equation 10 and 11 to estimate the ratio (Bester, 1981):

$$\frac{M}{Me} = a - \frac{b}{V} \quad (v > V\min) \quad \cdots\cdots (10)$$

$$= c \quad (v \leq V\min) \quad \cdots\cdots (11)$$

The acceleration model was calibrated for South African conditions by Bester (1981). Results are given in Table 3.2

Table 3.2: Acceleration parameters for South African design vehicles

Parameter	Passenger cars
a	1.85
a/ß	33.0
a	0.99
b	0.87
c	0.607
Vmin	2.272

The table above lists parameters for an average South African passenger car which is not necessarily the design passenger car. In practice, however, drivers of passenger cars only use a fraction of the available power of a vehicle and even this fraction can be expected to differ from driver to driver. In cases of more powerful vehicles drivers will most probably use a lower fraction of the available power than drivers of less powerful vehicles. The empirical model for acceleration by Bester is probably the best model to be used since it is based on South African research and conditions. See Annexure B for an example calculation of Bester's non-constant acceleration model.

3.3.3 FIELD SURVEYS

The field surveys to determine the acceleration of passenger car vehicles were performed at three different priority controlled intersections in the Bloemfontein area namely, the Waverley Road/Whites Road, the Furstenburg Road / Pierre Ollemans Street and the Benade Drive / Stals Road intersections. At the first two intersections listed above, vehicles stopped at the stop line, turned left and accelerated. At the other intersection the acceleration of straight moving vehicles were measured.

Seven sets of inductor loops were placed at specific intervals on the road surface along the exit lanes of the relevant intersections (see Figures 3.1 to 3.3). The inductor loops were linked to a control box and computer which captured the time each vehicle passed the loops from a stationary position (from the stop line). Distances were added/subtracted for the first distance interval depending on the position the surveyed vehicle stopped relative to the stop line before accelerating from rest.

From the field surveys time/distance graphs were produced to compare with existing acceleration models. See Annexures C, D and E for detailed results (graphs) of the field surveys performed.

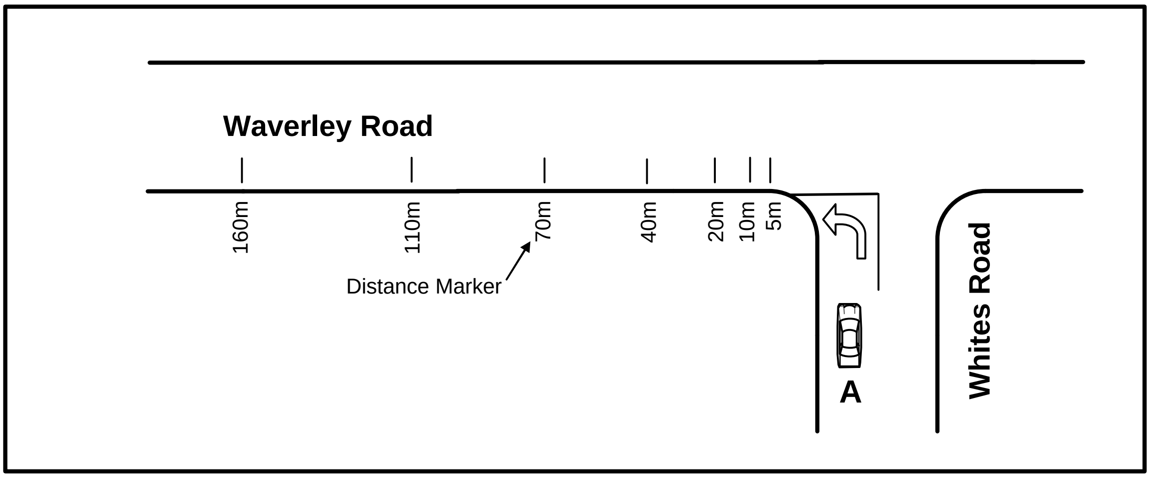


Figure 3.2: Waverley Road / Whites Road intersection: Time & distance survey

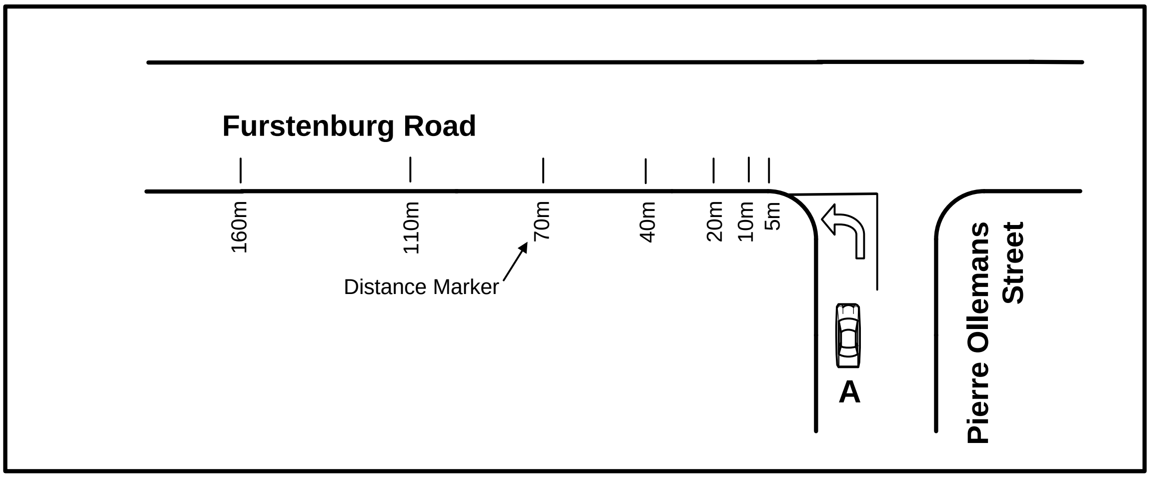


Figure 3.3: Furstenburg Road / Pierre Ollemans Street intersection: Time & distance survey

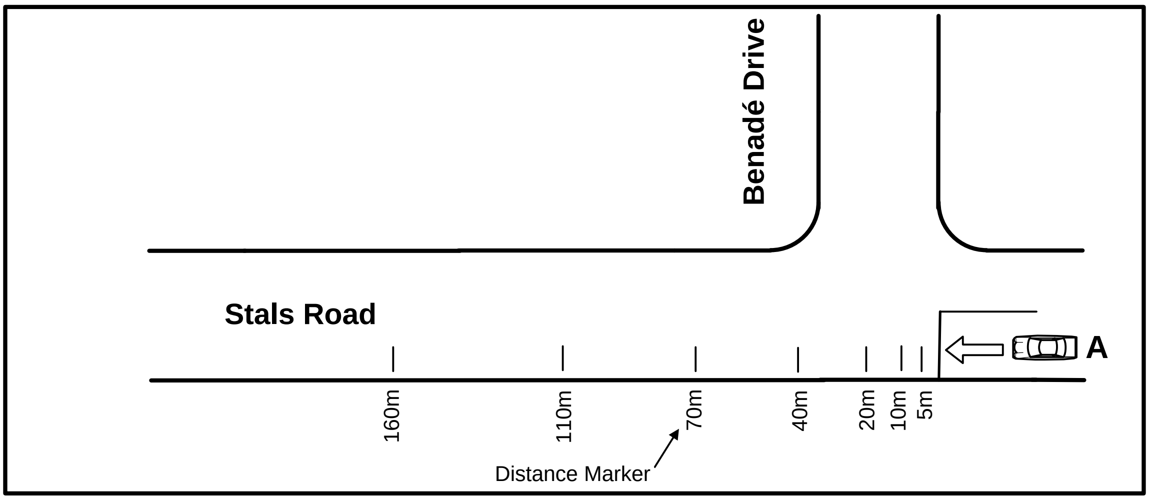


Figure 3.4: Benade Drive / Stals Road intersection: Time & distance survey

3.3.4 COMPARISON OF GRAPHS

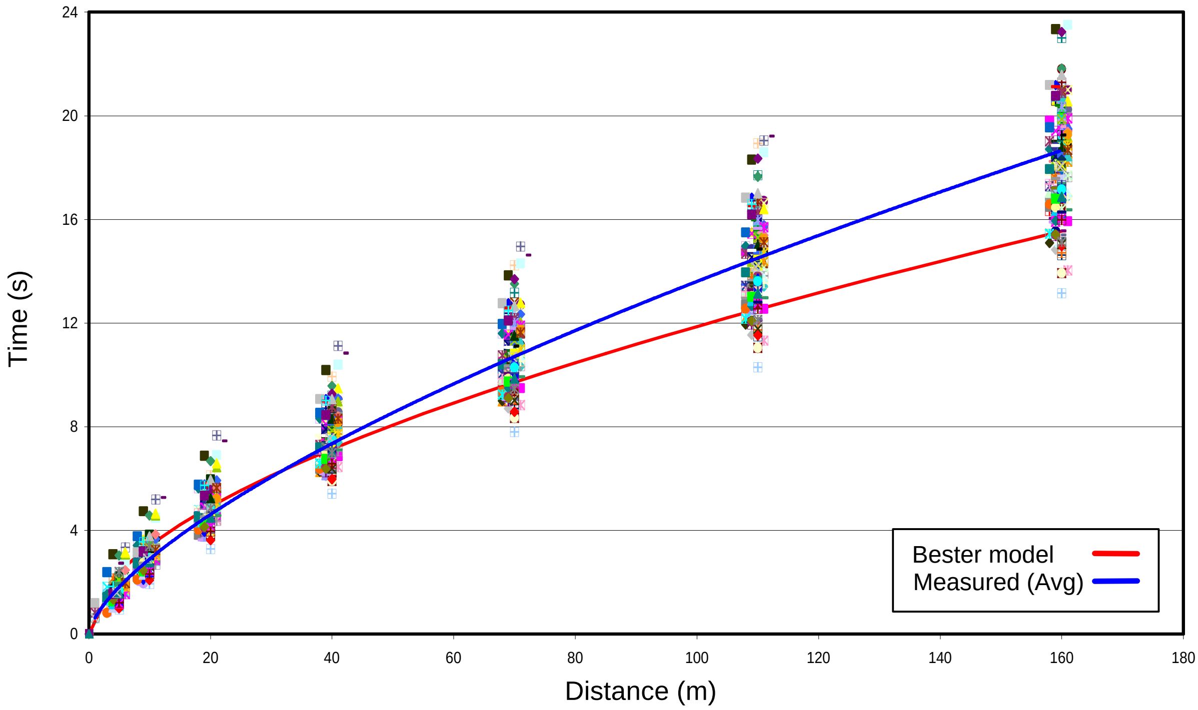


Figure 3.5: Waverley Road / Whites Road intersection

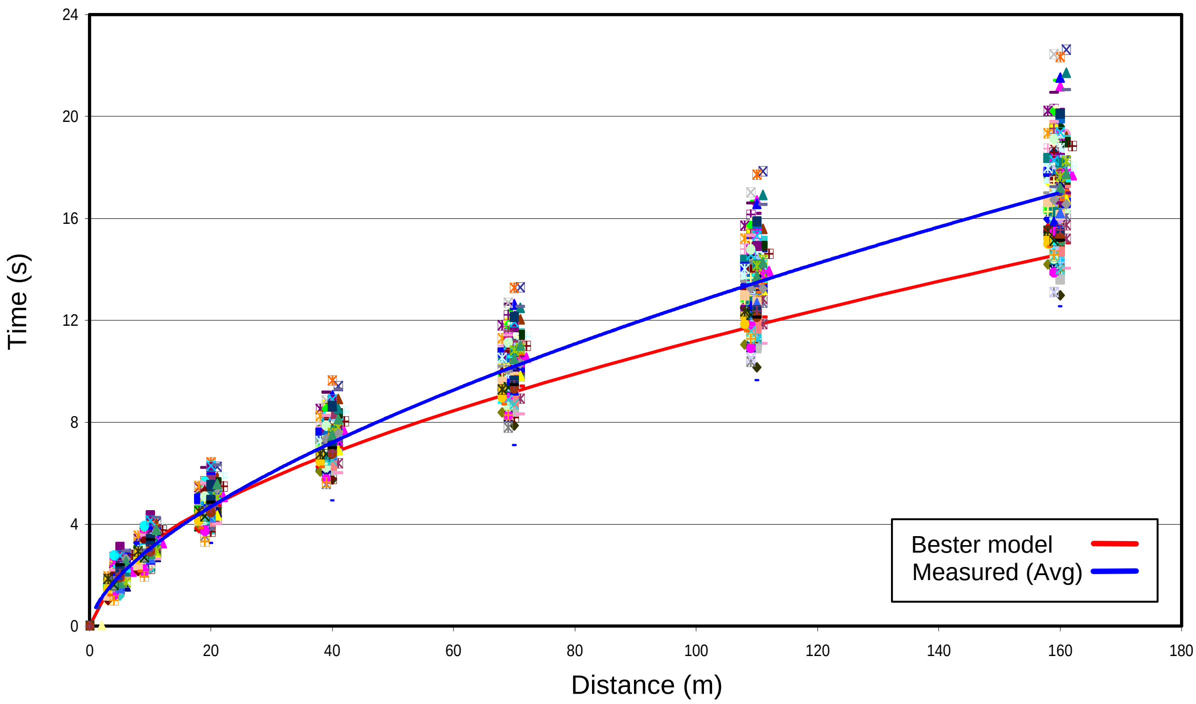


Figure 3.6: Furstenburg Road / Pierre Ollemans Street intersection

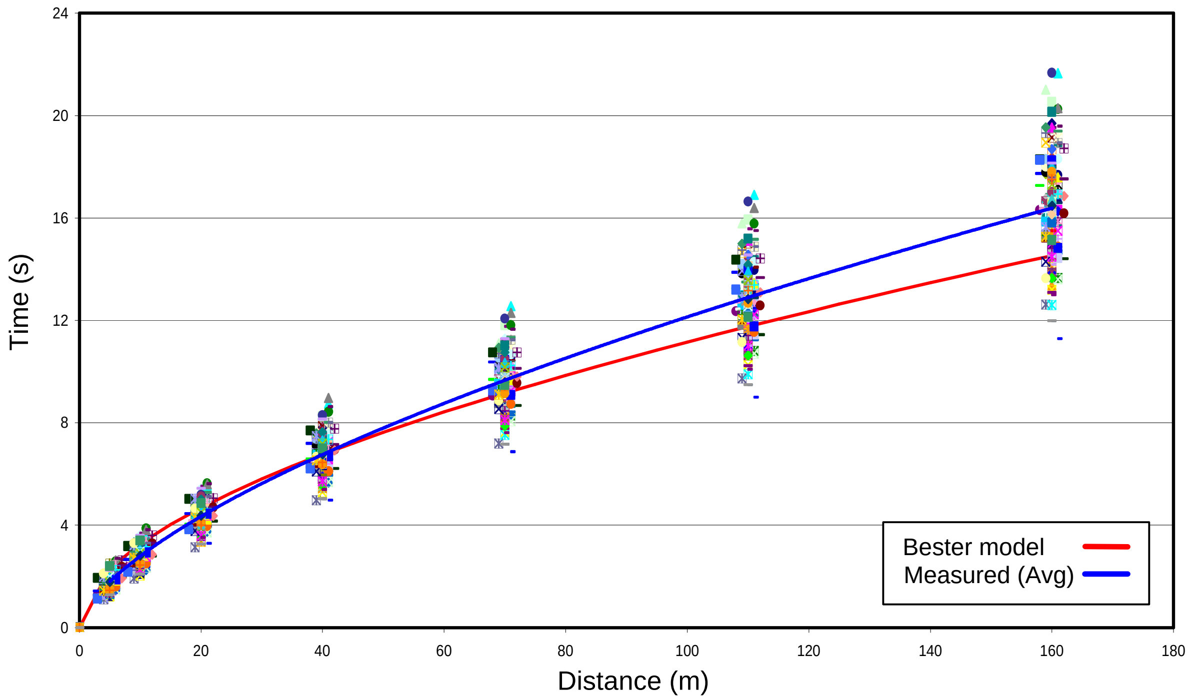


Figure 3.7: Benade Drive / Stals Road intersection

From the above graphs a noticeable difference between Bester's model and the results obtained from the field surveys by means of the inductor loops is observed. The survey results show that drivers take longer than the model (lower acceleration rate) to reach the 160m marker.

One of the main reasons for the deviations can be attributed to the fact that driver behaviour could have been influenced by the presence of the inductor loops on the road. To test this possibility, it was decided to determine the acceleration of vehicles without the influence of the inductor loops and comparing it with the inductor loop survey results. This was done by recording the time required for the vehicles turning left (at the same intersections the surveys were conducted) from a stationary position, (from the stop line), to accelerate and get to the same position the last inductor loop was located on the road. The mean speeds for vehicles between the start and end position were calculated for both the surveyed methods and in both instances found to be normally distributed as is typically the case in speed studies. As a result, the same traffic engineering procedure, as applied in before- and after speed statistical analysis (Van As & Joubert, 1993) could be used for the purpose of comparing the manual survey results with the inductor loop survey results.

To determine the significance of the difference in mean speeds between the two surveyed methods, the standard deviations for both surveyed methods were calculated in equation 12:

$$S^2 = \frac{\sum N_j * (V_j - V)^2}{N-1} \qquad \cdots\cdots\cdots (12)$$

Where:

S = Standard deviation

N_j = Number of observations in interval j

V_j = Midpoint value of speed interval j

N = Total number of observations

V = Mean speed

With both sample sizes large (more than 30), the difference in the before and after means $V_1 - V_2$ will be normally distributed with mean zero and the variance in equation 13:

$$S_d^{\,2} \quad = \quad \frac{S_1^{\,2}}{N_1} + \frac{S_2^{\,2}}{N_2} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (13)$$

Where:

S_1 = Standard deviation (inductor loops)

N_1 = Total number of observations (inductor loops)

S_2 = Standard deviation (manually)

N_2 = Total number of observations (manually)

S_d = Standard deviation for before and after survey calculation

It can then be stated in equation 14 with a level of confidence of 95% that the before and after means differ if :

$$V_1 - V_2 > 1.96 * S_d \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (14)$$

Where:

V_1 = Mean speed (inductor loops)

V_2 = Mean speed (manually)

S_d = Standard deviation for before and after survey calculation

WAVERLEY ROAD / WHITES ROAD

Using the above statistical analysis for the for Waverley Road / Whites Road Intersection with V1 = 18.04, V2 = 17.17 and S_d = 0.2601 (see annexure F for detailed calculations), it can be concluded that V1 – V2 > 1.96S_d proving that it can be stated with a 95% level of confidence that the before and after means differ.

FURSTENBURG ROAD / PIERRE OLLEMANS STREET INTERSECTION

The same calculation for the Furstenburg Road/ Pierre Ollemans Street Intersection with V1 = 17.0, V2 = 15.5 and S_d = 0.2174 (see Annexure G for detailed calculations), also revealed that V1 – V2 > $1.96S_d$ also proving that it can be stated with a 95% level of confidence that the before and after means differ.

3.4 CONCLUSION

It can therefore be concluded that the impact of the inductor loops on driver behaviour is significant and as a result the inductor loop survey results should not be used further. Bester's formula will therefore be used in all non-constant acceleration calculations in the report.

4. EVALUATION AND COMPARISON OF CURRENT INTERSECTION/ACCESS SPACING METHODOLOGY

4.1 INTRODUCTION

The evaluation and comparison of current intersection/access spacing methodology is necessary in order to make recommendations pertaining to intersection/access spacing requirements for urban collector roads. Functional boundary, stopping sight distance, gap acceptance, corner clearance and left turn conflict overlap criteria with the influence of acceleration, deceleration, gap acceptance and perception-reaction time variations are evaluated in the next section of this chapter.

4.2 FUNCTIONAL BOUNDARY

The functional boundary can be determined by calculating the distance travelled during perception-reaction time and the distance to decelerate from the design speed of the through road to enter the downstream intersection/access (taking lane changes into consideration where applicable). If queues are expected at the intersection/access due to access control (including control measures such as stops or signal control) or due to high turning traffic volumes, the queuing distance needs to be added with the entering speed at the back of the queue assumed to be 0km/h. If no queues are expected, the access bell-mouth radius will determine the entering speed. According to Pretorius (1994) the entering speed of a vehicle for a specific horizontal curve can be determined in equation 15 as follows:

$$V = 17.34 \quad R^{0.26057} \qquad \text{...} (15)$$

Where:

V = Entering speed at horizontal curve in km/h

R = Applicable horizontal curve radius in m

4.2.1 FUNCTIONAL BOUNDARY VARIABLES

Calculations for functional boundary distances are influenced by different entering bell-mouth radii, variable deceleration rates, variable perception-reaction times and design speed. Bell-mouth radii are dependant on the detail intersection/access design which is generally affected by the type of vehicle utilizing the intersection/access. Constant deceleration rates are typically applied for design purposes and are also influenced by the complexity of the vehicular movement that is executed whilst decelerating. For example, a higher deceleration rate is expected for vehicles decelerating in a straight line compared to a situation where lane changing, weaving or turning is executed whilst decelerating. Perception-reaction time is generally affected by the type of driver and complexity of the decision that needs to be taken. Table 4.1 lists deceleration rates and perception-reaction times recommended in various design documents.

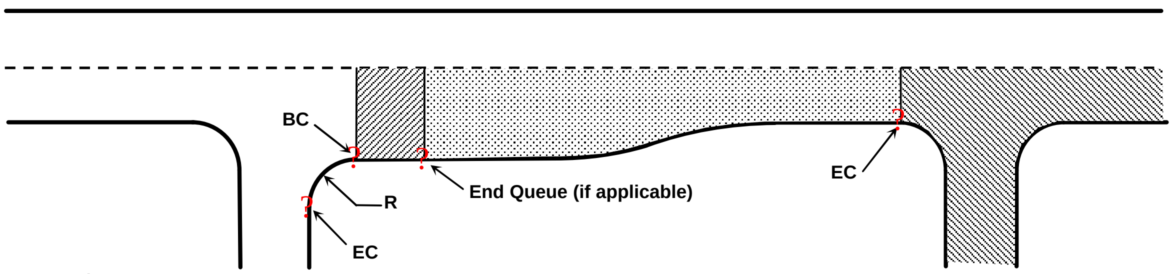
Table 4.1: Deceleration rates and perception-reaction times

	REFERENCE	Lateral Movement Deceleration Rate (m/s^2)	Straight Movement Deceleration Rate (m/s^2)	Perception Reaction time (s)
1.	**SPACING OF ACCESSES ON MAJOR ARTERIALS** *(Department of Transport, 1993)*	1.20	1.8	-
2.	**DRAFT ROAD ACCESS MANAGEMENT GUIDELINES (RAM)** (Department of Public Transport, Roads & Works, 2003)	1.50	2.25 (with queue)	1.5
3.	**ROAD ACCESS GUIDELINES** *(*Provincial Administration Western Cape, 2002)	-	-	1.5
4.	**NATIONAL GUIDELINES FOR ROAD ACCESS MANAGEMENT IN SOUTH AFRICA** (Committee of Transportation Officials, 2002)	1.20	1.50 (no queue) 2.25 (with queue)	1.5
5.	**ROAD ACCESS MANAGEMENT MANUAL** (SAICE Transport Engineering Division, 1999)	-	1.90	1.5

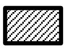
From Table 4.1 above it can be concluded that a 1.5s perception-reaction time can be used confidently. Also, a $1.2m/s^2$ rate for deceleration that requires lateral movement (typically where dedicated left or right turn lanes are provided), $1.5m/s^2$ for deceleration that requires straight movement (with no queue expected) and $2.25m/s^2$ with a queue expected will provide conservative results. According to UTG5 (CUTA, 1988), lateral movement is typically performed at taper rates of 1:10, 1:15 and 1:20 for 50km/h, 60km/h and 80km/h respectively. Therefore, to move laterally from one lane to another (assuming a 3.5m lane width) a deceleration rate of $1.2m/s^2$ will be used for the first 35m, 53m, 61m and 70m for design speeds of 50km/h, 60km/h, 70km/h and 80km/h respectively.

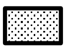
4.2.2 CALCULATIONS FOR FUNCTIONAL BOUNDARY (LEFT-IN DOWNSTREAM INTERSECTION/ACCESS)

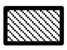
According to AASHTO (2001) intersections or accesses should ideally not be located within the functional boundary of other intersection or accesses. To ensure that this criterion is met, it must be concluded that the distance between the end of the functional boundary of an upstream intersection/access must not overlap with the start of the functional boundary of the downstream intersection/access. Figure 4.1 shows the typical components of functional boundary that needs to be calculated for downstream left-in intersection/access:



Legend:

 Queue component of downstream functional boundary area (if applicable) for downstream intersection with the queue begin at **BC** (conservatively)

 Perception-reaction and deceleration component of functional boundary area for downstream intersection

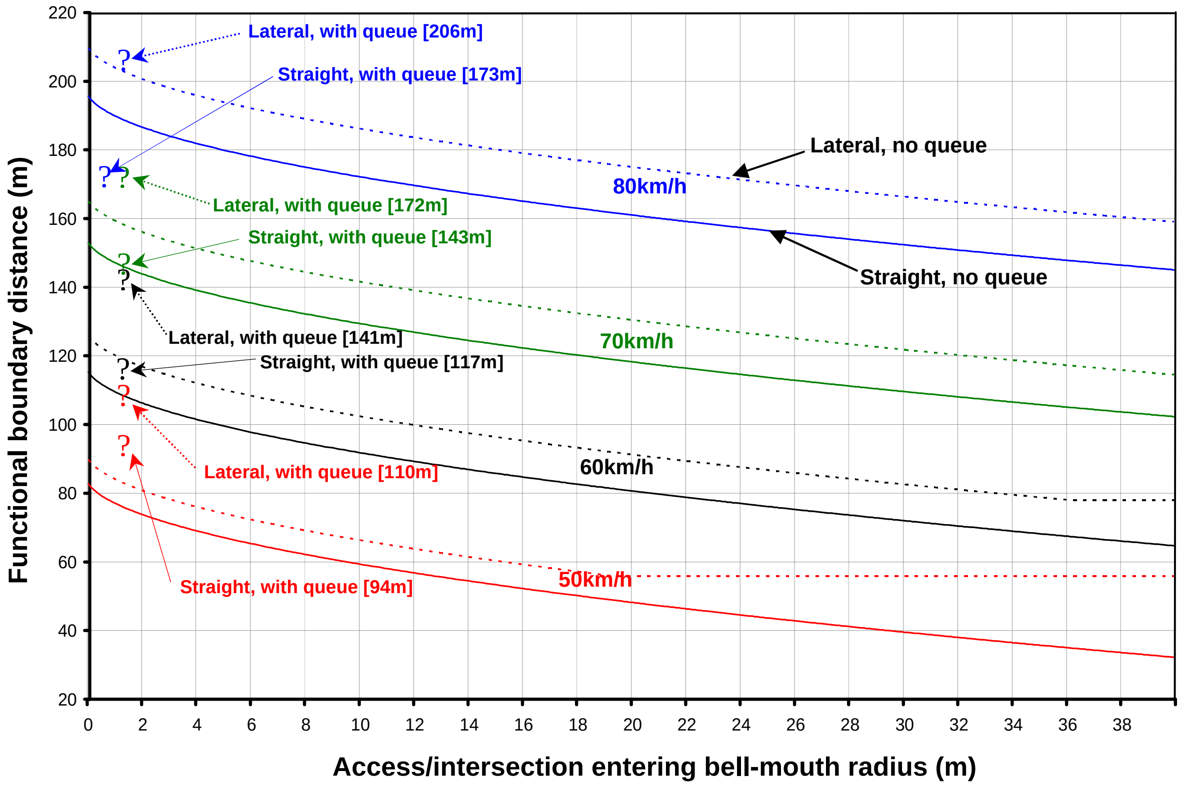
 End component of functional boundary area of upstream intersection ending at the **EC** of the upstream intersection exiting bell-mouth radius

R: Entering radius for left-in downstream intersection/access

Note: It no queue or access control is expected at the downstream intersection/access for entering vehicles, (free flow condition), the queue component of the downstream functional boundary area can be omitted.

Figure 4.1: Functional boundary elements (left-in movement)

Figure 4.1 shows functional boundary distances for left-in downstream intersections/accesses (with and without single lane lateral movement where lateral movement is assumed to be performed during the first part of the deceleration section). Where no queues are expected the entering speed at the end of curve (EC) of the downstream intersection/access is dependant on the entering radius. Where queues are expected the end speed is 0km/h and a minimum queuing distance of 30m should be allowed for (National Guidelines for Road Access Management in South Africa, COTO, 2002). The applicable distance on the y axis is the distance between the EC of the upstream intersection/access and the beginning of curve (BC) of the downstream intersection/access (See Figure 4.2). Detailed calculations are listed in Annexure H.



Note: For 50km/h and 60km/h the functional boundary, where lateral movement is applicable, cannot be less than 56m (21m perception-reaction + 35m lateral movement) and 78m (25m perception-reaction + 53m lateral movement) respectively to ensure that lateral movement of at least 3.5m (one lane change) after a perception reaction time of 1.5 second can be executed.

Figure 4.2: Functional boundary distances for left-in downstream access/intersection

From Figure 4.2 above it is evident that as the design speed increases, as can be expected, the functional boundary distances increases significantly. If lateral movement is required, the functional boundary also increases due to the lower deceleration rate applied. It is furthermore concluded that the entering radius at the downstream intersection/access (if no queues are expected) has an important effect on the functional boundary distances when measured between the EC of the upstream intersection/access and the BC of the downstream entering intersection/access.

It is, however, important to note that since the functional boundary distances calculated above are measured from the BC of the entering intersection/access, an increase in radius will have an marginal effect on the actual position of the downstream intersection/access (at the EC of the downstream intersection/access). The reason for this is that the straight distance (as measured along the through lanes) between the BC of the upstream intersection/access and the EC of the downstream intersection/access will also increase (due to the increase in radius).

For example, for 60km/h the functional boundary distance required for an entering radius of 3.2m (practical minimum for passenger car turning) is 104m between the EC of the upstream intersection/access and BC of the downstream entering radius, whereas the functional boundary distance required for a 32m radius is 70m. The actual distance between the EC of the upstream intersection/access and the EC of the downstream intersection/access measured along the through lane direction will therefore only differ by 5m.

For practical purposes, the functional boundary distance for intersections or accesses, where no queues are expected, can therefore conservatively be measured between the EC of the upstream intersection/access and the EC of the downstream intersection/access ignoring the impact of the entering radius. Table 4.2 lists the functional boundary distances required for different design speeds using this approach. The table also includes the functional boundary distances for situations where the queues are expected with the radius of the left-in downstream intersection/access added for comparison purposes.

Table 4.2: Left-in downstream intersection/access functional boundary distances for different design speeds

Entering radius (m)	Design speed (km/h)															
	50km/h				60km/h				70km/h				80km/h			
	Queue		No queue		Queue		No queue		Queue		No queue		Queue		No queue	
	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat
3	97	113	74	81	120	144	107	117	146	175	144	157	176	209	187	201
5	**99**	**115**	**72**	**79**	**122**	**146**	**105**	**115**	**148**	**177**	**142**	**155**	**178**	**211**	**185**	**199**
10	**104**	**120**	**69**	**76**	**127**	**151**	**102**	**113**	**153**	**182**	**140**	**152**	**183**	**216**	**182**	**196**
15	**109**	**125**	**68**	**75**	**132**	**156**	**101**	**111**	**158**	**187**	**138**	**151**	**188**	**221**	**181**	**195**
20	114	130	68	76	137	161	101	111	163	192	138	151	193	226	181	195
25	119	135	69	81	142	166	101	112	168	197	139	151	198	231	182	196
30	124	140	70	86	147	171	102	113	173	202	140	152	203	236	182	196
35	129	145	71	91	152	176	103	114	178	207	141	153	208	241	184	198
40	134	150	72	96	157	181	105	118	183	213	142	155	213	246	185	199

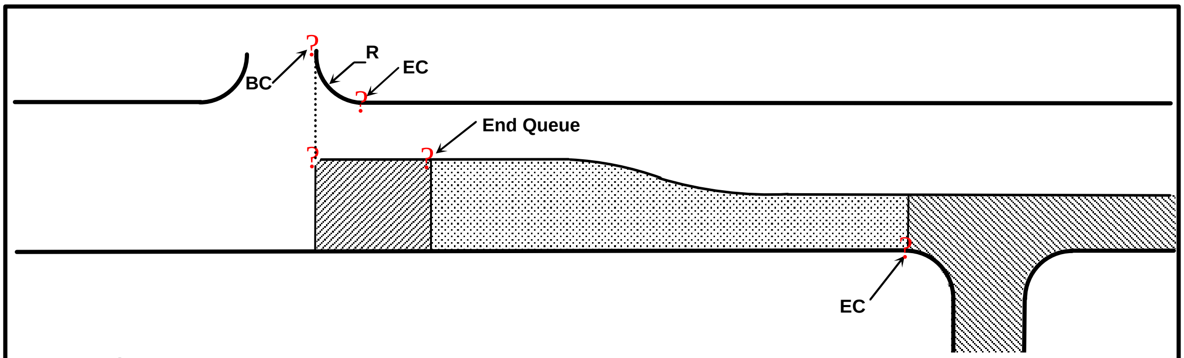
Notes:

(a) Str = only straight deceleration movement executed
(b) Lat = lateral deceleration maneuver executed
(c) Distances measured from EC upstream intersection/access to EC (taking radius distance into account) of downstream intersection/access. Radius distance is also added to queue scenario as the queue part of the functional boundary conservatively starts at the BC of the downstream intersection/access
(d) 30m queue length included in table above for queue scenarios

From the table above it is clear that the limiting functional boundary distance is always the lateral movement with queue scenario. The table also highlights the functional boundary distances expected at typical geometric design radii for collector roads with, which generally vary between 5m (for intersections/accesses) and 10m to 15m (for main road intersections/accesses).

4.2.3 CALCULATIONS FOR FUNCTIONAL BOUNDARY (RIGHT-IN DOWNSTREAM INTERSECTION/ACCESS)

As with the left-in downstream intersection/access calculation the distance between the end of the functional boundary of an upstream intersection/access must not overlap with the start of the functional boundary of the downstream intersection/access. Figure 4.3 shows the typical components of a functional boundary that needs to be calculated for a downstream right-in intersection/access:



Legend:

Queue component of downstream functional boundary area for downstream intersection with the queue begin at **BC (Typical stop position before turning right). Queuing distance not applicable if no opposing traffic (e.g. one-way street) and no other control measures at the intersection/access (treat then same as left-in)**

Perception-reaction and deceleration component of functional boundary area for downstream intersection

End component of functional boundary area of upstream intersection ending at the **EC** of the upstream intersection exiting bell-mouth radius

Figure 4.3: Functional boundary elements (right-in movement)

Table 4.2 lists the functional boundary distances for right turn downstream intersection/access measured between the EC of the upstream intersection/access and the BC of the intersection/access (see Figure 4.3).

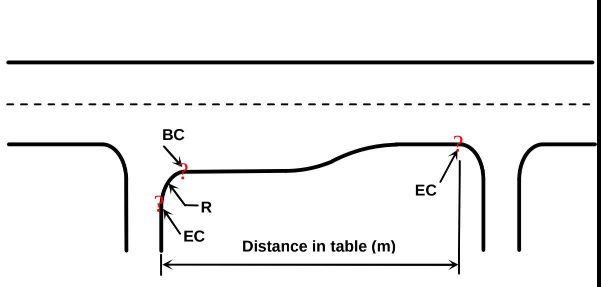
Table 4.3: Right-in downstream intersection/access functional boundary distances for different design speeds

Design Speed (km/h)							
50km/h		60km/h		70km/h		80km/h	
Queue		Queue		Queue		Queue	
Str	Lat	Str	Lat	Str	Lat	Str	Lat
94	110	117	141	143	172	173	206

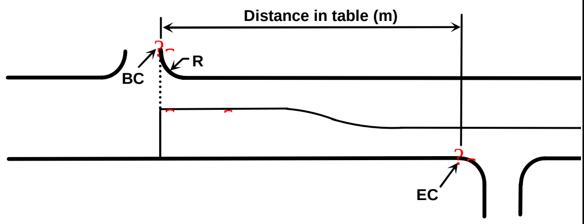
Table 4.4: Summary of the left-in and right-in downstream intersection/access functional boundary distances for different design speeds

Move-ment	Entering Radius (m)	Design speed (km/h)															
		50km/h				60km/h				70km/h				80km/h			
		Queue		No queue		Queue		No queue		Queue		No queue		Queue		No queue	
		Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat	Str	Lat
Left-in	3	97	113	74	81	120	144	107	117	146	175	144	157	176	209	187	201
	5	**99**	**115**	**72**	**79**	**122**	**146**	**105**	**115**	**148**	**177**	**142**	**155**	**178**	**211**	**185**	**199**
	10	**104**	**120**	**69**	**76**	**127**	**151**	**102**	**113**	**153**	**182**	**140**	**152**	**183**	**216**	**182**	**196**
	15	**109**	**125**	**68**	**75**	**132**	**156**	**101**	**111**	**158**	**187**	**138**	**151**	**188**	**221**	**181**	**195**
	20	114	130	68	76	137	161	101	111	163	192	138	151	193	226	181	195
	25	119	135	69	81	142	166	101	112	168	197	139	151	198	231	182	196
	30	124	140	70	86	147	171	102	113	173	202	140	152	203	236	182	196
	35	129	145	71	91	152	176	103	114	178	207	141	153	208	241	184	198
	40	134	150	72	96	157	181	105	118	183	213	142	155	213	246	185	199
Right-in	not applicable	**94**	**110**	not applicable		**117**	**141**	not applicable		**143**	**172**	not applicable		**173**	**206**	not applicable	

Left-in movement



Right-in movement



4.3 STOPPING SIGHT DISTANCE

4.3.1 CURRENT STOPPING SIGHT DISTANCE CRITERIA

The reasoning for using intersection/access spacing based on stopping sight distance is that it allows a straight moving vehicle passing intersections/accesses to observe one intersection/access at a time and have sufficient distance to bring the vehicle to a stop before reaching the downstream intersection/access.

Table 4.5: Stopping sight distances for urban collector roads

Stopping sight distance for different design and operating speeds (m)				
Design Speed (km/h)	AASHTO (2001)	Guidelines for: Human settlement planning & design (2003)	National Guidelines for Road Access Management (COTO, 2002)	Geometric Design of Urban Collector Roads Draft UTG5 (1988)
40	50	50	-	45
50	65	65	-	65
60	85	80	85	80
70	105	95	110	95
80	130	115	140	115

From the table above and based on the fact that AASHTO is a well documented and internationally acceptable geometric design reference, it can be concluded that minimum stopping sight distances of 65m, 85m, 105m and 130m for design speeds of 50km/h, 60km/h, 70km/h and 80km/h can be regarded as acceptable.

4.3.2 FIXED POINTS FOR STOPPING SIGHT DISTANCE INTERSECTION/ACCESS SPACING

Intersection/access spacing based on stopping sight distance criteria is usually measured from centerline to centerline of intersections/accesses (Committee of Transportation Officials, COTO, 2002).

Because of the fact that intersections/accesses are not always standard an alternative and more conservative approach is proposed as an alternative for measuring stopping sight distance for different intersection/access configurations, which is still based on the fact that a driver is able to observe one intersection/access at a time.

As already mentioned, intersection/access configurations are not always standard. It can also be argued that the upstream intersection/access practically ends at the EC of the exiting bell-mouth with the downstream intersection/access practically starting at the BC of the entering bell-mouth. Figures 4.4 to 4.6 below show that by measuring the intersection/access spacing between these two points, different types of intersection/access configurations can be accommodated in a conservative manner. It is thus proposed that this approach be used for measuring intersection/access spacing based on stopping sight distance criteria.

Due to the fact that intersection/access configurations are not always standard, as already mentioned, as well as the fact that it could be argued that the upstream intersection/access practically ends at the EC of the exiting bell-mouth, and the downstream intersection/access practically starts at the BC of the entering bell-mouth, Figures 4.4 to 4.6 below show that by measuring the intersection/access spacing between these two points, different types of intersection/access configurations can be accommodated in a conservative manner. It is thus proposed that this approach be used for measuring intersection/access spacing based on stopping sight distance criteria.

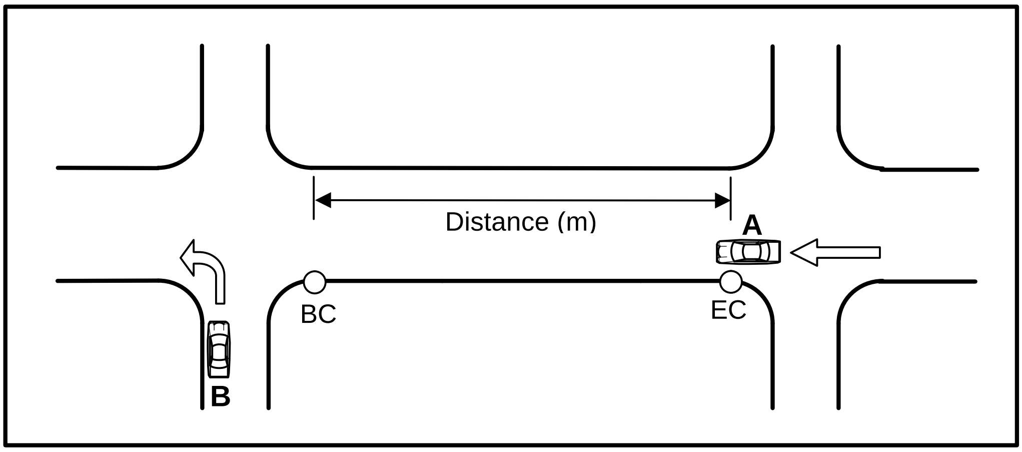


Figure 4.4: Stopping sight distance (no sliplane)

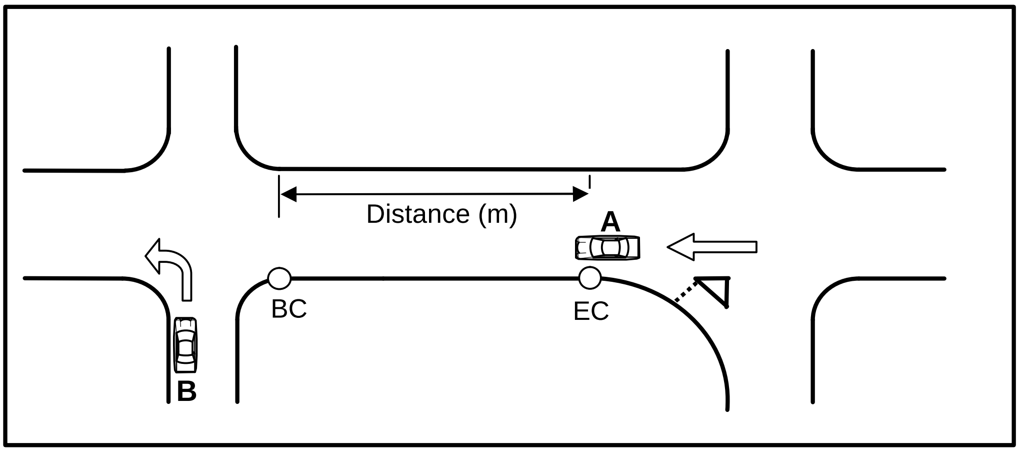


Figure 4.5: Stopping sight distance (with sliplane)

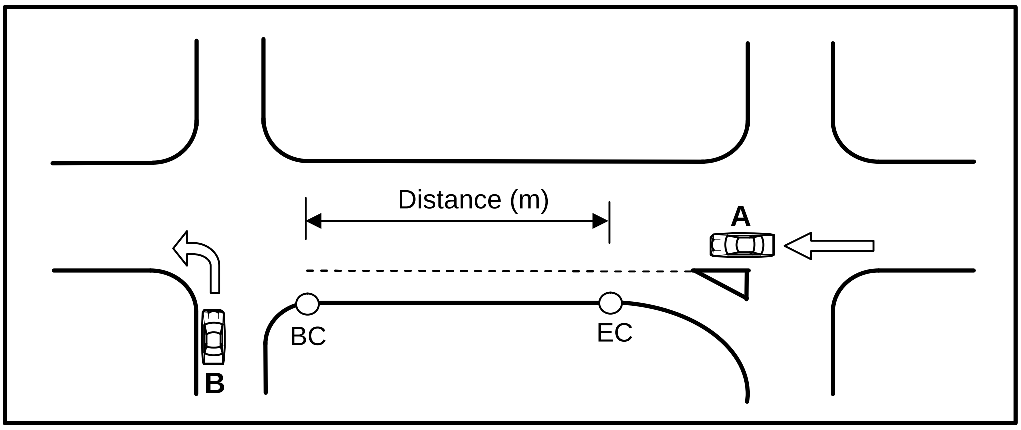


Figure 4.6: Stopping sight distance (left turn with acceleration lane)

4.4 GAP ACCEPTANCE

Critical gap acceptance for intersection/access spacing can be defined as the acceptable distance for left turning vehicles departing from the downstream intersection/access into the major road and not being uncomfortable with the available gap when perceiving the left turning vehicle around the corner of the upstream intersection/access entering the road without stopping (i.e. left turn slip lane or acceleration lane).

4.4.1 GAP ACCEPTANCE VARIABLES

Calculations for gap acceptance distances are primarily affected by the acceptable gap, acceleration rate of vehicles turning left and entering from the upstream intersection/access, the acceleration rate of vehicle entering the main road from downstream intersection/access and turning left as well as the acceptable speed differential allowed between vehicles in the upstream and the downstream intersection/access. Table 4.6 below lists acceptable gap acceptance and acceleration rates generally used in intersection/access spacing calculations.

Table 4.6: Gap acceptance parameters (Passenger vehicles)

Standard	Vehicle complete 90° left turn and acceleration at an average from stop (m/s^2)	Critical gap acceptance parameters, left turning movement (s)	Critical gap acceptance parameters, through movement (s)
Spacing of accesses on Major Arterials (1993)	0.6 preferable 0.9 limiting	-	
Traffic Flow Theory (1988)	-	5.5	6.3
Riglyne vir Toegange tot Vulstasies (1993)	0.85	5.5	6.5
Highway Capacity Manual (1985)	-	5.5 (2 lane) 5.5 (4 lane)	6.0 (2 lane) 6.5 (4 lane)
Jordaan P.W. and Joubert H.S. (1983)		5.5	6.3
Joubert H.S. (1988)		5.4	6.8
AASHTO (2001)		6.5	6.5

From Table 4.6 above it can be concluded that a 5.5s gap acceptance for passenger cars turning left on the main road and 6.5s for vehicles crossing the main road observing traffic from the right can be used confidently. Also, a $0.6 m/s^2$ constant acceleration rate is preferable in calculations but as an absolute maximum a $0.9 m/s^2$ will be acceptable. Non constant acceleration rate will most probably provide the more realistic and practical results.

4.4.2 CALCULATIONS FOR GAP ACCEPTANCE CRITERIA

The practical allowable speed of the upstream vehicle after travelling during the applicable gap acceptance time once it entered the main road could not be found in any of the available references. The most conservative approach would be to allow the upstream vehicle turning left and entering the main road to accelerate to the design speed of the main road (as a maximum) during the gap acceptance time if sufficient time is available for this purpose.

AASHTO, (2001), does allow a reduction of 15% of the design speed, i.e. 85% of the design speed, for main road vehicles in a number of design calculations. Using this design approach, the calculation can also be done allowing the upstream vehicle turning left and entering the main road to accelerate to 85% of the design speed (as a maximum) of the main road, again if sufficient time is available for this purpose, during the gap acceptance time. The absolute minimum speed that could be allowed for the upstream vehicle turning left and entering the main road without stopping is the same speed as negotiated around the entering radius (i.e. no acceleration).

The following assumptions are made in the calculations:

Vehicle A (upstream) only starts to accelerate once it clears the corner. Therefore, if the sight distance for vehicle B (downstream vehicle accepting a gap) observing vehicle A is such that vehicle A can be observed before clearing the corner, the distance travelled around the curve within the available sight distance should be based on the constant speed around the curve. However, to simplify the equation (because this sight distance will differ from intersection/access to intersection/access, and to take the fact into consideration that vehicle B will also look at the main stream and not only at vehicles around the street corner, the clearance gap is measured from the EC of the curve up to the centerline (normally used) of the downstream intersection/access. However, to be able to compare the results with spacing criteria used for stopping sight distance, it is proposed to also use the BC of the downstream intersection/access instead of the centerline. This will also provide more conservative results.

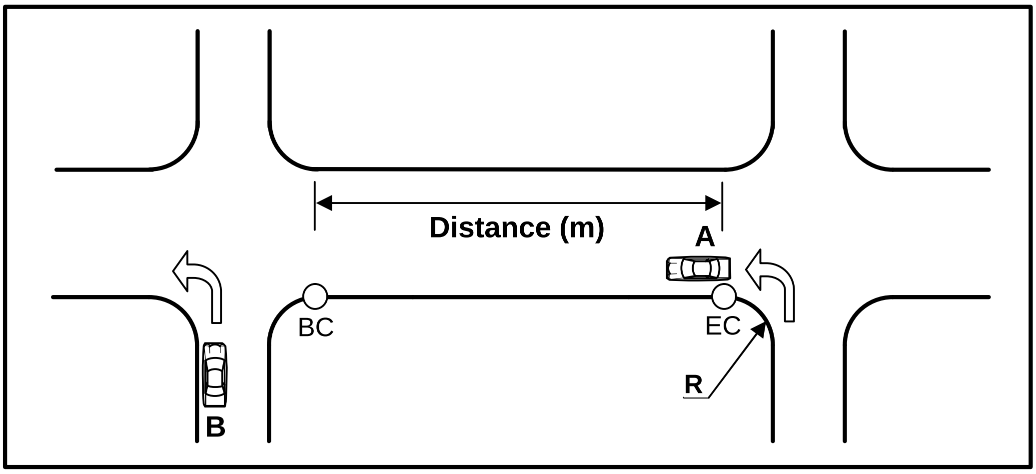


Figure 4.7: Gap acceptance intersection/access spacing

Figures 4.8 and 4.9 shows the results of the calculations for different radii and scenarios for a 60km/h design speed (also see Annexure I). Table 4.6 & 4.7 provides a summary of gap acceptance intersection/access spacing distances for different design speeds and radii.

5.5 Seconds gap acceptance (60 km/h)

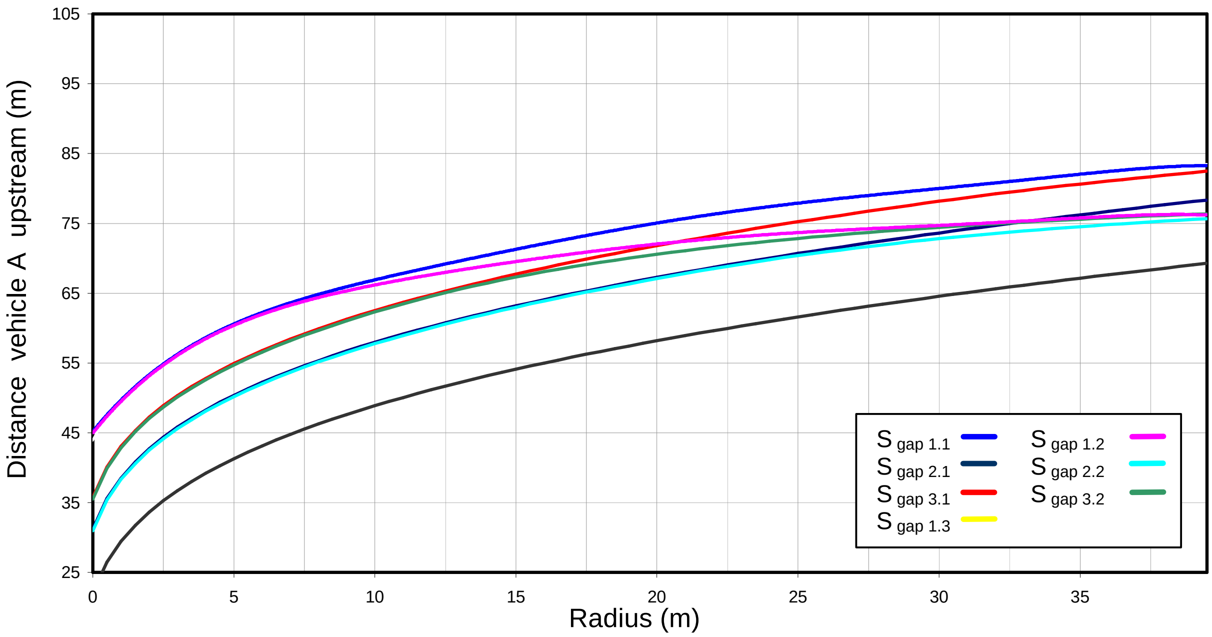


Figure 4.8: Gap acceptance distances (right-in movement)

6.5 Seconds gap acceptance (60 km/h)

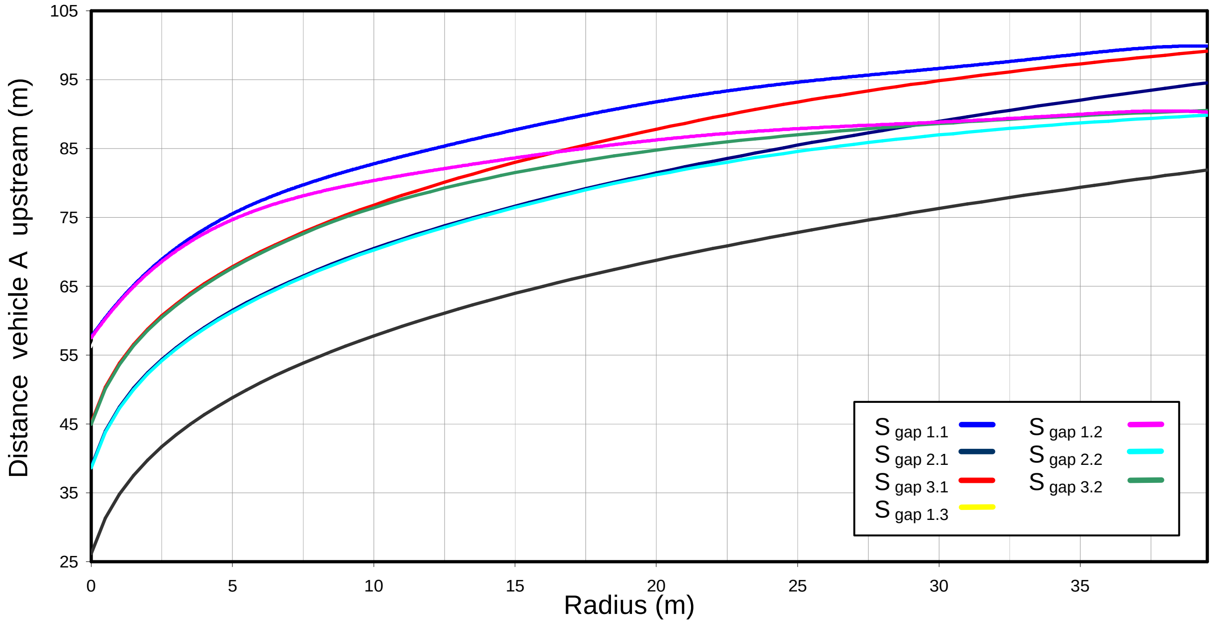


Figure 4.9: Gap acceptance distances (right-in movement)

Graph Descriptions:

$S_{gap1.1}$: Determined with non-constant acceleration rate and vehicle A acceleration to design speed
$S_{gap1.2}$: Determined with non-constant acceleration rate and vehicle A acceleration to 85 % of design speed
$S_{gap1.3}$: Determined with Vehicle A maintaining speed reached around the corner (acceleration=0) entering the main road upstream
$S_{gap2.1}$: Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to design speed
$S_{gap2.2}$: Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed
$S_{gap3.1}$: Determined with 0.9 m/s² acceleration rate and vehicle A accelerating to design speed
$S_{gap3.2}$: Determined with 0.9 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed

Table 4.7: Summary of 5.5 second gap acceptance intersection/access spacing distances for different design speeds

Street corner or slip lane radius R	5.5 Second gap acceptance																														
	40 km/h						50 km/h						60 km/h							70 km/h						80 km/h					
	Gap acceptance scenarios						Gap acceptance scenarios						Gap acceptance scenarios							Gap acceptance scenarios						Gap acceptance scenarios					
	1.1	1.2	2.1	2.2	3.1	3.2	1.1	1.2	2.1	2.2	3.1	3.2	1.1	1.2	1.3	2.1	2.2	3.1	3.2	1.1	1.2	2.1	2.2	3.1	3.2	1.1	1.2	2.1	2.2	3.1	3.2
3	53	49	44	44	49	47	55	54	44	44	49	49	55	55	35	44	44	49	49	55	55	44	44	49	49	55	55	44	44	49	49
5	56	50	49	48	53	49	60	57	49	49	54	54	60	60	40	49	49	54	54	60	60	49	49	54	54	60	60	49	49	54	54
10	59	52	57	52	58	52	66	61	57	57	62	60	66	66	48	57	57	62	62	66	66	57	57	62	62	66	66	57	57	62	62
15	60	52	60	52	60	52	69	63	63	63	67	63	71	69	54	63	63	67	67	71	71	63	63	67	67	71	71	63	63	67	67
20	61	52	61	52	61	52	71	64	67	67	70	64	75	72	58	67	67	71	71	75	75	67	67	71	71	75	75	67	67	71	71
25	61	52	61	52	61	52	73	65	70	70	72	65	77	74	61	70	70	75	73	78	77	70	70	75	75	78	78	70	70	75	75
30	61	52	61	52	61	52	74	65	72	73	74	65	80	75	64	73	73	78	74	80	80	73	73	78	78	80	80	73	73	78	78
35	61	52	61	52	61	52	74	65	74	76	75	65	82	76	67	76	75	80	76	82	82	76	76	81	80	82	82	76	76	81	81
40	61	52	61	52	61	52	75	65	75	78	75	65	84	77	69	78	76	82	77	85	83	78	78	83	82	85	85	78	78	83	83

Table 4.8: Summary of 6.5 second gap acceptance intersection/access spacing distances for different design speeds

Street corner or slip lane radius R	6.5 Second gap acceptance																														
	40 km/h						50 km/h						60 km/h							70 km/h						80 km/h					
	Gap acceptance scenarios						Gap acceptance scenarios						Gap acceptance scenarios							Gap acceptance scenarios						Gap acceptance scenarios					
	1.1	1.2	2.1	2.2	3.1	3.2	1.1	1.2	2.1	2.2	3.1	3.2	1.1	1.2	1.3	2.1	2.2	3.1	3.2	1.1	1.2	2.1	2.2	3.1	3.2	1.1	1.2	2.1	2.2	3.1	3.2
3	64	58	54	54	60	56	69	66	54	54	61	61	69	69	42	54	54	61	61	69	69	54	54	61	61	69	69	54	54	61	61
5	67	60	60	58	64	59	74	69	60	60	67	66	74	74	48	60	60	67	67	74	74	60	60	67	67	74	74	60	60	67	67
10	70	61	68	61	69	61	80	73	70	70	76	72	82	80	57	70	70	76	76	82	82	70	70	76	76	82	82	70	70	76	76
15	71	61	71	61	71	61	83	75	76	76	81	74	87	84	63	76	76	82	81	87	87	76	76	82	82	87	87	76	76	82	82
20	72	61	72	61	72	61	85	76	81	81	84	76	91	86	68	81	81	87	85	92	91	81	81	87	87	92	92	81	81	87	87
25	72	61	72	61	72	61	87	76	84	85	86	76	94	88	72	85	84	91	87	95	94	85	85	91	91	95	95	85	85	91	91
30	72	61	72	61	72	61	88	77	86	89	88	77	97	89	76	89	87	95	89	98	96	89	89	95	95	98	98	89	89	95	95
35	72	61	72	61	72	61	88	77	88	92	89	77	99	90	79	92	89	97	90	100	98	92	92	98	97	100	100	92	92	98	98
40	72	61	72	61	72	61	89	77	89	95	89	77	100	91	82	95	90	99	91	103	100	95	95	101	99	103	103	95	95	101	101

☐ = 5 – 15m radii as typical radius in intersection bell-mouth design

4.5 CORNER CLEARANCE

As indicated in Chapter 2, corner clearance ensuring a safe operational design involves two scenarios namely:

- *Functional boundary scenario* where corner clearance is measured as the distance from an upstream intersection/access to a downstream intersections/accesses comprising of a perception-reaction time distance (after clearing the upstream intersection/access), followed by maneuver distance and finally estimated queue length storage distance of the downstream intersection/access (the longest of either the expected right turn or left turn queue).
- *Around the corner scenario* where a vehicle turning left or right from an upstream intersection/access has sufficient time to safely observe a vehicle entering the road from a downstream intersection/access without colliding with it.

4.5.1 CORNER CLEARANCE VARIABLES

For the functional boundary scenario the same distances as applied for the function boundary calculations in paragraph 4.2. For the *around the corner* scenario, as previously stated, the reference document only states that the upstream vehicle after turning must has sufficient time **to stop** if necessary in order to avoid a collision with the downstream vehicle pulling out of the downstream intersection/access. It could, however, be argued that a number of possible calculations can be done to determine the required corner clearance distance for the *around the corner* scenario. For example, another possibility is to determine the distance required for the situation where a downstream vehicle is allowed to enter the road and turning left, accelerating to such an extent as to still allow the upstream vehicle to decelerate or even maintain its speed around the corner without colliding with the downstream vehicle which entered the road. For the latter alternative, calculations for corner clearance are affected by perception-reaction times, the acceleration rates of the downstream vehicles turning left and entering the main road, the deceleration rate of upstream vehicle (where applicable) and acceptable speed differential allowed between the vehicles where it meets.

As alluded to in the gap acceptance Table 4.6, a $0.6m/s^2$ constant acceleration rate is preferable in calculations but as an absolute maximum a $0.9m/s^2$ will be acceptable. Non-constant acceleration rate will most probably provide the more realistic and practical result. For critical corner clearance spacing where the upstream vehicle (vehicle A) needs to decelerate to avoid colliding with the downstream vehicle (vehicle B), a $1.8m/s^2$ (straight movement) deceleration rate, as previously indicated in Table 4.1, can be used with confidence for intersection/access spacing design purposes. In (Riglyne vir toegange tot vulstasies, 1993), critical intersection/access spacing is also calculated with a $1.8m/s^2$ deceleration rate and a 2 second perception-reaction time for vehicle A. This perception-reaction time is half a second more than the 1.5 second perception-reaction time used in previous calculations. It can, however, be motivated by the fact that the driver in an upstream vehicle (vehicle A), turning left into the main road, will need some additional time having to firstly look to the right for other upstream vehicles on the main road (if yield control) before looking left as it enters the main road and observing the downstream vehicle (vehicle B) entering the main road and accelerating at $0.6 m/s^2$.

4.5.2 CALCULATIONS FOR CORNER CLEARANCE CRITERIA

Scenario 1: *Vehicle A (upstream) accelerates to design speed and maintain design speed while vehicle B (downstream) accelerate to design speed.*

The speed with which vehicle A enters the main road is again calculated with equation (15):

$$V = 17.34 \quad R^{0.26057} \qquad \text{(15)}$$

Where:

V = Entering speed at horizontal curve in km/h

R = Applicable horizontal curve radius in m

For constant acceleration rates ($a_{constant}$) of $0.6 m/s^2$ and $0.9 m/s^2$ the time (t_B) required for vehicle B to accelerate from rest to the design speed (V_{ds}) and the time (t_A) required for vehicle A to accelerate from the speed at the EC of the upstream intersection/access (V_{ec}) to the design speed (V_{ds}) are calculated as follows in equations 16 and 17:

$$t_B = \frac{(V_{ds})}{a_{constant}} \quad \cdots\cdots\cdots\cdots (16)$$

$$t_A = \frac{(V_{ds} \quad V_{ec})}{a_{constant}} \quad \cdots\cdots\cdots\cdots (17)$$

The applicable intersection/access spacing (S) is calculated as follows in equation 18:

$$S = [V_{ec} \quad t_A + 0.5a_{constant}(t_A)^2 + V_{ds}(t_B - t_A)] \quad 0.5a_{constant} \quad t_B \cdots (18)$$

The same calculation procedure is followed for calculation with non-constant acceleration rate by firstly determining the time and distance required for vehicle B to accelerate at a non-constant rate to the design speed and subtracting this distance from the distance vehicle A travels during the same time.

Scenario 2: *Vehicle A (upstream) decelerates at 1.8m/s^2 after a 1.5s perception-reaction time and avoids colliding with vehicle B (downstream) accelerating at 0.6m/s^2. (Critical spacing)*

Critical intersection/access spacing is calculated as follows in equation 19 (Riglyne vir toegange tot vulstasies, 1993):

$$S = \frac{V_{ec}(V_{ec} + 6a)}{4a} \quad \frac{3(u \quad 2a)^2}{32a} \quad \frac{(u + 6a)^2}{32a} \quad \cdots\cdots\cdots (19)$$

For details of how the equation 19 is derived see Annexure J.

In all instances the intersection/access spacing distance (S) is measured from the EC of the upstream intersection/access curve up to the centerline of the downstream intersection/access (normally used). However, to be able to compare the results with spacing criteria used for stopping sight distance and gap acceptance, it is proposed to also use the BC of the downstream intersection/access instead of the centerline. This will also provide more conservative results. Figure 4.10 below schematically illustrates this distance whilst Figure 4.11 graphically indicates the required intersection/access spacing for 60km/h design speed for the different scenarios (also see Annexure K), whilst Table 4.9 summarises the required intersection/access spacing for different design speeds and scenarios.

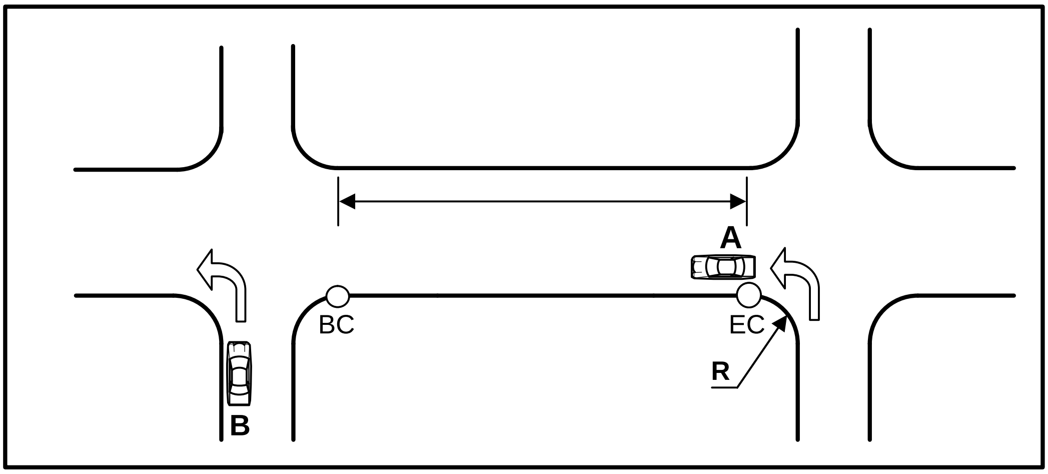


Figure 4.10: Corner clearance intersection/access spacing

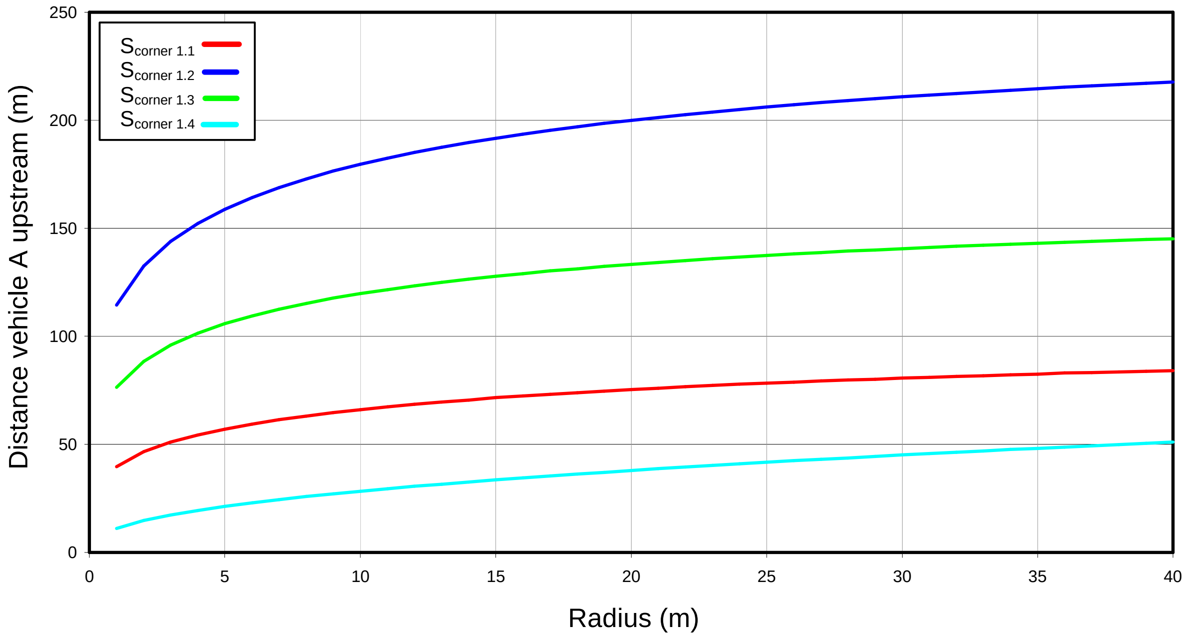


Figure 4.11: Corner clearance (60km/h design speed – main road)

Graph Descriptions:

$S_{corner\ 1.1}$: Spacing allowed to ensure that Vehicle A which accelerates from around curve at non-constant acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a non-constant acceleration rate.

$S_{corner\ 1.2}$: Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.6 m/s² acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.6 m/s² acceleration rate.

$S_{corner\ 1.3}$: Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.9 m/s² acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.9 m/s² acceleration rate.

$S_{corner\ 1.4}$: **Critical spacing** allowed to ensure that Vehicle A which decelerates at 1.8 m/s² after a perception-reaction time of 2.0s from the EC around the curve does not collide with Vehicle B which also accelerates at a 0.6 m/s².

Table 4.9: Corner clearance intersection/access spacing

Entering radius (m)	Corner clearance															
	40 km/h			50 km/h			60 km/h				70 km/h			80 km/h		
	Corner clearance scenarios (S_{corner})			Corner clearance scenarios (S_{corner})			Corner clearance scenarios (S_{corner})				Corner clearance scenarios (S_{corner})			Corner clearance scenarios (S_{corner})		
	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.4	1.1	1.2	1.3	1.1	1.2	1.3
3	30	84	56	40	114	76	51	144	96	17	61	174	116	71	203	135
5	33	91	61	45	125	83	**57**	**159**	**106**	**21**	69	193	128	81	227	151
10	36	98	66	51	139	93	**66**	**180**	**120**	**28**	81	220	147	96	261	174
15	37	101	68	54	147	98	**72**	**192**	**128**	**34**	88	237	158	105	282	188
20	38	103	68	57	151	101	75	200	133	38	93	249	166	112	297	198
25	-	-	-	58	154	103	78	206	137	42	98	258	172	118	309	206
30	-	-	-	59	157	104	81	211	141	45	101	265	177	123	319	213
35	-	-	-	60	158	106	83	215	143	48	104	271	181	127	327	218
40	-	-	-	61	159	106	84	218	145	51	107	276	184	130	334	223

☐ = 5 – 15m radii as typical radius in intersection bell-mouth design

4.6 LEFT-TURN CONFLICT OVERLAP

Left-turn conflict overlap refers to the conflict between a through vehicle and a vehicle turning from the minor road. Left-turn conflict overlap assumes that the driver on the main road must observe and react to an egress vehicle from the minor road into the main stream not to collide with it.

4.6.1 LEFT-TURN CONFLICT OVERLAP VARIABLES

Calculations for left-turn conflict overlap are affected by perception reaction-time, deceleration rate of the main road vehicle, acceleration rate of the side road vehicle turning right or left in entering the main road and acceptable speed differential allowed between the upstream and the downstream intersection/access.

As alluded to in the gap acceptance Table 4.5, a $0.6 m/s^2$ constant acceleration rate is preferable in calculations but as an absolute maximum a $0.9 m/s^2$ will be acceptable. Non-constant acceleration rate will most probably provide the more realistic and practical result. For critical left-turn conflict overlap spacing where the upstream vehicle (vehicle A) needs to decelerate to avoid colliding with the downstream vehicle (vehicle B), a $1.8 m/s^2$ (straight movement) deceleration rate, as previously indicated in Table 4.1, can be used with confidence for intersection/access spacing design purposes. In the document Spacing of Accesses on Major Arterials (1993), critical intersection/access spacing is also calculated with a $1.8 m/s^2$ deceleration rate and a 2 second perception-reaction time for vehicle A. It is, however, recommended that the standard 1.5 second perception-reaction time as used in previous criteria (except for corner clearance) be used for the purposed of calculating left-turn conflict overlap intersection/access spacing distances for collector roads.

4.6.2 CALCULATIONS FOR LEFT-TURN CONFLICT OVERLAP

Scenario 1: Vehicle A (upstream) maintains design speed while vehicle B (downstream) accelerate to design speed.

For constant acceleration rates ($a_{constant}$) of 0.6m/s^2 and 0.9m/s^2 the time (t_B) required for vehicle B to accelerate from rest to the design speed (V_{ds}) is calculated as follows in equation 16:

$$t_B = \frac{(V_{ds})}{a_{constant}} \quad \text{..........(16)}$$

The applicable intersection/access spacing (S) is calculated as the difference between the distance travelled by vehicle A during t_B and the distance travelled by vehicle B also during t_B in equation 21:

$$S = (V_{ds} t_B) \quad [+0.5 a_{constant} (t_A)^2] \quad \text{..........(21)}$$

The same calculation procedure is followed for calculation with non-constant acceleration rate.

Scenario 2: *Vehicle A (upstream) decelerates at 1.8m/s^2 after a 1.5s perception-reaction time and avoids colliding with vehicle B (downstream) accelerating at 0.6m/s^2. (Critical spacing)*

Critical intersection/access spacing is calculated as follows in equation 21 (Riglyne vir toegange tot vulstasies, 1993):

$$S = \frac{V_{ec}\left(V_{ec} + 6a\right)}{4a} - \frac{3\left(u - 2a\right)^2}{32a} - \frac{\left(u + 6a\right)^2}{32a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

For details of how the above equation is derived see Annexure J.

However, to be able to compare the results with spacing criteria used for stopping sight distance, gap acceptance and corner clearance, it is proposed to also use the BC of the downstream intersection/access instead of the centerline. This will also provide more conservative results.

In all instances the intersection/access spacing distance (S) is measured from the EC of the upstream intersection/access curve up to the BC of the downstream intersection/access. Figure 4.12 below schematically illustrates this distance whilst Figure 4.13 graphically indicates the required intersection/access s pacing for design speeds between 40 - 80km/h for the different scenarios (also see Annexure L), whilst Table 4.10 summarises the required intersection/access spacing for different design speeds and scenarios.

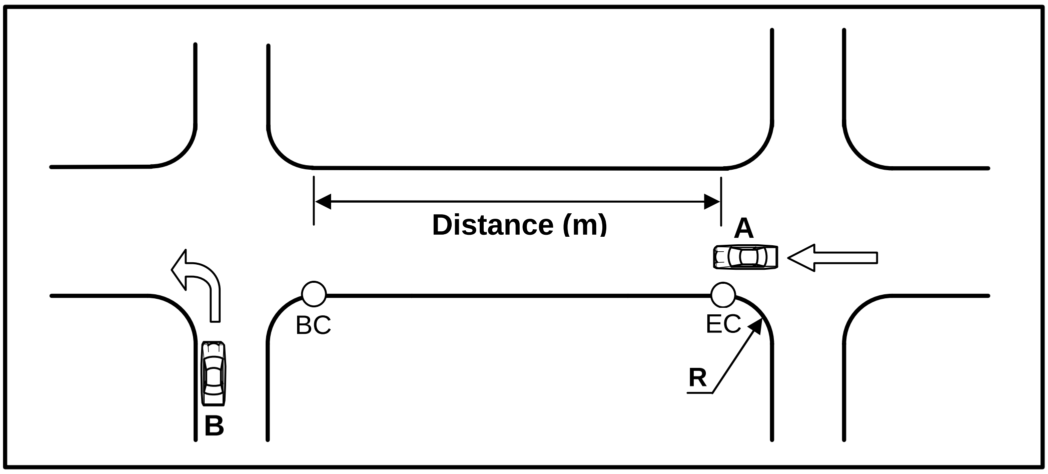


Figure 4.12: Left-turn conflict overlap intersection/access spacing

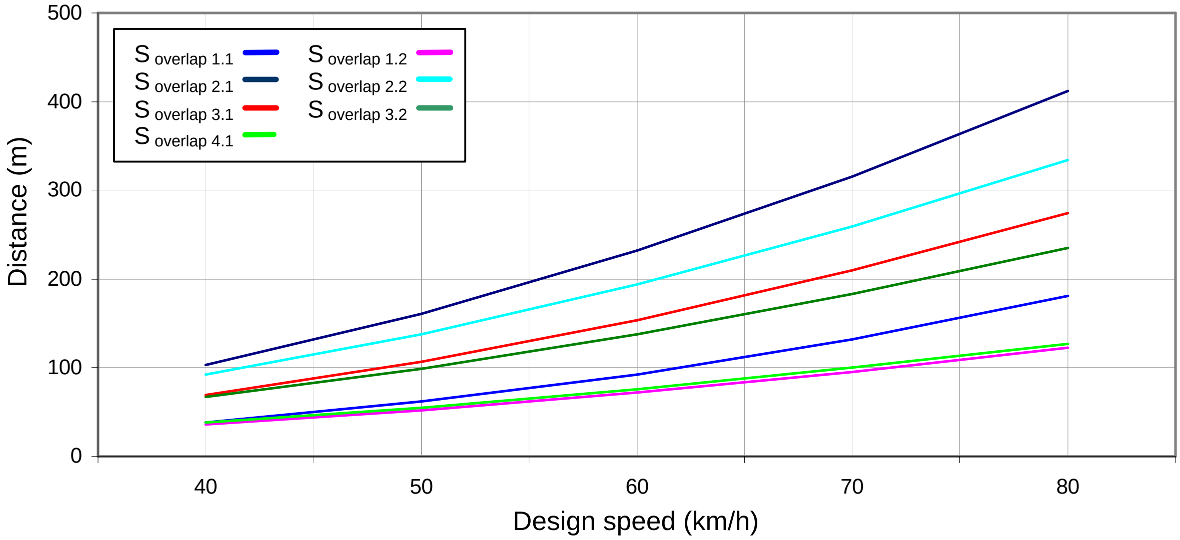


Figure 4.13: Left-turn conflict overlap distances for various design speed

Graph Descriptions:

$S_{overlap1.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at a non-constant rate

$S_{overlap1.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at a non-constant rate

$S_{overlap2.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.6 m/s²

$S_{overlap2.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.6 m/s²

$S_{overlap3.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.9 m/s²

$S_{overlap3.2}$: Spacing required for vehicle A travelling along the main road r educing speed after a 1.5 second perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.9 m/s²

$S_{overlap4.1}$: **Critical spacing** required for vehicle A travelling along the main road reducing speed after a 1.5 second perception-reaction time at 1.8 m/s² and not colliding with Vehicle B which accelerates at 0.6 m/s²

Table 4.10: Left-turn conflict overlap intersection/access spacing

Speed (km/h)	Left-turn conflict overlap scenarios ($S_{overlap}$, Independent of radius)						
	1.1	1.2	2.1	2.2	3.1	3.2	4.1
40	38	36	103	92	69	67	38
50	62	52	161	138	107	99	55
60	**92**	**72**	**232**	**194**	**154**	**138**	**76**
70	132	95	315	259	210	183	100
80	181	123	412	334	274	235	127

5. PROCEDURE FOR ESTABLISHING INTERSECTION / ACCESS SPACING FOR PRIORITY CONTROLLED URBAN COLLECTOR ROADS.

5.1 INTRODUCTION

The evaluation and comparison of current intersection/access spacing methodology is necessary in order to make recommendations pertaining to intersection/access spacing requirements for urban collector roads. Functional boundary, stopping sight distance, gap acceptance, corner clearance and left turn conflict overlap criteria with the influence of acceleration, deceleration, gap acceptance and perception-reaction time variations are evaluated in the next section of this chapter.

5.2 COMPARISSON OF INTERSECTION/ACCESS SPACING CRITERIA

In order to be able to evaluate the results, a graph (Figure 5.1) was compiled by plotting intersection/access spacing distances for the different intersection/access spacing criteria against design speed. To simplify the results of this graph and for easier comparison purposes between the different intersection/access spacing criteria, Table 5.1 provides a summary of the intersection/access spacing distances for design speeds of 50km/h, 60km/h, 70km/h and 80km/h.

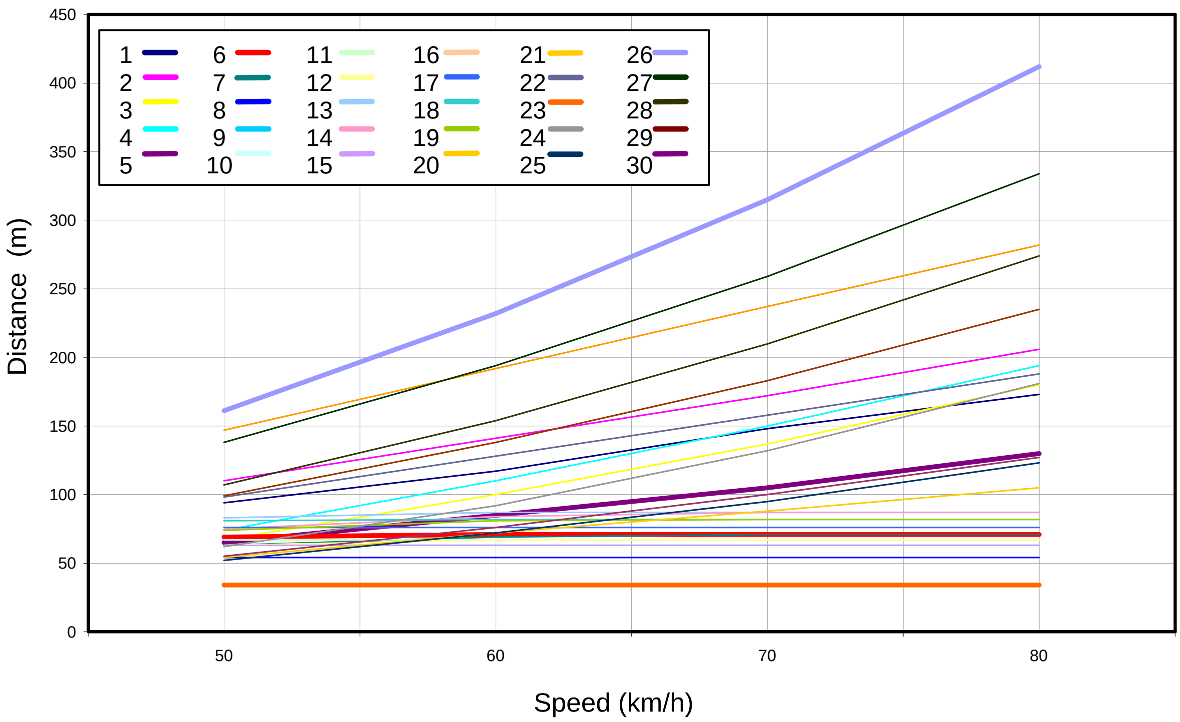


Figure 5.1: Comparison of intersection/access spacing criteria

Graph Descriptions:

1	=	S_{func1}:	With Queue – Straight deceleration movement Queue = 30m for Right turn downstream from main road and left turn where access control is applicable
2	=	S_{func2}:	With Queue – Lateral deceleration maneuver
3	=	S_{func3}:	No Queue - Straight deceleration movement
4	=	S_{func4}:	No Queue – Lateral deceleration maneuver
5	=		Stopping sight distance
6	=	$S_{gap1.1}$:	Determined with non-constant acceleration rate and vehicle A acceleration to design speed
7	=	$S_{gap1.2}$:	Determined with non-constant acceleration rate and vehicle A acceleration to 85 % of design speed
8	=	$S_{gap1.3}$:	Determined with Vehicle A maintaining speed reached around the corner (acceleration=0) entering the main road upstream
9	=	$S_{gap2.1}$:	Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to design speed
10	=	$S_{gap2.2}$:	Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed
11	=	$S_{gap3.1}$:	Determined with 0.9 m/s² acceleration rate and vehicle A accelerating to design speed
12	=	$S_{gap3.2}$:	Determined with 0.9 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed
13	=	$S_{gap1.1}$:	Determined with non-constant acceleration rate and vehicle A acceleration to design speed
14	=	$S_{gap1.2}$:	Determined with non-constant acceleration rate and vehicle A acceleration to 85 % of design speed
15	=	$S_{gap1.3}$:	Determined with Vehicle A maintaining speed reached around the corner (acceleration=0) entering the main road upstream
16	=	$S_{gap2.1}$:	Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to design speed
17	=	$S_{gap2.2}$:	Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed

18 =	$S_{gap3.1}$:	Determined with 0.9 m/s^2 acceleration rate and vehicle A accelerating to design speed
19 =	$S_{gap3.2}$:	Determined with 0.9 m/s^2 acceleration rate and vehicle A accelerating to 85 % of design speed
20 =	$S_{corner\ 1.1}$:	Spacing allowed to ensure that Vehicle A which accelerates from around curve at non-constant acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a non-constant acceleration rate.
21 =	$S_{corner\ 1.2}$:	Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.6 m/s^2 acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.6 m/s^2 acceleration rate.
22 =	$S_{corner\ 1.3}$:	Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.9 m/s^2 acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.9 m/s^2 acceleration rate.
23 =	$S_{corner\ 1.4}$:	**Critical spacing** allowed to ensure that Vehicle A which decelerates at 1.8 m/s^2 after a perception-reaction time of 2.0 second from the EC around the curve does not collide with Vehicle B which also accelerates at a 0.6 m/s^2.
24 =	$S_{overlap1.1}$:	Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at a non-constant rate
25 =	$S_{overlap1.2}$:	Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s^2 until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at a non-constant rate
26 =	$S_{overlap2.1}$:	Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.6 m/s^2
27 =	$S_{overlap2.2}$:	Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s^2 until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.6 m/s^2
28 =	$S_{overlap3.1}$:	Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.9 m/s^2
29 =	$S_{overlap3.2}$:	Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s^2 until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.9 m/s^2
30 =	$S_{overlap4.1}$:	**Critical spacing** required for vehicle A travelling along the main road reducing speed after a 1.5 second perception-reaction time at 1.8 m/s^2 and not colliding with Vehicle B which accelerates at 0.6 m/s^2

Table 5.1: Summary of intersection/access spacing distances for different criteria

	Intersection/access spacing criteria's	Design speed			
		50km/h	60km/h	70km/h	80km/h
	Functional Boundary				
1	F_{func1}: With Queue - Straight deceleration movement Queue = 30m for Right turn downstream from main road and left turn where access control is applicable	**94**	**117**	**148**	**173**
2	F_{func2}: With Queue - Lateral deceleration maneuver	**110**	**141**	**172**	**206**
3	F_{func3}: No Queue - Straight deceleration movement	**67**	**100**	**137**	**180**
4	F_{func4}: No Queue - Lateral deceleration maneuver	**74**	**110**	**150**	**194**
5	**Stopping sight distance**	**65**	**85**	**105**	**130**
	Gap acceptance				
	5.5 second gap acceptance distance (Only for left turning vehicles from minor downstream intersection)				
6	$S_{gap1.1}$: non-constant acceleration rate and vehicle A acceleration to design speed	69	71	71	71
7	$S_{gap1.2}$: non-constant acceleration rate and vehicle A acceleration to 85 % of design speed	63	69	71	71
8	$S_{gap1.3}$: vehicle A maintaining speed reached around the corner (acceleration=o) entering the main road upstream	54	54	54	54
9	$S_{gap2.1}$: 0.6 m/s² acceleration rate and vehicle A accelerating to design speed	63	63	63	63
10	$S_{gap2.2}$: 0.6 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed	63	63	63	63
11	$S_{gap3.1}$: 0.9 m/s² acceleration rate and vehicle A accelerating to design speed	67	67	67	67
12	$S_{gap3.2}$: 0.9 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed	63	67	67	67
	6.5 second gap acceptance distance (Crossing and Right turn downstream from minor road)				
13	$S_{gap1.1}$: non-constant acceleration rate and vehicle A acceleration to design speed	83	87	87	87
14	$S_{gap1.2}$: non-constant acceleration rate and vehicle A acceleration to 85 % of design speed	75	84	87	87
15	$S_{gap1.3}$: vehicle A maintaining speed reached around the corner (acceleration=o) entering the main road upstream	63	63	63	63
16	$S_{gap2.1}$: 0.6 m/s² acceleration rate and vehicle A accelerating to design speed	76	76	76	76
17	$S_{gap2.2}$: 0.6 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed	76	76	76	76
18	$S_{gap3.1}$: 0.9 m/s² acceleration rate and vehicle A accelerating to design speed	81	82	82	82
19	$S_{gap3.2}$: 0.9 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed	74	81	82	82
	Corner clearance				
20	$S_{corner\ 1.1}$: Spacing allowed to ensure that Vehicle A which accelerates from around curve at non-constant acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a non-constant acceleration rate.	**54**	**72**	**88**	**105**
21	$S_{corner\ 1.2}$: Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.6 m/s² acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.6 m/s² acceleration rate.	147	192	237	282
22	$S_{corner\ 1.3}$: Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.9 m/s² acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.9 m/s² acceleration rate.	98	128	158	188
23	$S_{corner\ 1.4}$: **Critical spacing** allowed to ensure that Vehicle A which decelerates at 1.8 m/s² after a perception-reaction time of 2.0 second from the EC around the curve does not collide with Vehicle B which also accelerates at a 0.6 m/s².	34	34	34	34
	Left-turn conflict overlap				
24	$S_{overlap1.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at a non-constant rate	62	92	132	181
25	$S_{overlap1.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at a non-constant rate	52	72	95	123
26	$S_{overlap2.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.6 m/s²	161	232	315	412
27	$S_{overlap2.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1,8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.6 m/s²	138	194	259	334
28	$S_{overlap3.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.9 m/s²	107	154	210	274
29	$S_{overlap3.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5 second perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.9 m/s²	99	138	183	235
30	$S_{overlap4.1}$:**Critical spacing** required for vehicle A travelling along the main road reducing speed after a 1.5 second perception-reaction time at 1.8 m/s² and not colliding with Vehicle B which accelerates at 0.6 m/s²	55	76	100	127

From Figure 5.1 and Table 5.1 it is concluded that left-turn conflict overlap ($S_{overlap2.1}$) provides the maximum intersection/access spacing results when allowing for vehicles traveling along the main road (vehicle A) maintaining design speed and not colliding with vehicles entering the main road from the side (vehicle B) accelerating at a rate of $0.6m/s^2$. The intersection/access spacing values varies between 161m for 50km/h design speed to 412m for 80km/h design speed. The minimum intersection/access spacing is calculated for the corner clearance criterion which ensures that a vehicle (vehicle A) which enters the main road from an upstream intersection (turning left around the bell mouth of maximum 15m radius with associated speed around the curve of 35km/h at EC) decelerating at $1.8m/s^2$ after a 2 seconds perception-reaction does not collide with a vehicle (vehicle B) entering the main road from an upstream intersection and accelerating at $0.6m/s^2$.

Based on sound engineering judgment the maximum results for left-turn conflict overlap is unrealistically high for practical purposes, especially in the urban context. Furthermore, due to the fact that functional boundary criteria are set as a benchmark for ideal intersection/access spacing criteria by AASHTO (2001), it is recommended that functional boundary be used as criteria for ideal intersection/access spacing along collector roads.

It should, however, also be kept in mind that collectors, in the hierarchy of roads context, must balance the accessibility and mobility function.

As a result, it is recommended that a preferable intersection/access spacing distance for collector roads be used. Because of the fact that stopping sight distance is probably the most widely used criteria in geometric engineering design, incorporating basic traffic safety principles and is also recommended by other references such as Spacing of Accesses on Major Arterials (1993), stopping sight distance can be recommended as the preferable intersection/access spacing criteria for collector roads. This spacing varies between 65m for 50km/h to 130m for 80km/h, which is regarded as acceptable.

In some instances demand for intersection/access is high. An example is where erf frontage along a collector road is less than would allow stopping sight distance intersection/access spacing. In these situations it is recommended that as an absolute minimum, corner clearance distance ($S_{corner\ 1.1}$) be used. This will ensure that a vehicle (vehicle A) which enters the main road from an upstream intersection (turning left around the bell mouth of maximum 15m radius with associated speed around the curve of 35km/h at EC) accelerating at a non-constant acceleration rate and reaches a speed of 85% of the design speed of the main road does not collide with a vehicle (vehicle B) entering the main road from an upstream intersection and also accelerating at a non-constant rate. The latter corner clearance intersection/access spacing can be recommended since it measures up to basic engineering design principles, like 85% design speed standards and also a realistic non-constant acceleration rate, best describing practically the corner clearance intersection/access spacing criteria.

For marginal intersection/access spacing, where spacing is measured between left-in and left-out intersections/accesses, critical intersection/access spacing of 34m can be considered (independent of design speed). In such cases, however, this decision must be based on a comprehensively motivated traffic engineering analysis taking aspects such as expected number of conflicts (i.e. vehicles that will be using the intersection/access), driver familiarity with the area, etc. into consideration.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The existing literature provides limited detail with regard to the rationale behind the intersection spacing distances, exact reference points for measuring intersection spacing as well as different intersection layout configurations which may affect spacing distances. However, by evaluating and comparing intersection/ access spacing standards for overseas and local conditions and by performing traffic engineering surveys, it was possible to develop specific recommendations for priority controlled intersection/access spacing along urban collector roads that can be used as a tentative South African guideline.

The subsequent recommendations can be used as useful tool and input for further research in establishing national standards for spacing of priority controlled intersections along urban collector roads. It can also be concluded that the objectives of the study have been reached and it is envisaged that the results of the study will make a contribution towards creating uniform intersection spacing standards promoting road traffic safety in South-Africa.

6.2 RECOMMENDATIONS

Table 6.1 provides a summary of the recommended intersection/access spacing distances for design speeds of 50km/h, 60km/h, 70km/h and 80km/h.

Table 6.1: Summary of recommended priority controlled intersection/access spacing distances

Design speed (km/h)	Intersection/access spacing criteria's					
	Ideal				Preferable	Minimum
	Functional boundary				Stopping sight distance	Corner clearance
	F_{func1}	F_{func2}	F_{func3}	F_{func4}		$S_{corner\ 1.1}$
50km/h	94	110	67	74	65	54
60km/h	117	141	100	110	85	72
70km/h	148	172	137	150	105	88
80km/h	173	206	180	194	130	105

Descriptions:

S_{func1} : With Queue – Straight deceleration movement Queue = 30m for right-turn downstream from main road and left turn where access control is applicable

S_{func2} : With Queue – Lateral deceleration maneuver

S_{func3} : No Queue - Straight deceleration movement

S_{func4} : No Queue – Lateral deceleration maneuver

$S_{corner\ 1.1}$: Spacing allowed ensuring that vehicle A which accelerates from around curve at non-constant acceleration rate reaches a speed of 85% of the design speed of the main road before reaching vehicle B who also accelerates at a non-constant acceleration rate

Due to the sharing of accessibility and mobility function of collector roads, this dissertation further recommends the use of the **preferred** priority controlled intersection/access spacing distances for urban collector roads between fixed points as alluded to earlier in this dissertation.

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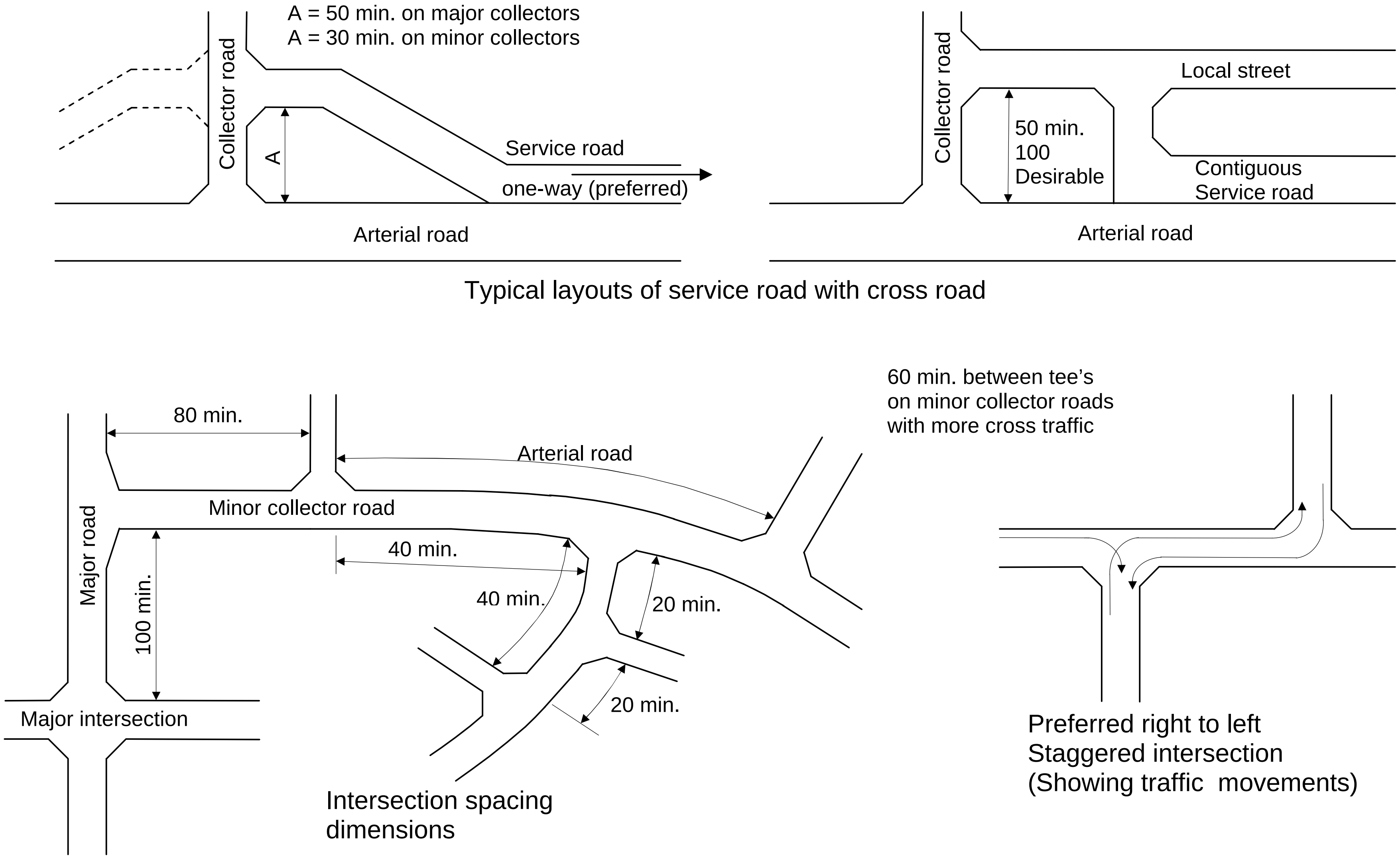
ANNEXURE A

Example of road reserve boundary used as reference for intersection/access spacing



Intersection spacing and staggered intersections

Not to scale

ANNEXURE B

Bester's non-constant acceleration model

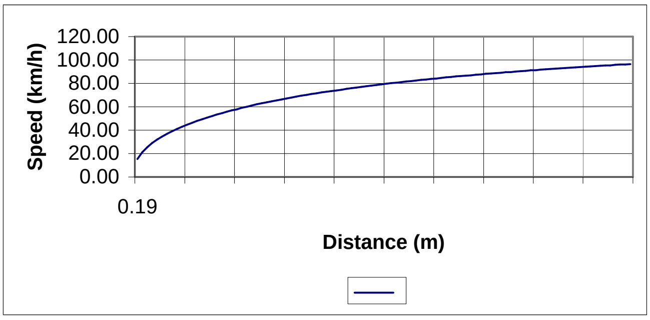
Example calculation: Bester's non-constant acceleration model

Plotting of Speed

Calculation of acceleration at 5 m interval

Vehicle 1

Light vehicle	yes
Initial Speed	0 km/h
Avg grade	0 m/m
Start Distance	0 m
Interval	5 m

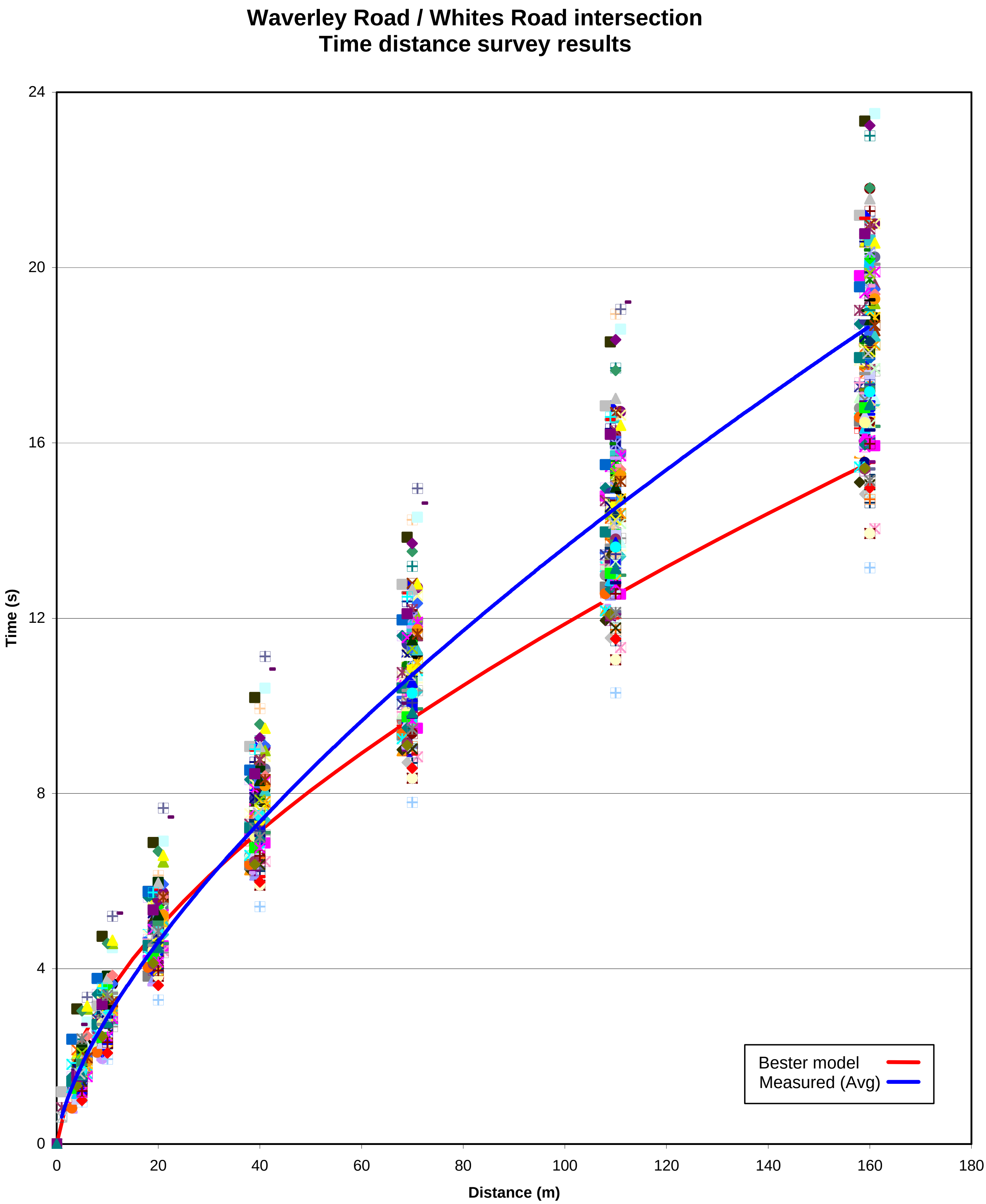


Interval	Intitial V in m/s	End V in m/s	Accel	Grade m/m	Alfa	Alfa'	Beta	a	b	c	Vm	M/Me	Distan	End km/h Veh1	TIME	TIME Cum
0	0.00	4.30	1.85	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.61	0.00		2.32	2.32
5	4.30	5.88	1.61	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.79	5.00	15.48	0.98	3.31
10	5.88	7.06	1.52	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.84	10.00	21.17	0.77	4.08
15	7.06	8.02	1.45	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.87	15.00	25.40	0.66	4.74
20	8.02	8.85	1.40	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.88	20.00	28.88	0.59	5.34
25	8.85	9.59	1.35	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.89	25.00	31.87	0.54	5.88
30	9.59	10.25	1.31	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.90	30.00	34.51	0.50	6.38
35	10.25	10.85	1.28	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.91	35.00	36.89	0.47	6.86
40	10.85	11.41	1.24	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.91	40.00	39.07	0.45	7.31
45	11.41	11.93	1.21	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.91	45.00	41.08	0.43	7.73
50	11.93	12.42	1.18	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.92	50.00	42.95	0.41	8.14
55	12.42	12.87	1.15	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.92	55.00	44.70	0.40	8.54
60	12.87	13.30	1.13	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.92	60.00	46.34	0.38	8.92
65	13.30	13.71	1.11	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.92	65.00	47.89	0.37	9.29
70	13.71	14.10	1.08	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	70.00	49.36	0.36	9.65
75	14.10	14.47	1.06	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	75.00	50.77	0.35	10.00
80	14.47	14.83	1.04	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	80.00	52.10	0.34	10.34
85	14.83	15.17	1.02	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	85.00	53.38	0.33	10.68
90	15.17	15.49	1.00	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	90.00	54.60	0.33	11.00
95	15.49	15.81	0.98	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	95.00	55.78	0.32	11.32
100	15.81	16.11	0.96	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.93	100.00	56.91	0.31	11.64
105	16.11	16.40	0.95	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	105.00	58.00	0.31	11.94
110	16.40	16.68	0.93	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	110.00	59.04	0.30	12.25
115	16.68	16.96	0.92	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	115.00	60.06	0.30	12.54
120	16.96	17.22	0.90	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	120.00	61.04	0.29	12.84
125	17.22	17.47	0.89	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	125.00	61.99	0.29	13.12
130	17.47	17.72	0.87	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	130.00	62.91	0.28	13.41
135	17.72	17.96	0.86	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	135.00	63.80	0.28	13.69
140	17.96	18.20	0.84	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	140.00	64.66	0.28	13.96
145	18.20	18.42	0.83	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	145.00	65.50	0.27	14.24
150	18.42	18.64	0.82	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	150.00	66.32	0.27	14.51
155	18.64	18.86	0.81	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	155.00	67.12	0.27	14.77
160	18.86	19.07	0.79	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	160.00	67.89	0.26	15.04
165	19.07	19.27	0.78	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	165.00	68.64	0.26	15.30
170	19.27	19.47	0.77	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.94	170.00	69.38	0.26	15.56
175	19.47	19.66	0.76	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	175.00	70.09	0.26	15.81
180	19.66	19.85	0.75	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	180.00	70.79	0.25	16.07
185	19.85	20.04	0.74	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	185.00	71.47	0.25	16.32
190	20.04	20.22	0.73	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	190.00	72.14	0.25	16.56
195	20.22	20.40	0.72	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	195.00	72.79	0.25	16.81
200	20.40	20.57	0.71	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	200.00	73.43	0.24	17.05
205	20.57	20.74	0.70	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	205.00	74.05	0.24	17.30
210	20.74	20.90	0.69	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	210.00	74.66	0.24	17.54
215	20.90	21.07	0.68	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	215.00	75.25	0.24	17.77
220	21.07	21.22	0.67	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	220.00	75.84	0.24	18.01
225	21.22	21.38	0.66	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	225.00	76.41	0.23	18.25
230	21.38	21.53	0.65	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	230.00	76.97	0.23	18.48
235	21.53	21.68	0.64	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	235.00	77.51	0.23	18.71
240	21.68	21.83	0.64	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	240.00	78.05	0.23	18.94
245	21.83	21.97	0.63	0.00	1.85	1.85	0.06	0.99	0.87	0.61	2.27	0.95	245.00	78.58	0.23	19.17

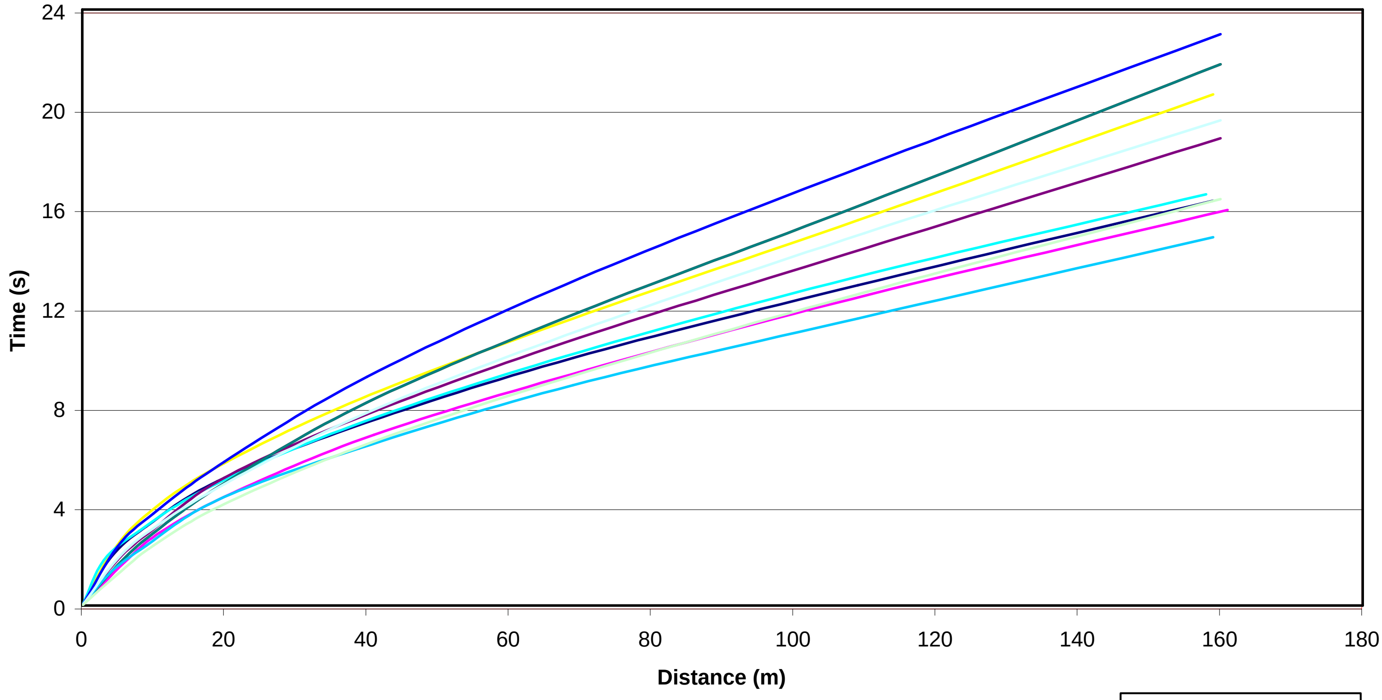
ANNEXURE C

Detail results (graphs) of the field surveys performed

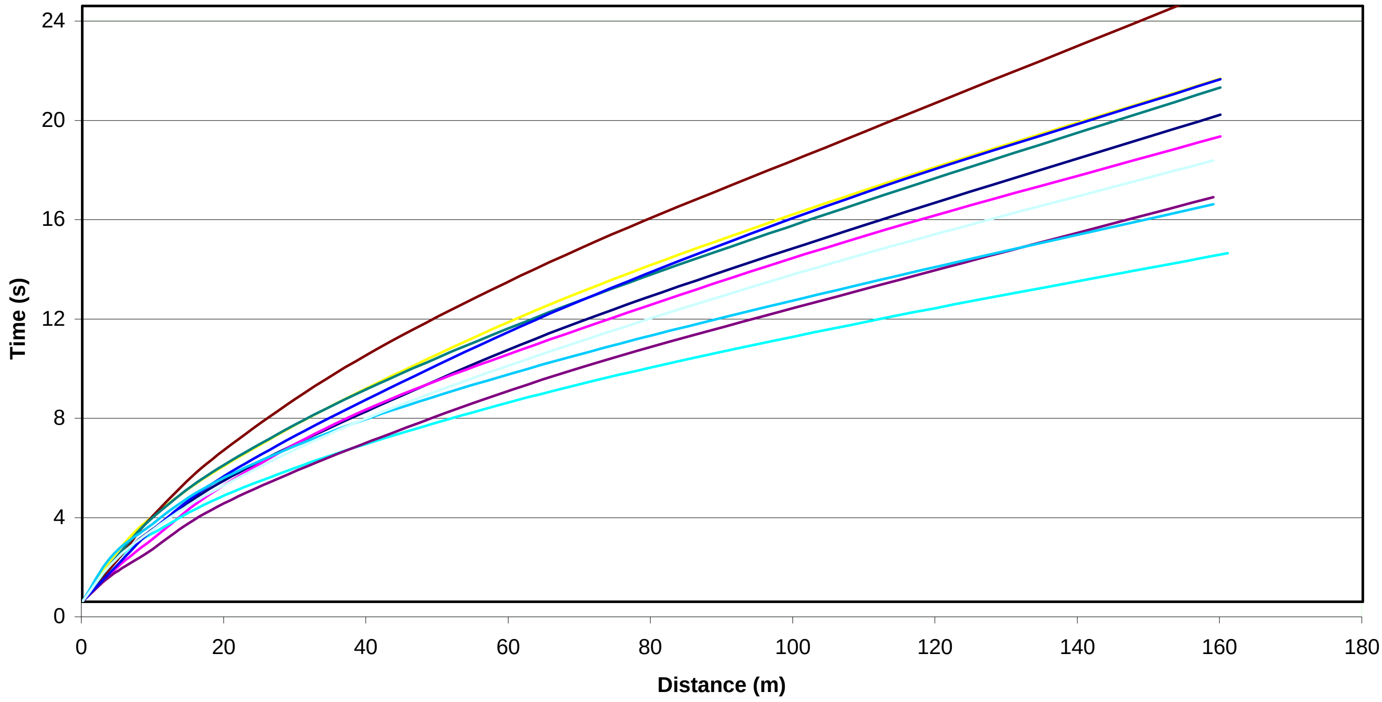
Waverley Road / Whites Road


Waverley Road / Whites Road intersection
Time distance survey results
Time (s)
Distance (m)
0
4
8
12
16
20
24
0
20
40
60
80
100
120
140
160
180
Bester model
Measured (Avg)

Waverley Road / Whites Road intersection
Time distance survey results

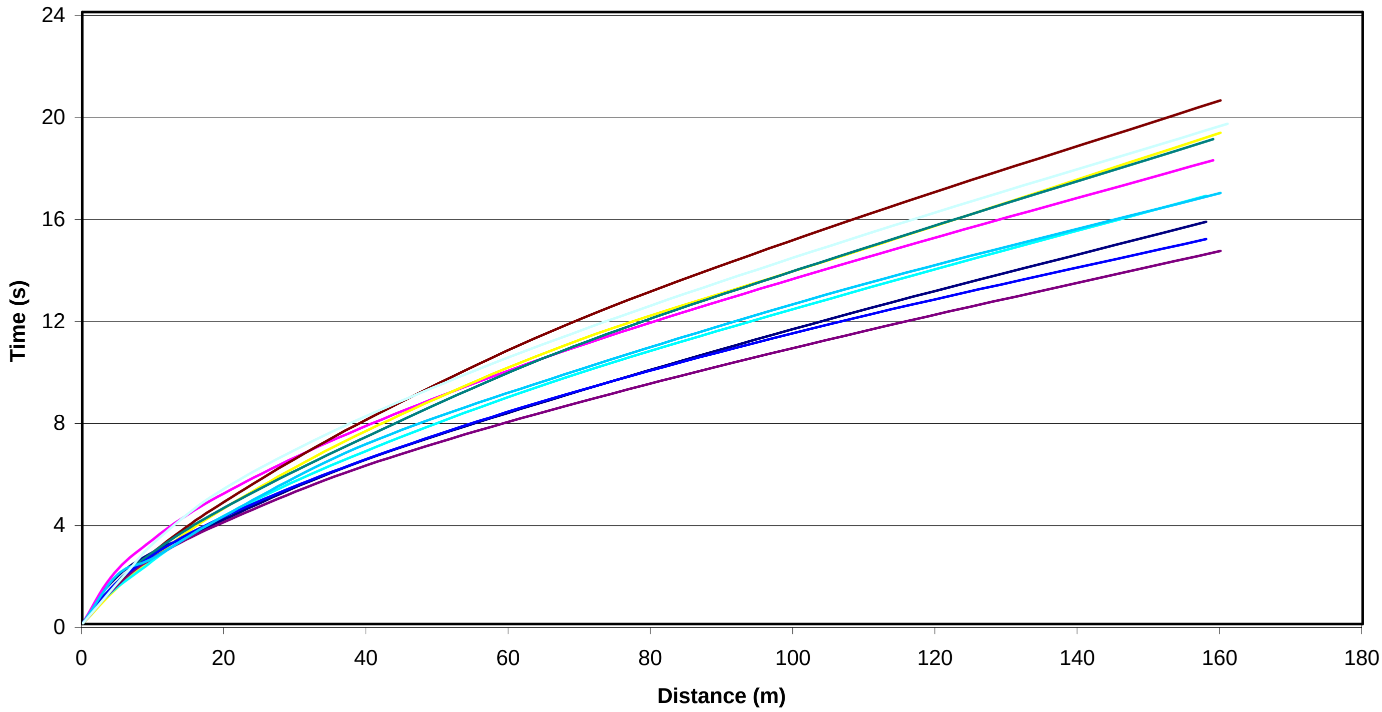


Dataset 1-10

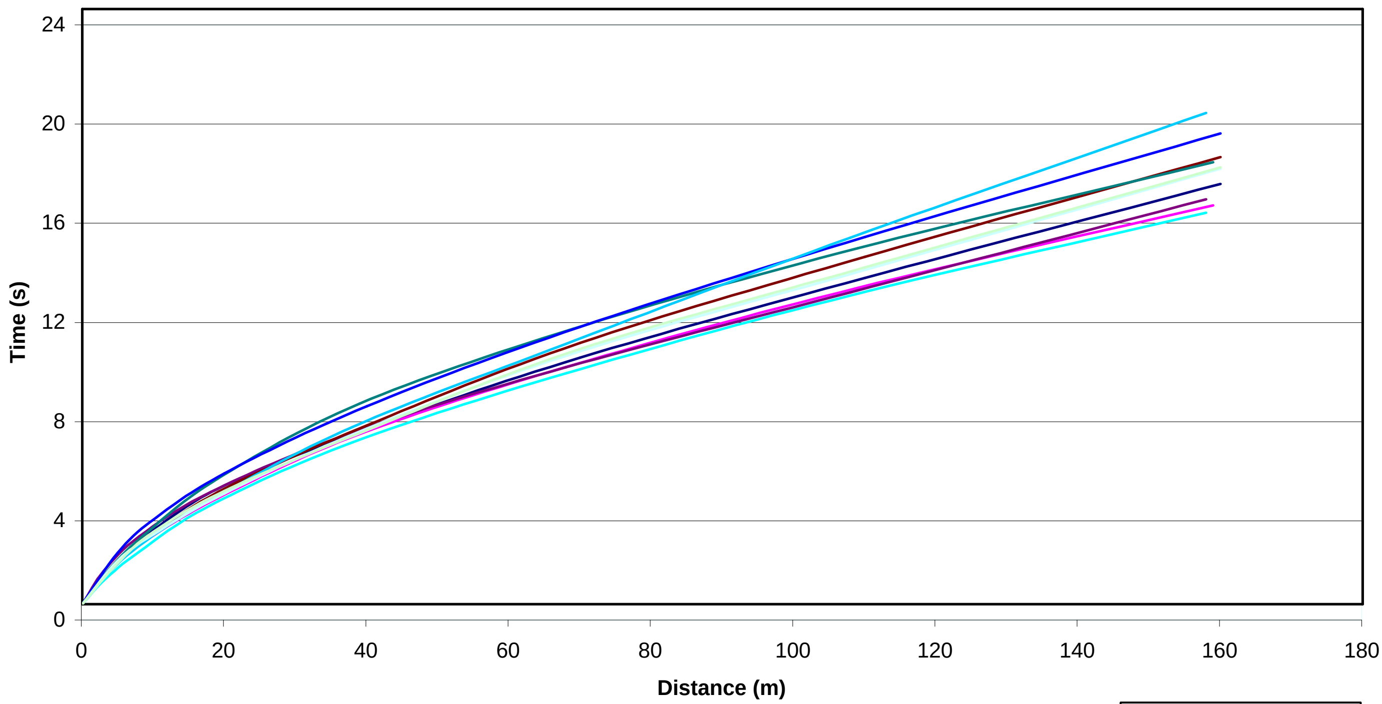


Dataset 11-20

Waverley Road / Whites Road intersection
Time distance survey results

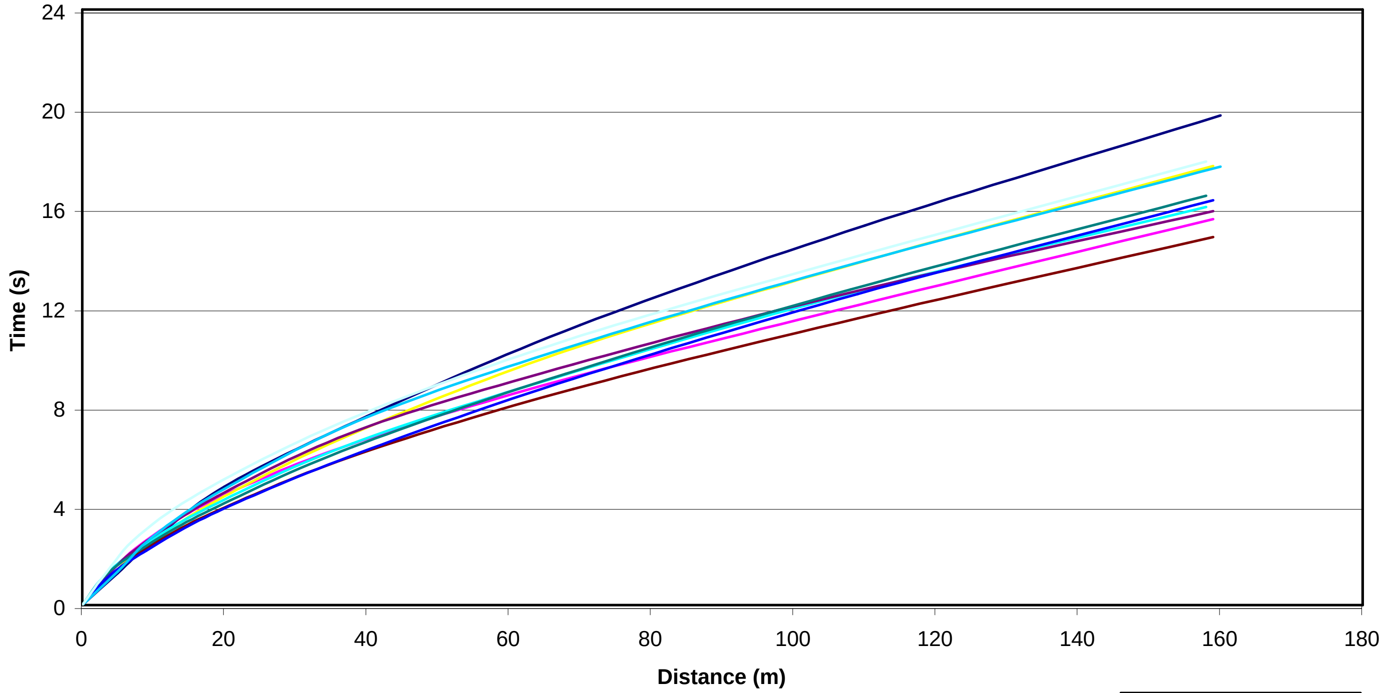


Dataset 21-30

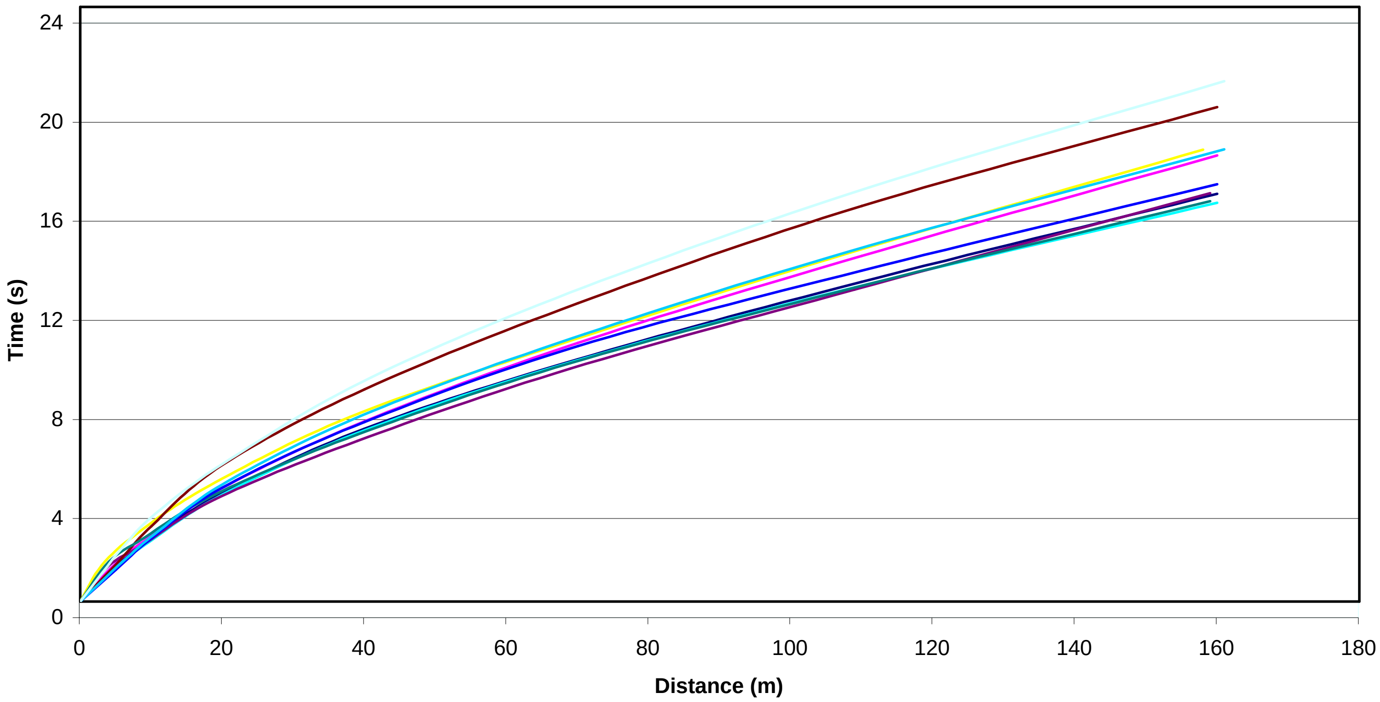


Dataset 31-40

Waverley Road / Whites Road intersection
Time distance survey results

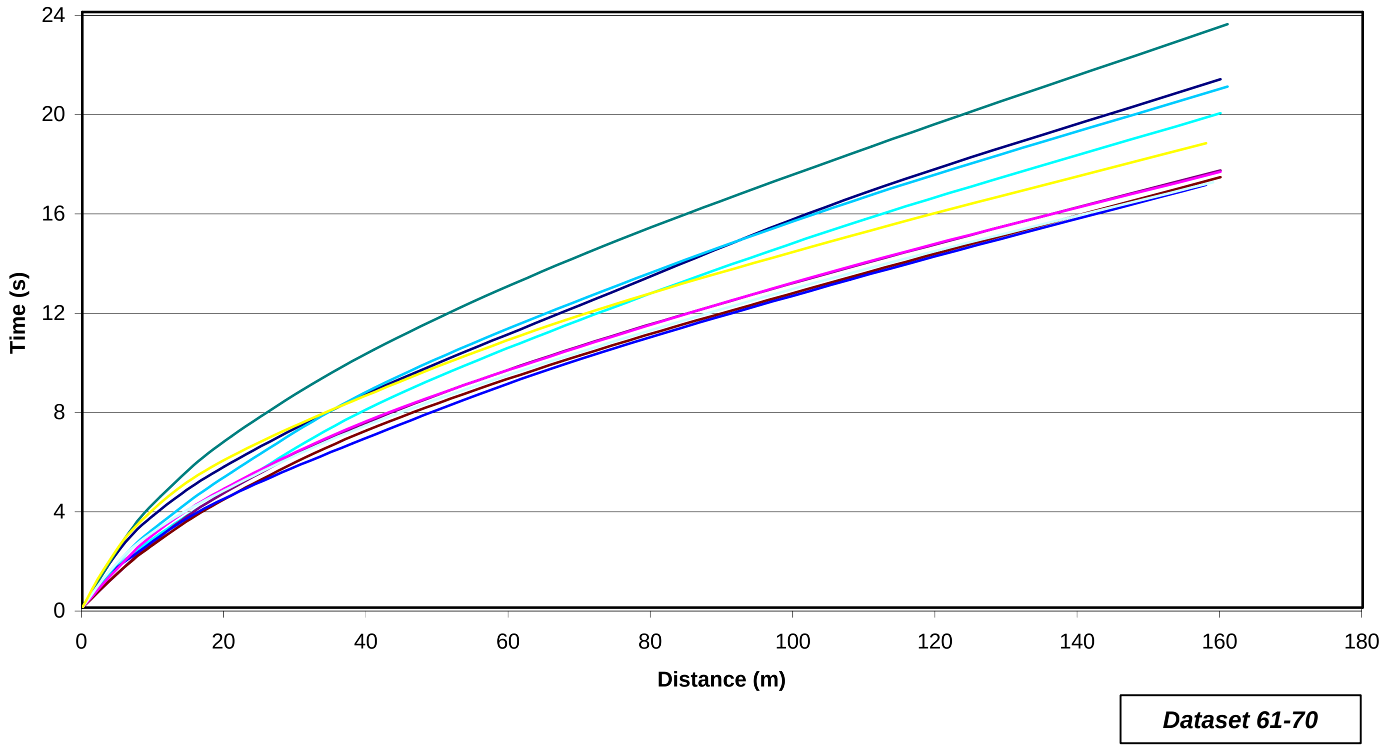


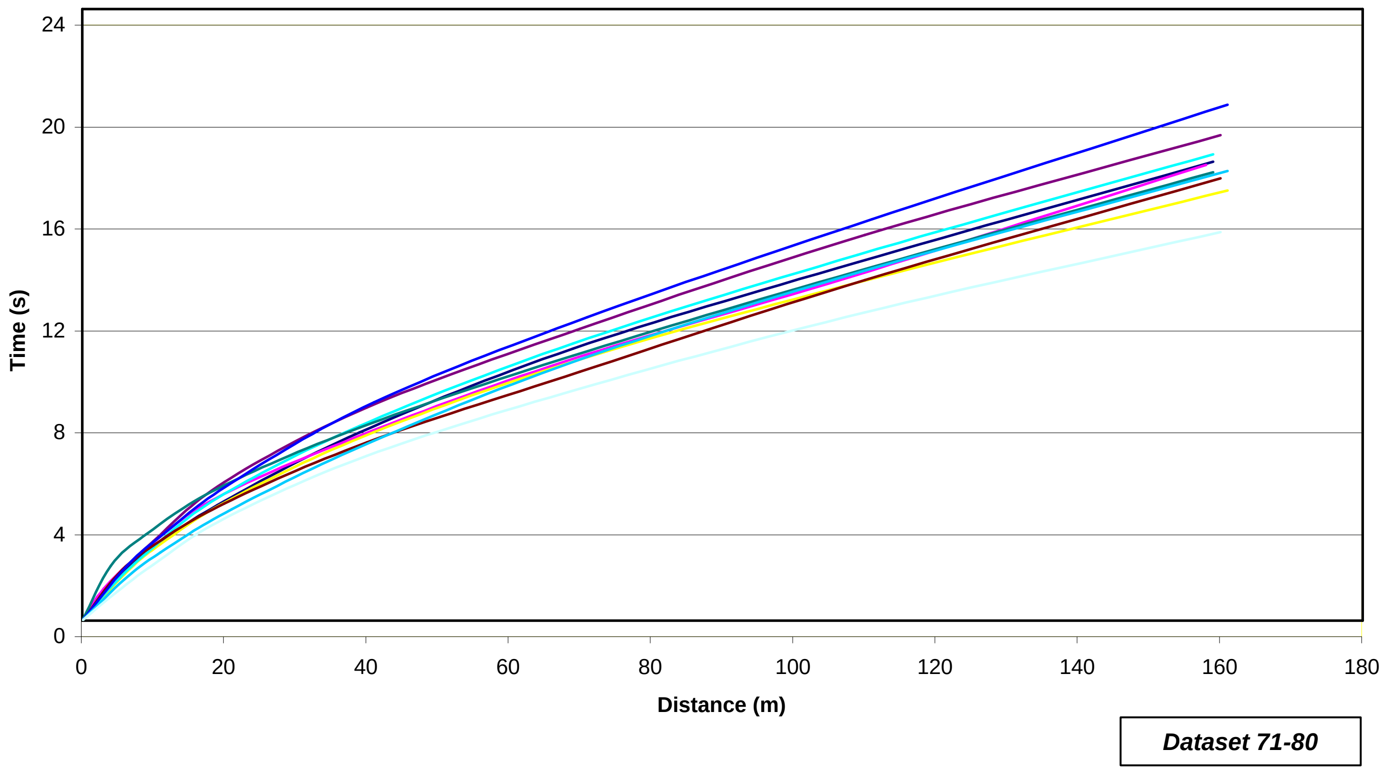
Dataset 41-50



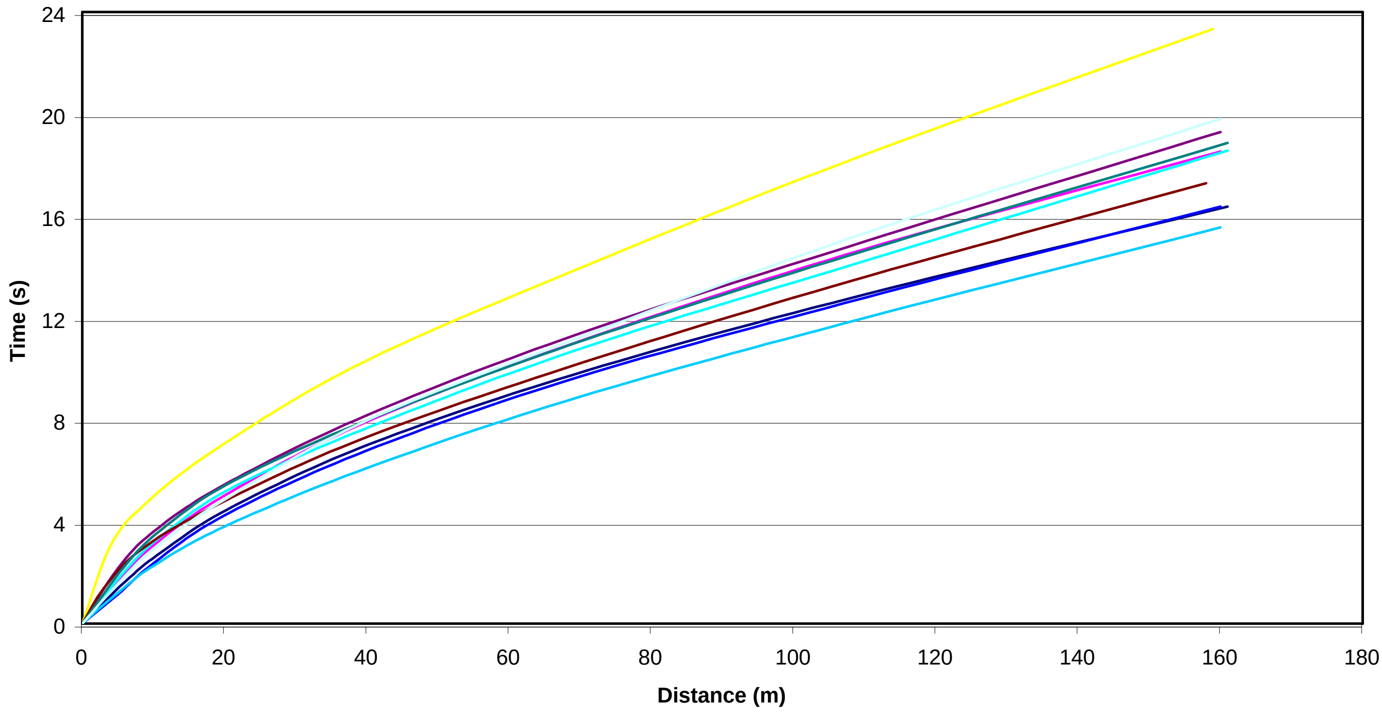
Dataset 51-60

Waverley Road / Whites Road intersection
Time distance survey results

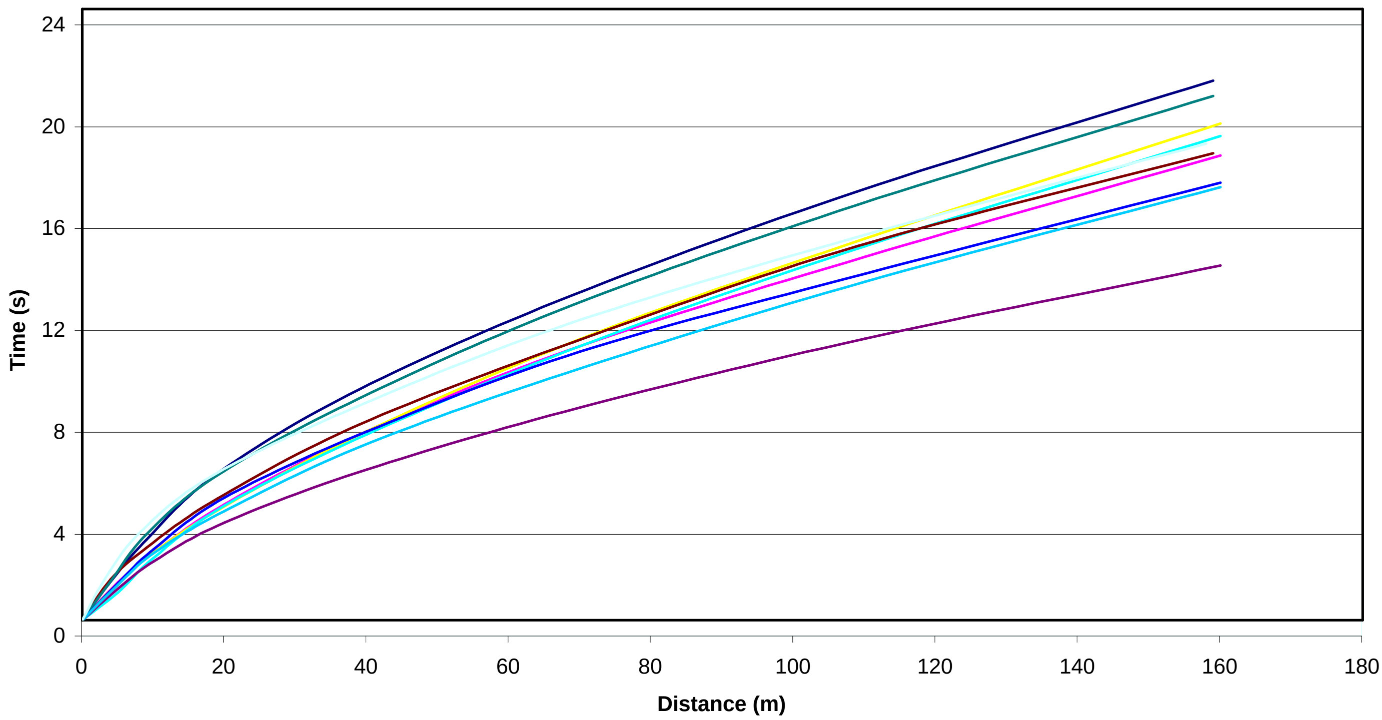




Waverley Road / Whites Road intersection
Time distance survey results

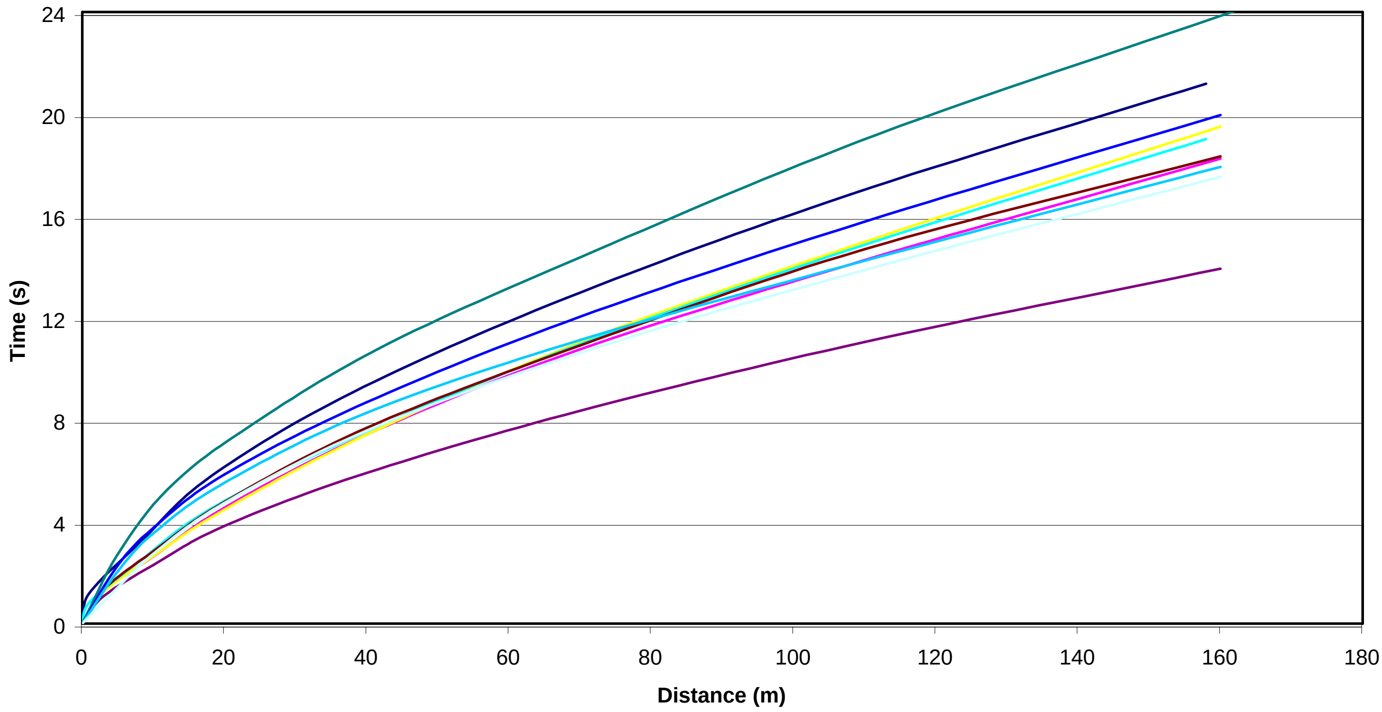


Dataset 81-90

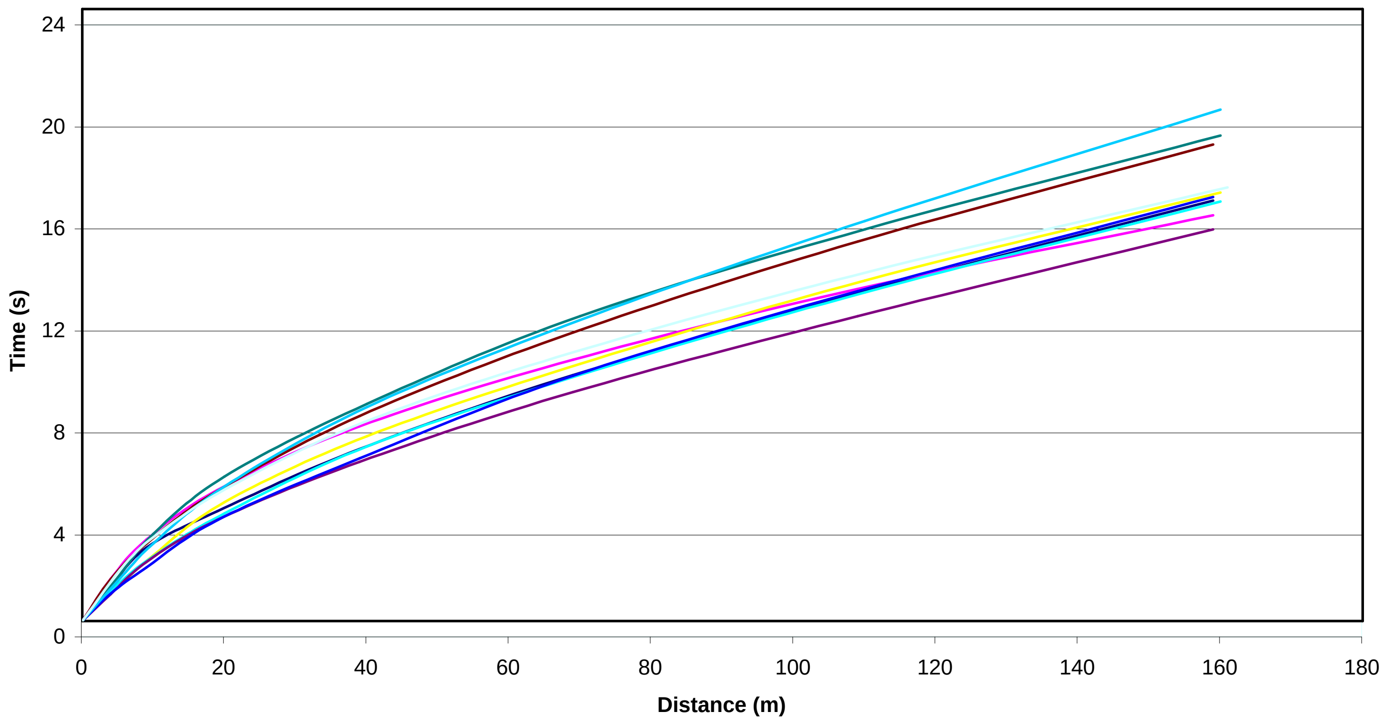


Dataset 91-100

Waverley Road / Whites Road intersection
Time distance survey results

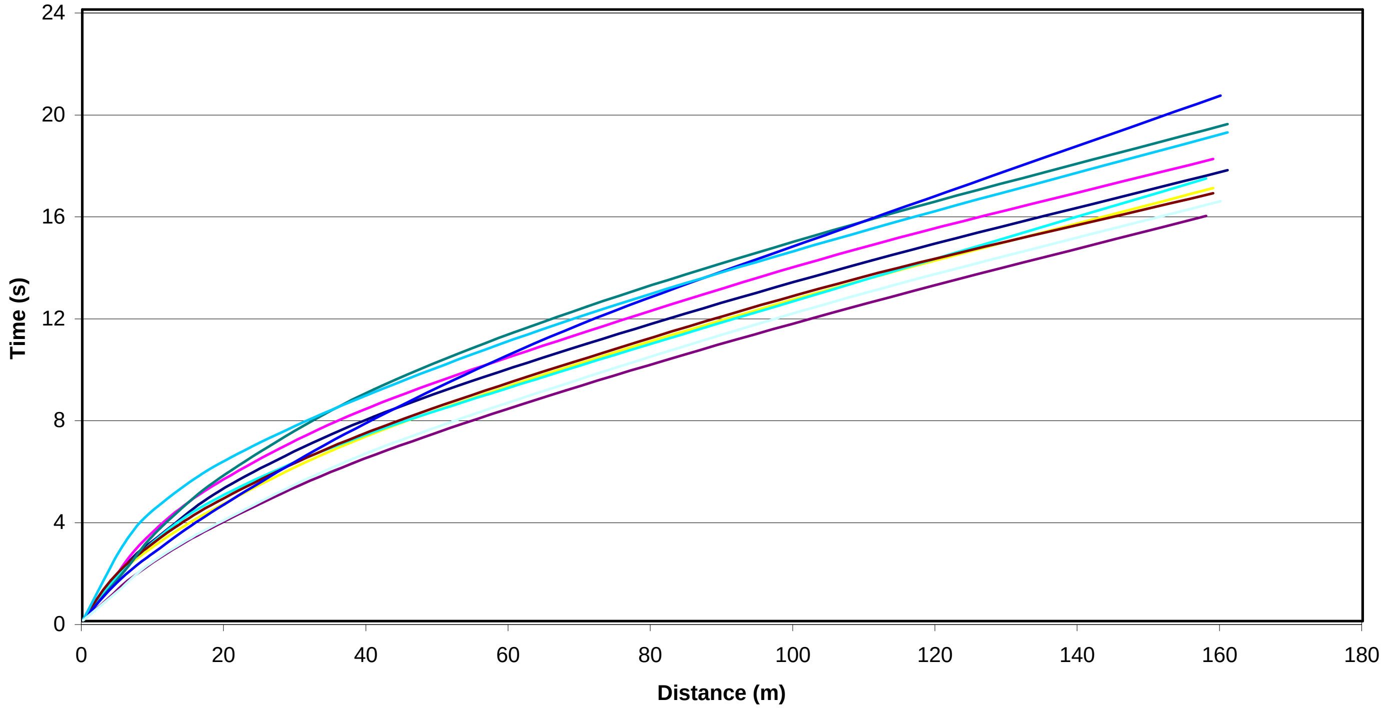


Dataset 101-110

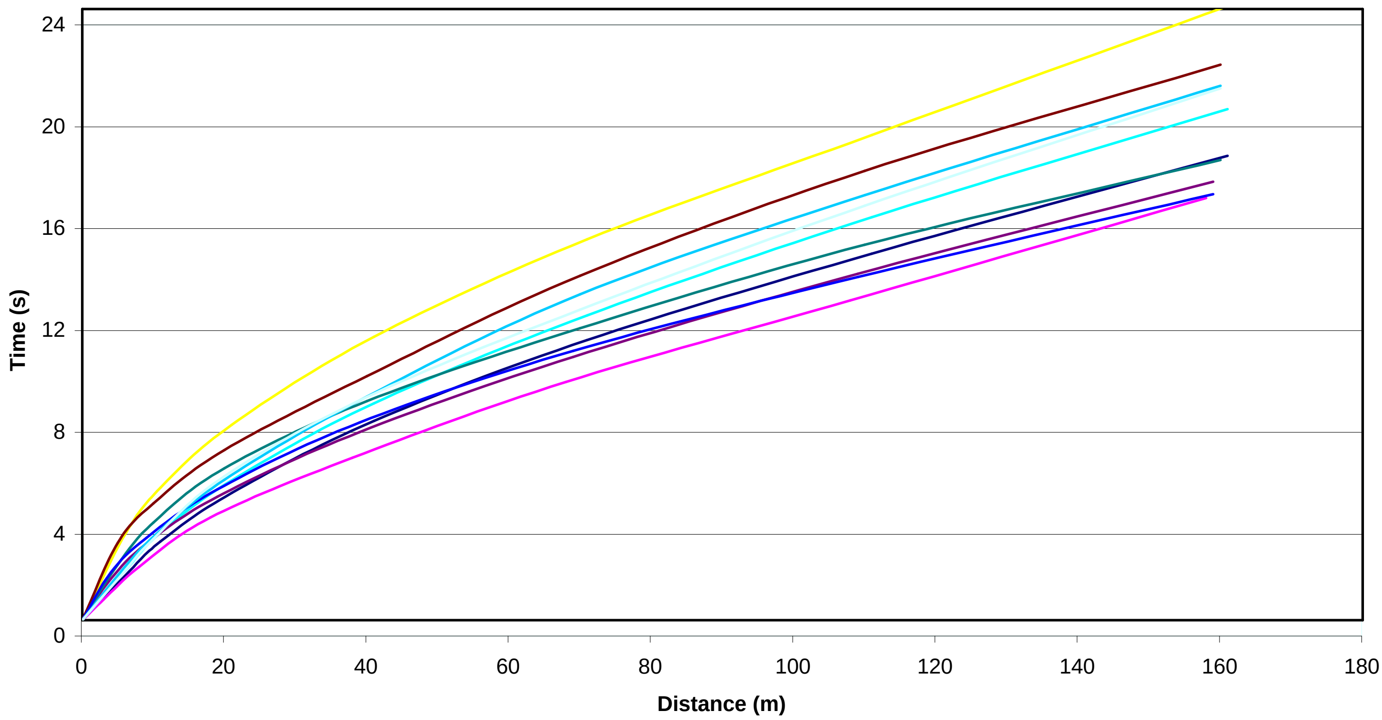


Dataset 111-120

Waverley Road / Whites Road intersection
Time distance survey results

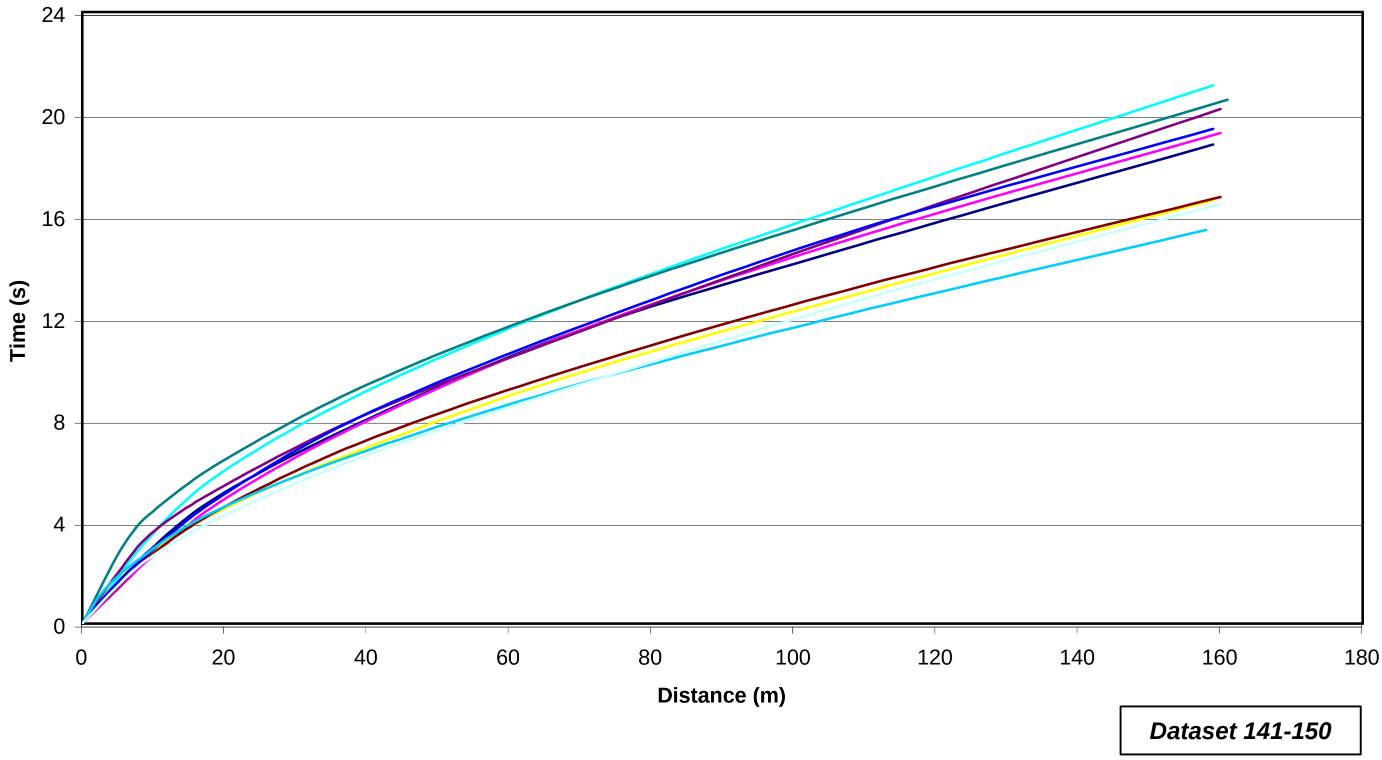


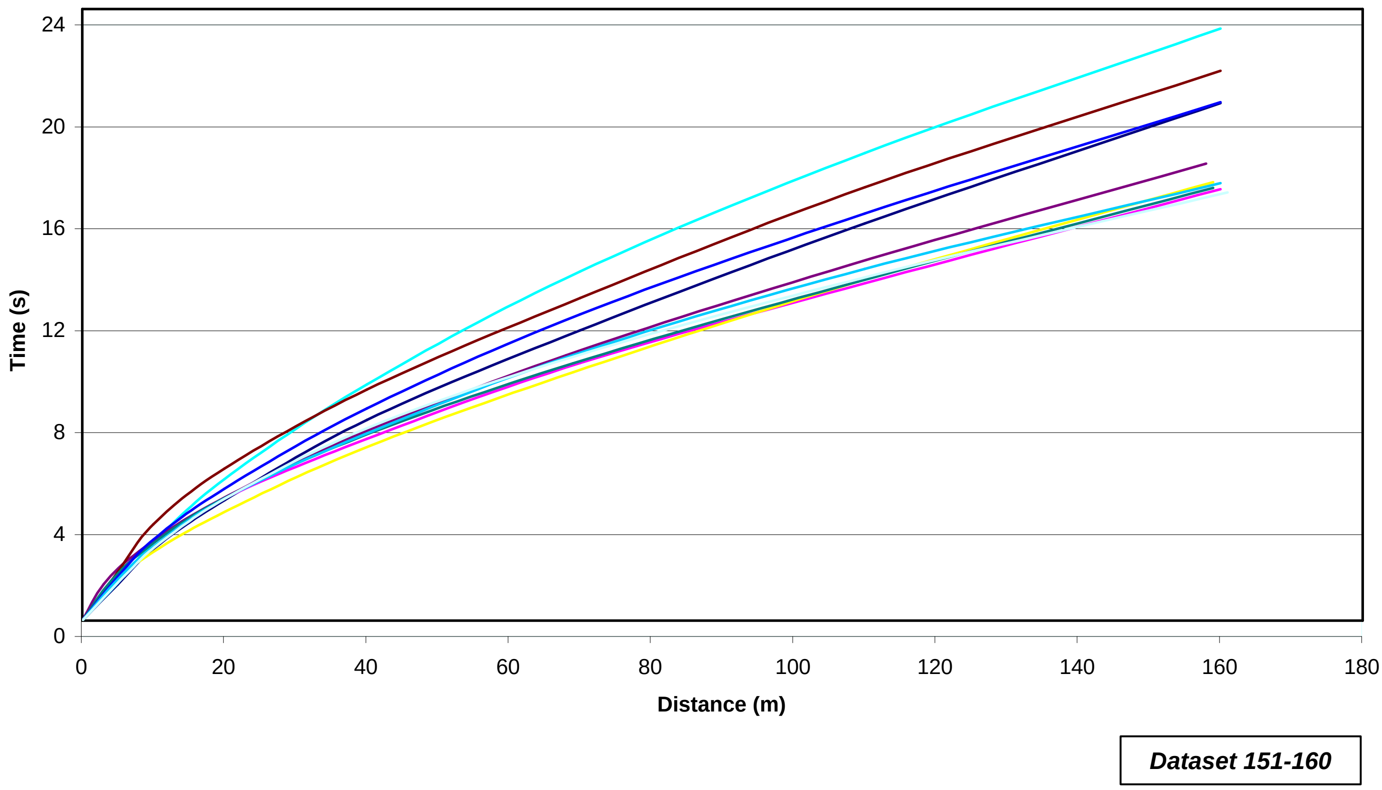
Dataset 121-130



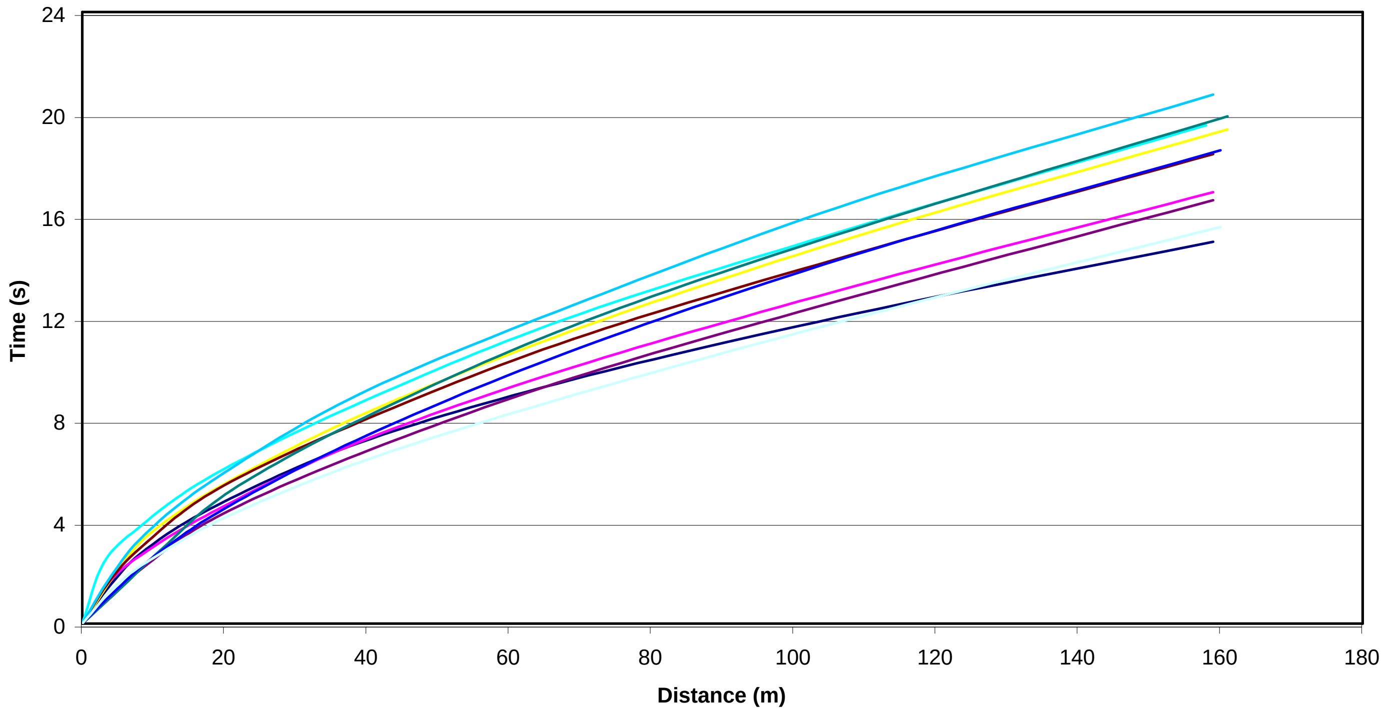
Dataset 131-140

Waverley Road / Whites Road intersection
Time distance survey results

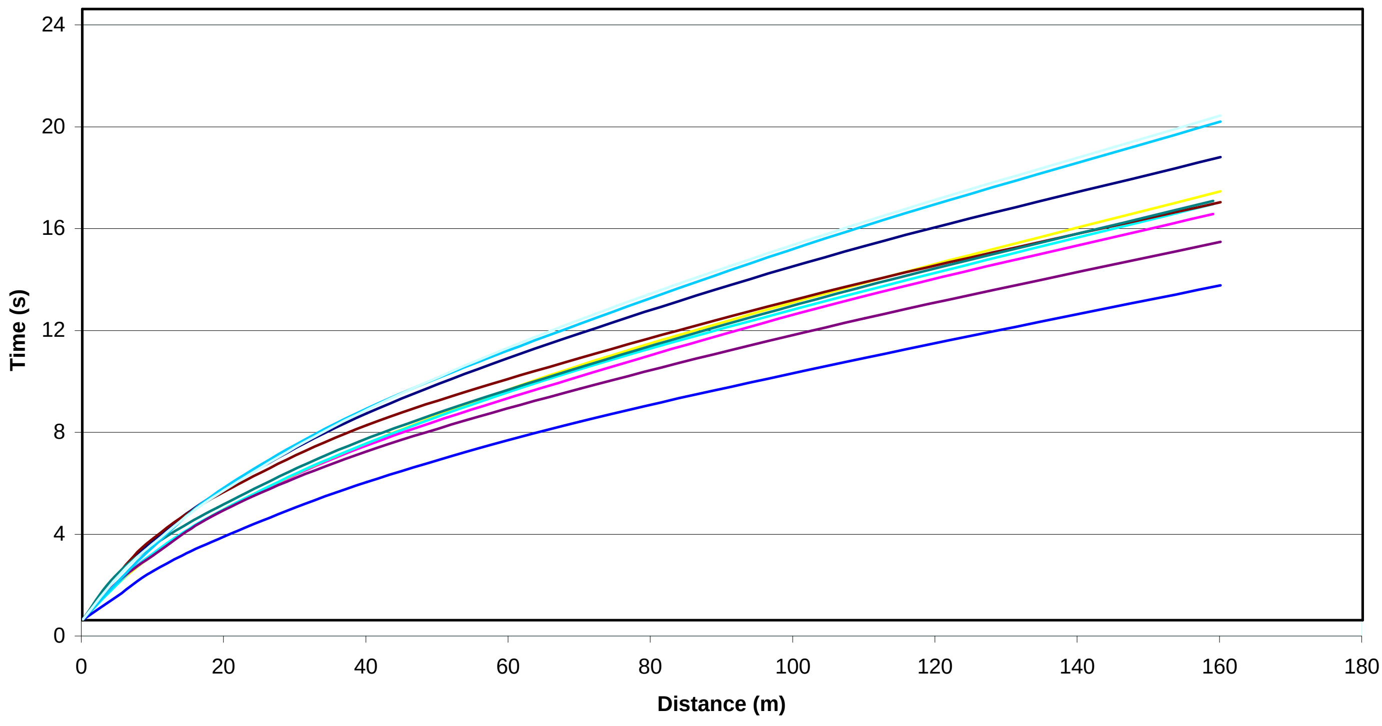




Waverley Road / Whites Road intersection
Time distance survey results

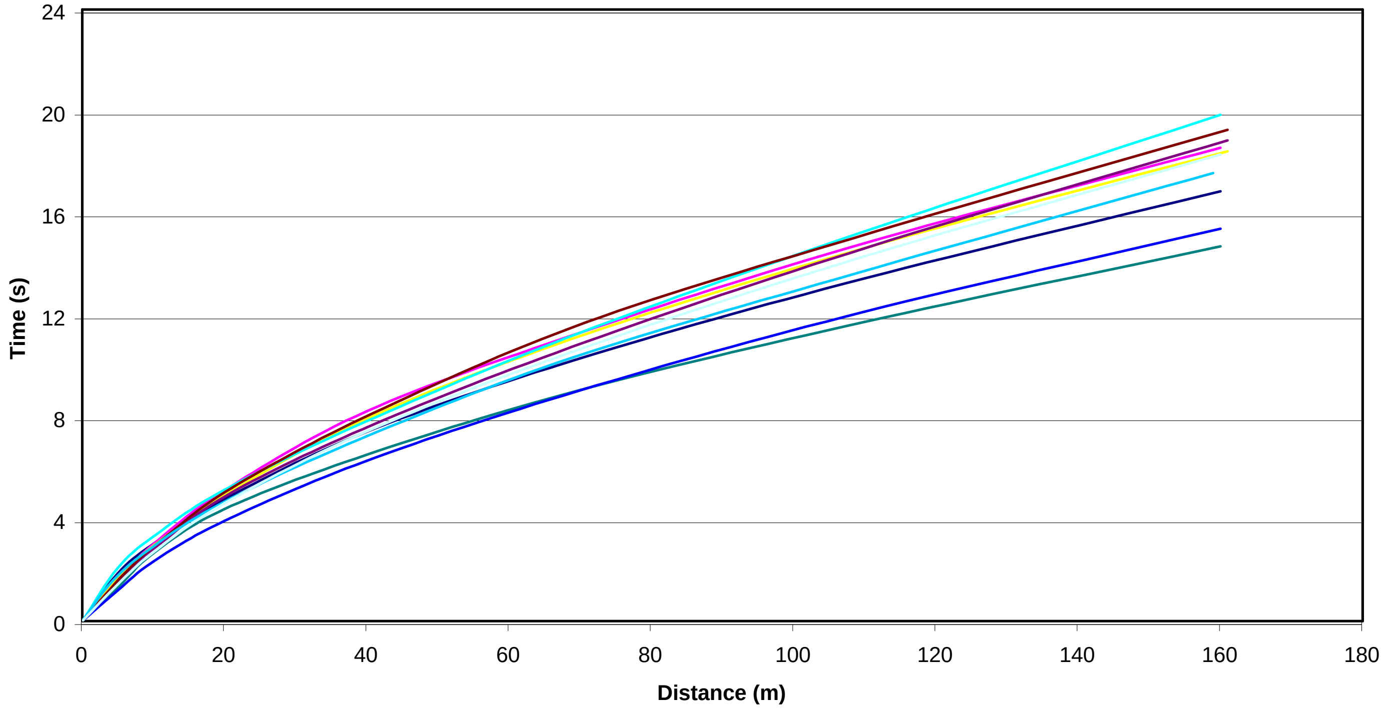


Dataset 161-170

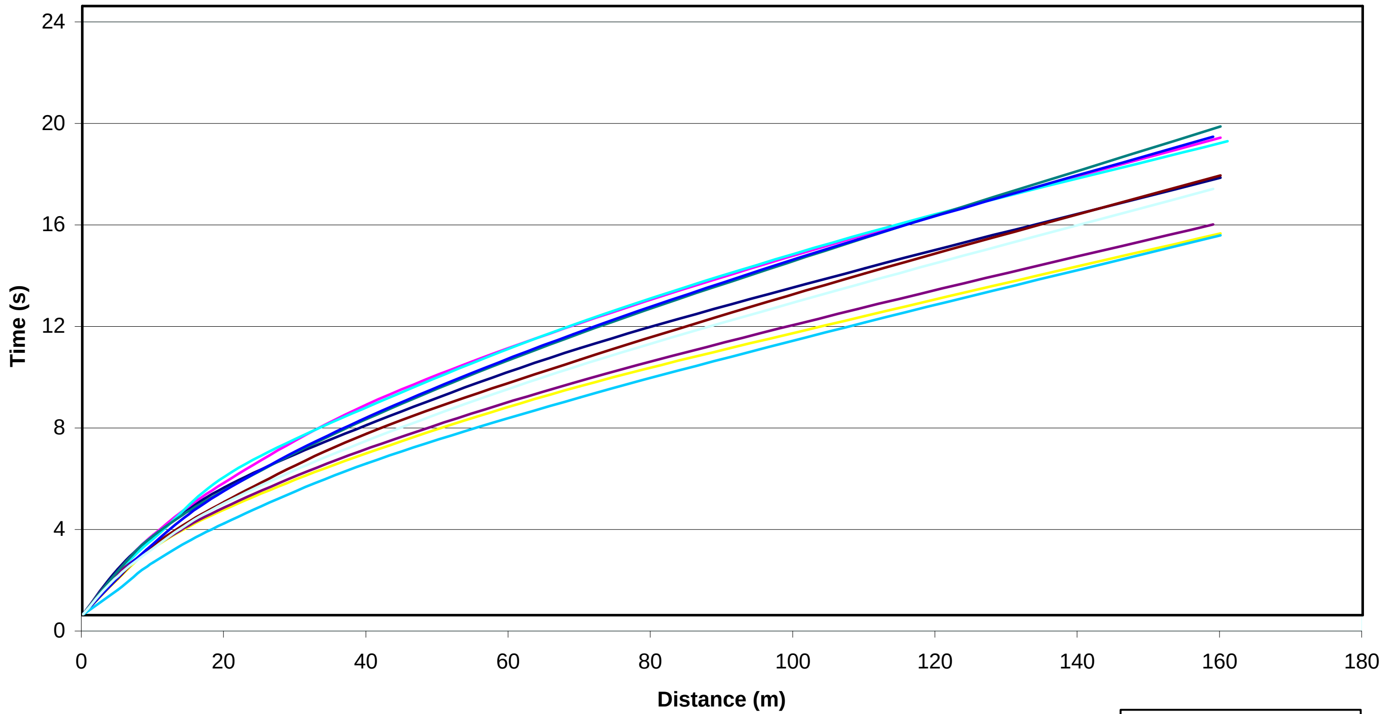


Dataset 171-180

Waverley Road / Whites Road intersection
Time distance survey results

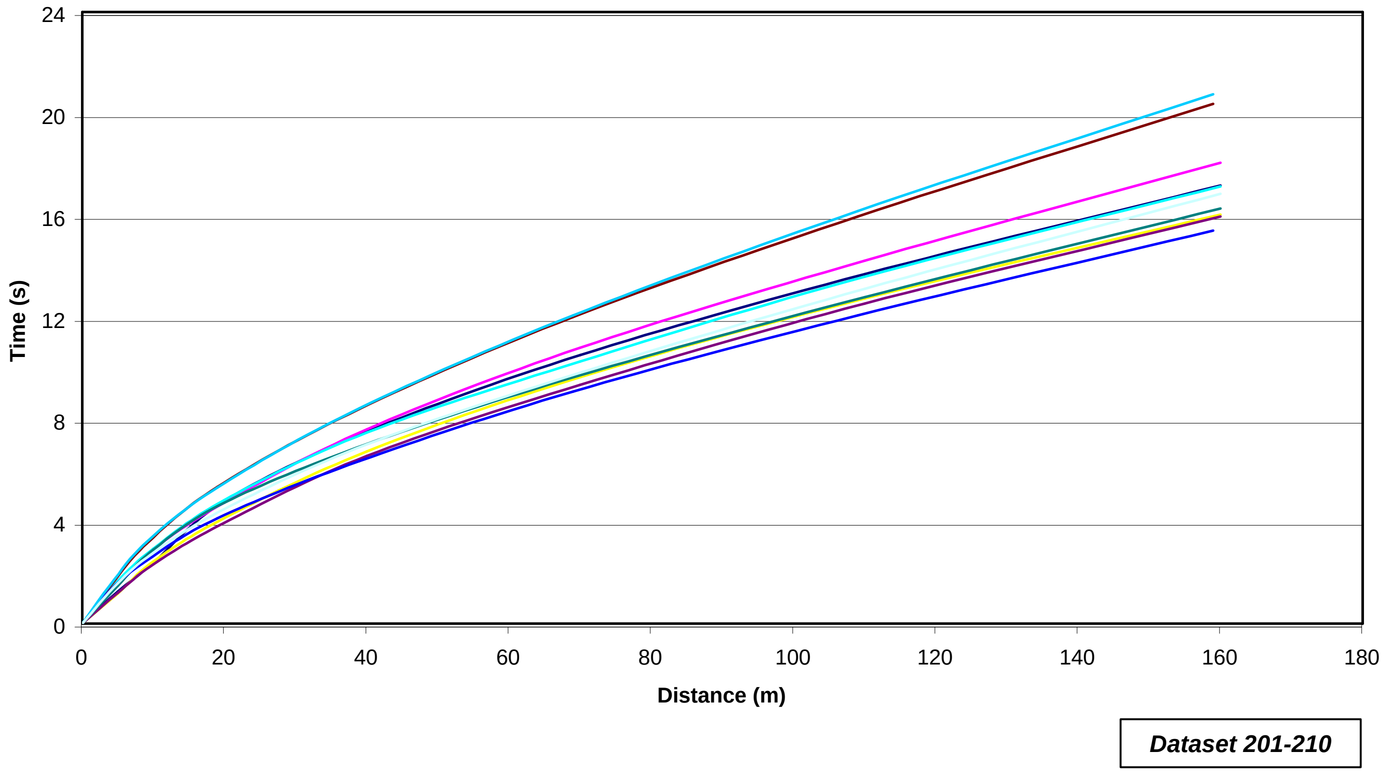


Dataset 181-190



Dataset 191-200

Waverley Road / Whites Road intersection
Time distance survey results



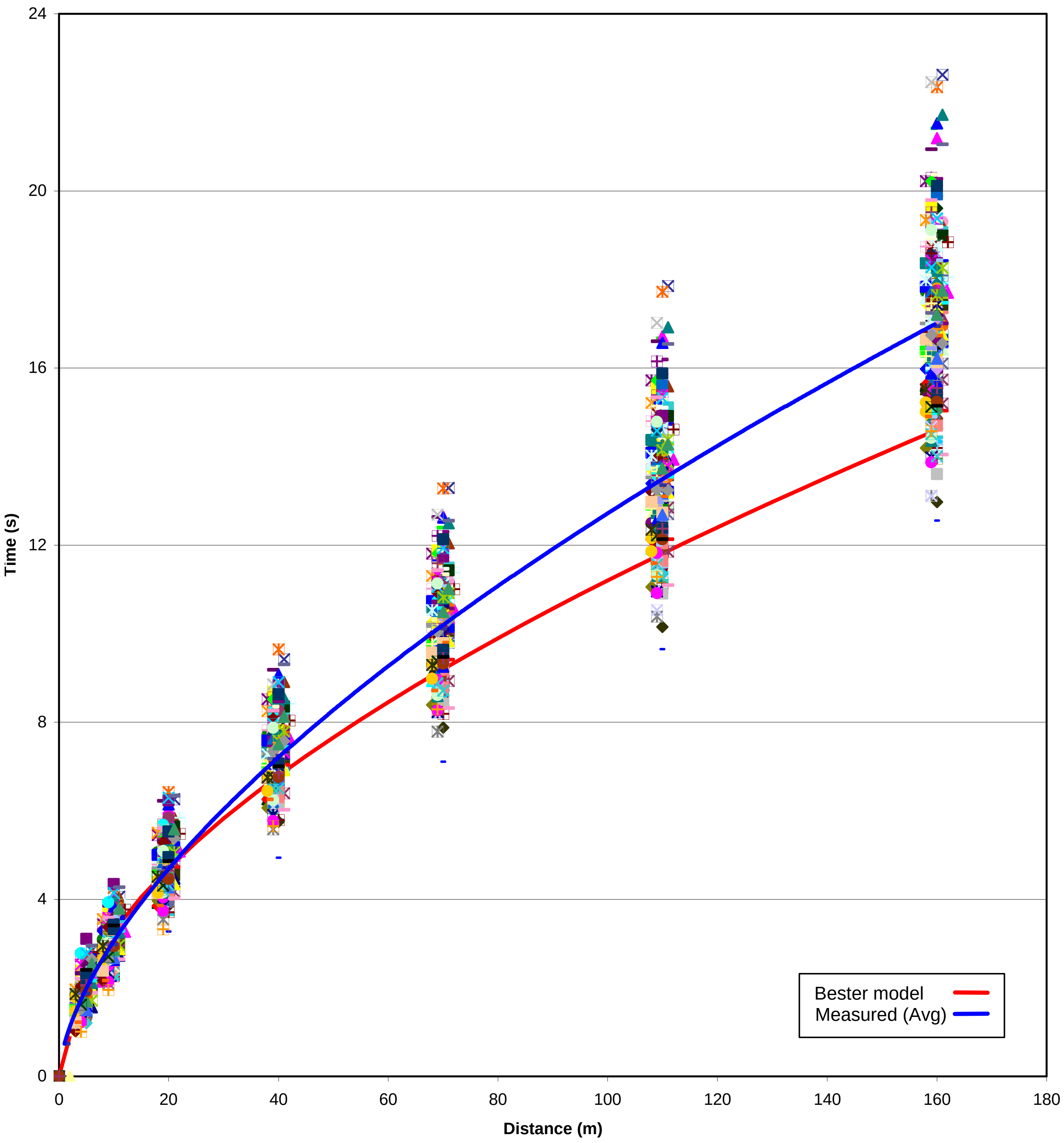
ANNEXURE D

Detailed statistical analysis

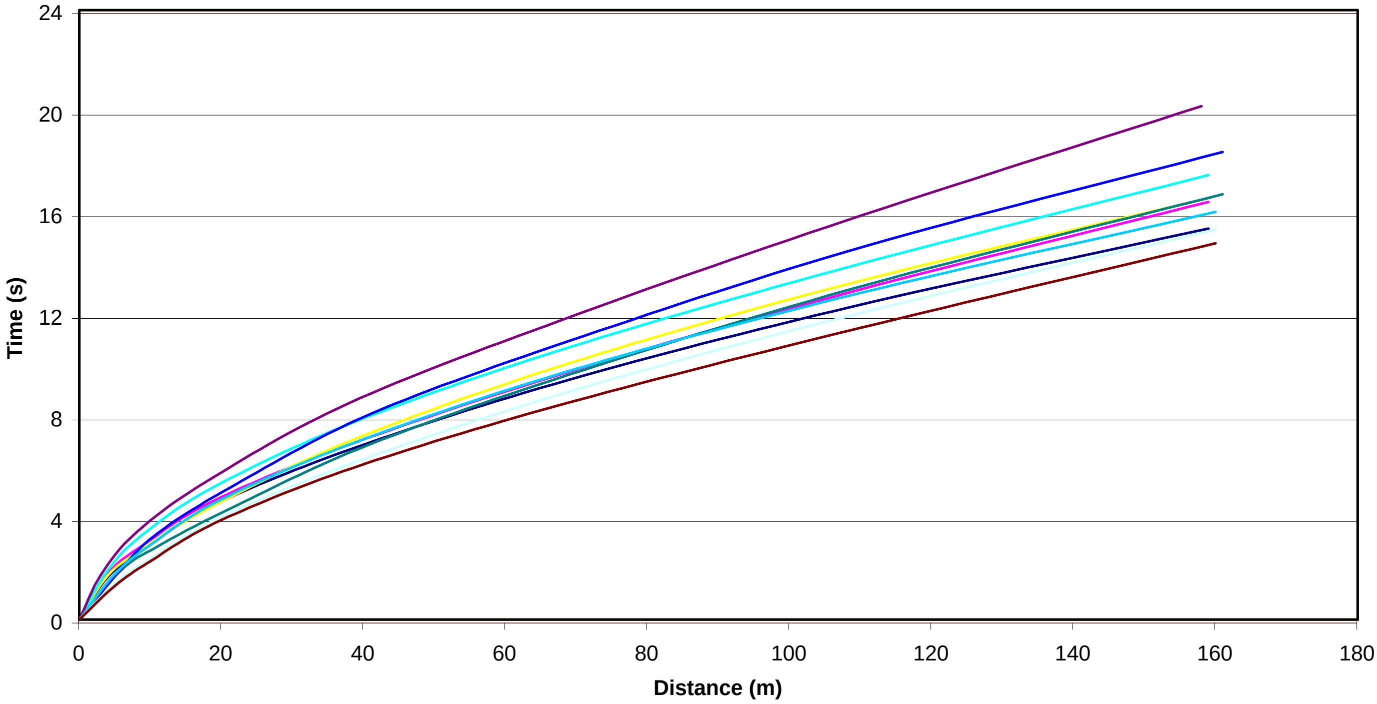
calculations

Furstenburg Road / Pierre Ollemans Street

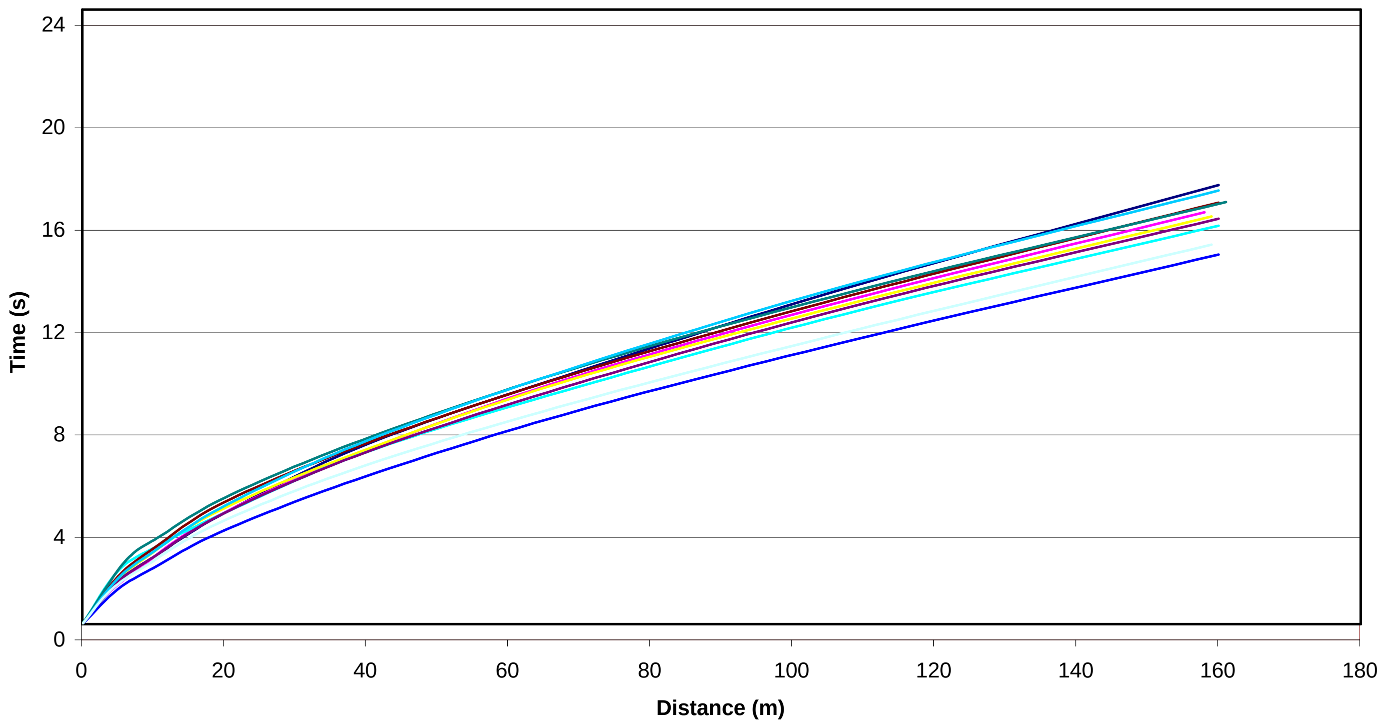
Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results



Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

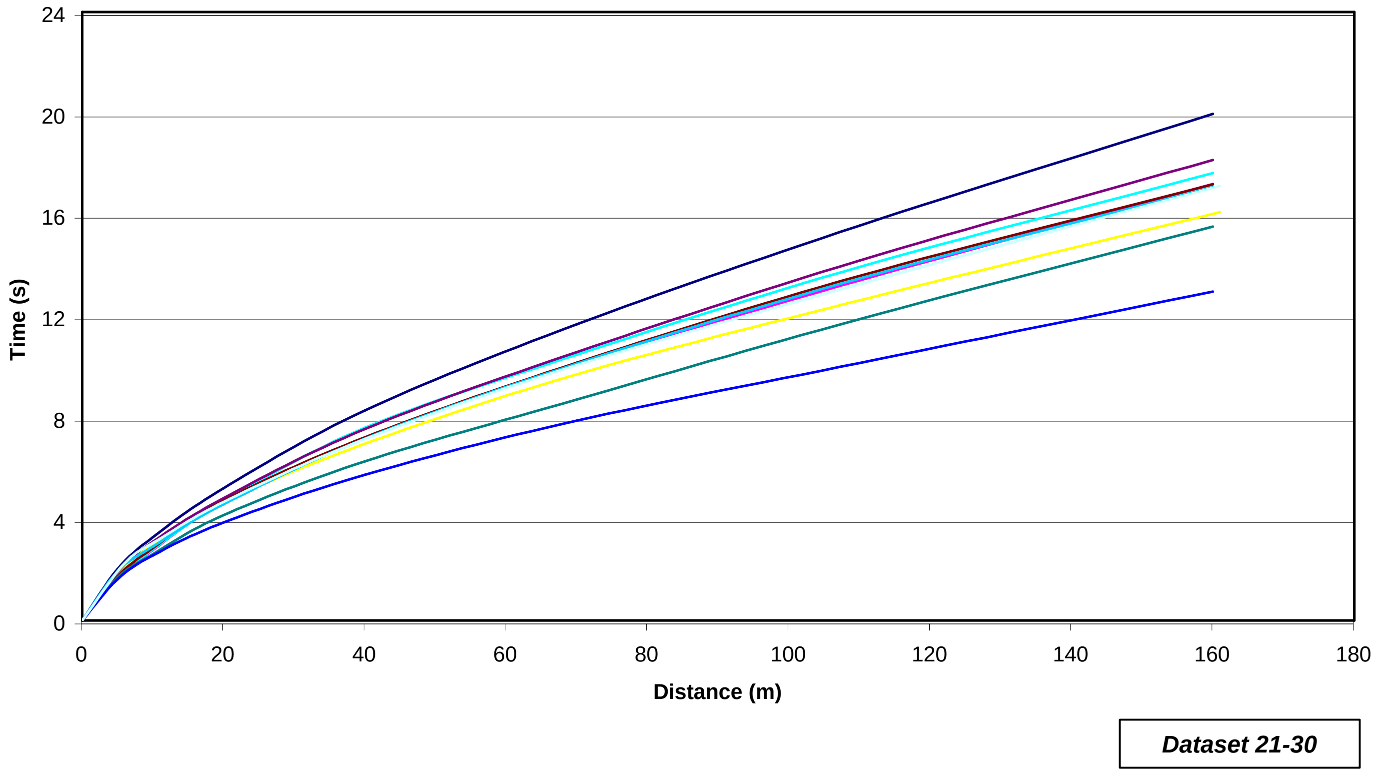


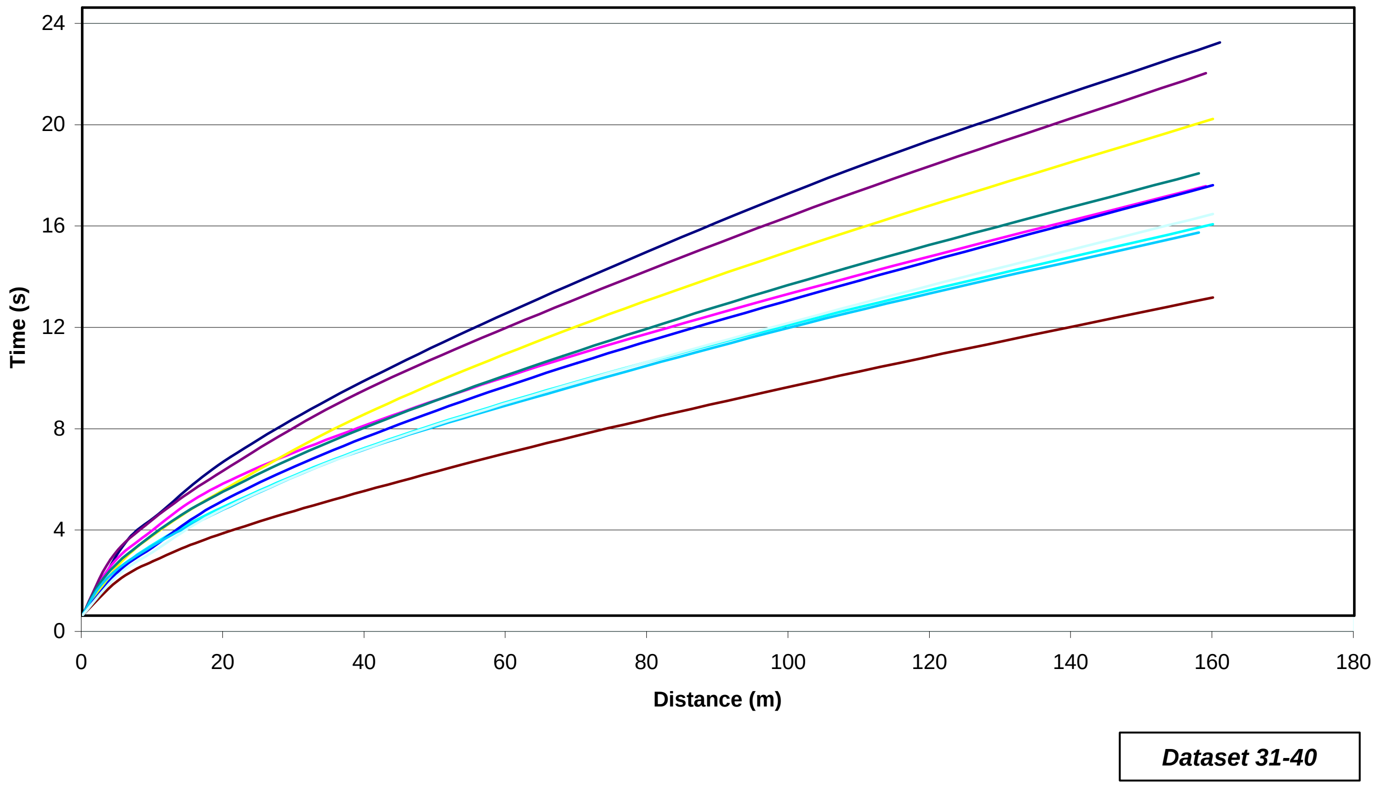
Dataset 1-10



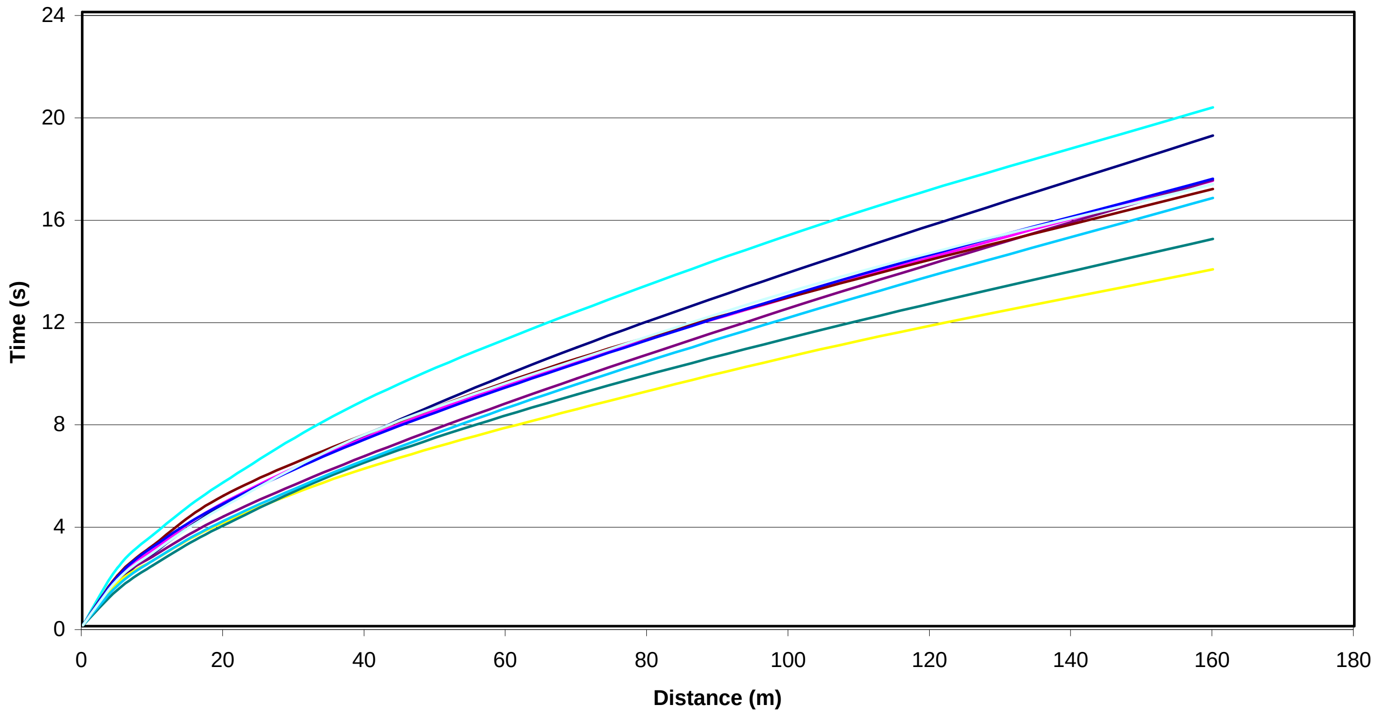
Dataset 11-20

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

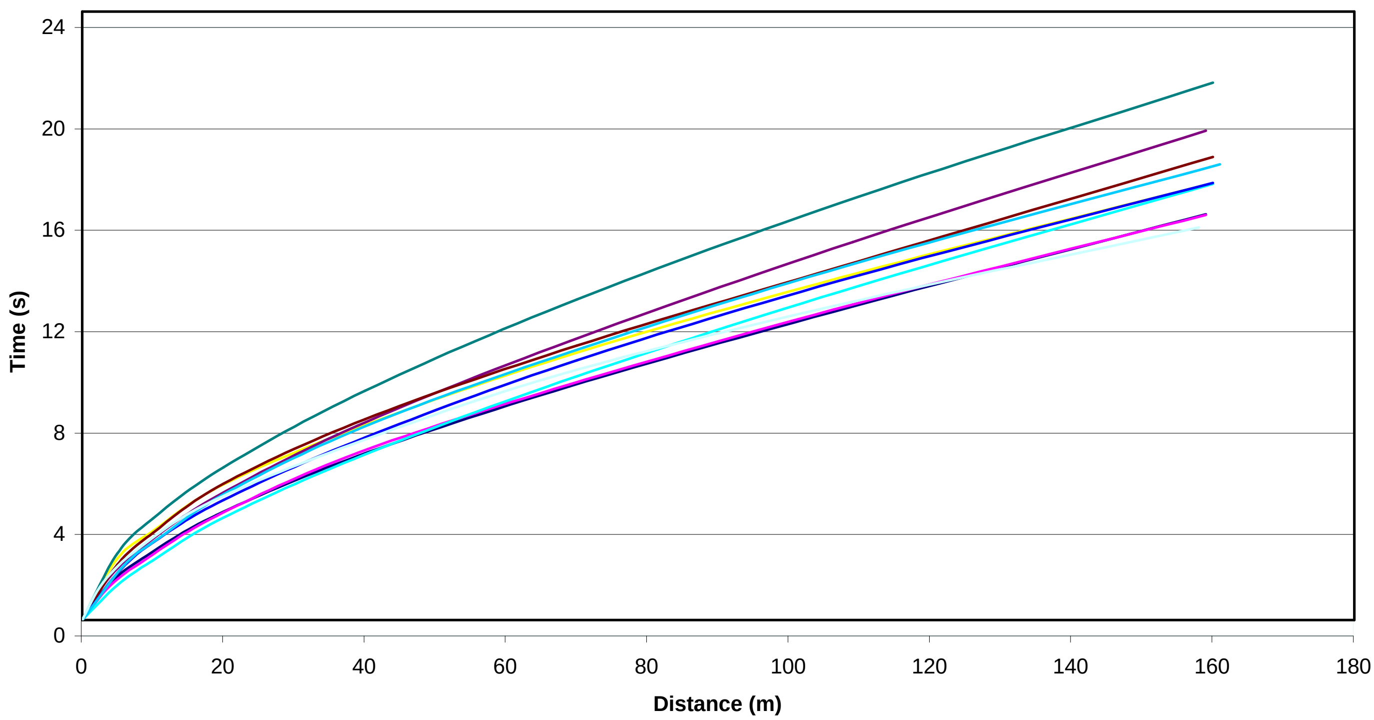




Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

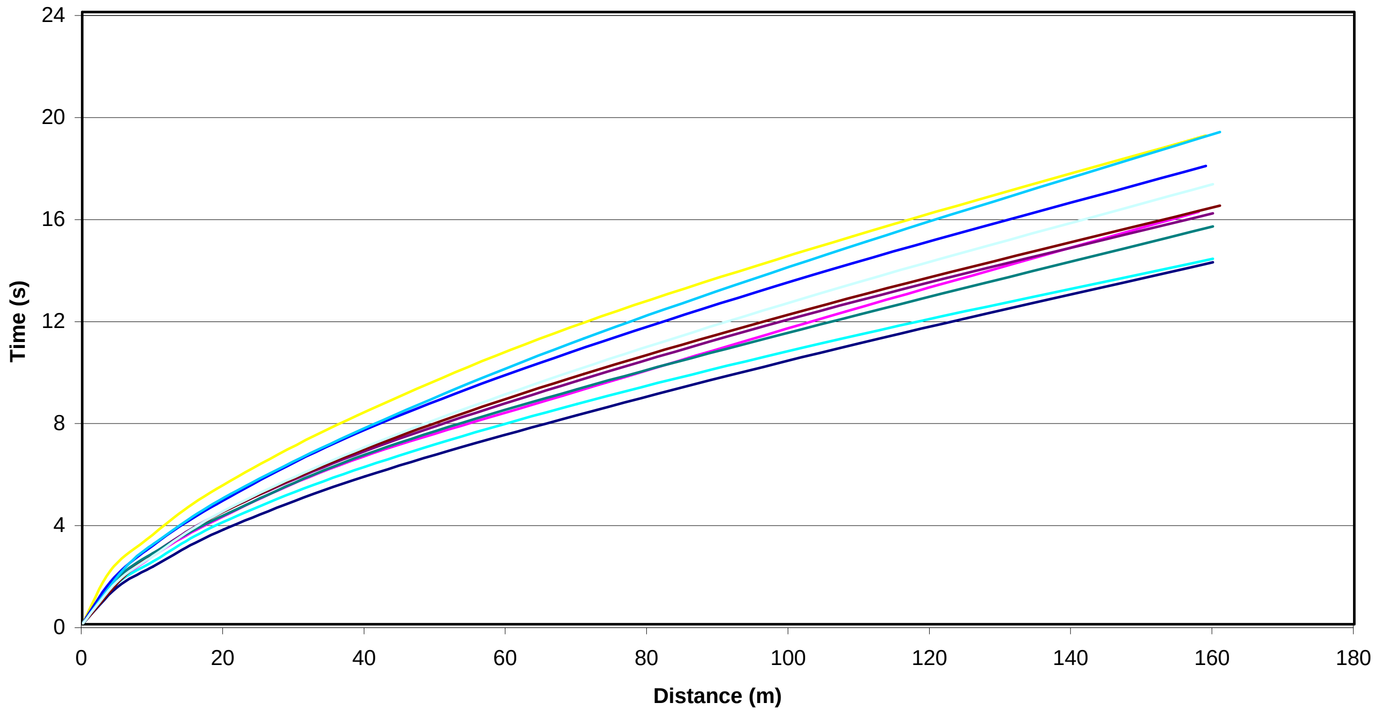


Dataset 41-50

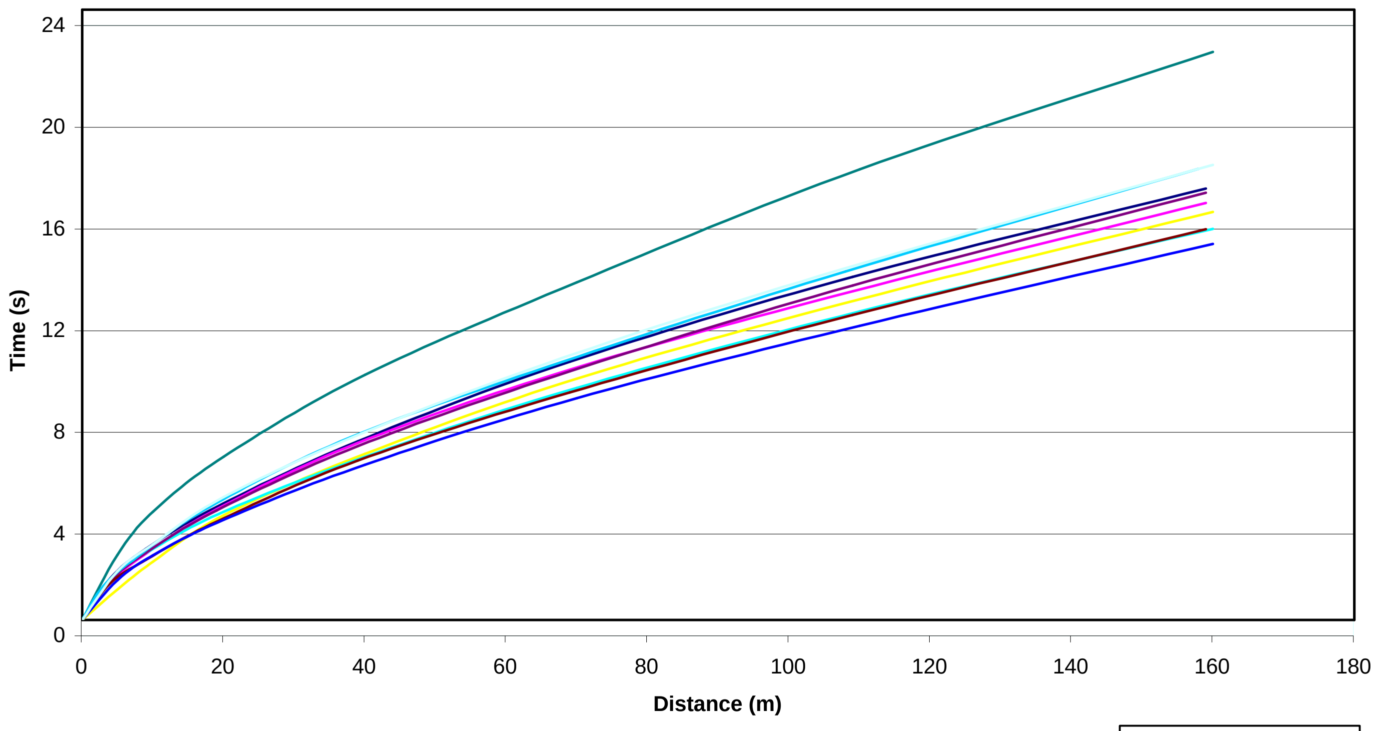


Dataset 51-60

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

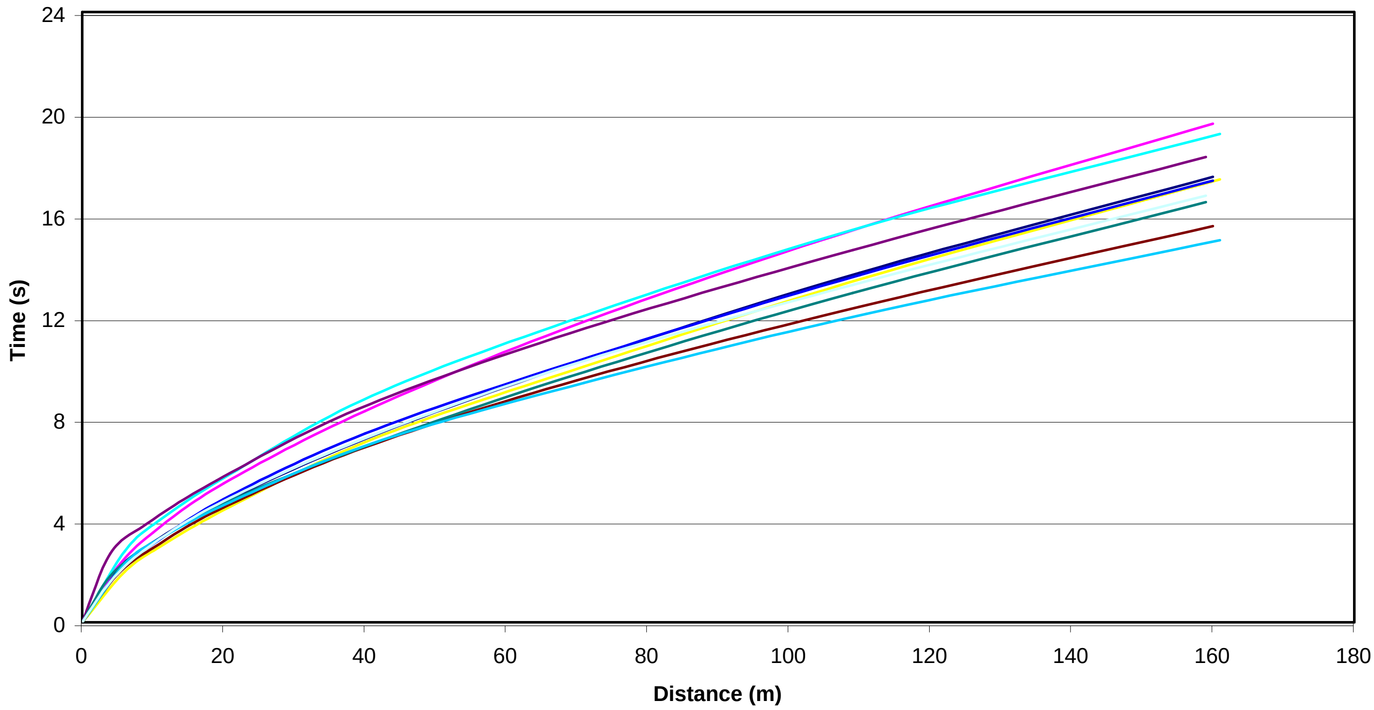


Dataset 61-70

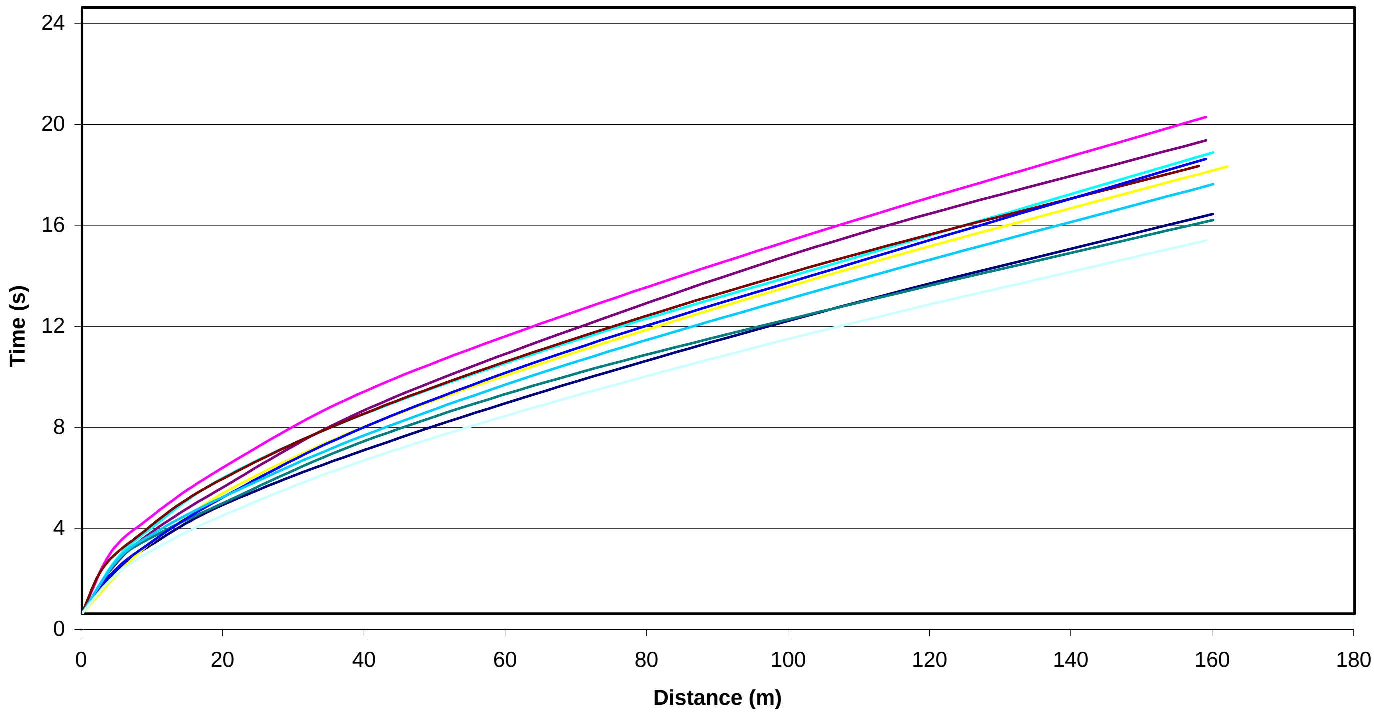


Dataset 71-80

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

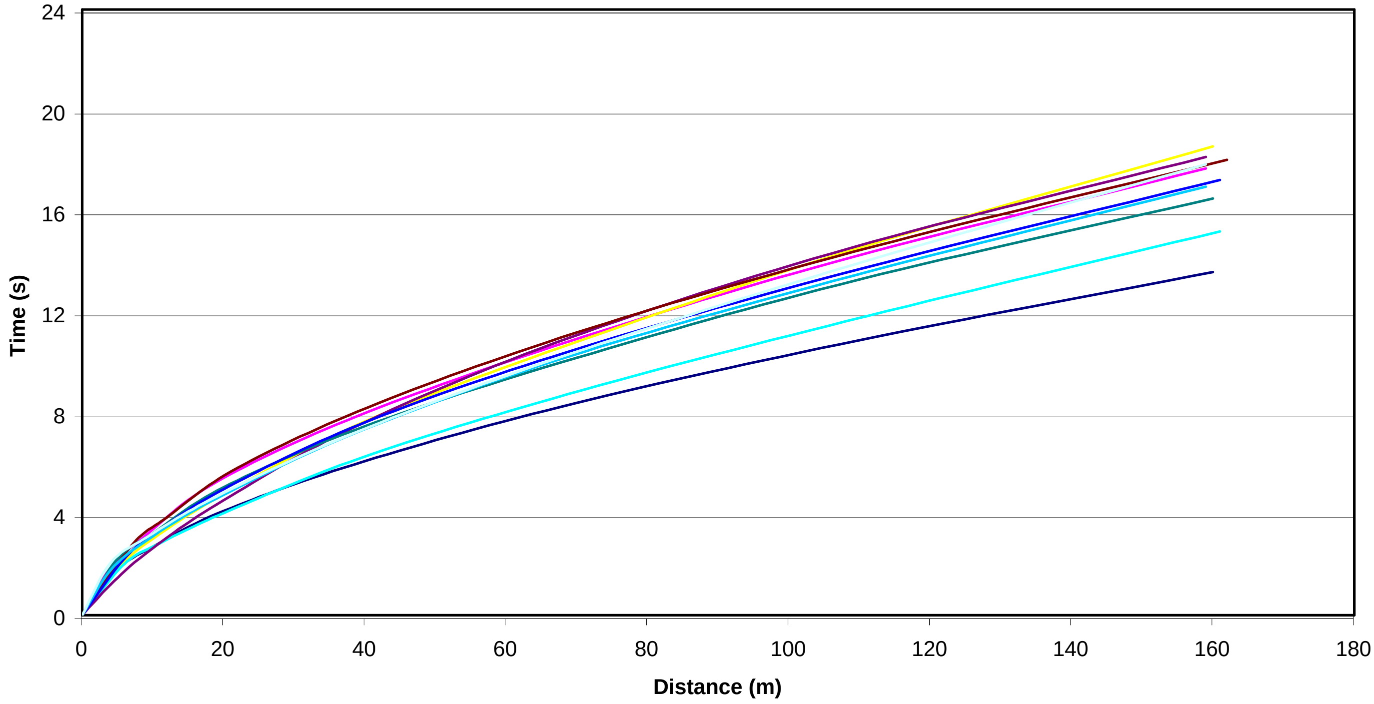


Dataset 81-90

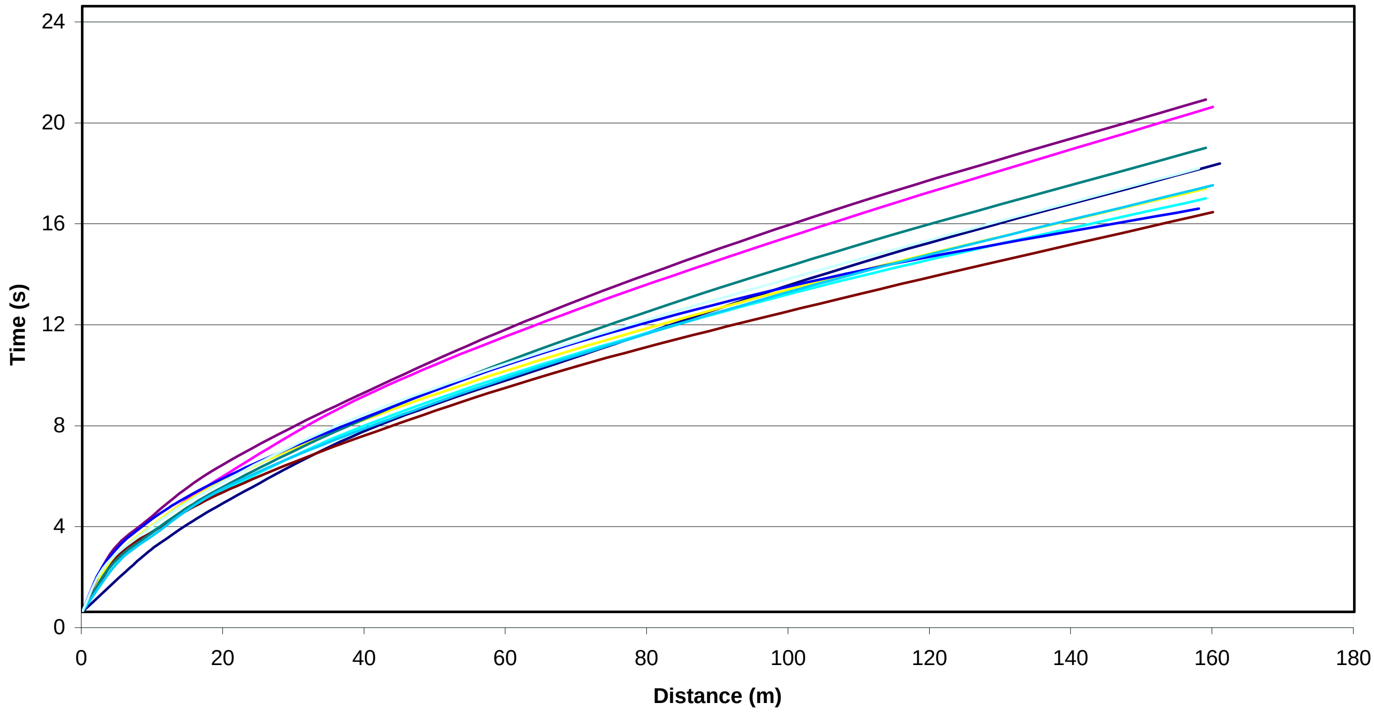


Dataset 91-100

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

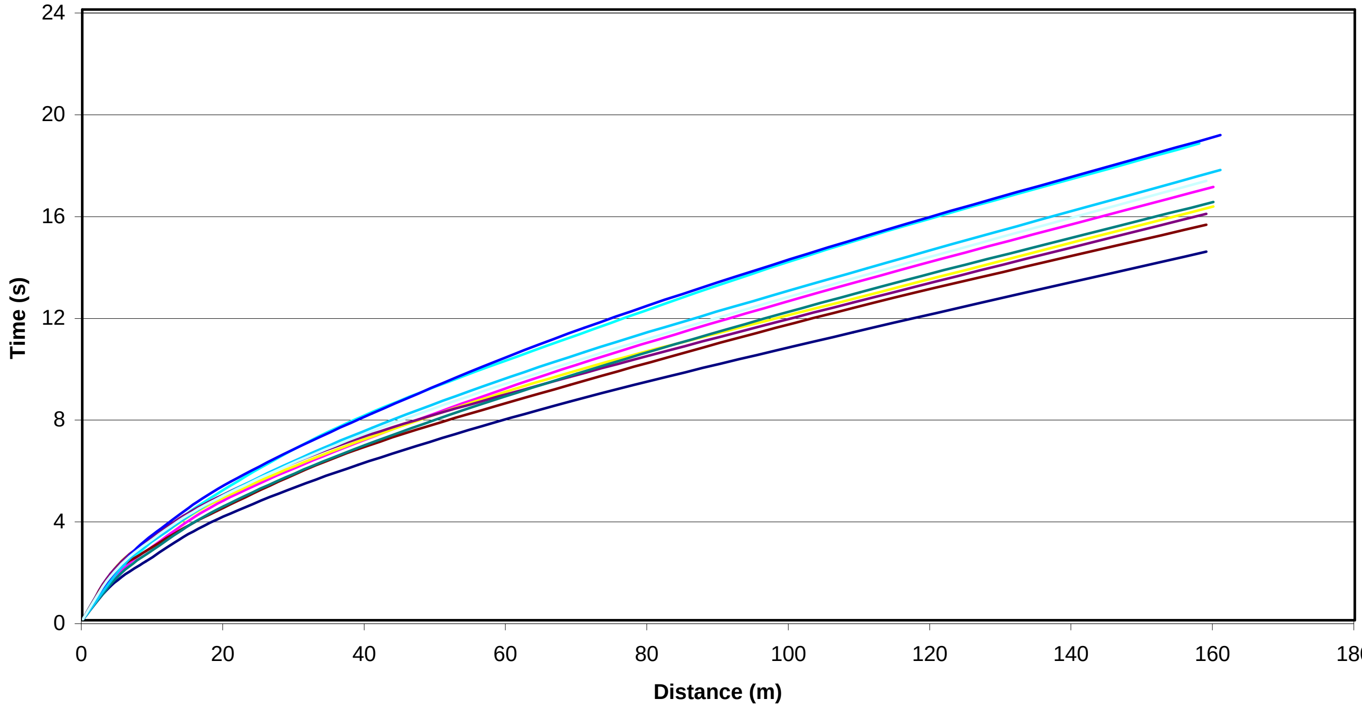


Dataset 101-110

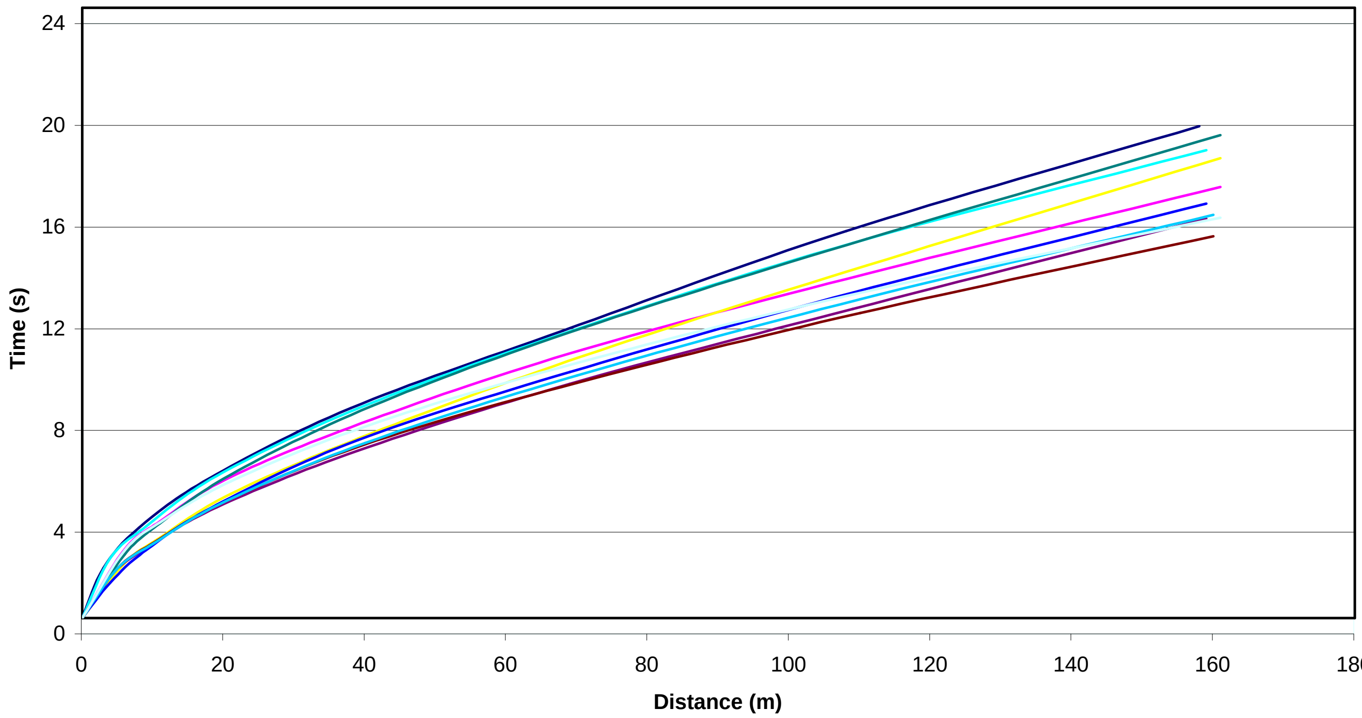


Dataset 111-120

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

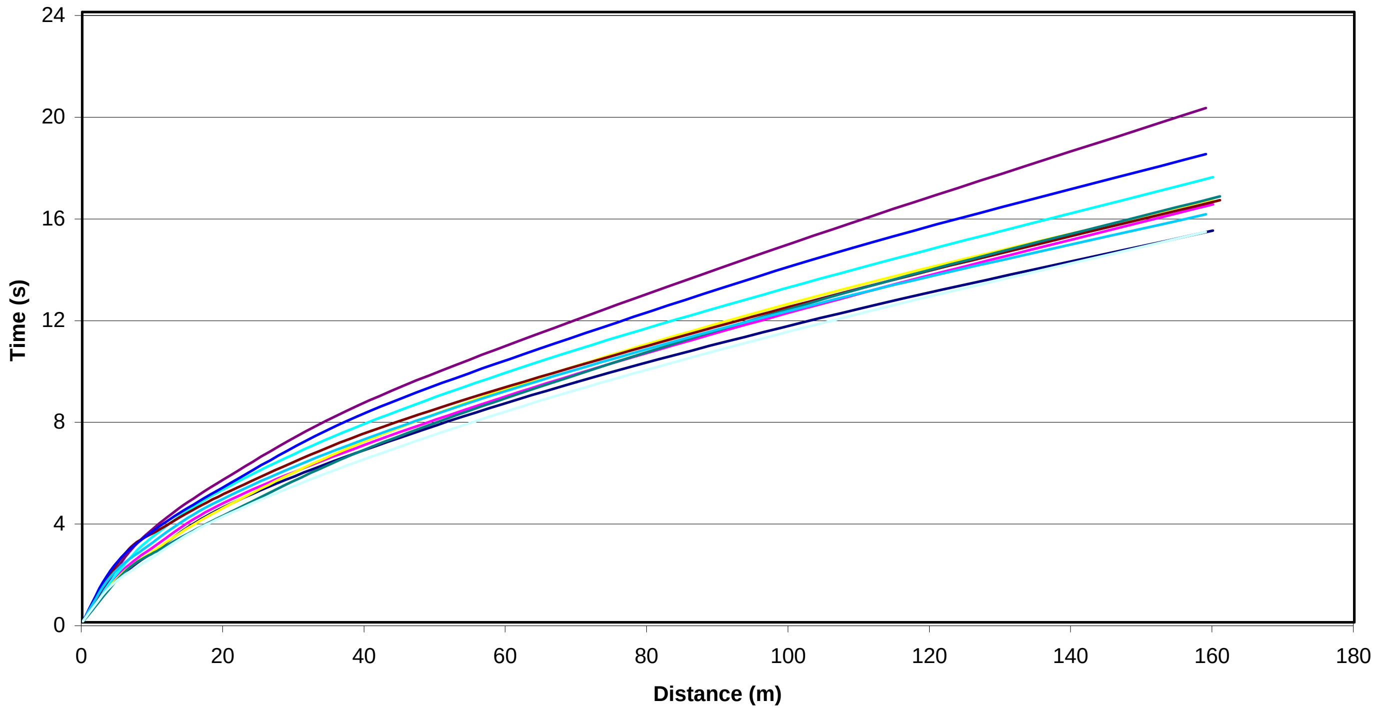


Dataset 121-130

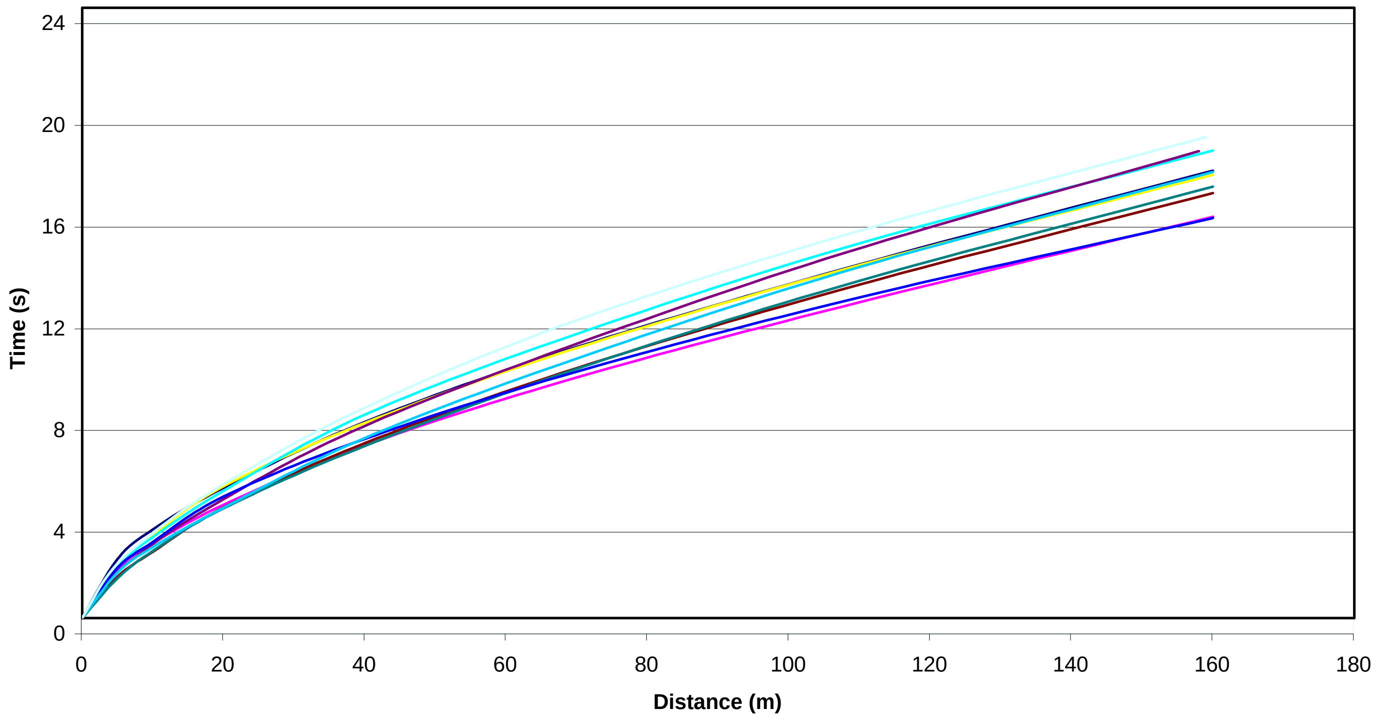


Dataset 131-140

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

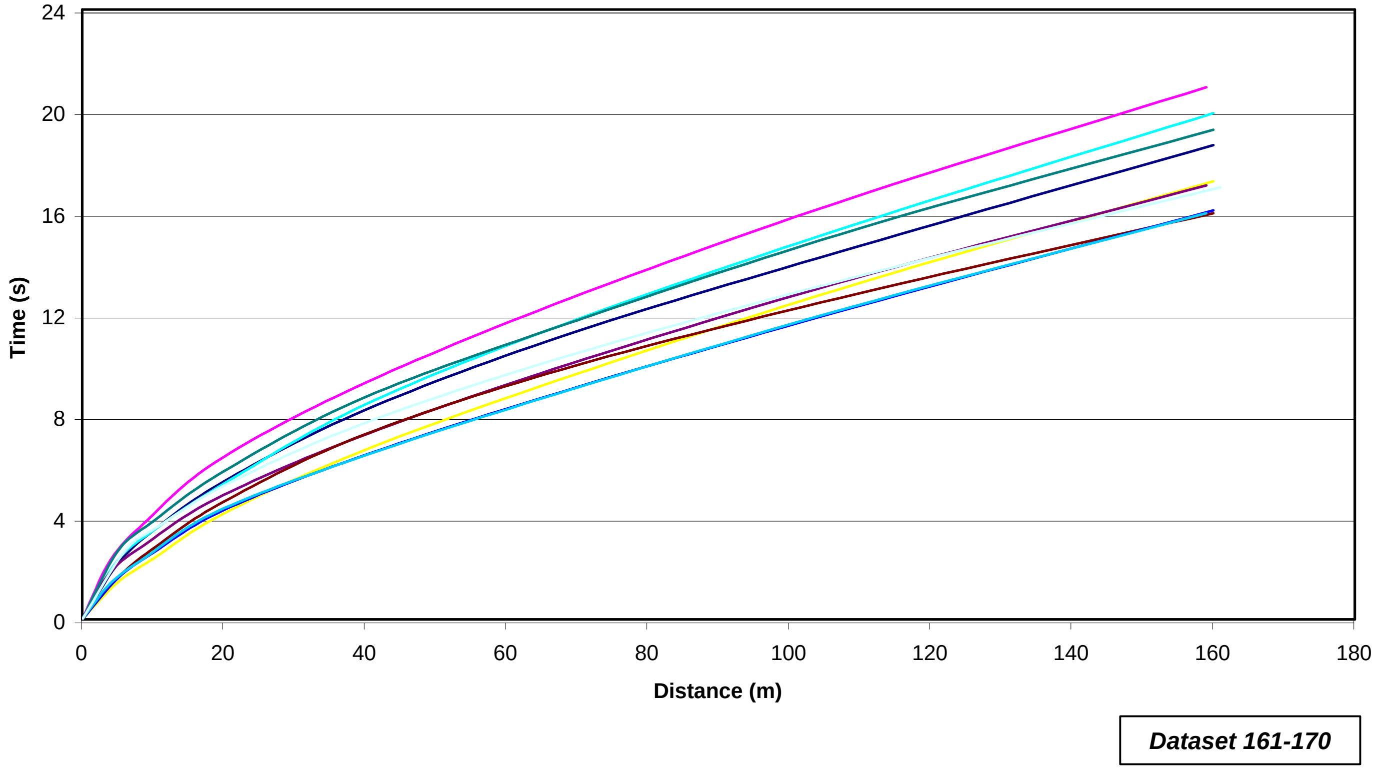


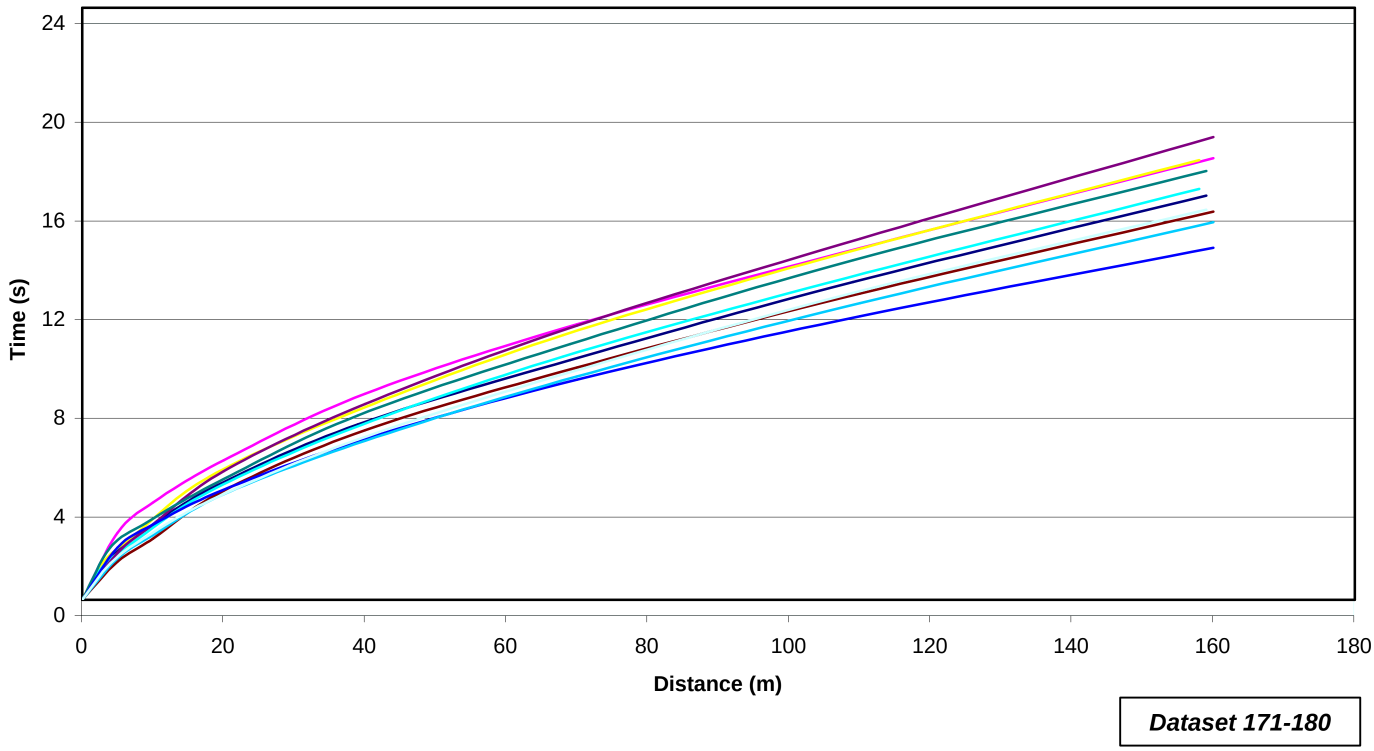
Dataset 141-150



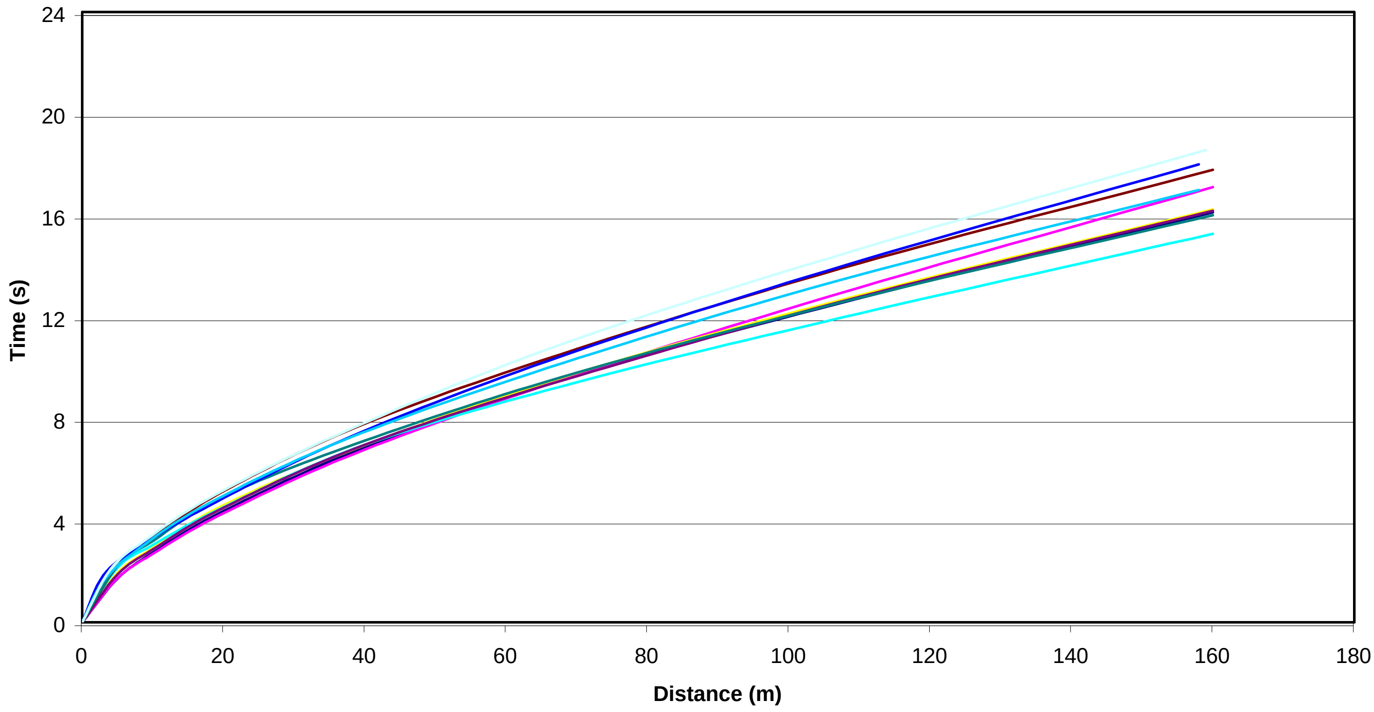
Dataset 151-160

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

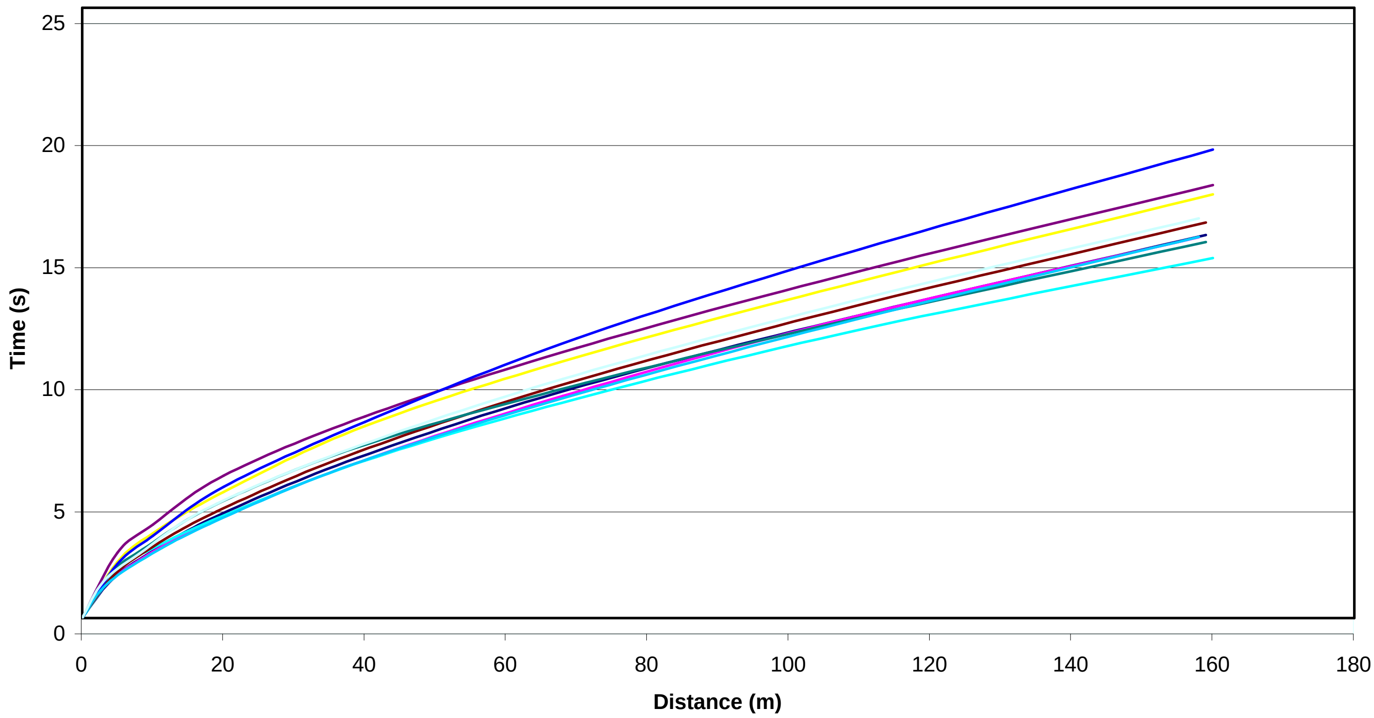




Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

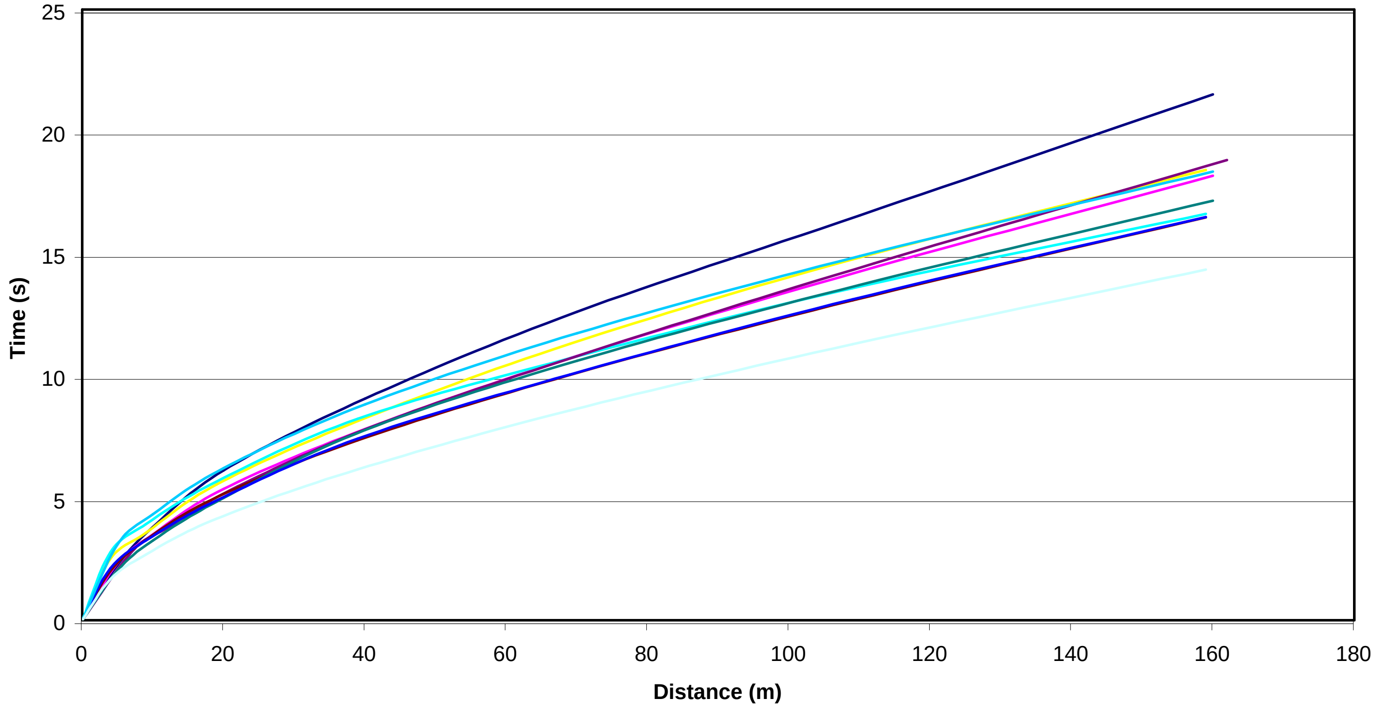


Dataset 181-190

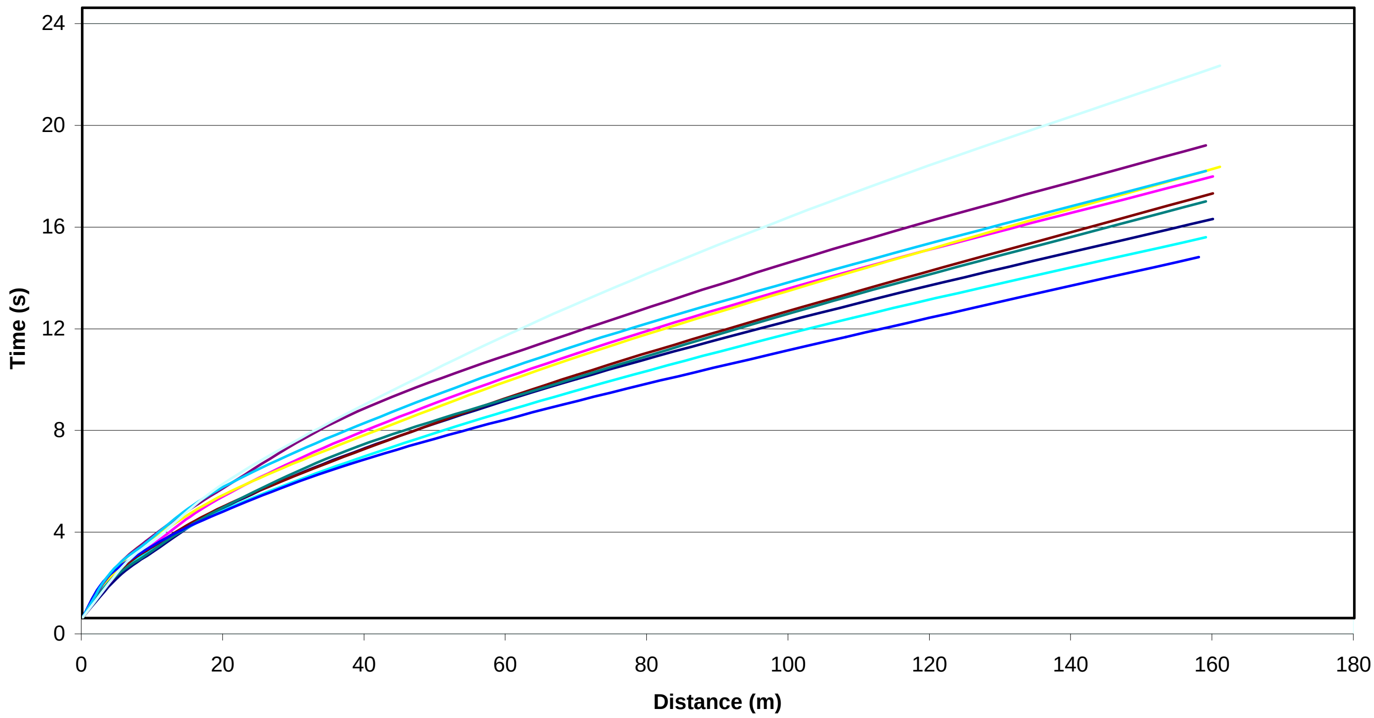


Dataset 191-200

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

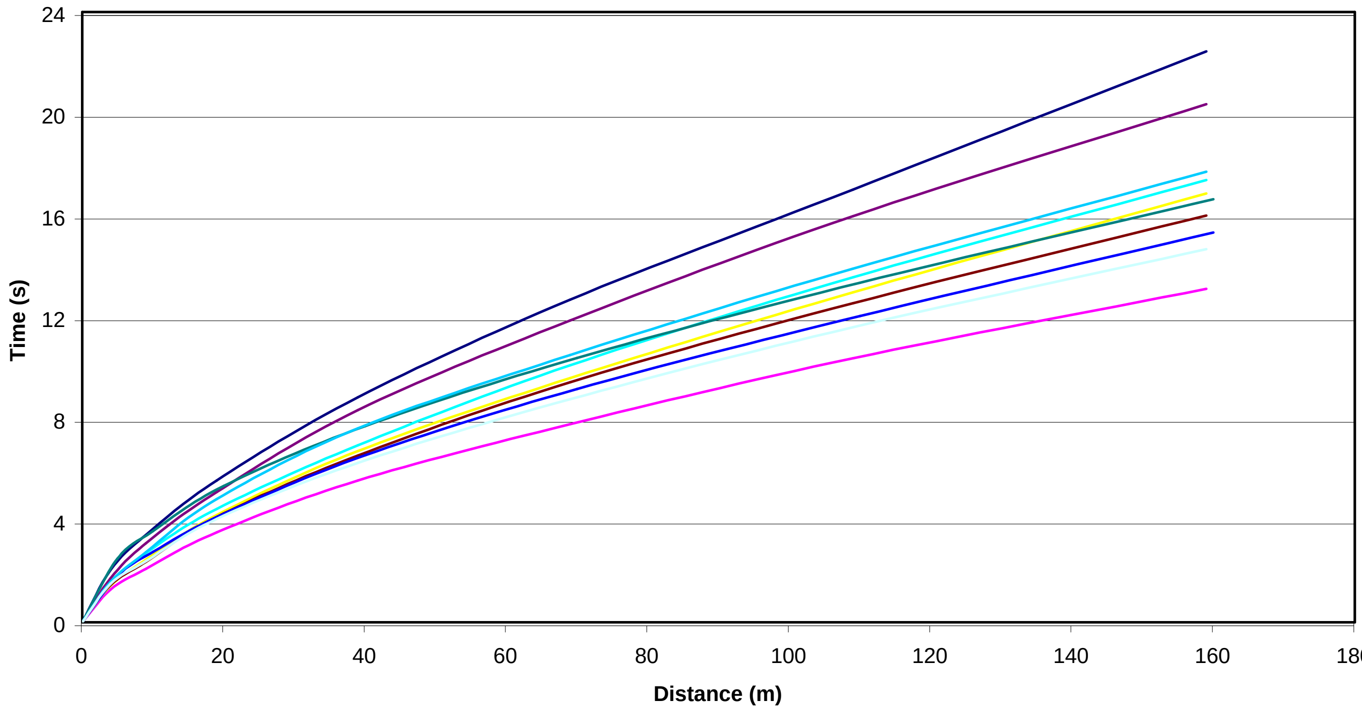


Dataset 201-210

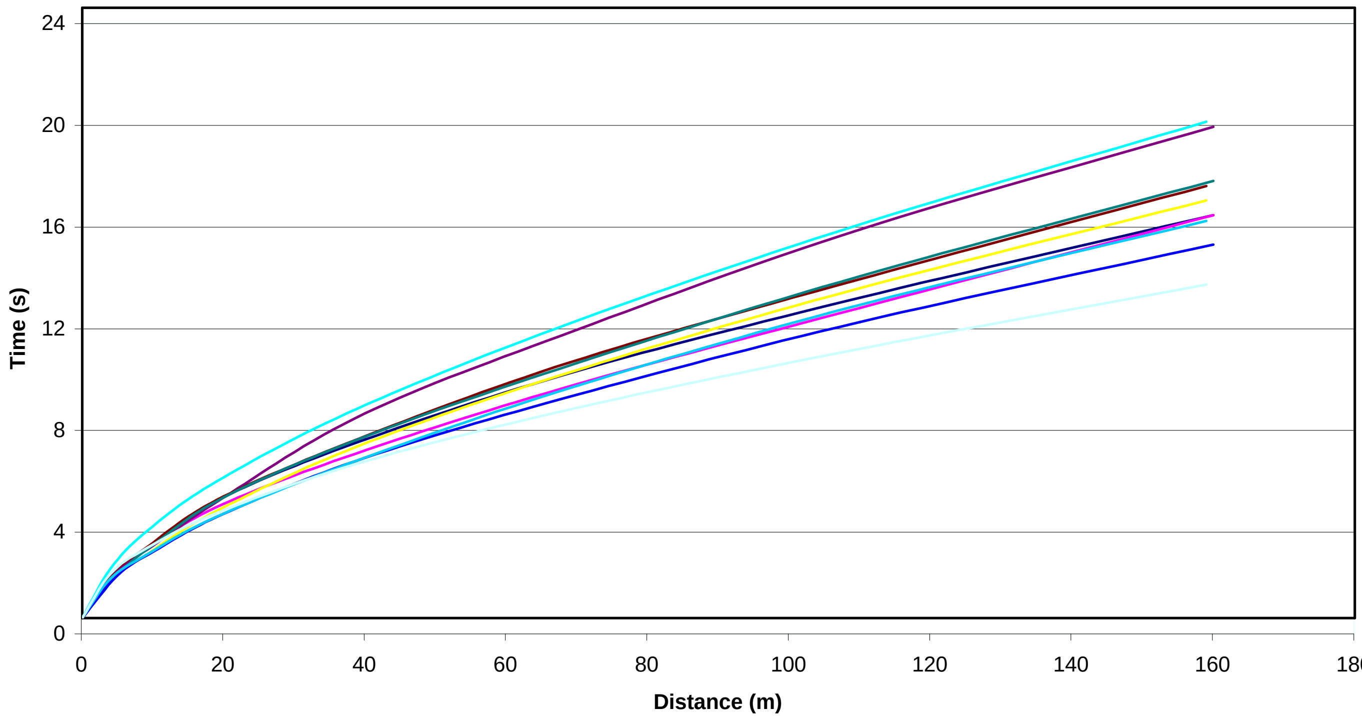


Dataset 211-220

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

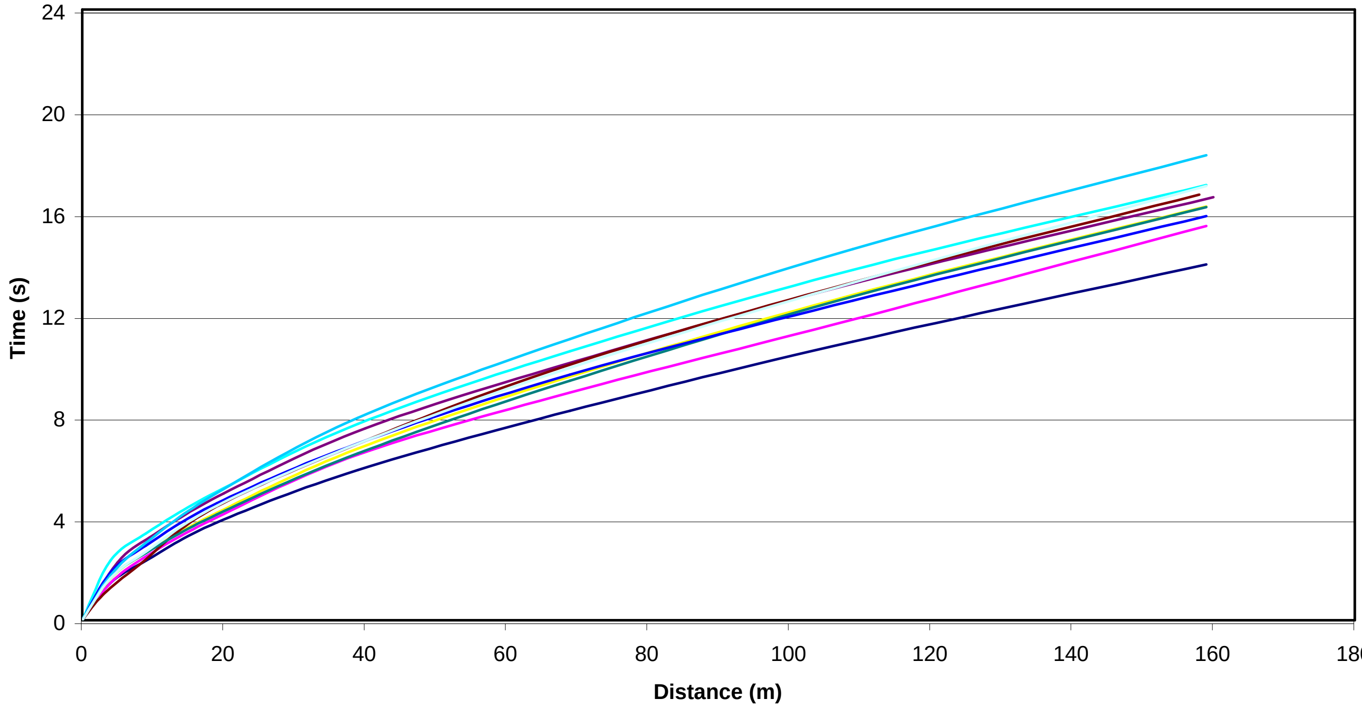


Dataset 221-230

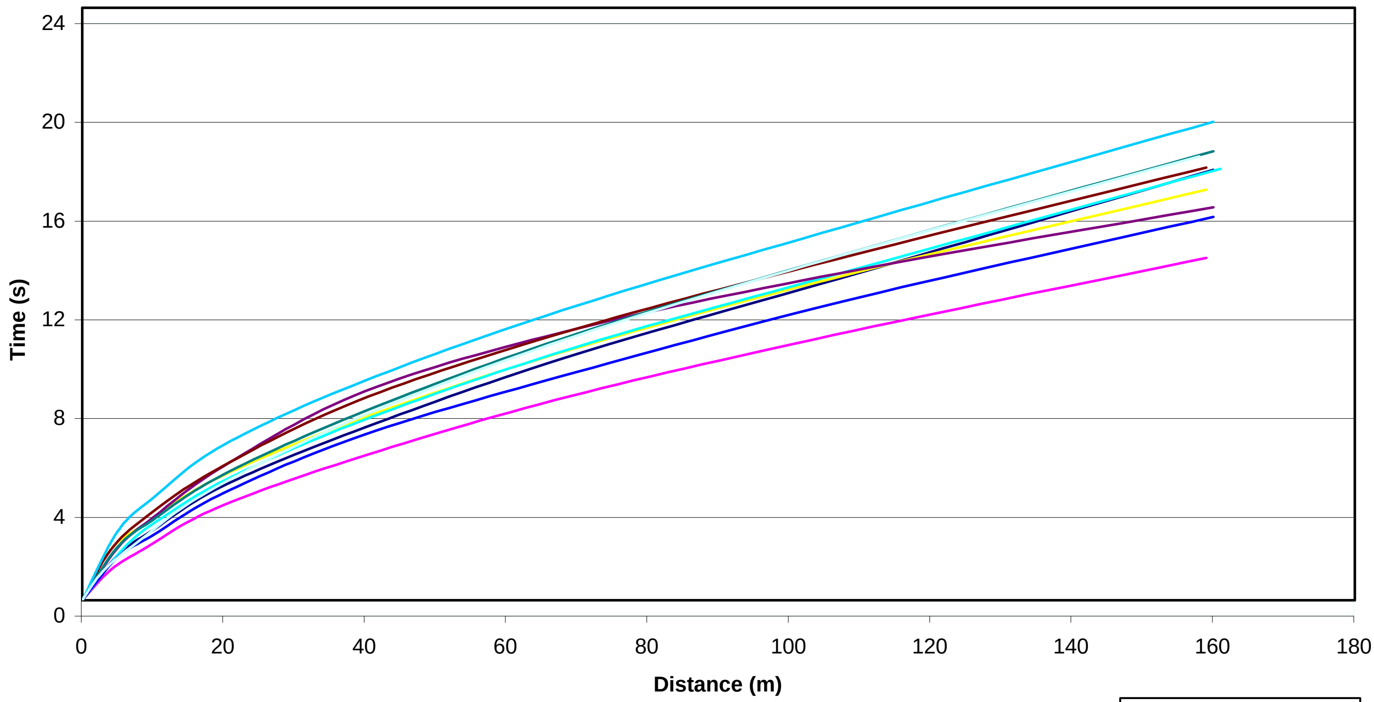


Dataset 231-240

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

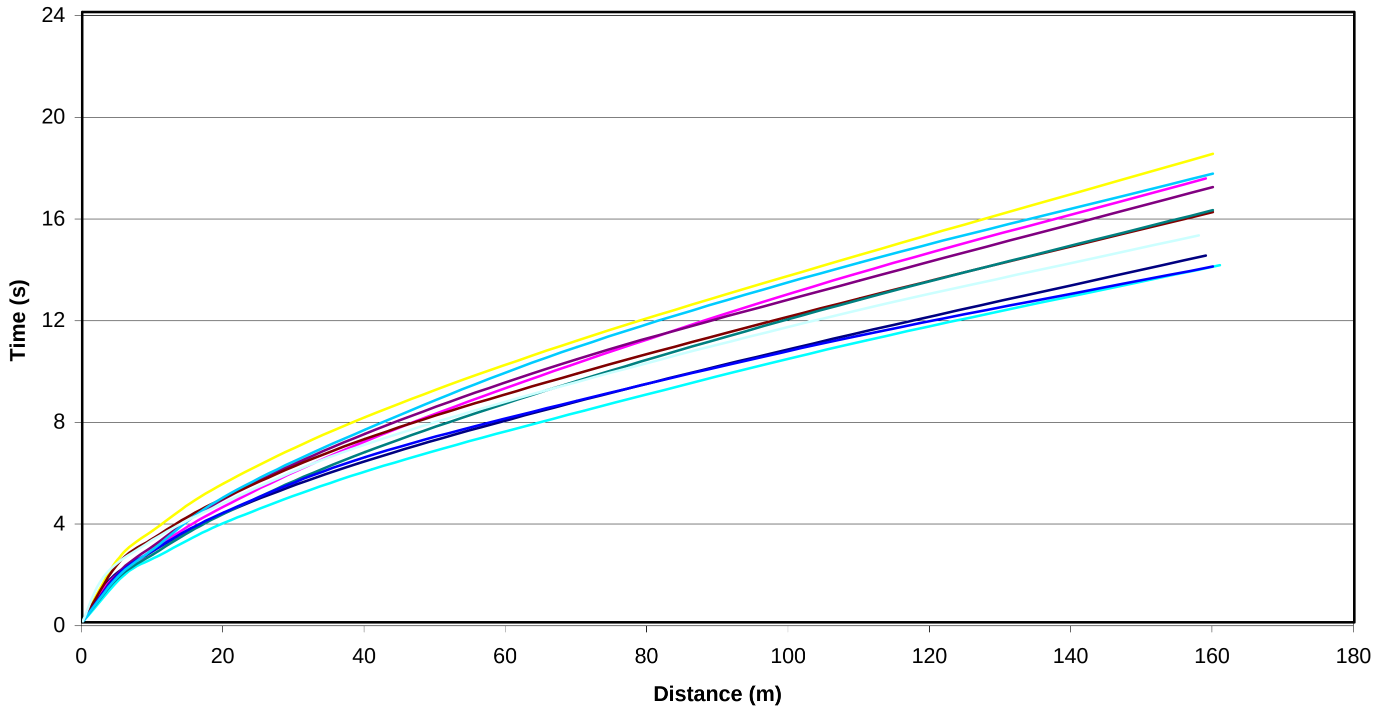


Dataset 241-250

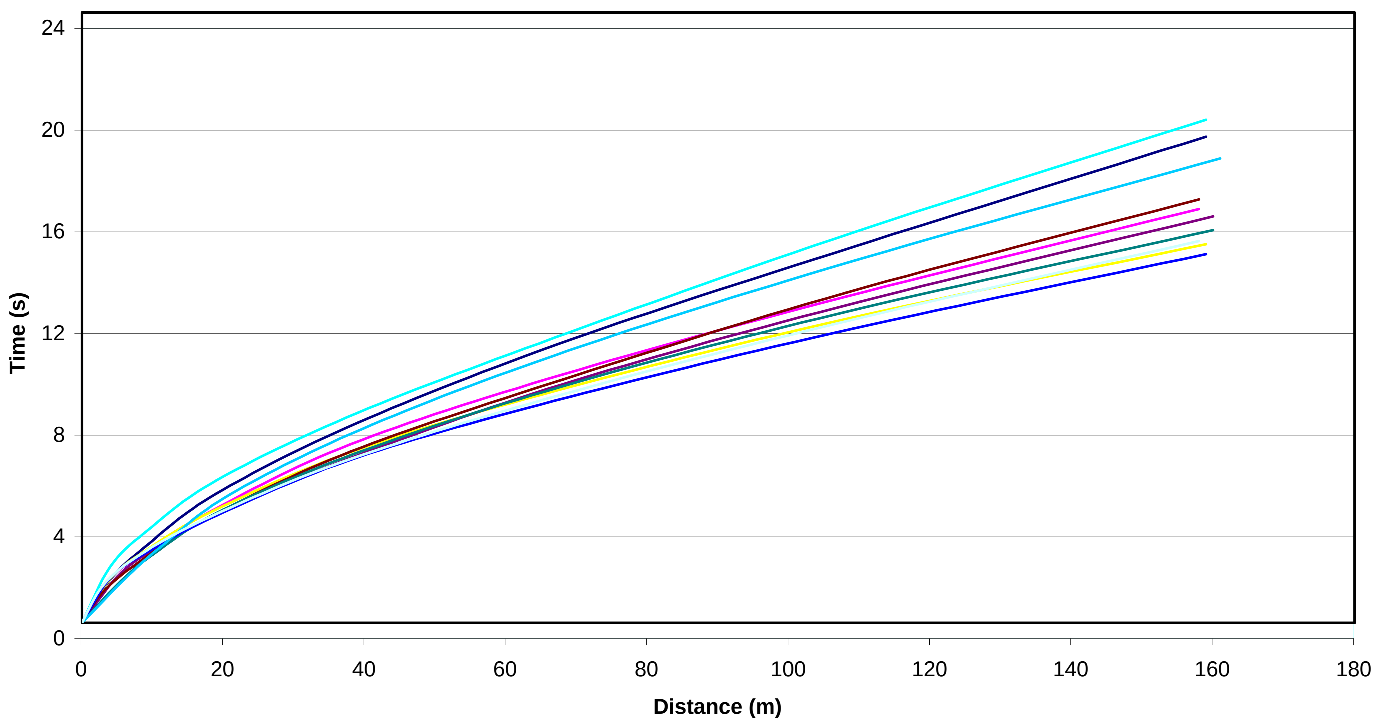


Dataset 251-260

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results

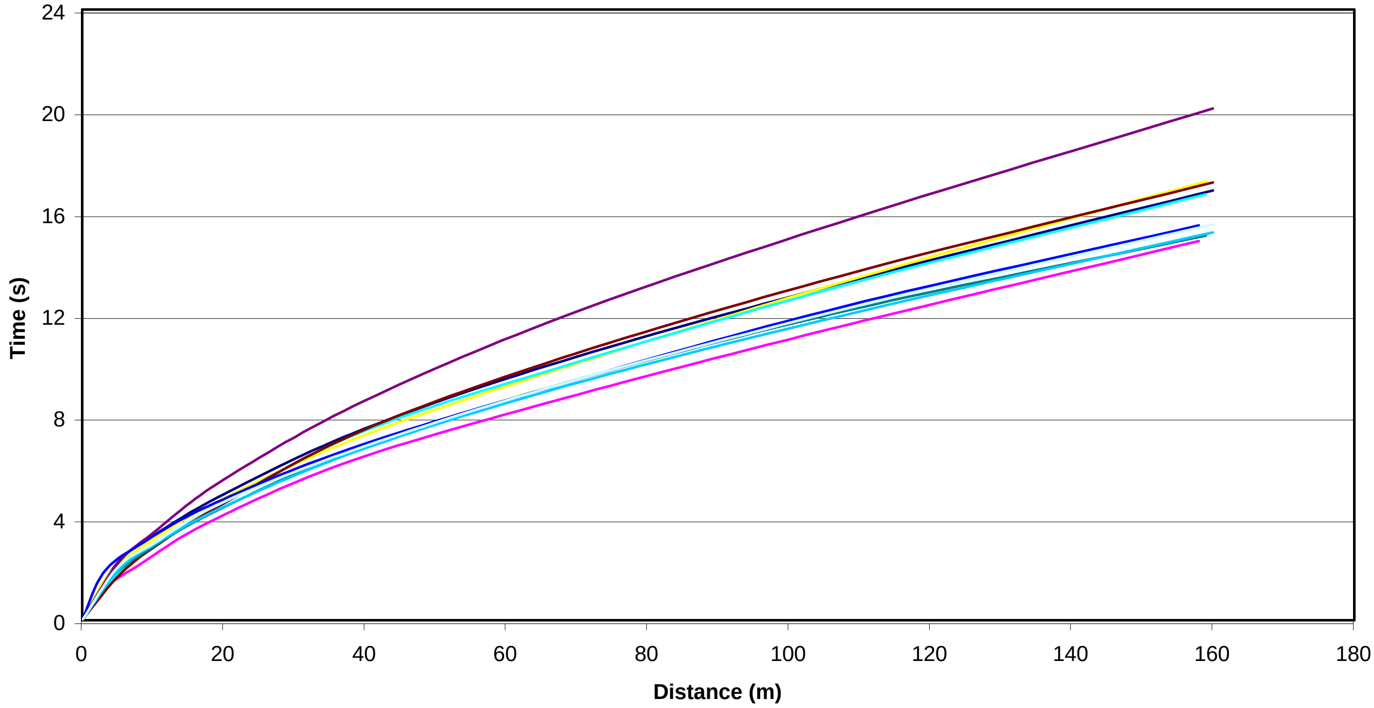


Dataset 261-270

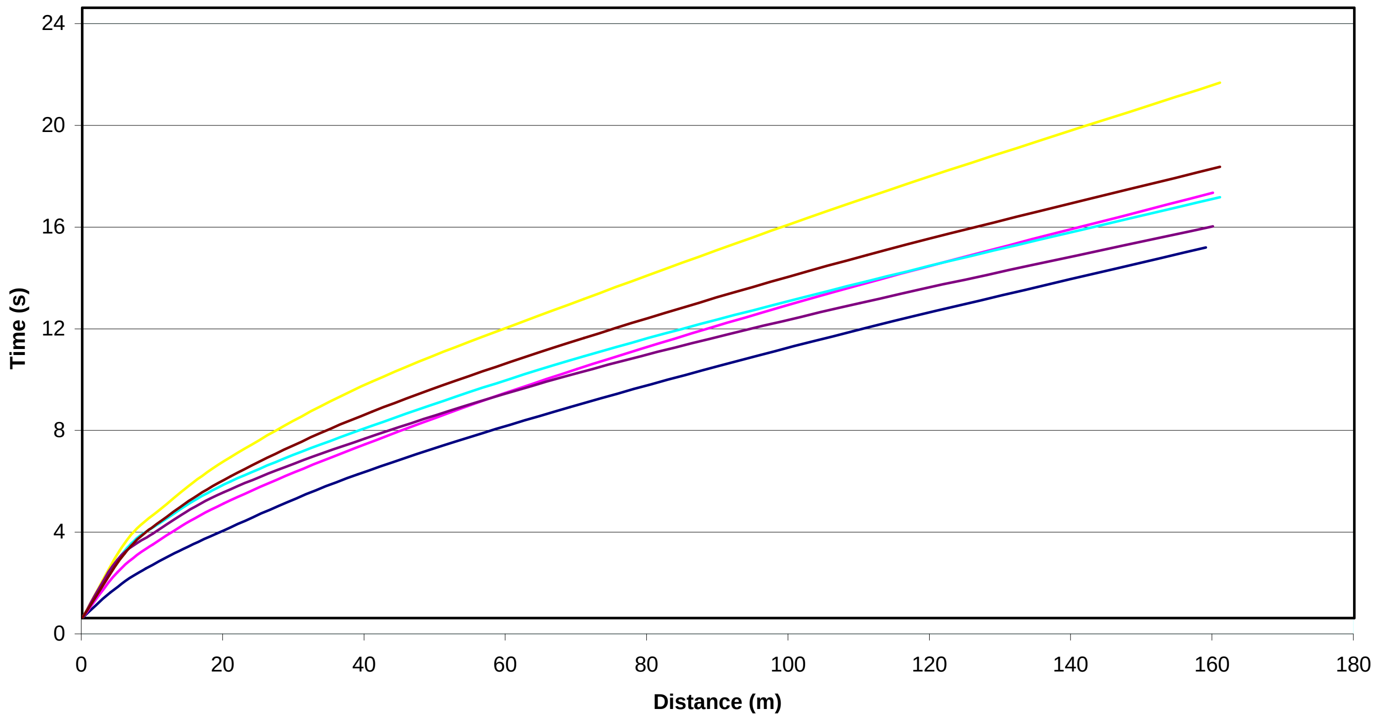


Dataset 271-280

Furstenburg Road / Pierre Ollemans Street intersection
Time distance survey results



Dataset 281-290



Dataset 291-296

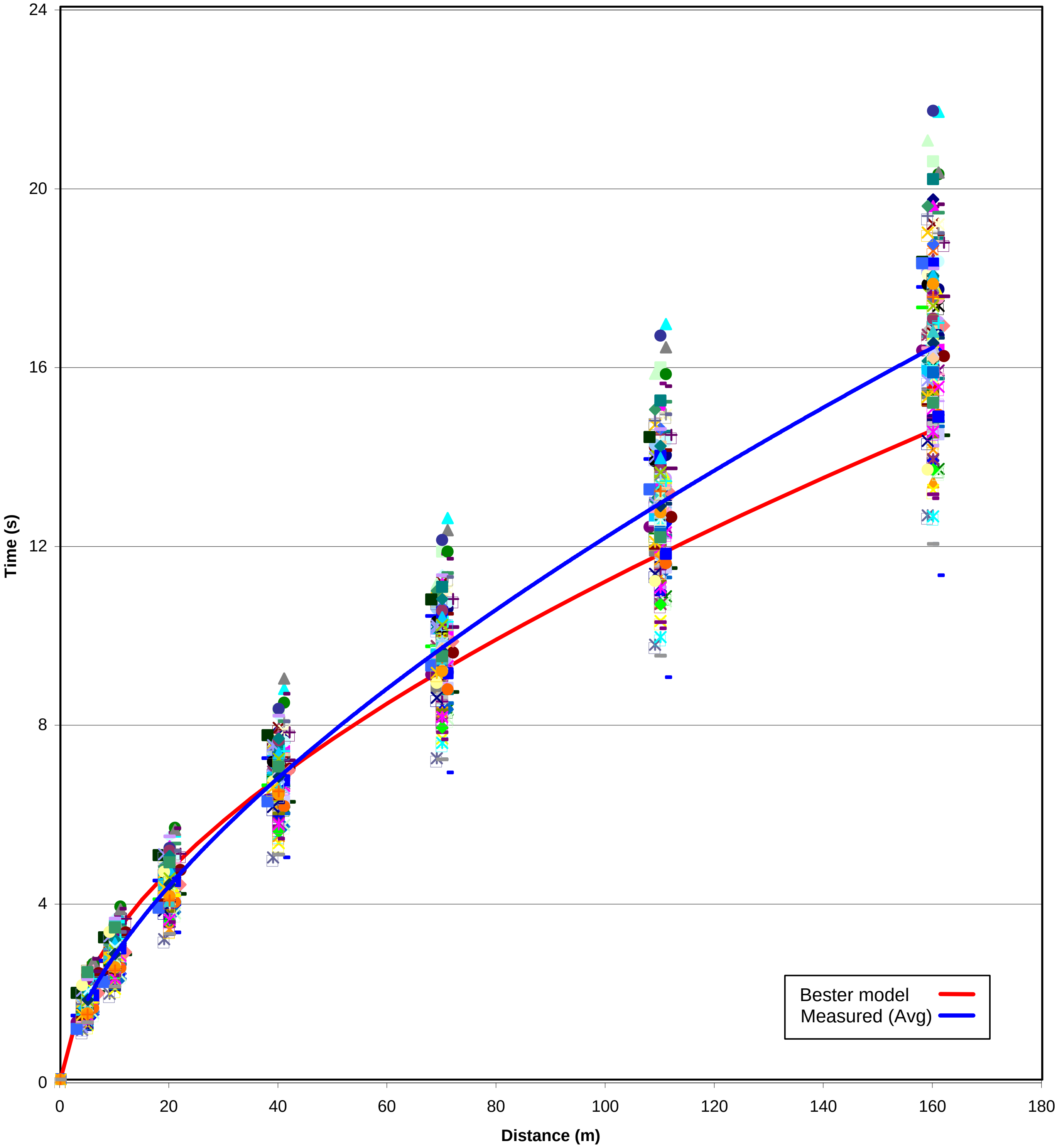
ANNEXURE E

Detailed results (graphs) of the

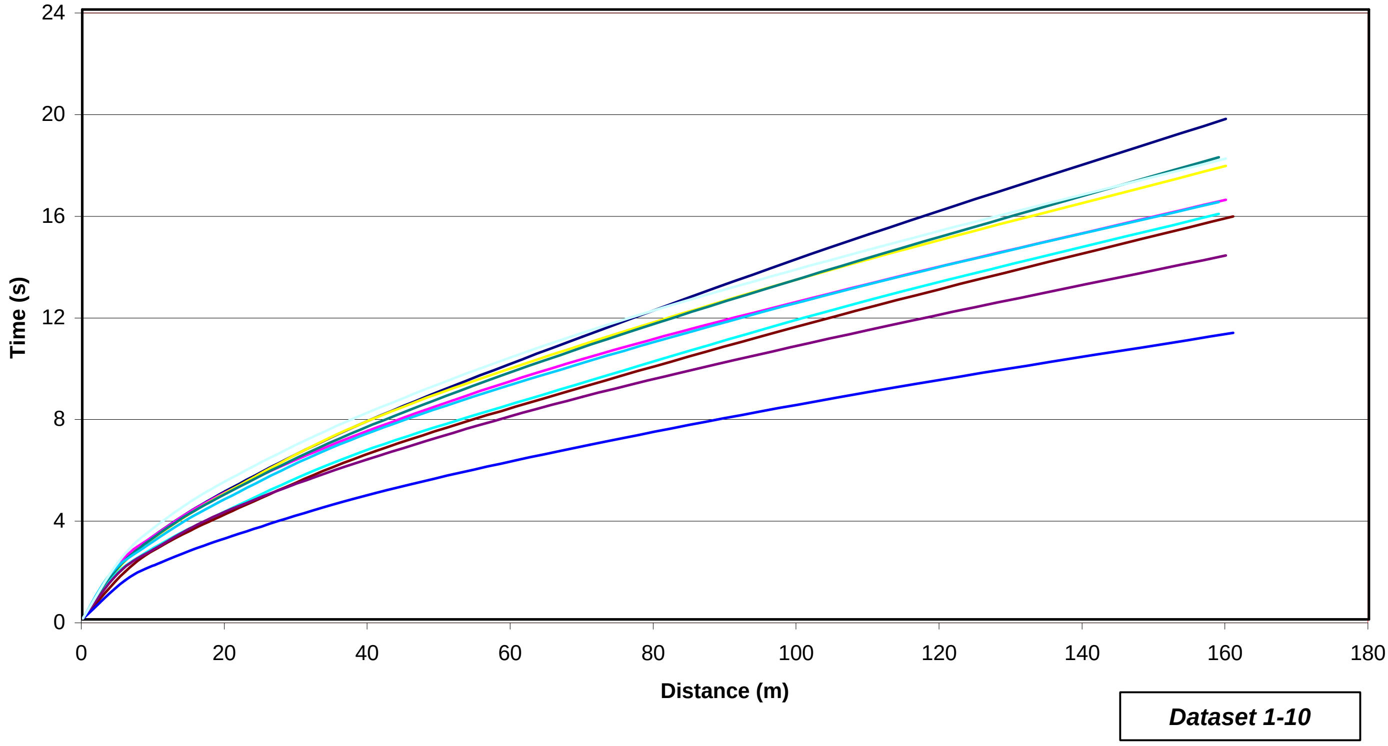
field surveys performed

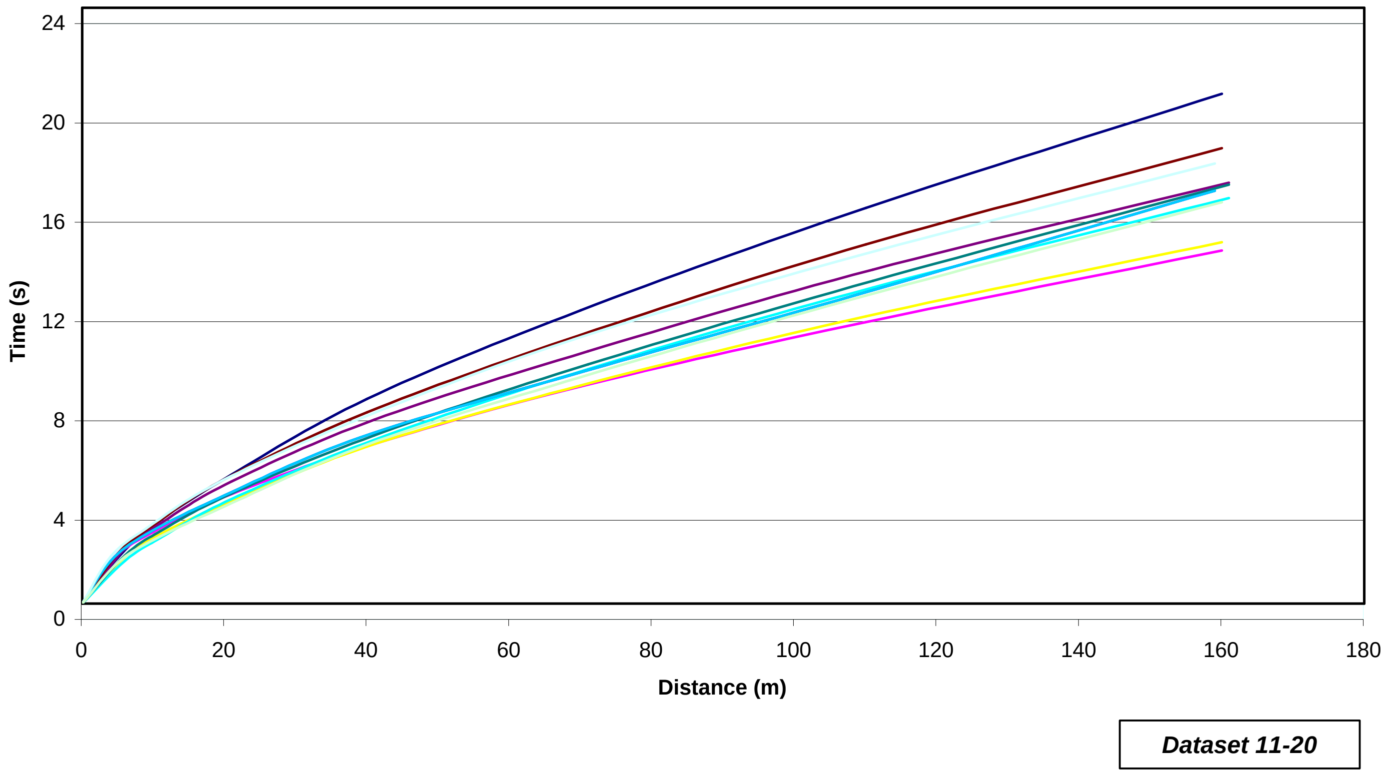
Benade Drive / Stals Road

Benade Drive / Stals Road intersection
Time distance survey results

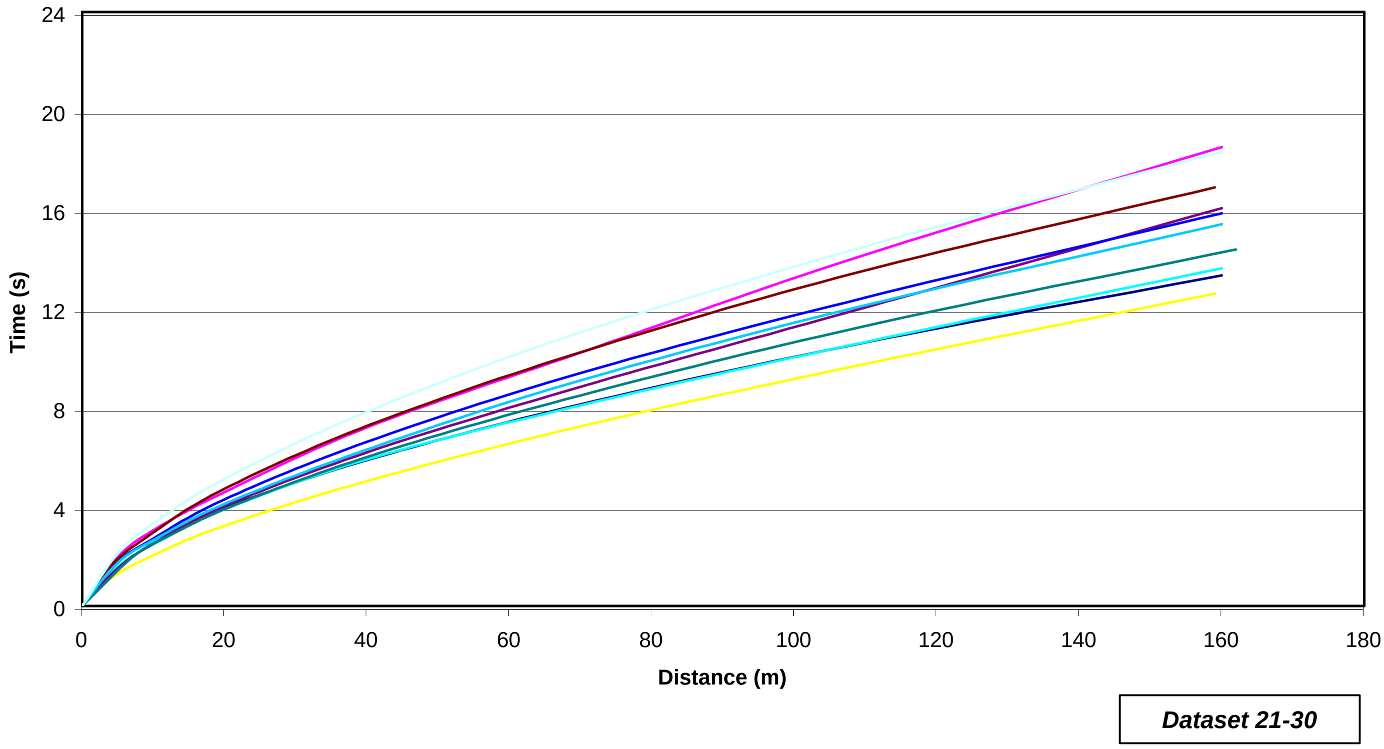


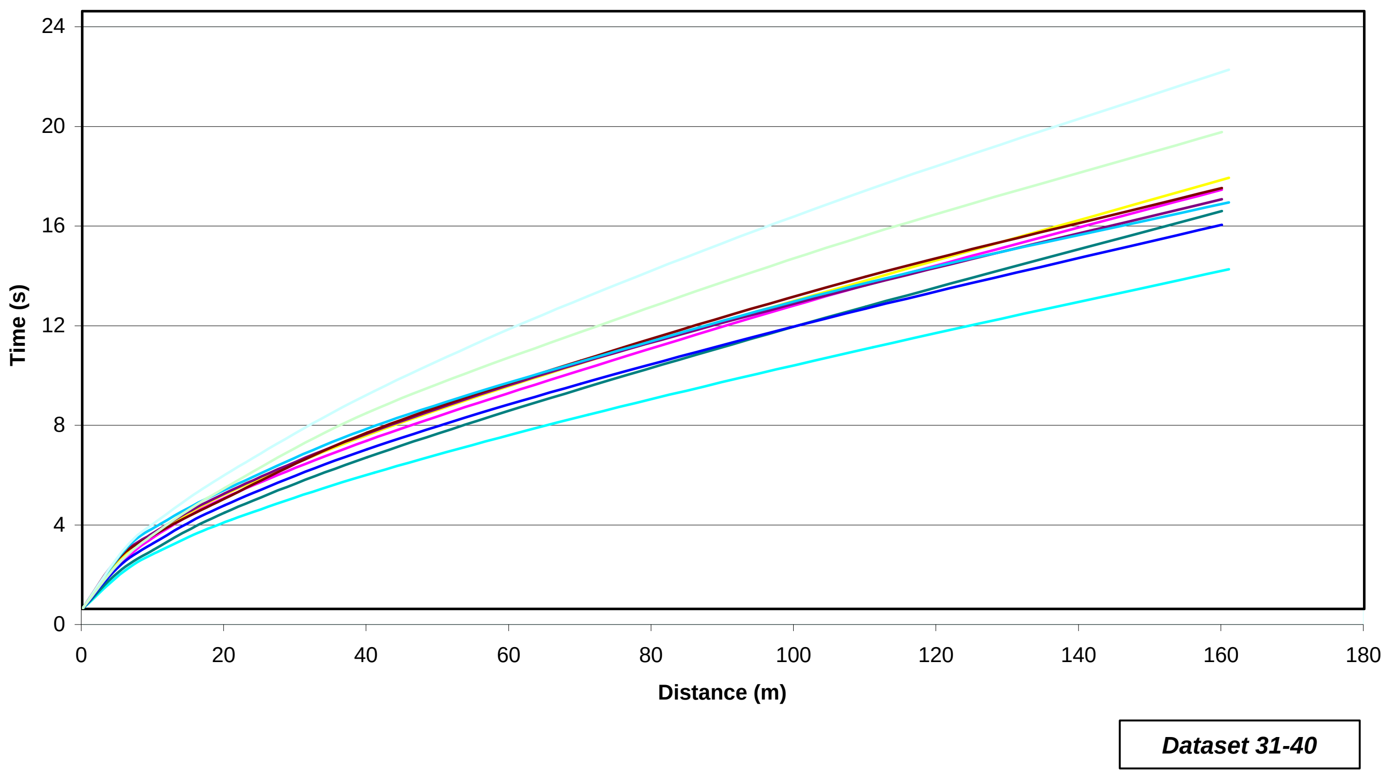
Benade Drive / Stals Road intersection
Time distance survey results



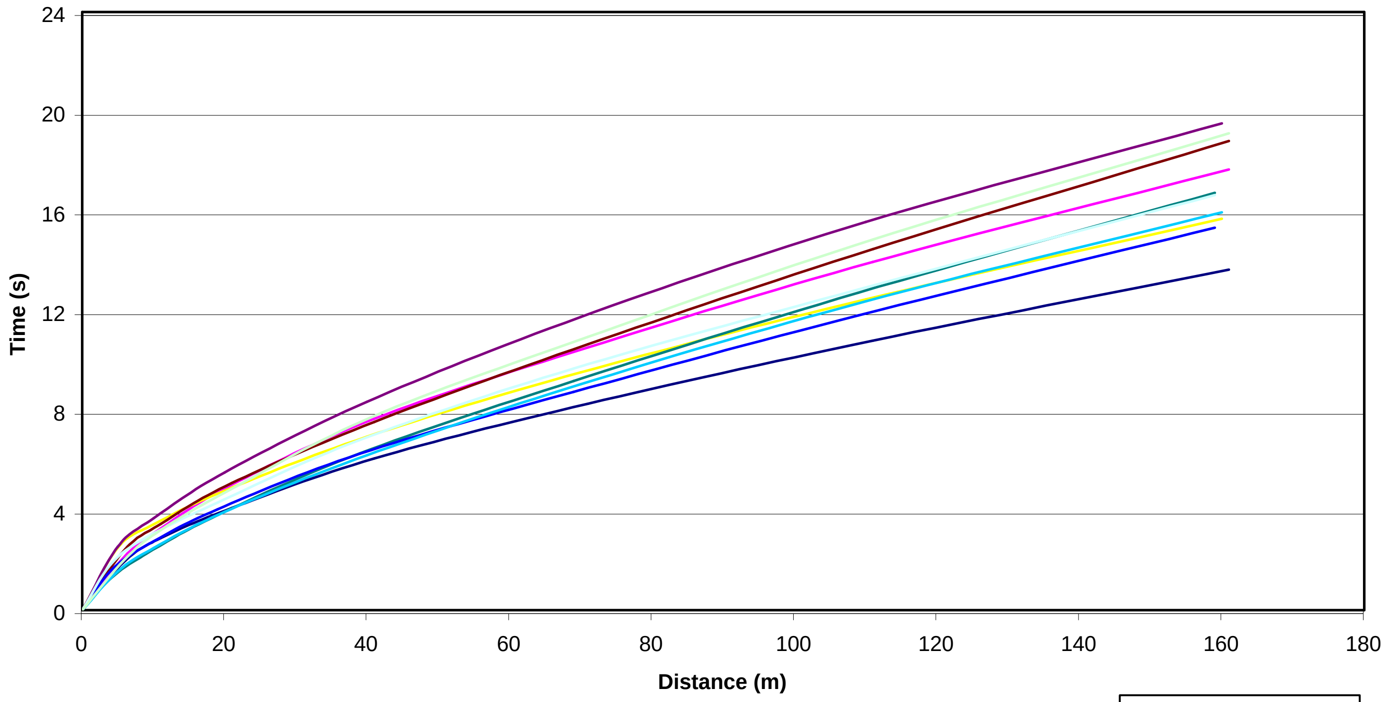


Benade Drive / Stals Road intersection
Time distance survey results

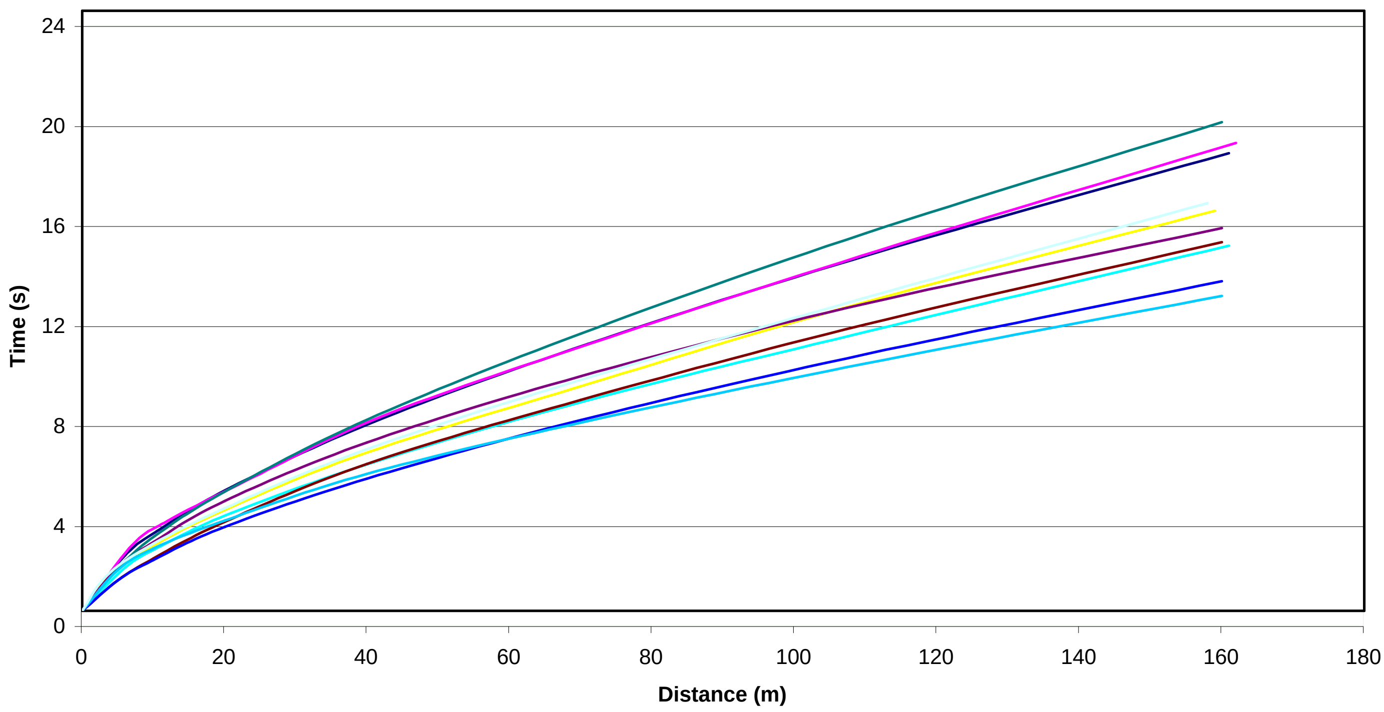




Benade Drive / Stals Road intersection
Time distance survey results

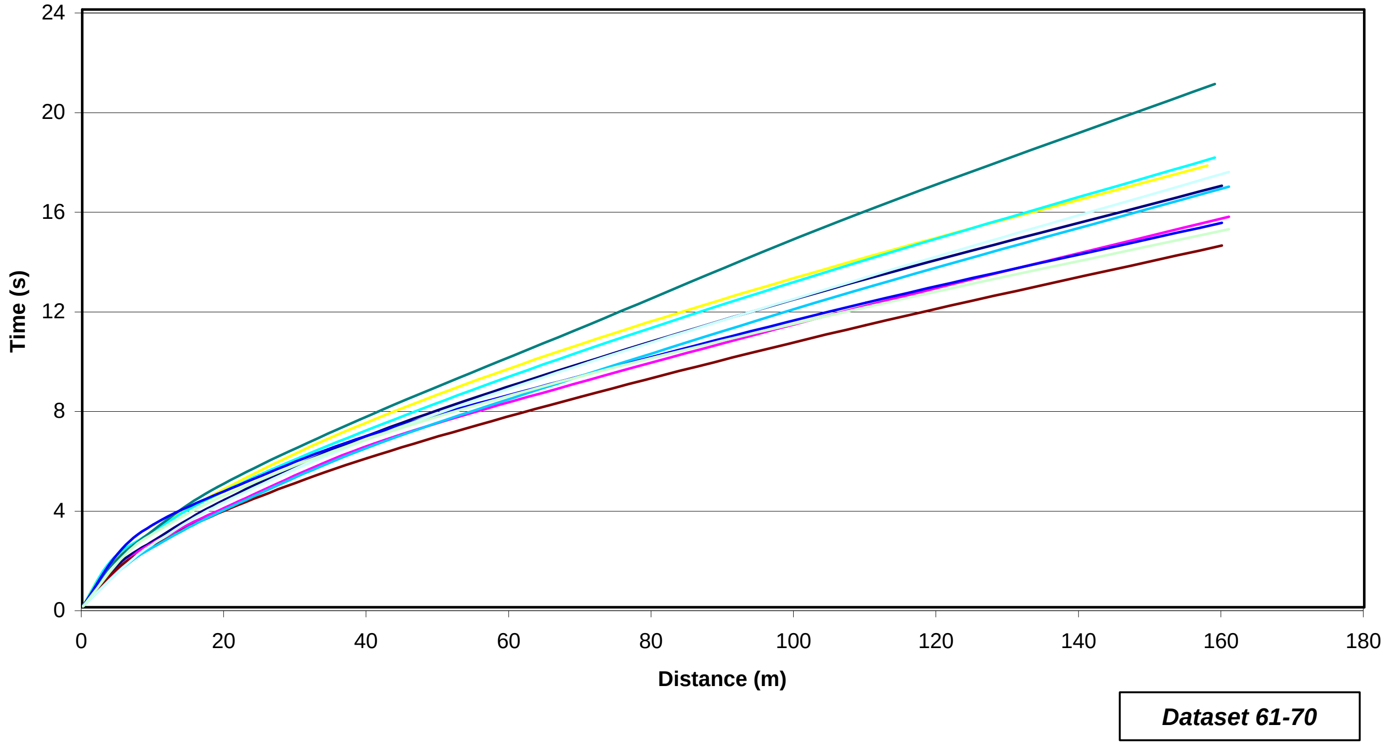


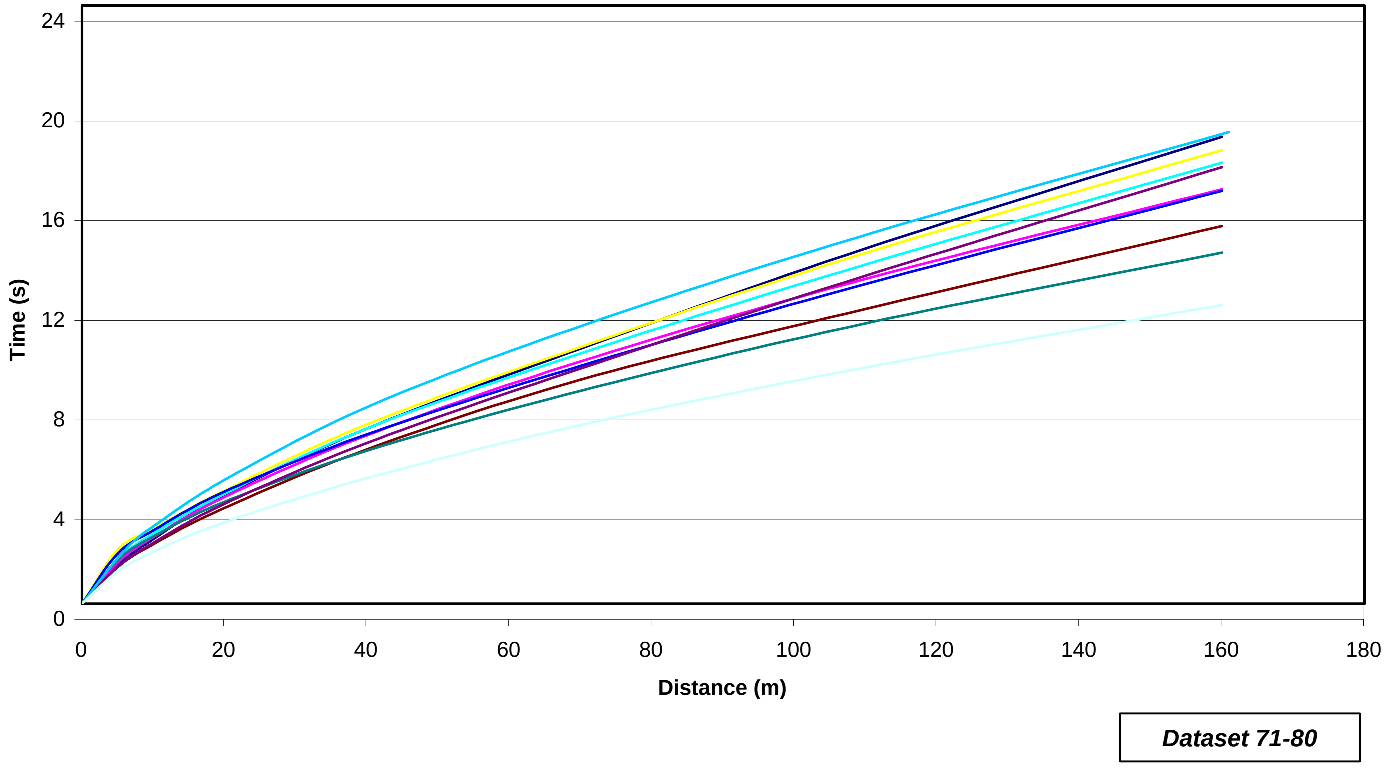
Dataset 41-50



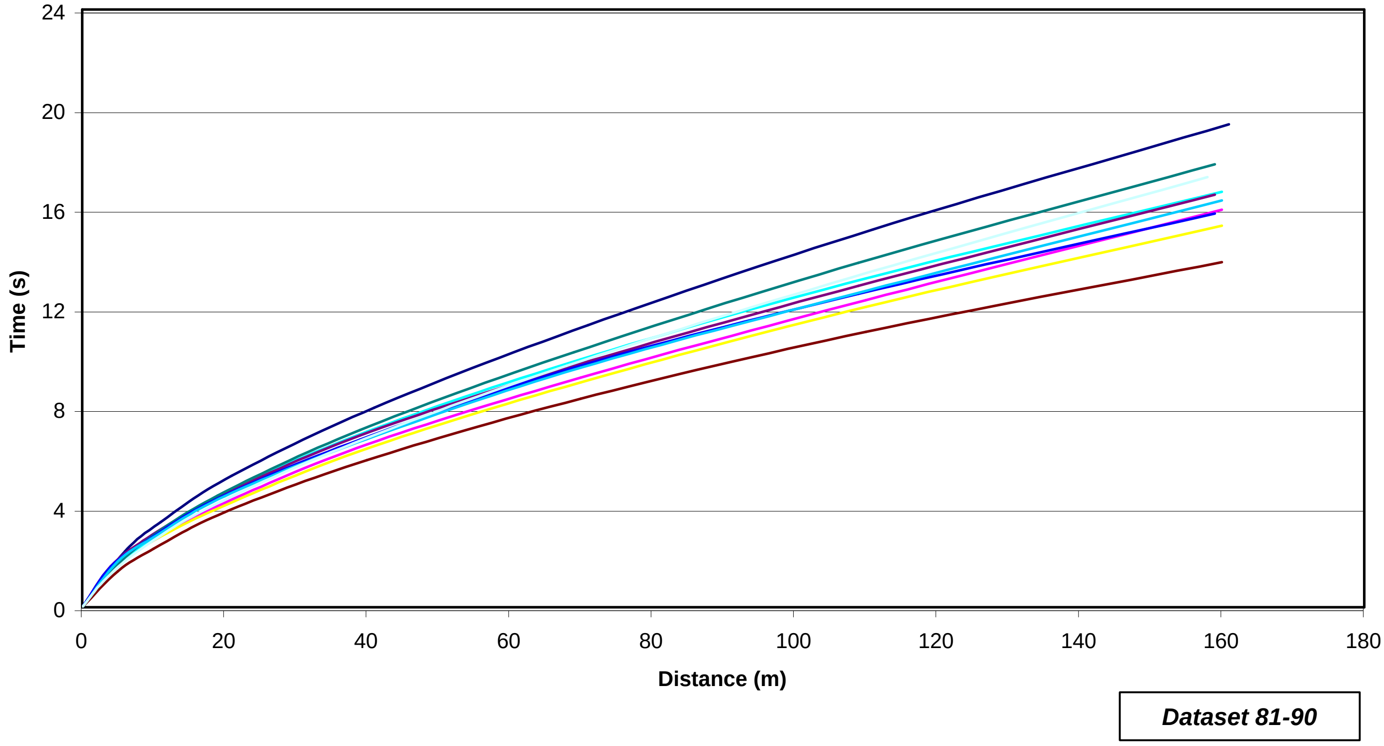
Dataset 51-60

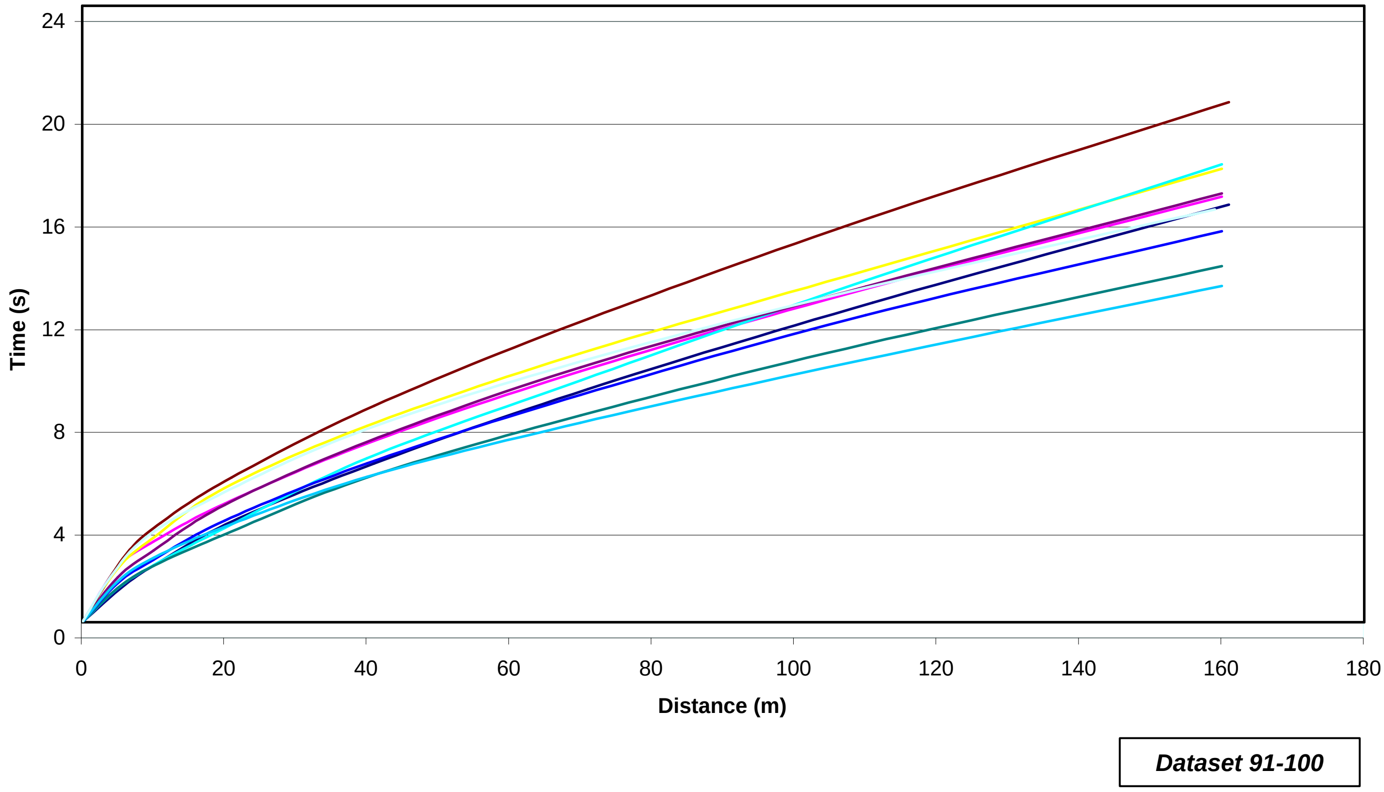
Benade Drive / Stals Road intersection
Time distance survey results



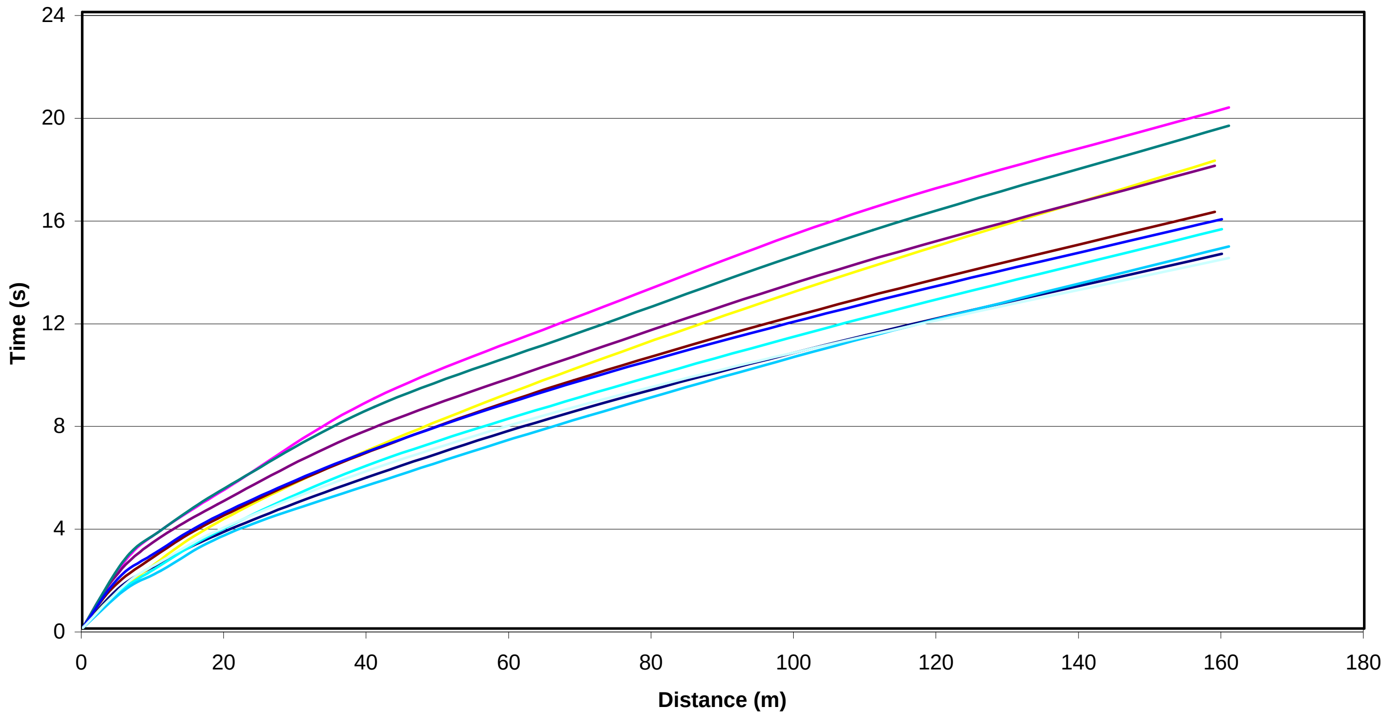


Benade Drive / Stals Road intersection
Time distance survey results

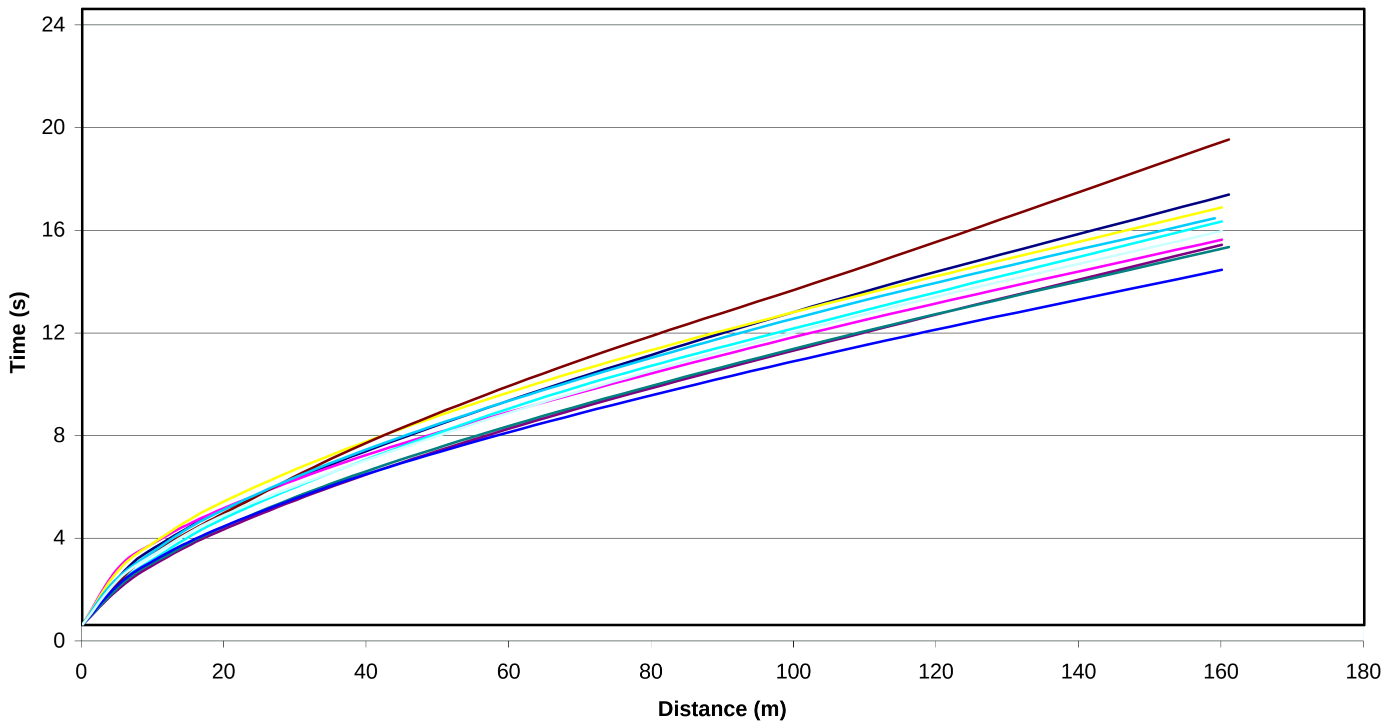




Benade Drive / Stals Road intersection
Time distance survey results

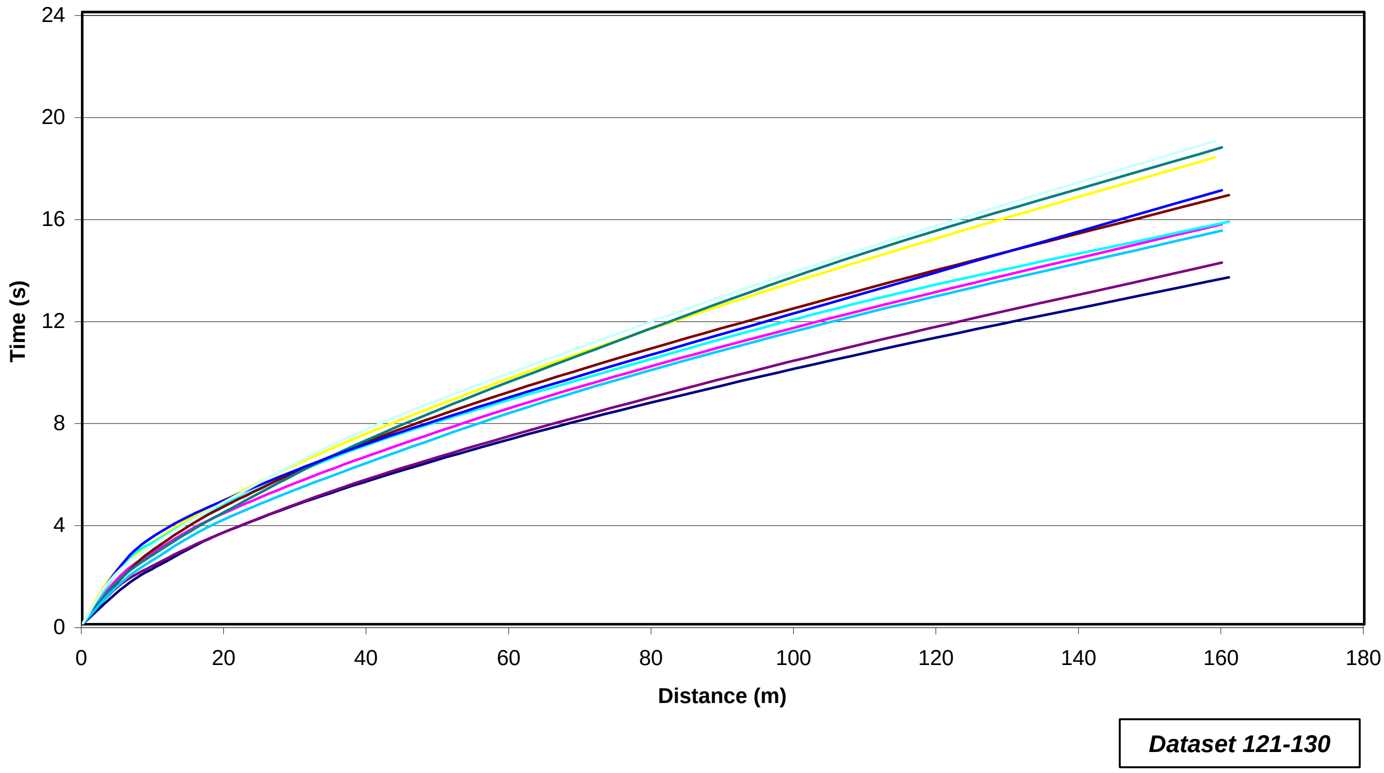


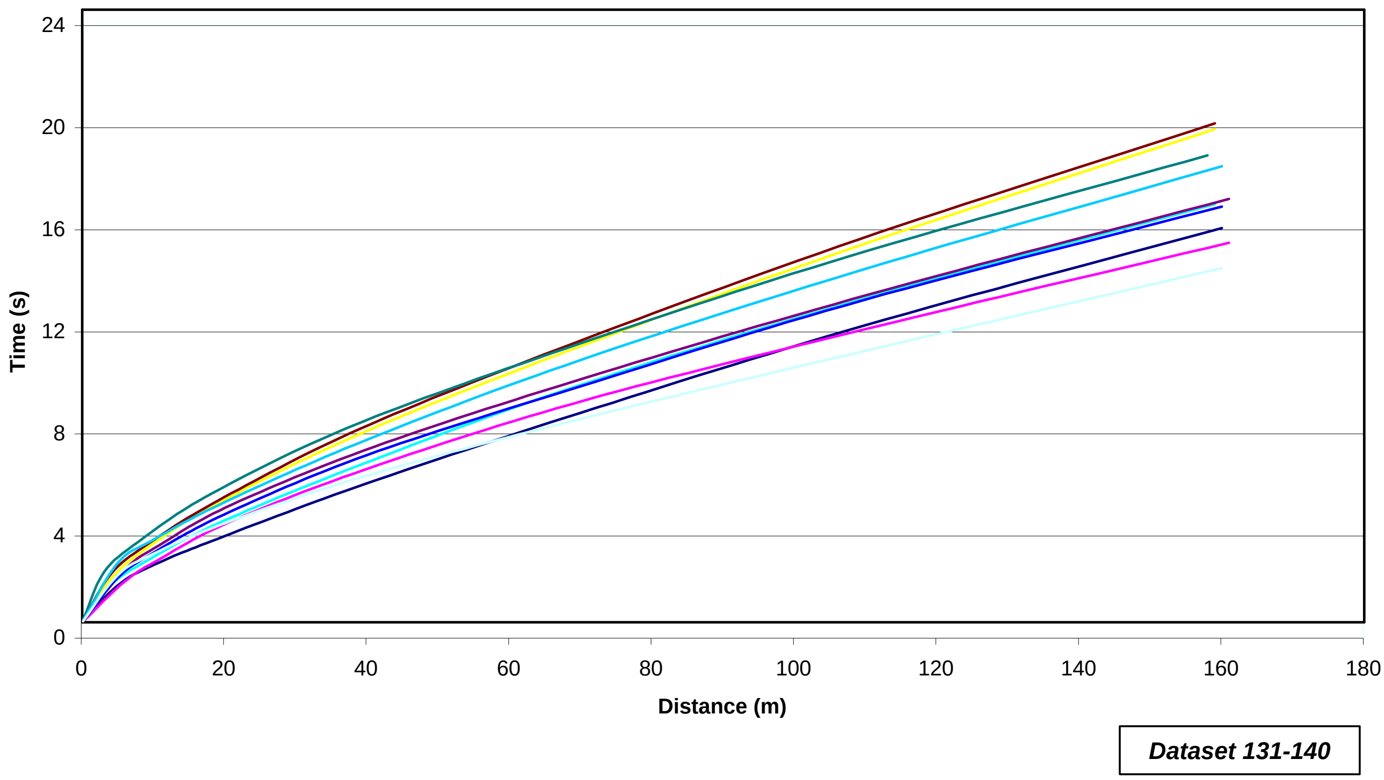
Dataset 101-110



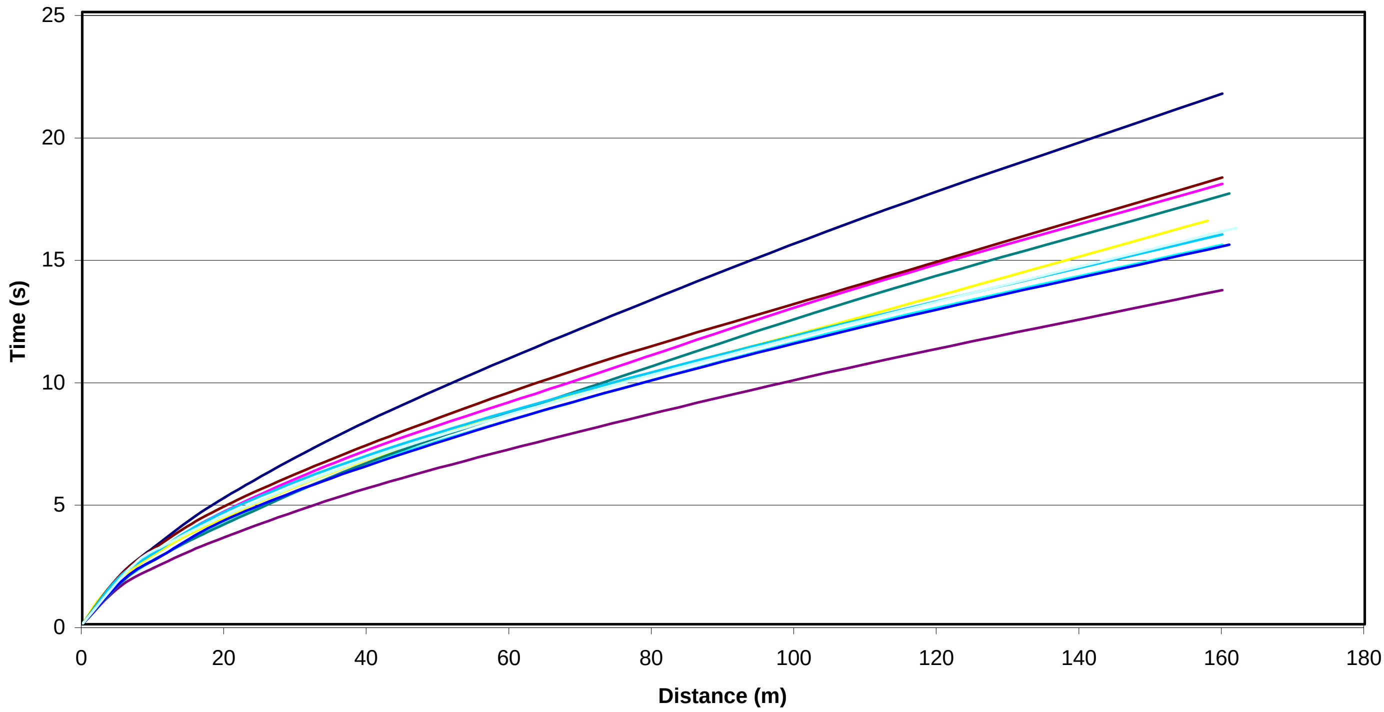
Dataset 111-120

Benade Drive / Stals Road intersection
Time distance survey results

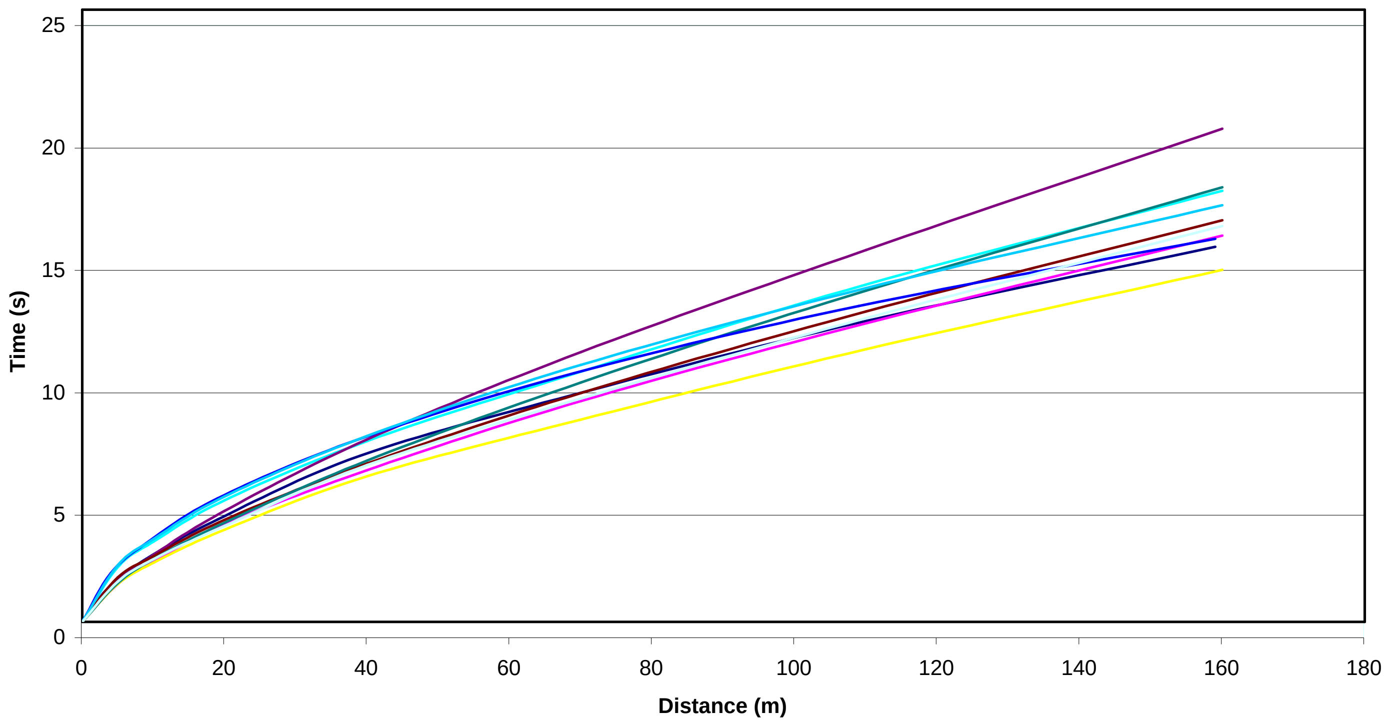




Benade Drive / Stals Road intersection
Time distance survey results

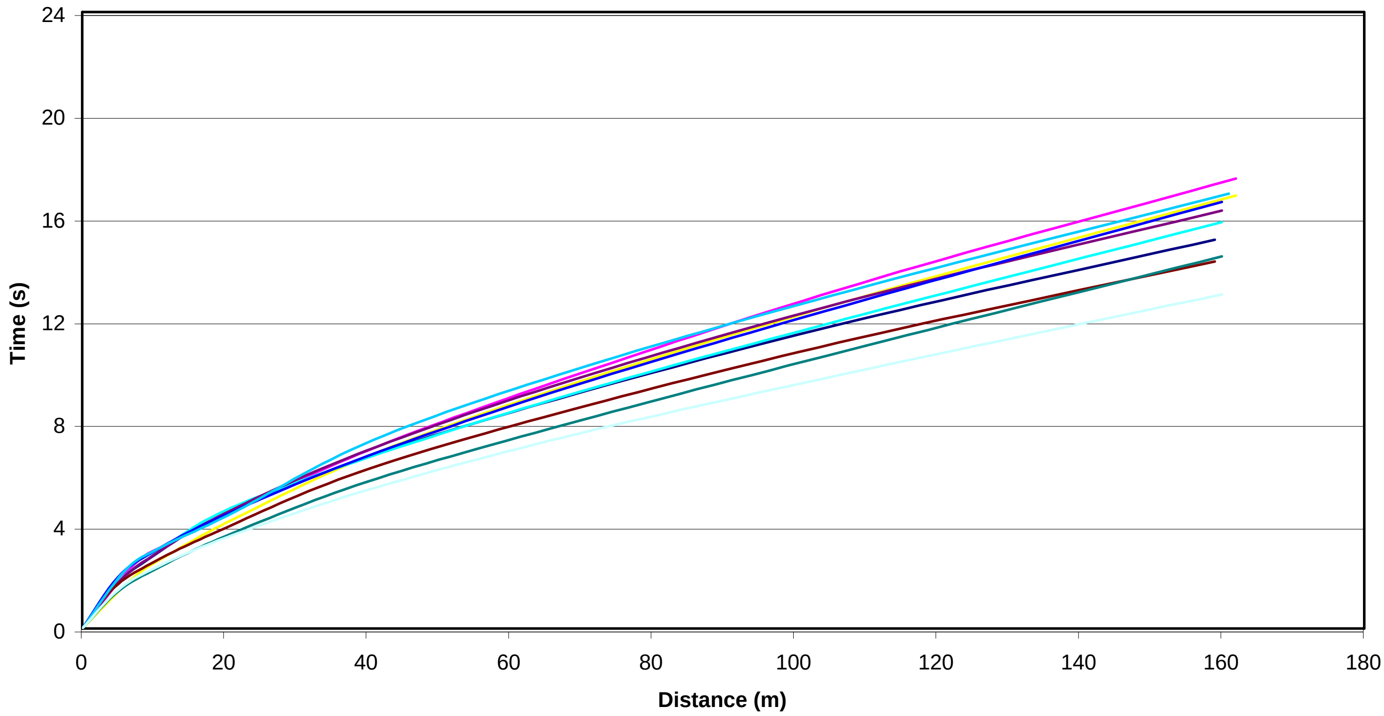


Dataset 141-150

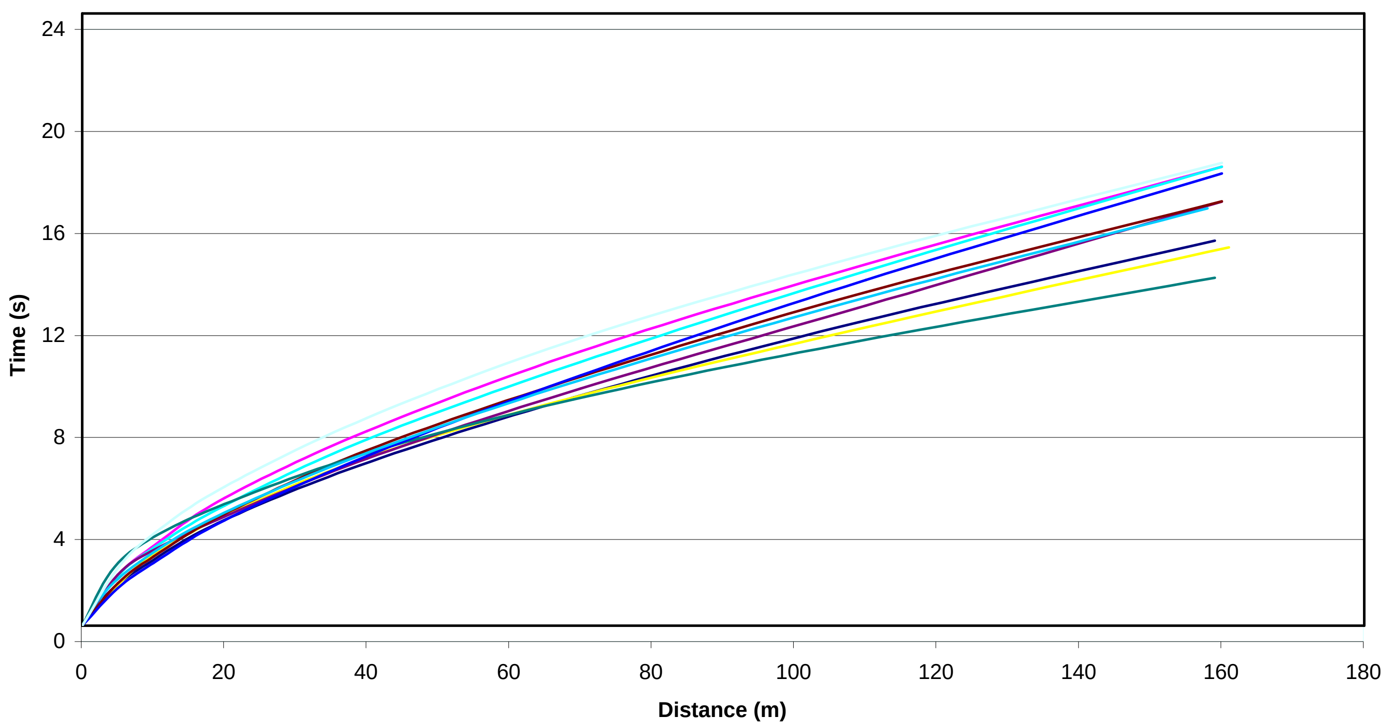


Dataset 151-160

Benade Drive / Stals Road intersection
Time distance survey results

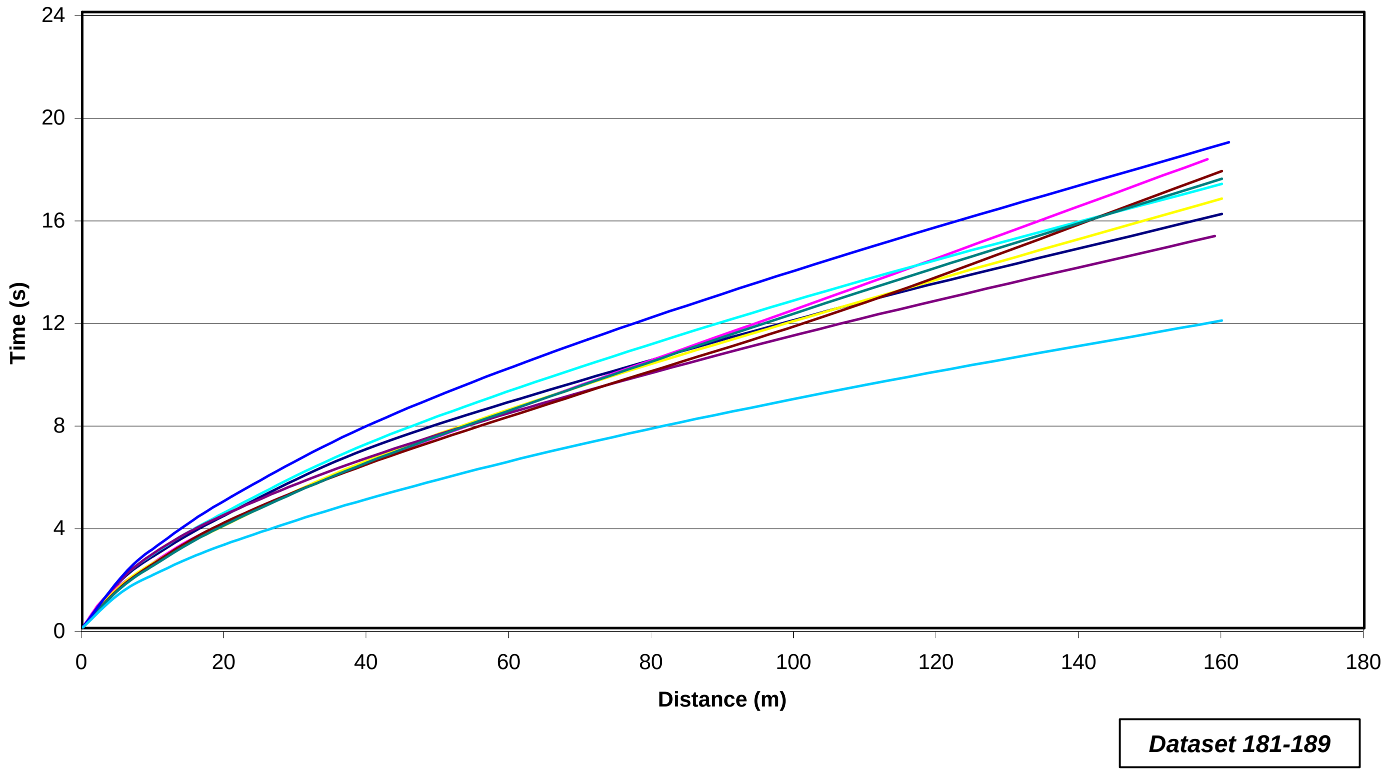


Dataset 161-170



Dataset 171-180

Benade Drive / Stals Road intersection
Time istance survey results



ANNEXURE F

Detailed statistical analysis calculations

Waverley Road / Whites Road

Waverley Road / Whites Road intersection: Time & distance survey
Standard deviation of speed measurements (Inductor loops)

Speed group from - to	Middle value sec	Number of observation	Percentage observations	Cumulative percentage	V	Nj	Vj	N	$N_j.(V_j-V)^2$	$(S)^2$	Standard Deviation
13.20 - 13.60	13.40	1	0.5	0.5	18.04	1	13.40	210	21.5		
13.60 - 14.00	13.80	2	1.0	1.4	18.04	2	13.80	210	35.9		
14.00 - 14.40	14.20	1	0.5	1.9	18.04	1	14.20	210	14.7		
14.40 - 14.80	14.60	2	1.0	2.9	18.04	2	14.60	210	23.6		
14.80 - 15.20	15.00	7	3.3	6.2	18.04	7	15.00	210	64.6		
15.20 - 15.60	15.40	9	4.3	10.5	18.04	9	15.40	210	62.6		
15.60 - 16.00	15.80	8	3.8	14.3	18.04	8	15.80	210	40.1		
16.00 - 16.40	16.20	15	7.1	21.4	18.04	15	16.20	210	50.7		
16.40 - 16.80	16.60	19	9.0	30.5	18.04	19	16.60	210	39.3		
16.80 - 17.20	17.00	21	10.0	40.5	18.04	21	17.00	210	22.6		
17.20 - 17.60	17.40	13	6.2	46.7	18.04	13	17.40	210	5.3		
17.60 - 18.00	17.80	12	5.7	52.4	18.04	12	17.80	210	0.7		
18.00 - 18.40	18.20	17	8.1	60.5	18.04	17	18.20	210	0.4		
18.40 - 18.80	18.60	12	5.7	66.2	18.04	12	18.60	210	3.8	**4.3**	**2.075**
18.80 - 19.20	19.00	12	5.7	71.9	18.04	12	19.00	210	11.1		
19.20 - 19.60	19.40	13	6.2	78.1	18.04	13	19.40	210	24.1		
19.60 - 20.00	19.80	11	5.2	83.3	18.04	11	19.80	210	34.1		
20.00 - 20.40	20.20	7	3.3	86.7	18.04	7	20.20	210	32.7		
20.40 - 20.80	20.60	8	3.8	90.5	18.04	8	20.60	210	52.5		
20.80 - 21.20	21.00	9	4.3	94.8	18.04	9	21.00	210	79.0		
21.20 - 21.60	21.40	2	1.0	95.7	18.04	2	21.40	210	22.6		
21.60 - 22.00	21.80	2	1.0	96.7	18.04	2	21.80	210	28.3		
22.00 - 22.40	22.20	0	0.0	96.7	18.04	0	22.20	210	0.0		
22.40 - 22.80	22.60	0	0.0	96.7	18.04	0	22.60	210	0.0		
22.80 - 23.20	23.00	1	0.5	97.1	18.04	1	23.00	210	24.6		
23.20 - 23.60	23.40	3	1.4	98.6	18.04	3	23.40	210	86.3		
23.60 - 24.00	23.80	0	0.0	98.6	18.04	0	23.80	210	0.0		
24.00 - 24.40	24.20	2	1.0	99.5	18.04	2	24.20	210	75.9		
24.40 - 24.80	24.60	1	0.5	100.0	18.04	1	24.60	210	43.1		
		210	100			210			900.3		

$$S^2 = \frac{?\ N_j \cdot (V_j - V)^2}{N - 1}$$

Waverley Road / Whites Road intersection: Time & distance survey
Standard deviation of speed measurements (Manually)

Speed group from - to	Middle value sec	Number of observation	Percentage observations	Cumulative percentage	V	Nj	Vj	N	$N_j.(V_j-V)^2$	$(S)^2$	Standard Deviation
13.60 - 14.00	13.80	1	1.5	1.5	17.17	1	13.80	67	11.3		
14.00 - 14.40	14.20	3	4.5	6.0	17.17	3	14.20	67	26.4		
14.40 - 14.80	14.60	2	3.0	9.0	17.17	2	14.60	67	13.2		
14.80 - 15.20	15.00	2	3.0	11.9	17.17	2	15.00	67	9.4		
15.20 - 15.60	15.40	4	6.0	17.9	17.17	4	15.40	67	12.5		
15.60 - 16.00	15.80	4	6.0	23.9	17.17	4	15.80	67	7.5		
16.00 - 16.40	16.20	8	11.9	35.8	17.17	8	16.20	67	7.5		
16.40 - 16.80	16.60	5	7.5	43.3	17.17	5	16.60	67	1.6		
16.80 - 17.20	17.00	7	10.4	53.7	17.17	7	17.00	67	0.2		
17.20 - 17.60	17.40	8	11.9	65.7	17.17	8	17.40	67	0.4		
17.60 - 18.00	17.80	6	9.0	74.6	17.17	6	17.80	67	2.4		
18.00 - 18.40	18.20	1	1.5	76.1	17.17	1	18.20	67	1.1	**3.2**	**1.777**
18.40 - 18.80	18.60	5	7.5	83.6	17.17	5	18.60	67	10.3		
18.80 - 19.20	19.00	1	1.5	85.1	17.17	1	19.00	67	3.4		
19.20 - 19.60	19.40	5	7.5	92.5	17.17	5	19.40	67	24.9		
19.60 - 20.00	19.80	1	1.5	94.0	17.17	1	19.80	67	6.9		
20.00 - 20.40	20.20	0	0.0	94.0	17.17	0	20.20	67	0.0		
20.40 - 20.80	20.60	0	0.0	94.0	17.17	0	20.60	67	0.0		
20.80 - 21.20	21.00	3	4.5	98.5	17.17	3	21.00	67	44.1		
21.20 - 21.60	21.40	0	0.0	98.5	17.17	0	21.40	67	0.0		
21.60 - 22.00	21.80	0	0.0	98.5	17.17	0	21.80	67	0.0		
22.00 - 22.40	22.20	1	1.5	100.0	17.17	1	22.20	67	25.3		
		67	100						208.4		

$$S^2 = \frac{?\ N_j \cdot (V_j - V)^2}{N - 1}$$

ANNEXURE G

Detailed statistical analysis calculations

Furstenburg Road / Pierre Ollemans Street

Furstenburg Road / Pierre Ollemans Street intersection: Time & distance survey
Standard deviation of speed measurements (Inductor loops)

Speed group from - to	Middle value sec	Number of observation	Percentage observations	Cumulative percentage	V	Nj	Vj	N	$N_j \cdot (V_j - V)^2$	$(S)^2$	Standard Deviation
12.00 - 12.40	12.20	0	0.0	0.0	17.0	0	12.20	296	0.0		
12.40 - 12.80	12.60	1	0.3	0.3	17.0	1	12.60	296	19.1		
12.80 - 13.20	13.00	3	1.0	1.4	17.0	3	13.00	296	47.2		
13.20 - 13.60	13.40	1	0.3	1.7	17.0	1	13.40	296	12.7		
13.60 - 14.00	13.80	4	1.4	3.0	17.0	4	13.80	296	40.1		
14.00 - 14.40	14.20	5	1.7	4.7	17.0	5	14.20	296	38.3		
14.40 - 14.80	14.60	10	3.4	8.1	17.0	10	14.60	296	56.1		
14.80 - 15.20	15.00	12	4.1	12.2	17.0	12	15.00	296	46.5		
15.20 - 15.60	15.40	24	8.1	20.3	17.0	24	15.40	296	59.0		
15.60 - 16.00	15.80	26	8.8	29.1	17.0	26	15.80	296	35.4		
16.00 - 16.40	16.20	26	8.8	37.8	17.0	26	16.20	296	15.3		
16.40 - 16.80	16.60	31	10.5	48.3	17.0	31	16.60	296	4.2		
16.80 - 17.20	17.00	35	11.8	60.1	17.0	35	17.00	296	0.0		
17.20 - 17.60	17.40	28	9.5	69.6	17.0	28	17.40	296	5.2		
17.60 - 18.00	17.80	22	7.4	77.0	17.0	22	17.80	296	15.2	**2.93861**	**1.7**
18.00 - 18.40	18.20	17	5.7	82.8	17.0	17	18.20	296	25.8		
18.40 - 18.80	18.60	12	4.1	86.8	17.0	12	18.60	296	32.0		
18.80 - 19.20	19.00	8	2.7	89.5	17.0	8	19.00	296	33.0		
19.20 - 19.60	19.40	8	2.7	92.2	17.0	8	19.40	296	47.3		
19.60 - 20.00	19.80	7	2.4	94.6	17.0	7	19.80	296	56.2		
20.00 - 20.40	20.20	6	2.0	96.6	17.0	6	20.20	296	62.7		
20.40 - 20.80	20.60	1	0.3	97.0	17.0	1	20.60	296	13.2		
20.80 - 21.20	21.00	3	1.0	98.0	17.0	3	21.00	296	48.8		
21.20 - 21.60	21.40	2	0.7	98.6	17.0	2	21.40	296	39.3		
21.60 - 22.00	21.80	1	0.3	99.0	17.0	1	21.80	296	23.4		
22.00 - 22.40	22.20	1	0.3	99.3	17.0	1	22.20	296	27.4		
22.40 - 22.80	22.60	2	0.7	100.0	17.0	2	22.60	296	63.4		
22.80 - 23.20	23.00	0	0.0	100.0	17.0	0	23.00	296	0.0		
23.20 - 23.60	23.40	0	0.0	100.0	17.0	0	23.40	296	0.0		
23.60 - 24.00	23.80	0	0.0	100.0	17.0	0	23.80	296	0.0		
		296							**866.9**		

$$S^2 = \frac{?\ N_j \cdot (V_j - V)^2}{N - 1}$$

Furstenburg Road / Pierre Ollemans Street intersection: Time & distance survey
Standard deviation of speed measurements (Manually)

Speed group from - to	Middle value sec	Number of observation	Percentage observations	Cumulative percentage	V	Nj	Vj	N	$N_j.(V_j-V)^2$	$(S)^2$	Standard Deviation
11.80 - 12.20	12.00	1	1.7	1.7	15.5	1	12.00	60	12.3		
12.20 - 12.60	12.40	1	1.7	3.3	15.5	1	12.40	60	9.6		
12.60 - 13.00	12.80	2	3.3	6.7	15.5	2	12.80	60	14.6		
13.00 - 13.40	13.20	2	3.3	10.0	15.5	2	13.20	60	10.6		
13.40 - 13.80	13.60	2	3.3	13.3	15.5	2	13.60	60	7.2		
13.80 - 14.20	14.00	2	3.3	16.7	15.5	2	14.00	60	4.5		
14.20 - 14.60	14.40	4	6.7	23.3	15.5	4	14.40	60	4.8		
14.60 - 15.00	14.80	7	11.7	35.0	15.5	7	14.80	60	3.4		
15.00 - 15.40	15.20	6	10.0	45.0	15.5	6	15.20	60	0.5		
15.40 - 15.80	15.60	10	16.7	61.7	15.5	10	15.60	60	0.1	**2.287**	**1.5**
15.80 - 16.20	16.00	7	11.7	73.3	15.5	7	16.00	60	1.8		
16.20 - 16.60	16.40	2	3.3	76.7	15.5	2	16.40	60	1.6		
16.60 - 17.00	16.80	5	8.3	85.0	15.5	5	16.80	60	8.4		
17.00 - 17.40	17.20	2	3.3	88.3	15.5	2	17.20	60	5.8		
17.40 - 17.80	17.60	2	3.3	91.7	15.5	2	17.60	60	8.8		
17.80 - 18.20	18.00	3	5.0	96.7	15.5	3	18.00	60	18.7		
18.20 - 18.60	18.40	1	1.7	98.3	15.5	1	18.40	60	8.4		
18.60 - 19.00	18.80	0	0.0	98.3	15.5	0	18.80	60	0.0		
19.00 - 19.40	19.20	1	1.7	100.0	15.5	1	19.20	60	13.7		
19.40 - 19.80	19.60	0	0.0	100.0	15.5	0	19.60	60	0.0		
		60	**100.0**			**60**			**134.9**		

$$S^2 = \frac{?\ N_j \cdot (V_j - V)^2}{N - 1}$$

ANNEXURE H

Detailed functional boundary criteria calculations (60km/h)

S_{func1}: With Queue – Straight deceleration movement Queue = 30m for Right turn downstream from main road and left turn where access control is applicable

Perception Reaction Time	1.5	seconds
Speed	60	km/h
Interval	0.1	
Deceleration lateral (a_{lat})	-1.2	m/s^2
Deceleration straight (a_{str})	-2.25	m/s^2

Initial Speed Start lateral u (m/s)	End Speed V (m/s)	Deceleration during lateral a (m/s2)	Distance lateral (m)	Initial Speed Start Straight m/s^2	Deceleration during straight a $(m/s)^2$	Perception-reaction distance v*	Distance during straight (m) $s=v^* + (v^2-u^2/2a)$	Distance during lateral (m)	Queue	Total Distance (m)
u=Design speed/3.6	v=Design speed/3.6	a_{lat}	d_{lat}	$v= (u^2 + 2a_{lat}*d_{lat})^{0.5}$	a_{lat}	(u*perseption-reaction time)	d_{str}	d_{lat}	d_{queue}	$s_{tot}=d_{str} + d_{lat} + d_{queue}$
16.67	16.67	-1.20	53.00	12.27	-2.25	25.00	-3	53	30	**80**

S_{func2}: With Queue – Lateral deceleration maneuver

Perception Reaction Time	1.5	seconds
Speed	60	km/h
Interval	0.1	
Deceleration (a)	-2.25	m/s^2

Radius R (m)	Initial Speed U (m/s) u=Design speed/3.6	End Speed V (km/h) $V=17.34R^{0.26057}$	End Speed V (m/s) V = v /3.6	Deceleration a $(m/s)^2$	Perception-reaction distance v* (u*perseption-reaction time)	Distance (m) $s=v^* + (v^2-u^2/2a)$	Queue m d_{queue}	Total Distance(m) $s_{tot}=s + d_{queue}$
0.0	16.67	0.00	0.00	-2.25	25.00	87	30	117

S_{func3}: No Queue - Straight deceleration movement

Perception Reaction Time	1.5	seconds
Design Speed	60	km/h
Interval	1	
Deceleration	-1.5	m/s^2

Radius R (m)	Initial Speed u (m/s) u=Design speed/3.6	End Speed v (km/h) $V=17.34R^{0.26057}$	End Speed v (m/s) V=v/3.6	Deceleration Rate a (m/s)	Perception-reaction distance v* (m) (u*perseption-reaction time)	Distance (m) $s=v^* + (v^2-u^2/2a)$
1.0	16.67	17.34	4.82	-1.5	25.00	110
2.0	16.67	20.77	5.77	-1.5	25.00	106
3.0	16.67	23.09	6.41	-1.5	25.00	104
4.0	16.67	24.88	6.91	-1.5	25.00	102
5.0	16.67	26.37	7.33	-1.5	25.00	100
6.0	16.67	27.66	7.68	-1.5	25.00	98
7.0	16.67	28.79	8.00	-1.5	25.00	96
8.0	16.67	29.81	8.28	-1.5	25.00	95
9.0	16.67	30.74	8.54	-1.5	25.00	93
10.0	16.67	31.60	8.78	-1.5	25.00	92
11.0	16.67	32.39	9.00	-1.5	25.00	91
12.0	16.67	33.13	9.20	-1.5	25.00	89
13.0	16.67	33.83	9.40	-1.5	25.00	88
14.0	16.67	34.49	9.58	-1.5	25.00	87
15.0	16.67	35.12	9.75	-1.5	25.00	86
16.0	16.67	35.71	9.92	-1.5	25.00	85
17.0	16.67	36.28	10.08	-1.5	25.00	84
18.0	16.67	36.82	10.23	-1.5	25.00	83
19.0	16.67	37.35	10.37	-1.5	25.00	82
20.0	16.67	37.85	10.51	-1.5	25.00	81
21.0	16.67	38.33	10.65	-1.5	25.00	80
22.0	16.67	38.80	10.78	-1.5	25.00	79
23.0	16.67	39.25	10.90	-1.5	25.00	78
24.0	16.67	39.69	11.03	-1.5	25.00	77
25.0	16.67	40.12	11.14	-1.5	25.00	76
26.0	16.67	40.53	11.26	-1.5	25.00	75
27.0	16.67	40.93	11.37	-1.5	25.00	75
28.0	16.67	41.32	11.48	-1.5	25.00	74
29.0	16.67	41.70	11.58	-1.5	25.00	73
30.0	16.67	42.07	11.69	-1.5	25.00	72
31.0	16.67	42.43	11.79	-1.5	25.00	71
32.0	16.67	42.78	11.88	-1.5	25.00	71
33.0	16.67	43.12	11.98	-1.5	25.00	70
34.0	16.67	43.46	12.07	-1.5	25.00	69
35.0	16.67	43.79	12.16	-1.5	25.00	68
36.0	16.67	44.11	12.25	-1.5	25.00	68
37.0	16.67	44.43	12.34	-1.5	25.00	67
38.0	16.67	44.74	12.43	-1.5	25.00	66
39.0	16.67	45.04	12.51	-1.5	25.00	65
40.0	16.67	45.34	12.59	-1.5	25.00	65

S_{func4}: No Queue – Lateral deceleration maneuver

Perception Reaction Time	1.5	seconds
Design Speed	60	km/h
Interval	1	
Deceleration straight (a_{str})	-1.5	m/s²
Deceleration lateral (a_{lat})	-1.2	m/s²

Radius R	Initial Speed U (m/s) (start lateral) u=Design speed/3.6	End Speed V (km/h) at BC $V=17.34R^{0.26057}$	End Speed V (m/s) at BC V=v/3.6	Distance lateral (m) d_{lat}	Start Speed at end lateral interval (m/s) $v=(u^2+2ad_{lat})^{0.5}$	Deceleration a (m/s) lateral a_{lat}	Deceleration a (m/s) straight a_{str}	Distance straight (m) d_{str}	Perception-reaction distance v* (u*perseption-reaction time)	Total distance (m) $s=v^*+d_{lat}+d_{str}$
1.0	16.67	17.34	4.82	53.00	12.27	-1.2	-1.5	42	25.00	120
2.0	16.67	20.77	5.77	53.00	12.27	-1.2	-1.5	39	25.00	117
3.0	16.67	23.09	6.41	53.00	12.27	-1.2	-1.5	36	25.00	114
4.0	16.67	24.88	6.91	53.00	12.27	-1.2	-1.5	34	25.00	112
5.0	16.67	26.37	7.33	53.00	12.27	-1.2	-1.5	32	25.00	110
6.0	16.67	27.66	7.68	53.00	12.27	-1.2	-1.5	31	25.00	109
7.0	16.67	28.79	8.00	53.00	12.27	-1.2	-1.5	29	25.00	107
8.0	16.67	29.81	8.28	53.00	12.27	-1.2	-1.5	27	25.00	105
9.0	16.67	30.74	8.54	53.00	12.27	-1.2	-1.5	26	25.00	104
10.0	16.67	31.60	8.78	53.00	12.27	-1.2	-1.5	25	25.00	103
11.0	16.67	32.39	9.00	53.00	12.27	-1.2	-1.5	23	25.00	101
12.0	16.67	33.13	9.20	53.00	12.27	-1.2	-1.5	22	25.00	100
13.0	16.67	33.83	9.40	53.00	12.27	-1.2	-1.5	21	25.00	99
14.0	16.67	34.49	9.58	53.00	12.27	-1.2	-1.5	20	25.00	98
15.0	16.67	35.12	9.75	53.00	12.27	-1.2	-1.5	18	25.00	96
16.0	16.67	35.71	9.92	53.00	12.27	-1.2	-1.5	17	25.00	95
17.0	16.67	36.28	10.08	53.00	12.27	-1.2	-1.5	16	25.00	94
18.0	16.67	36.82	10.23	53.00	12.27	-1.2	-1.5	15	25.00	93
19.0	16.67	37.35	10.37	53.00	12.27	-1.2	-1.5	14	25.00	92
20.0	16.67	37.85	10.51	53.00	12.27	-1.2	-1.5	13	25.00	91
21.0	16.67	38.33	10.65	53.00	12.27	-1.2	-1.5	12	25.00	90
22.0	16.67	38.80	10.78	53.00	12.27	-1.2	-1.5	11	25.00	89
23.0	16.67	39.25	10.90	53.00	12.27	-1.2	-1.5	11	25.00	89
24.0	16.67	39.69	11.03	53.00	12.27	-1.2	-1.5	10	25.00	88
25.0	16.67	40.12	11.14	53.00	12.27	-1.2	-1.5	9	25.00	87
26.0	16.67	40.53	11.26	53.00	12.27	-1.2	-1.5	8	25.00	86
27.0	16.67	40.93	11.37	53.00	12.27	-1.2	-1.5	7	25.00	85
28.0	16.67	41.32	11.48	53.00	12.27	-1.2	-1.5	6	25.00	84
29.0	16.67	41.70	11.58	53.00	12.27	-1.2	-1.5	5	25.00	83
30.0	16.67	42.07	11.69	53.00	12.27	-1.2	-1.5	5	25.00	83
31.0	16.67	42.43	11.79	53.00	12.27	-1.2	-1.5	4	25.00	82
32.0	16.67	42.78	11.88	53.00	12.27	-1.2	-1.5	3	25.00	81
33.0	16.67	43.12	11.98	53.00	12.27	-1.2	-1.5	2	25.00	80
34.0	16.67	43.46	12.07	53.00	12.27	-1.2	-1.5	2	25.00	80
35.0	16.67	43.79	12.16	53.00	12.27	-1.2	-1.5	1	25.00	79
36.0	16.67	44.11	12.25	53.00	12.27	-1.2	-1.5	0	25.00	78
37.0	16.67	44.43	12.34	53.00	12.27	-1.2	-1.5	0	25.00	78
38.0	16.67	44.74	12.43	53.00	12.27	-1.2	-1.5	0	25.00	78
39.0	16.67	45.04	12.51	53.00	12.27	-1.2	-1.5	0	25.00	78
40.0	16.67	45.34	12.59	53.00	12.27	-1.2	-1.5	0	25.00	78

ANNEXURE I

Detailed gap acceptance criteria calculations (60km/h)

$S_{gap\ 1.1}$ Determined with non-constant acceleration rate and vehicle A acceleration to design speed

Vehicle B		
Design Speed	60	km/h
Design Speed	16.67	m/s
Acceleration rate	non-constant	
Gap acceptance time	5.5	seconds
Vehicle A		
Design Speed	60	km/h
Design Speed	16.67	m/s
Interval	1	
Acceleration rate	non-constant	

Radius R (m)	Initial Speed U (km/h) $u=17.34R^{0.26057}$	Initial Speed u (m/s) U=u/3.6	Distance at 60 km/h d_1	Time at 60 km/h $t_{1=}$	Time left to 5.5s $t_2 = 5.5-t_1$	Distance for time left (m) $d_2 = (t_2 * \text{design speed})$	Total Distance D (m)	Distance Rounded (m)	End Speed V (km/h)
0.0									
1.0	17.34	4.82					47.70	48	44.15
2.0	20.77	5.77					52.20	52	46.68
3.0	23.09	6.41					55.29	55	48.40
4.0	24.88	6.91					57.60	58	49.71
5.0	26.37	7.33					59.53	60	50.80
6.0	27.66	7.68					61.20	61	51.74
7.0	28.79	8.00					62.78	63	52.60
8.0	29.81	8.28					64.11	64	53.35
9.0	30.74	8.54					65.36	65	54.04
10.0	31.60	8.78					66.40	66	54.65
11.0	32.39	9.00					67.50	68	55.27
12.0	33.13	9.20					68.47	68	55.79
13.0	33.83	9.40					69.38	69	56.31
14.0	34.49	9.58					70.21	70	56.79
15.0	35.12	9.75					71.04	71	57.25
16.0	35.71	9.92					71.86	72	57.70
17.0	36.28	10.08					72.69	73	58.13
18.0	36.82	10.23					73.33	73	58.51
19.0	37.35	10.37					73.99	74	58.90
20.0	37.85	10.51					74.70	75	59.28
21.0	38.33	10.65					75.40	75	59.64
22.0	38.80	10.78					75.89	76	59.97
23.0	39.25	10.90	75.15	5.42	0.08	1.33	76.48	76	60.00
24.0	39.69	11.03	73.98	5.31	0.19	3.17	77.15	77	60.00
25.0	40.12	11.14	72.79	5.22	0.28	4.67	77.46	77	60.00
26.0	40.53	11.26	71.95	5.13	0.37	6.17	78.12	78	60.00
27.0	40.93	11.37	70.79	5.03	0.47	7.83	78.62	79	60.00
28.0	41.32	11.48	69.62	4.93	0.57	9.50	79.12	79	60.00
29.0	41.70	11.58	68.78	4.85	0.65	10.83	79.61	80	60.00
30.0	42.07	11.69	67.62	4.76	0.74	12.33	79.95	80	60.00
31.0	42.43	11.79	66.79	4.68	0.82	13.67	80.46	80	60.00
32.0	42.78	11.88	65.63	4.59	0.91	15.17	80.80	81	60.00
33.0	43.12	11.98	64.80	4.52	0.98	16.33	81.13	81	60.00
34.0	43.46	12.07	63.96	4.45	1.05	17.50	81.46	81	60.00
35.0	43.79	12.16	62.82	4.35	1.15	19.17	81.99	82	60.00
36.0	44.11	12.25	61.99	4.29	1.21	20.17	82.16	82	60.00
37.0	44.43	12.34	61.17	4.22	1.28	21.33	82.50	83	60.00
38.0	44.74	12.43	60.02	4.13	1.37	22.83	82.85	83	60.00
39.0	45.04	12.51	59.20	4.06	1.44	24.00	83.20	83	60.00
40.0	45.34	12.59	58.38	3.99	1.51	25.17	83.55	84	60.00

t_1 **(From Bester's non-constant acceleration model)**
d_2 **(From Bester's non-constant acceleration model)**

$S_{gap\ 1.2}$ Determined with non-constant acceleration rate and vehicle A acceleration to 85 % of design speed

Vehicle B		
85% Design Speed	51	km/h
85% Design Speed	14.17	m/s
Acceleration rate	non-constant	
Gap acceptance time	5.5	seconds
Vehicle A		
85% Design Speed	60	km/h
85% Design Speed	16.67	m/s
Interval	1	
Acceleration rate	non-constant	

Radius R (m)	Initial Speed U (km/h) $u=17.34R^{0.26057}$	Initial Speed u (m/s) U=u/3.6	Distance at 51 km/h d_1	Time at 51 km/h $t_{1=}$	Time left to 5.5s $t_2 = 5.5\text{-}t_1$	Distance fot time left $d_2 = (t_2 * \text{design speed})$	Total Distance D (m)	Distance Rounded (m) (m)	End Speed V (km/h)
1.0	17.34	4.82					47.70	48	44.15
2.0	20.77	5.77					52.20	52	46.68
3.0	23.09	6.41					55.29	55	48.40
4.0	24.88	6.91					57.60	58	49.71
5.0	26.37	7.33					59.53	60	50.80
6.0	27.66	7.68	58.40	5.30	0.20	2.83	61.23	61	51.00
7.0	28.79	8.00	56.66	5.08	0.42	5.95	62.61	63	51.00
8.0	29.81	8.28	55.01	4.87	0.63	8.93	63.94	64	51.00
9.0	30.74	8.54	53.41	4.69	0.81	11.48	64.89	65	51.00
10.0	31.60	8.78	51.92	4.51	0.99	14.03	65.95	66	51.00
11.0	32.39	9.00	50.49	4.35	1.15	16.29	66.78	67	51.00
12.0	33.13	9.20	49.08	4.20	1.30	18.42	67.50	67	51.00
13.0	33.83	9.40	47.70	4.05	1.45	20.54	68.24	68	51.00
14.0	34.49	9.58	46.41	3.91	1.59	22.53	68.94	69	51.00
15.0	35.12	9.75	45.13	3.78	1.72	24.37	69.50	69	51.00
16.0	35.71	9.92	43.87	3.65	1.85	26.21	70.08	70	51.00
17.0	36.28	10.08	42.63	3.53	1.97	27.91	70.54	71	51.00
18.0	36.82	10.23	41.45	3.41	2.09	29.61	71.06	71	51.00
19.0	37.35	10.37	40.27	3.30	2.20	31.17	71.44	71	51.00
20.0	37.85	10.51	39.13	3.19	2.31	32.73	71.86	72	51.00
21.0	38.33	10.65	38.00	3.08	2.42	34.28	72.28	72	51.00
22.0	38.80	10.78	36.90	2.98	2.52	35.70	72.60	73	51.00
23.0	39.25	10.90	35.79	2.87	2.63	37.26	73.05	73	51.00
24.0	39.69	11.03	34.71	2.77	2.73	38.68	73.39	73	51.00
25.0	40.12	11.14	33.64	2.68	2.82	39.95	73.59	74	51.00
26.0	40.53	11.26	32.60	2.58	2.92	41.37	73.97	74	51.00
27.0	40.93	11.37	31.59	2.49	3.01	42.64	74.23	74	51.00
28.0	41.32	11.48	30.56	2.40	3.10	43.92	74.48	74	51.00
29.0	41.70	11.58	29.54	2.35	3.15	44.63	74.17	74	51.00
30.0	42.07	11.69	28.56	2.23	3.27	46.33	74.89	75	51.00
31.0	42.43	11.79	27.56	2.14	3.36	47.60	75.16	75	51.00
32.0	42.78	11.88	26.59	2.06	3.44	48.73	75.32	75	51.00
33.0	43.12	11.98	25.65	1.98	3.52	49.87	75.52	76	51.00
34.0	43.46	12.07	24.69	1.90	3.60	51.00	75.69	76	51.00
35.0	43.79	12.16	23.73	1.82	3.68	52.13	75.86	76	51.00
36.0	44.11	12.25	22.79	1.75	3.75	53.13	75.92	76	51.00
37.0	44.43	12.34	21.85	1.67	3.83	54.26	76.11	76	51.00
38.0	44.74	12.43	20.94	1.60	3.90	55.25	76.19	76	51.00
39.0	45.04	12.51	20.03	1.52	3.98	56.38	76.41	76	51.00
40.0	45.34	12.59	19.14	1.45	4.05	57.38	76.52	77	51.00

t_1 **(From Bester's non-constant acceleration model)**
d_2 **(From Bester's non-constant acceleration model)**

$S_{gap\ 1.3}$ Determined with Vehicle A maintaining speed reached around the corner (acceleration=o) entering the main road upstream

Vehicle B		
Design Speed	60	km/h
Gap acceptance time (t_1)	5.5	seconds
Acceleration rate (a)	0	
Interval	1	

$v^2=u^2+2as$

Radius R (m)	Initial Speed U (km/h) $u=17.34R^{0.26057}$	Initial Speed u (m/s) U=u/3.6	Time (s) t_1	Distance (m) $d_1 = ut + ½at^2$	Distance Rounded (m)	End Speed V (km/h)
0.0	0.00	0.00				51.00
1.0	17.34	4.82	5.50	26.49	26	51.00
2.0	20.77	5.77	5.50	31.74	32	51.00
3.0	23.09	6.41	5.50	35.27	35	51.00
4.0	24.88	6.91	5.50	38.02	38	51.00
5.0	26.37	7.33	5.50	40.29	40	51.00
6.0	27.66	7.68	5.50	42.25	42	51.00
7.0	28.79	8.00	5.50	43.99	44	51.00
8.0	29.81	8.28	5.50	45.54	46	51.00
9.0	30.74	8.54	5.50	46.96	47	51.00
10.0	31.60	8.78	5.50	48.27	48	51.00
11.0	32.39	9.00	5.50	49.48	49	51.00
12.0	33.13	9.20	5.50	50.62	51	51.00
13.0	33.83	9.40	5.50	51.69	52	51.00
14.0	34.49	9.58	5.50	52.69	53	51.00
15.0	35.12	9.75	5.50	53.65	54	51.00
16.0	35.71	9.92	5.50	54.56	55	51.00
17.0	36.28	10.08	5.50	55.43	55	51.00
18.0	36.82	10.23	5.50	56.26	56	51.00
19.0	37.35	10.37	5.50	57.06	57	51.00
20.0	37.85	10.51	5.50	57.83	58	51.00
21.0	38.33	10.65	5.50	58.57	59	51.00
22.0	38.80	10.78	5.50	59.28	59	51.00
23.0	39.25	10.90	5.50	59.97	60	51.00
24.0	39.69	11.03	5.50	60.64	61	51.00
25.0	40.12	11.14	5.50	61.29	61	51.00
26.0	40.53	11.26	5.50	61.92	62	51.00
27.0	40.93	11.37	5.50	62.53	63	51.00
28.0	41.32	11.48	5.50	63.12	63	51.00
29.0	41.70	11.58	5.50	63.70	64	51.00
30.0	42.07	11.69	5.50	64.27	64	51.00
31.0	42.43	11.79	5.50	64.82	65	51.00
32.0	42.78	11.88	5.50	65.36	65	51.00
33.0	43.12	11.98	5.50	65.89	66	51.00
34.0	43.46	12.07	5.50	66.40	66	51.00
35.0	43.79	12.16	5.50	66.90	67	51.00
36.0	44.11	12.25	5.50	67.40	67	51.00
37.0	44.43	12.34	5.50	67.88	68	51.00
38.0	44.74	12.43	5.50	68.35	68	51.00
39.0	45.04	12.51	5.50	68.82	69	51.00
40.0	45.34	12.59	5.50	69.27	69	51.00

$S_{gap\ 2.1}$ Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to design speed

Vehicle B		
Design Speed	60	km/h
Gap acceptance time (t_1)	5.5	seconds
Acceleration Rate (a)	0.6	m/s^2
Interval	1	

Radius R (m)	End Speed U (km/h) $u=17.34R^{0.26057}$	End Speed u (m/s) U=u/3.6	Acceleration a (m/s^2)	Time (s) t_1	Distance (m) $d_1 = ut_1 * ½at^2$	Distance (m) Rounded (m)	End Speed (m/s) $v = (u^2 + 2as)^{0.5}$	End Speed (km/h) V = v * 3.6
1.0	17.34	4.82	0.6	5.5	35.57	36	8.12	29
2.0	20.77	5.77	0.6	5.5	40.81	41	9.07	33
3.0	23.09	6.41	0.6	5.5	44.35	44	9.71	35
4.0	24.88	6.91	0.6	5.5	47.09	47	10.21	37
5.0	26.37	7.33	0.6	5.5	49.37	49	10.63	38
6.0	27.66	7.68	0.6	5.5	51.33	51	10.98	40
7.0	28.79	8.00	0.6	5.5	53.06	53	11.30	41
8.0	29.81	8.28	0.6	5.5	54.62	55	11.58	42
9.0	30.74	8.54	0.6	5.5	56.04	56	11.84	43
10.0	31.60	8.78	0.6	5.5	57.35	57	12.08	43
11.0	32.39	9.00	0.6	5.5	58.56	59	12.30	44
12.0	33.13	9.20	0.6	5.5	59.69	60	12.50	45
13.0	33.83	9.40	0.6	5.5	60.76	61	12.70	46
14.0	34.49	9.58	0.6	5.5	61.77	62	12.88	46
15.0	35.12	9.75	0.6	5.5	62.72	63	13.05	47
16.0	35.71	9.92	0.6	5.5	63.63	64	13.22	48
17.0	36.28	10.08	0.6	5.5	64.50	65	13.38	48
18.0	36.82	10.23	0.6	5.5	65.33	65	13.53	49
19.0	37.35	10.37	0.6	5.5	66.13	66	13.67	49
20.0	37.85	10.51	0.6	5.5	66.90	67	13.81	50
21.0	38.33	10.65	0.6	5.5	67.64	68	13.95	50
22.0	38.80	10.78	0.6	5.5	68.35	68	14.08	51
23.0	39.25	10.90	0.6	5.5	69.05	69	14.20	51
24.0	39.69	11.03	0.6	5.5	69.71	70	14.33	52
25.0	40.12	11.14	0.6	5.5	70.36	70	14.44	52
26.0	40.53	11.26	0.6	5.5	70.99	71	14.56	52
27.0	40.93	11.37	0.6	5.5	71.60	72	14.67	53
28.0	41.32	11.48	0.6	5.5	72.20	72	14.78	53
29.0	41.70	11.58	0.6	5.5	72.78	73	14.88	54
30.0	42.07	11.69	0.6	5.5	73.34	73	14.99	54
31.0	42.43	11.79	0.6	5.5	73.90	74	15.09	54
32.0	42.78	11.88	0.6	5.5	74.43	74	15.18	55
33.0	43.12	11.98	0.6	5.5	74.96	75	15.28	55
34.0	43.46	12.07	0.6	5.5	75.47	75	15.37	55
35.0	43.79	12.16	0.6	5.5	75.98	76	15.46	56
36.0	44.11	12.25	0.6	5.5	76.47	76	15.55	56
37.0	44.43	12.34	0.6	5.5	76.95	77	15.64	56
38.0	44.74	12.43	0.6	5.5	77.43	77	15.73	57
39.0	45.04	12.51	0.6	5.5	77.89	78	15.81	57
40.0	45.34	12.59	0.6	5.5	78.35	78	15.89	57

$S_{gap\ 2.2}$ Determined with 0.6 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed

Vehicle B		
Design Speed	51	km/h
Gap acceptance time (t_1)	5.5	seconds
Acceleration Rate (a)	0.6	m/s^2
Interval	1	

Radius R (m)	End Speed U (km/h) $u=17.34R^{0.26057}$	End Speed u (m/s) U=u/3.6	Acceleration a (m/s^2)	Time (s) t_1	Distance (m) $d_1 = ut_1 * ½at^2$	Time at 51 km/h $t_2 = u + at$	Time left to 5.5s $t_3 = 5.5-t_1$	Distance fot time left $d_2 = (t_3 * \text{design speed})$	Distance (m) $d_3 = ut_1 * ½at^2$	Distance Rounded D (m)	End Speed (m/s) $v = (u^2 + 2as)^{0.5}$	End Speed (km/h) V = v * 3.6
1.0	17.34	4.82	0.6	5.5					35.57	36	8.12	29
2.0	20.77	5.77	0.6	5.5					40.81	41	9.07	33
3.0	23.09	6.41	0.6	5.5					44.35	44	9.71	35
4.0	24.88	6.91	0.6	5.5					47.09	47	10.21	37
5.0	26.37	7.33	0.6	5.5					49.37	49	10.63	38
6.0	27.66	7.68	0.6	5.5					51.33	51	10.98	40
7.0	28.79	8.00	0.6	5.5					53.06	53	11.30	41
8.0	29.81	8.28	0.6	5.5					54.62	55	11.58	42
9.0	30.74	8.54	0.6	5.5					56.04	56	11.84	43
10.0	31.60	8.78	0.6	5.5					57.35	57	12.08	43
11.0	32.39	9.00	0.6	5.5					58.56	59	12.30	44
12.0	33.13	9.20	0.6	5.5					59.69	60	12.50	45
13.0	33.83	9.40	0.6	5.5					60.76	61	12.70	46
14.0	34.49	9.58	0.6	5.5					61.77	62	12.88	46
15.0	35.12	9.75	0.6	5.5					62.72	63	13.05	47
16.0	35.71	9.92	0.6	5.5					63.63	64	13.22	48
17.0	36.28	10.08	0.6	5.5					64.50	65	13.38	48
18.0	36.82	10.23	0.6	5.5					65.33	65	13.53	49
19.0	37.35	10.37	0.6	5.5					66.13	66	13.67	49
20.0	37.85	10.51	0.6	5.5					66.90	67	13.81	50
21.0	38.33	10.65	0.6	5.5					67.64	68	13.95	50
22.0	38.80	10.78	0.6	5.5					68.35	68	14.08	51
23.0	39.25	10.90	0.6	5.5	68.17	5.44	0.06	0.87	69.05	69	14.17	51
24.0	39.69	11.03	0.6	5.5	65.95	5.24	0.26	3.74	69.69	70	14.17	51
25.0	40.12	11.14	0.6	5.5	63.77	5.04	0.46	6.53	70.30	70	14.17	51
26.0	40.53	11.26	0.6	5.5	61.63	4.85	0.65	9.23	70.86	71	14.17	51
27.0	40.93	11.37	0.6	5.5	59.54	4.66	0.84	11.86	71.39	71	14.17	51
28.0	41.32	11.48	0.6	5.5	57.48	4.48	1.02	14.41	71.89	72	14.17	51
29.0	41.70	11.58	0.6	5.5	55.45	4.31	1.19	16.90	72.35	72	14.17	51
30.0	42.07	11.69	0.6	5.5	53.46	4.14	1.36	19.33	72.79	73	14.17	51
31.0	42.43	11.79	0.6	5.5	51.50	3.97	1.53	21.70	73.19	73	14.17	51
32.0	42.78	11.88	0.6	5.5	49.56	3.81	1.69	24.01	73.57	74	14.17	51
33.0	43.12	11.98	0.6	5.5	47.66	3.65	1.85	26.27	73.93	74	14.17	51
34.0	43.46	12.07	0.6	5.5	45.79	3.49	2.01	28.48	74.26	74	14.17	51
35.0	43.79	12.16	0.6	5.5	43.94	3.34	2.16	30.64	74.58	75	14.17	51
36.0	44.11	12.25	0.6	5.5	42.11	3.19	2.31	32.75	74.87	75	14.17	51
37.0	44.43	12.34	0.6	5.5	40.32	3.04	2.46	34.83	75.14	75	14.17	51
38.0	44.74	12.43	0.6	5.5	38.54	2.90	2.60	36.86	75.40	75	14.17	51
39.0	45.04	12.51	0.6	5.5	36.78	2.76	2.74	38.85	75.64	76	14.17	51
40.0	45.34	12.59	0.6	5.5	35.05	2.62	2.88	40.81	75.86	76	14.17	51

$S_{gap\ 3.1}$ Determined with 0.9 m/s² acceleration rate and vehicle A accelerating to design speed

Vehicle B		
Design Speed	60	km/h
Gap acceptance time (t_1)	5.5	seconds
Acceleration Rate (a)	0.9	m/s²
Interval	1	

$s=ut+0.5at^2$ $t=(v-u)/a$, $v=u+at$ $s=ut+0.5at^2$ $v^2=u^2+2as$

Radius R (m)	End Speed U (km/h) $u=17.34R^{0.26057}$	End Speed u (m/s) U=u/3.6	Acceleration a (m/s^2)	Time (s) t_1	Distance (m) $d_1 = ut_1 * ½at^2$	Time at 60 km/h $t_2 = u + at$	Time left to 5.5s $t_3 = 5.5-t_1$	Distance fot time left $d_2 = (t_3 * \text{design speed})$	Distance (m) $d_3 = ut_1 * ½at^2$	Distance Rounded D (m)	End Speed (m/s) $v = (u^2 + 2as)^{0.5}$	End Speed (km/h) V = v * 3.6
1.0	17.34	4.82	0.9	5.5					40.10	40	9.77	35
2.0	20.77	5.77	0.9	5.5					45.35	45	10.72	39
3.0	23.09	6.41	0.9	5.5					48.88	49	11.36	41
4.0	24.88	6.91	0.9	5.5					51.63	52	11.86	43
5.0	26.37	7.33	0.9	5.5					53.91	54	12.28	44
6.0	27.66	7.68	0.9	5.5					55.87	56	12.63	45
7.0	28.79	8.00	0.9	5.5					57.60	58	12.95	47
8.0	29.81	8.28	0.9	5.5					59.16	59	13.23	48
9.0	30.74	8.54	0.9	5.5					60.58	61	13.49	49
10.0	31.60	8.78	0.9	5.5					61.88	62	13.73	49
11.0	32.39	9.00	0.9	5.5					63.10	63	13.95	50
12.0	33.13	9.20	0.9	5.5					64.23	64	14.15	51
13.0	33.83	9.40	0.9	5.5					65.30	65	14.35	52
14.0	34.49	9.58	0.9	5.5					66.31	66	14.53	52
15.0	35.12	9.75	0.9	5.5					67.26	67	14.70	53
16.0	35.71	9.92	0.9	5.5					68.17	68	14.87	54
17.0	36.28	10.08	0.9	5.5					69.04	69	15.03	54
18.0	36.82	10.23	0.9	5.5					69.87	70	15.18	55
19.0	37.35	10.37	0.9	5.5					70.67	71	15.32	55
20.0	37.85	10.51	0.9	5.5					71.44	71	15.46	56
21.0	38.33	10.65	0.9	5.5					72.18	72	15.60	56
22.0	38.80	10.78	0.9	5.5					72.89	73	15.73	57
23.0	39.25	10.90	0.9	5.5					73.58	74	15.85	57
24.0	39.69	11.03	0.9	5.5					74.25	74	15.98	58
25.0	40.12	11.14	0.9	5.5					74.90	75	16.09	58
26.0	40.53	11.26	0.9	5.5					75.53	76	16.21	58
27.0	40.93	11.37	0.9	5.5					76.14	76	16.32	59
28.0	41.32	11.48	0.9	5.5					76.74	77	16.43	59
29.0	41.70	11.58	0.9	5.5					77.32	77	16.53	60
30.0	42.07	11.69	0.9	5.5					77.88	78	16.64	60
31.0	42.43	11.79	0.9	5.5	77.15	5.42	0.08	1.28	78.43	78	16.67	60
32.0	42.78	11.88	0.9	5.5	75.87	5.31	0.19	3.09	78.96	79	16.67	60
33.0	43.12	11.98	0.9	5.5	74.60	5.21	0.29	4.86	79.46	79	16.67	60
34.0	43.46	12.07	0.9	5.5	73.35	5.10	0.40	6.59	79.94	80	16.67	60
35.0	43.79	12.16	0.9	5.5	72.12	5.00	0.50	8.29	80.40	80	16.67	60
36.0	44.11	12.25	0.9	5.5	70.90	4.90	0.60	9.95	80.85	81	16.67	60
37.0	44.43	12.34	0.9	5.5	69.70	4.81	0.69	11.57	81.27	81	16.67	60
38.0	44.74	12.43	0.9	5.5	68.52	4.71	0.79	13.17	81.68	82	16.67	60
39.0	45.04	12.51	0.9	5.5	67.35	4.62	0.88	14.73	82.08	82	16.67	60
40.0	45.34	12.59	0.9	5.5	66.19	4.52	0.98	16.26	82.46	82	16.67	60

$S_{gap\ 3.2}$ Determined with 0.9 m/s² acceleration rate and vehicle A accelerating to 85 % of design speed

Vehicle B		
Design Speed	60	km/h
Gap acceptance time (t_1)	5.5	seconds
Acceleration Rate (a)	0.9	m/s^2
Interval	1	

Radius R (m)	End Speed U (km/h) $u=17.34R^{0.26057}$	End Speed u (m/s) U=u/3.6	Acceleration a (m/s^2)	Time (s) t_1	Distance (m) $d_1 = ut_1 * ½at^2$	Time at 51 km/h $t_2 = (v - u)/a$	Time left to 5.5s $t_3 = t_1 - t_2$	Distance fot time left $d_2 = (t_3 * \text{design speed})$	Distance (m) $d_3 = ut_1 * ½at_1^2$	Distance Rounded D (m)	End Speed (m/s) $v = (u^2 + 2as)^{0.5}$	End Speed (km/h) V = v * 3.6
1.0	17.34	4.82	0.9	5.5					40.10	40	9.77	35
2.0	20.77	5.77	0.9	5.5					45.35	45	10.72	39
3.0	23.09	6.41	0.9	5.5					48.88	49	11.36	41
4.0	24.88	6.91	0.9	5.5					51.63	52	11.86	43
5.0	26.37	7.33	0.9	5.5					53.91	54	12.28	44
6.0	27.66	7.68	0.9	5.5					55.87	56	12.63	45
7.0	28.79	8.00	0.9	5.5					57.60	58	12.95	47
8.0	29.81	8.28	0.9	5.5					59.16	59	13.23	48
9.0	30.74	8.54	0.9	5.5					60.58	61	13.49	49
10.0	31.60	8.78	0.9	5.5					61.88	62	13.73	49
11.0	32.39	9.00	0.9	5.5					63.10	63	13.95	50
12.0	33.13	9.20	0.9	5.5					64.23	64	14.15	51
13.0	33.83	9.40	0.9	5.5	62.44	5.30	0.20	2.84	65.28	65	14.17	51
14.0	34.49	9.58	0.9	5.5	60.50	5.10	0.40	5.73	66.23	66	14.17	51
15.0	35.12	9.75	0.9	5.5	58.64	4.90	0.60	8.46	67.10	67	14.17	51
16.0	35.71	9.92	0.9	5.5	56.83	4.72	0.78	11.07	67.90	68	14.17	51
17.0	36.28	10.08	0.9	5.5	55.07	4.54	0.96	13.55	68.63	69	14.17	51
18.0	36.82	10.23	0.9	5.5	53.37	4.38	1.12	15.93	69.30	69	14.17	51
19.0	37.35	10.37	0.9	5.5	51.71	4.21	1.29	18.22	69.93	70	14.17	51
20.0	37.85	10.51	0.9	5.5	50.09	4.06	1.44	20.42	70.50	71	14.17	51
21.0	38.33	10.65	0.9	5.5	48.51	3.91	1.59	22.53	71.04	71	14.17	51
22.0	38.80	10.78	0.9	5.5	46.96	3.77	1.73	24.58	71.54	72	14.17	51
23.0	39.25	10.90	0.9	5.5	45.45	3.63	1.87	26.55	72.00	72	14.17	51
24.0	39.69	11.03	0.9	5.5	43.97	3.49	2.01	28.47	72.43	72	14.17	51
25.0	40.12	11.14	0.9	5.5	42.51	3.36	2.14	30.32	72.84	73	14.17	51
26.0	40.53	11.26	0.9	5.5	41.09	3.23	2.27	32.13	73.22	73	14.17	51
27.0	40.93	11.37	0.9	5.5	39.69	3.11	2.39	33.88	73.57	74	14.17	51
28.0	41.32	11.48	0.9	5.5	38.32	2.99	2.51	35.58	73.90	74	14.17	51
29.0	41.70	11.58	0.9	5.5	36.97	2.87	2.63	37.24	74.21	74	14.17	51
30.0	42.07	11.69	0.9	5.5	35.64	2.76	2.74	38.86	74.50	74	14.17	51
31.0	42.43	11.79	0.9	5.5	34.33	2.65	2.85	40.44	74.77	75	14.17	51
32.0	42.78	11.88	0.9	5.5	33.04	2.54	2.96	41.98	75.02	75	14.17	51
33.0	43.12	11.98	0.9	5.5	31.77	2.43	3.07	43.48	75.26	75	14.17	51
34.0	43.46	12.07	0.9	5.5	30.52	2.33	3.17	44.96	75.48	75	14.17	51
35.0	43.79	12.16	0.9	5.5	29.29	2.22	3.28	46.40	75.69	76	14.17	51
36.0	44.11	12.25	0.9	5.5	28.08	2.13	3.37	47.81	75.88	76	14.17	51
37.0	44.43	12.34	0.9	5.5	26.88	2.03	3.47	49.19	76.07	76	14.17	51
38.0	44.74	12.43	0.9	5.5	25.69	1.93	3.57	50.54	76.24	76	14.17	51
39.0	45.04	12.51	0.9	5.5	24.52	1.84	3.66	51.87	76.40	76	14.17	51
40.0	45.34	12.59	0.9	5.5	23.37	1.75	3.75	53.18	76.54	77	14.17	51

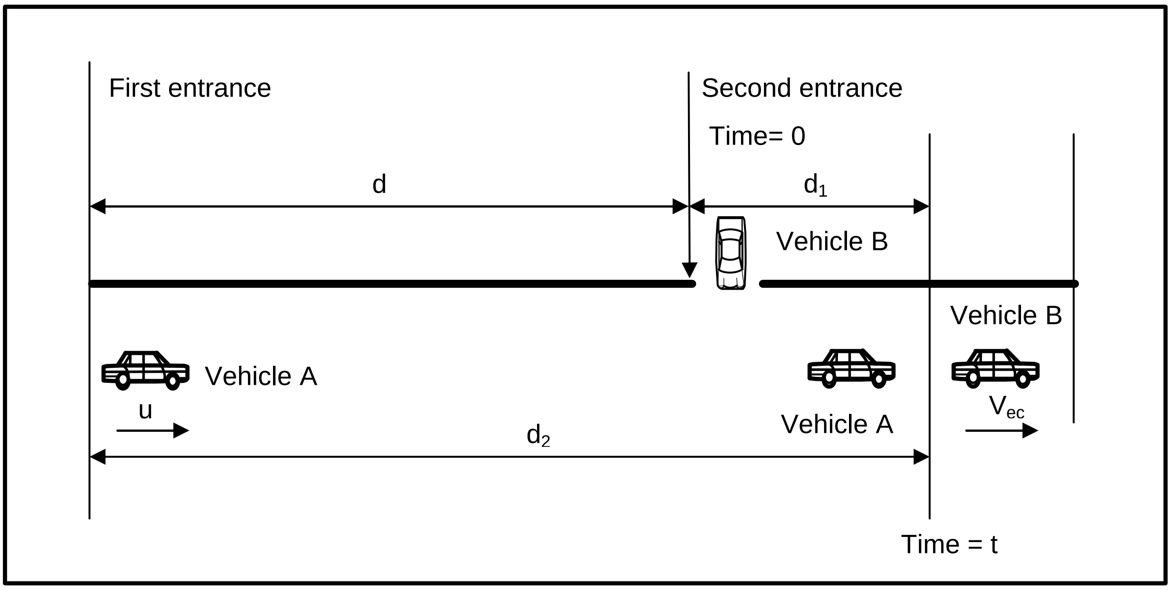
ANNEXURE J

Detail derived equation

CALCULATIONS TO DETERMINE THE INTERSECTIONS / ACCESSES SPACING FOR LEFT-TURN CONFLICT OVERLAP

Critical access/intersection spacing is calculated as follows in equation 20. (*Riglyne vir toegange tot vulstasies, 1993):*

$$S = \frac{V_{ec}(V_{ec} + 4.5a)}{4a} - \frac{3(u - 2a)^2}{32a} - \frac{(u + 4.5a)^2}{32a} \quad \cdots\cdots (20)$$



Equation 20 above is derived:

Where:

d	=	Distance between intersections/accesses
d_1	=	Distance vehicle B travelled when the two vehicles reach the same speed and point (after time = t)
d_2	=	Distance that vehicle A travelled in time t
$a_{constant}$	=	Acceleration of vehicle B

To decrease the variables, assume that the delay rate of vehicle A is 3 times the acceleration rate of vehicle B.

Where:

3a	=	Deceleration of vehicle A
u	=	Speed of vehicle A when starting to brake
V_{ec}	=	Speed of vehicles after time t
t	=	Time for vehicle B to travel distance d_1 and vehicle A to travel distance d_2

For vehicle B:

$$V_{ec} = a_{constant}\, t \quad \text{(speed after time t)} \quad \cdots\cdots (22)$$

For vehicle A assume a reaction time of 1.5 seconds :

$$V = u - 3\, a_{constant}\,(t - 1.5) \quad \cdots\cdots (23)$$

Eliminate V in equations 22 and 23:

$$t = \frac{(u + 4.5a)}{4a} \quad \cdots\cdots (24)$$

Distance vehicle B travel in time t:

$$\begin{aligned} d &= \tfrac{1}{2}at^2 \\ &= \tfrac{1}{2}a\left\{\frac{(u+4.5a)}{4a}\right\}^2 \\ &= \frac{a(u+4.5a)^2}{2 * 16a^2} \\ &= \frac{(u+4.5a)^2}{32a} \quad \cdots\cdots (25) \end{aligned}$$

Distance vehicle A travel, assume a reaction time of 1.5 seconds and a delay rate of 3at:

$$d_2 = 1.5u + u(t-1.5) - \frac{3a}{2}\ (t-1.5)^2$$

$$= \frac{u(u+4.5a)}{4a} - \frac{3a}{2}\{(u+4.5a)-1.5\}^2$$

$$= \frac{u(u+4.5a)}{4a} - \frac{3a}{2}\left\{\frac{(u+4.5a)}{4a} - \frac{(6a)}{4a}\right\}^2$$

$$= \frac{u(u+4.5a)}{4a} - \frac{3a}{2}\left\{\frac{(u+4.5a-6a)^2}{16a}\right\}$$

$$= \frac{u(u+4.5a)}{4a} - \frac{3(u-1.5a)^2}{32a} \quad \cdots\cdots(26)$$

$$d = d_2 - d_1$$

Substitute d_2 and d_1 with equations 26 and 25:

$$d = \frac{V_{ec}(V_{ec}+4.5a)}{4a} - \frac{3(u-1.5a)^2}{32a} - \frac{(u+4.5a)^2}{32a} \quad \cdots\cdots(27)$$

ANNEXURE K

Detailed corner clearance criteria calculations (60km/h)

$S_{corner\ 1.1}$	**Spacing allowed to ensure that Vehicle A which accelerates from around curve at non-constant acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a non-constant acceleration rate.**

Vehicle B	**D = 116m in 12.53 sec to 60km/h**		
Time (t_1)	12.53		seconds
Distance (d_1)	116.35		meter
Design Speed		60	km/h
Design Speed		16.67	m/s
Interval		1	

Vehicle A

Radius R (m)	Start Speed U (km/h) $u=17.34R^{0.26057}$	Start Speed (m/s) U=u/3.6	Time D (s) $t_{2=}$	Distance (m) d_2	Time to 12.53 t= t1 - t2	Distance at 60km/h m/s d_4=d2 * design speed	Distance after 12.53s $d_5= d_4 + d_2$	Distance (m) $S= d_5 - d_1$	Spacing Distance (m)
0.0	0.00	0.00							
1.0	17.34	4.82	9.74	109.51	2.79	46.50	156.01	39.66	**40**
2.0	20.77	5.77	9.13	106.29	3.40	56.67	162.96	46.61	**47**
3.0	23.09	6.41	8.71	103.70	3.82	63.67	167.37	51.02	**51**
4.0	24.88	6.91	8.37	101.42	4.16	69.33	170.75	54.40	**54**
5.0	26.37	7.33	8.09	99.43	4.44	74.00	173.43	57.08	**57**
6.0	27.66	7.68	7.84	97.52	4.69	78.17	175.69	59.34	**59**
7.0	28.79	8.00	7.61	95.77	4.92	82.00	177.77	61.42	**61**
8.0	29.81	8.28	7.41	94.13	5.12	85.33	179.46	63.11	**63**
9.0	30.74	8.54	7.22	92.56	5.31	88.50	181.06	64.71	**65**
10.0	31.60	8.78	7.05	91.09	5.48	91.33	182.42	66.07	**66**
11.0	32.39	9.00	6.89	89.65	5.64	94.00	183.65	67.30	**67**
12.0	33.13	9.20	6.73	88.25	5.80	96.67	184.92	68.57	**69**
13.0	33.83	9.40	6.59	86.87	5.94	99.00	185.87	69.52	**70**
14.0	34.49	9.58	6.45	85.55	6.08	101.33	186.88	70.53	**71**
15.0	35.12	9.75	6.31	84.27	6.22	103.67	187.94	71.59	**72**
16.0	35.71	9.92	6.19	83.05	6.34	105.67	188.72	72.37	**72**
17.0	36.28	10.08	6.07	81.79	6.46	107.67	189.46	73.11	**73**
18.0	36.82	10.23	5.95	80.61	6.58	109.67	190.28	73.93	**74**
19.0	37.35	10.37	5.84	79.45	6.69	111.50	190.95	74.60	**75**
20.0	37.85	10.51	5.72	78.27	6.81	113.50	191.77	75.42	**75**
21.0	38.33	10.65	5.62	77.16	6.91	115.17	192.33	75.98	**76**
22.0	38.80	10.78	5.51	76.04	7.02	117.00	193.04	76.69	**77**
23.0	39.25	10.90	5.41	74.93	7.12	118.67	193.60	77.25	**77**
24.0	39.69	11.03	5.31	73.85	7.22	120.33	194.18	77.83	**78**
25.0	40.12	11.14	5.22	72.77	7.31	121.83	194.60	78.25	**78**
26.0	40.53	11.26	5.13	71.74	7.40	123.33	195.07	78.72	**79**
27.0	40.93	11.37	5.03	70.73	7.50	125.00	195.73	79.38	**79**
28.0	41.32	11.48	4.94	69.68	7.59	126.50	196.18	79.83	**80**
29.0	41.70	11.58	4.86	68.67	7.67	127.83	196.50	80.15	**80**
30.0	42.07	11.69	4.77	67.67	7.76	129.33	197.00	80.65	**81**
31.0	42.43	11.79	4.69	66.72	7.84	130.67	197.39	81.04	**81**
32.0	42.78	11.88	4.61	65.76	7.92	132.00	197.76	81.41	**81**
33.0	43.12	11.98	4.53	64.78	8.00	133.33	198.11	81.76	**82**
34.0	43.46	12.07	4.45	63.82	8.08	134.67	198.49	82.14	**82**
35.0	43.79	12.16	4.37	62.90	8.16	136.00	198.90	82.55	**83**
36.0	44.11	12.25	4.29	61.97	8.24	137.33	199.30	82.95	**83**
37.0	44.43	12.34	4.22	61.02	8.31	138.50	199.52	83.17	**83**
38.0	44.74	12.43	4.14	60.10	8.39	139.83	199.93	83.58	**84**
39.0	45.04	12.51	4.07	59.21	8.46	141.00	200.21	83.86	**84**
40.0	45.34	12.59	4.00	58.30	8.53	142.17	200.47	84.12	**84**

t_1 **(From Bester's non-constant acceleration model)**

d_2 **(From Bester's non-constant acceleration model)**

$S_{corner\ 1.2}$ **Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.6 m/s² acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.6 m/s² acceleration rate.**

Vehicle B:		
Initial speed (u)	0	m/s
Distance for 60km/h in 27.8sec (s_1)	231.5	m
Time (t_1)	27.8	seconds
Acceleration rate (a)	0.6	m/s²
Design speed	60	km/h
Design speed (v)	16.67	m/s
Interval	1	

$s_1 = (v^2 - u^2)/2a$
$s_1 = ((60/3.6)^2 - 0)/2*0.6$
=231.5m

t = (v - u) / a
s=(60/3.6) - 0)/0.6
=27.8s

Vehicle A

Radius R (m)	Start Speed U (km/h) $u=17.34R^{0.26057}$	Start Speed U (m/s) U=u/3.6	Time (s) $t_2 = (v-u)/a$	Distance (m) $s_1 = (v^2 - u^2)/2a$	Time to 27.8s $t = t_1 - t_2$	Distance 60km/h $s_2 = t * v$	Distance after 27.8s $s = s_1 + s_2$	Spacing Distance (m) $s_{tot} = s - s1$	**Total Distance (m)**
0.0	0.00	0.00							
1.0	17.34	4.82	19.75	212.15	8.03	133.80	345.94	114.46	**114**
2.0	20.77	5.77	18.16	203.74	9.62	160.28	364.02	132.54	**133**
3.0	23.09	6.41	17.09	197.21	10.69	178.14	375.35	143.87	**144**
4.0	24.88	6.91	16.26	191.66	11.52	192.01	383.67	152.19	**152**
5.0	26.37	7.33	15.57	186.75	12.21	203.50	390.26	158.78	**159**
6.0	27.66	7.68	14.97	182.30	12.80	213.41	395.70	164.22	**164**
7.0	28.79	8.00	14.45	178.18	13.33	222.15	400.33	168.85	**169**
8.0	29.81	8.28	13.98	174.34	13.80	230.02	404.36	172.88	**173**
9.0	30.74	8.54	13.55	170.72	14.23	237.19	407.91	176.43	**176**
10.0	31.60	8.78	13.15	167.29	14.63	243.79	411.08	179.60	**180**
11.0	32.39	9.00	12.78	164.03	15.00	249.92	413.94	182.46	**182**
12.0	33.13	9.20	12.44	160.90	15.34	255.65	416.55	185.06	**185**
13.0	33.83	9.40	12.12	157.89	15.66	261.04	418.93	187.45	**187**
14.0	34.49	9.58	11.81	154.99	15.97	266.13	421.12	189.64	**190**
15.0	35.12	9.75	11.52	152.19	16.26	270.96	423.15	191.67	**192**
16.0	35.71	9.92	11.24	149.48	16.53	275.55	425.03	193.55	**194**
17.0	36.28	10.08	10.98	146.85	16.80	279.94	426.79	195.30	**195**
18.0	36.82	10.23	10.73	144.29	17.05	284.14	428.43	196.95	**197**
19.0	37.35	10.37	10.49	141.80	17.29	288.17	429.97	198.48	**198**
20.0	37.85	10.51	10.25	139.37	17.52	292.05	431.41	199.93	**200**
21.0	38.33	10.65	10.03	136.99	17.75	295.78	432.78	201.30	**201**
22.0	38.80	10.78	9.81	134.68	17.96	299.39	434.07	202.59	**203**
23.0	39.25	10.90	9.61	132.41	18.17	302.88	435.29	203.80	**204**
24.0	39.69	11.03	9.40	130.18	18.38	306.26	436.44	204.96	**205**
25.0	40.12	11.14	9.21	128.01	18.57	309.53	437.54	206.06	**206**
26.0	40.53	11.26	9.02	125.87	18.76	312.71	438.58	207.10	**207**
27.0	40.93	11.37	8.83	123.77	18.95	315.80	439.57	208.09	**208**
28.0	41.32	11.48	8.65	121.71	19.13	318.81	440.52	209.04	**209**
29.0	41.70	11.58	8.47	119.69	19.30	321.74	441.42	209.94	**210**
30.0	42.07	11.69	8.30	117.69	19.48	324.59	442.28	210.80	**211**
31.0	42.43	11.79	8.14	115.73	19.64	327.38	443.11	211.63	**212**
32.0	42.78	11.88	7.97	113.80	19.81	330.10	443.90	212.42	**212**
33.0	43.12	11.98	7.81	111.90	19.97	332.75	444.65	213.17	**213**
34.0	43.46	12.07	7.66	110.02	20.12	335.35	445.38	213.89	**214**
35.0	43.79	12.16	7.50	108.17	20.27	337.90	446.07	214.59	**215**
36.0	44.11	12.25	7.35	106.35	20.42	340.38	446.74	215.25	**215**
37.0	44.43	12.34	7.21	104.55	20.57	342.82	447.37	215.89	**216**
38.0	44.74	12.43	7.06	102.78	20.71	345.21	447.99	216.51	**217**
39.0	45.04	12.51	6.92	101.02	20.85	347.56	448.58	217.10	**217**
40.0	45.34	12.59	6.79	99.29	20.99	349.86	449.15	217.67	**218**

$S_{corner\ 1.3}$ **Spacing allowed to ensure that Vehicle A which accelerates from around curve at 0.9 m/s² acceleration rate reaches a speed of 85% of the design speed of the main road before reaching Vehicle B who also accelerates at a 0.9 m/s² acceleration rate.**

Vehicle B:		
Initial speed (u)	0	m/s
Distance for 60km/h in 18.5sec	154.3	m
Time	18.5	seconds
Acceleration rate	0.9	m/s²
Design speed	60	km/h
Design speed (v)	16.7	m/s
Interval	1	

$s_1 = (v^2 - u^2)/2a$
s_1 = ((60/3.6)² - 0)/2*0.9
=154.3m

t = (v - u) / a
s=(60/3.6) - 0)/0.6
=27.8s

Vehicle A

Radius R (m)	Start Speed U (km/h) $u=17.34R^{0.26057}$	Start Speed U (m/s) U=u/3.6	Time (s) t_2 = (v-u)/a	Distance (m) $s_1 = (v^2 - u^2)/2a$	Time to 27.8s $t = t_1 - t_2$	Distance 60km/h s_2 = t * v	Distance after 18.5s $s = s_1 + s_2$	Spacing Distance (m) s_{tot} = s - s1	**Total Distance (m)**
0.0	0.00	0.00							
1.0	17.34	4.82	13.17	141.43	5.35	89.20	230.63	76.31	**76**
2.0	20.77	5.77	12.11	135.82	6.41	106.85	242.68	88.36	**88**
3.0	23.09	6.41	11.39	131.47	7.13	118.76	250.23	95.91	**96**
4.0	24.88	6.91	10.84	127.78	7.68	128.01	255.78	101.46	**101**
5.0	26.37	7.33	10.38	124.50	8.14	135.67	260.17	105.85	**106**
6.0	27.66	7.68	9.98	121.53	8.54	142.27	263.80	109.48	**109**
7.0	28.79	8.00	9.63	118.79	8.89	148.10	266.89	112.57	**113**
8.0	29.81	8.28	9.32	116.23	9.20	153.35	269.57	115.25	**115**
9.0	30.74	8.54	9.03	113.82	9.49	158.12	271.94	117.62	**118**
10.0	31.60	8.78	8.77	111.53	9.75	162.53	274.06	119.73	**120**
11.0	32.39	9.00	8.52	109.35	10.00	166.61	275.96	121.64	**122**
12.0	33.13	9.20	8.29	107.26	10.23	170.43	277.70	123.38	**123**
13.0	33.83	9.40	8.08	105.26	10.44	174.03	279.29	124.96	**125**
14.0	34.49	9.58	7.87	103.33	10.65	177.42	280.75	126.43	**126**
15.0	35.12	9.75	7.68	101.46	10.84	180.64	282.10	127.78	**128**
16.0	35.71	9.92	7.50	99.65	11.02	183.70	283.35	129.03	**129**
17.0	36.28	10.08	7.32	97.90	11.20	186.63	284.52	130.20	**130**
18.0	36.82	10.23	7.15	96.19	11.37	189.43	285.62	131.30	**131**
19.0	37.35	10.37	6.99	94.53	11.53	192.11	286.64	132.32	**132**
20.0	37.85	10.51	6.84	92.91	11.68	194.70	287.61	133.29	**133**
21.0	38.33	10.65	6.69	91.33	11.83	197.19	288.52	134.20	**134**
22.0	38.80	10.78	6.54	89.78	11.98	199.59	289.38	135.06	**135**
23.0	39.25	10.90	6.40	88.27	12.12	201.92	290.19	135.87	**136**
24.0	39.69	11.03	6.27	86.79	12.25	204.17	290.96	136.64	**137**
25.0	40.12	11.14	6.14	85.34	12.38	206.35	291.69	137.37	**137**
26.0	40.53	11.26	6.01	83.91	12.51	208.47	292.39	138.07	**138**
27.0	40.93	11.37	5.89	82.51	12.63	210.53	293.05	138.73	**139**
28.0	41.32	11.48	5.77	81.14	12.75	212.54	293.68	139.36	**139**
29.0	41.70	11.58	5.65	79.79	12.87	214.49	294.28	139.96	**140**
30.0	42.07	11.69	5.53	78.46	12.98	216.39	294.86	140.54	**141**
31.0	42.43	11.79	5.42	77.15	13.10	218.25	295.41	141.08	**141**
32.0	42.78	11.88	5.31	75.87	13.20	220.06	295.93	141.61	**142**
33.0	43.12	11.98	5.21	74.60	13.31	221.84	296.43	142.11	**142**
34.0	43.46	12.07	5.10	73.35	13.41	223.57	296.92	142.60	**143**
35.0	43.79	12.16	5.00	72.12	13.52	225.26	297.38	143.06	**143**
36.0	44.11	12.25	4.90	70.90	13.62	226.92	297.82	143.50	**144**
37.0	44.43	12.34	4.81	69.70	13.71	228.55	298.25	143.93	**144**
38.0	44.74	12.43	4.71	68.52	13.81	230.14	298.66	144.34	**144**
39.0	45.04	12.51	4.62	67.35	13.90	231.71	299.05	144.73	**145**
40.0	45.34	12.59	4.52	66.19	13.99	233.24	299.43	145.11	**145**

$S_{corner\ 1.4}$: Critical spacing allowed to ensure that Vehicle A which decelerates at 1.8 m/s² after aperception-reaction time of 2.0s from the EC around the curve does not collide with Vehicle B which also accelerates at a 0.6 m/s².

Vehicle B		
Vehicle A decelerate	-1.8	m/s²
Vehicle B accelerate	0.6	m/s²
Perception reation time	2	seconds
Speed	60	km/h
Interval	1	

$S=[V_{ec}((V_{ec}+4.5a)/4a)]-3(u-1.5a)^2/32a-(u+4.5a)^2/32a$

Vehicle A

Radius R (m)	Start Speed U (km/h) $u=17.34R^{0.26057}$	Start Speed U (m/s) U=u/3.6	Time D (s) t = (u+6a)/4a	Distance (m) S	End Speed V (m/s) v = u - 3a(t-2)	End Speed V (km/h) V (km/h)
0.0	0.00	0.00			0.00	
1.0	17.34	4.82	3.51	11	2.10	7.6
2.0	20.77	5.77	3.90	15	2.34	8.4
3.0	23.09	6.41	4.17	17	2.50	9.0
4.0	24.88	6.91	4.38	19	2.63	9.5
5.0	26.37	7.33	4.55	21	2.73	9.8
6.0	27.66	7.68	4.70	23	2.82	10.2
7.0	28.79	8.00	4.83	24	2.90	10.4
8.0	29.81	8.28	4.95	26	2.97	10.7
9.0	30.74	8.54	5.06	27	3.03	10.9
10.0	31.60	8.78	5.16	28	3.09	11.1
11.0	32.39	9.00	5.25	29	3.15	11.3
12.0	33.13	9.20	5.33	31	3.20	11.5
13.0	33.83	9.40	5.42	32	3.25	11.7
14.0	34.49	9.58	5.49	33	3.30	11.9
15.0	35.12	9.75	5.56	34	3.34	12.0
16.0	35.71	9.92	5.63	34	3.38	12.2
17.0	36.28	10.08	5.70	35	3.42	12.3
18.0	36.82	10.23	5.76	36	3.46	12.4
19.0	37.35	10.37	5.82	37	3.49	12.6
20.0	37.85	10.51	5.88	38	3.53	12.7
21.0	38.33	10.65	5.94	39	3.56	12.8
22.0	38.80	10.78	5.99	39	3.59	12.9
23.0	39.25	10.90	6.04	40	3.63	13.1
24.0	39.69	11.03	6.09	41	3.66	13.2
25.0	40.12	11.14	6.14	42	3.69	13.3
26.0	40.53	11.26	6.19	42	3.71	13.4
27.0	40.93	11.37	6.24	43	3.74	13.5
28.0	41.32	11.48	6.28	44	3.77	13.6
29.0	41.70	11.58	6.33	44	3.80	13.7
30.0	42.07	11.69	6.37	45	3.82	13.8
31.0	42.43	11.79	6.41	46	3.85	13.8
32.0	42.78	11.88	6.45	46	3.87	13.9
33.0	43.12	11.98	6.49	47	3.89	14.0
34.0	43.46	12.07	6.53	48	3.92	14.1
35.0	43.79	12.16	6.57	48	3.94	14.2
36.0	44.11	12.25	6.61	49	3.96	14.3
37.0	44.43	12.34	6.64	49	3.99	14.3
38.0	44.74	12.43	6.68	50	4.01	14.4
39.0	45.04	12.51	6.71	50	4.03	14.5
40.0	45.34	12.59	6.75	51	4.05	14.6

ANNEXURE L

Detailed Left-turn Conflict Overlap criteria calculations (60km/h)

$S_{overlap1.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at a non-constant rate

<u>Vehicle B:</u>

Vehicle B accelerating from rest to reach design speed of 60 km/h

Distance required	:	116.61	meter	(From Bester's non-constant acceleration model)
Time required	:	12.54	seconds	(From Bester's non-constant acceleration model)

<u>Vehicle A:</u>

Vehicle A does not decelerate and remains at design speed

Design speed	:	16.66667	m/s	
Distance travelled in 12.54 seconds	:	209.0	m	(S = Time required x Design speed)
therefore access spacing	:	**92**	m	(Spacing = S - Distance required)

$S_{overlap1.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5s perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B accelerates at a non-constant rate

Vehicle B

Vehicle B accelerating from rest to reach 85% design speed 51 km/h

Distance required =	77.4	m	(From Bester's non-constant acceleration model)
Time required =	10	seconds	(From Bester's non-constant acceleration model)

Vehicle A

Percep reaction time	:	1.5	seconds
Deceleration rate	:	-1.8	m/s^2
Design speed	:	16.67	m/s
85 % Design speed	:	14.17	m/s

Time 1	**:**	1.5		perception-reaction time
Time 2	**:**	1.39		t=v-u/a (time during decelerating @ $-1.8m/s^2$ from design speed to 85% of design speed)
Time 3	**:**	7.11		time travelling at 85% of design speed
Distance	**:**	25.000	m	s=ut+0. with a = 0
Distance	**:**	21.412	m	s=ut+0. with a = -1.8
Distance	**:**	100.741	m	s=ut+0. with a =0
Distance	**:**	147.15	m	
Spacing	**:**	**70**	**m**	

$S_{overlap2.1}$:	**Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.6 m/s²**

Vehicle B

Vehicle B accelerating from rest at 0.6m/s² to reach design speed 60 km/h

Acceleration rate	:	0.6	m/s²
Design speed	:	16.667	m/s
Time 1	**:**	27.8	t=v-u/a
Distance 1	**:**	231.48	s=v²-u²/2a

Vehicle A

Vehicle A does not decelerate and remains at design speed 60km/h

Distance 2	**:**	462.96	m	s=ut+0.5at² (distance travelled in27.8 seconds)
Spacing	**:**	**231**	**m**	

$S_{overlap2.2}$:	**Spacing required for vehicle A travelling along the main road reducing speed after a 1.5s perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.6 m/s²**

Vehicle B

Vehicle B accelerates at 0.6m/s² up to 85% of design speed and remains at that speed

Design speed	:	60	km/h	
Acceleration rate	:	0.6	m/s²	
85 % Design speed	:	14.2	m/s	0
Distance B	**:**	**167.25**	m	$s=v^2-u^2/2a$
Time B	**:**	**23.6**	seconds	t=v-u/a

Vehicle A

Vehicle A decelerates at 1.8m/s² to reach 85% of design speed and remains at that speed 51 km/h

Percep reaction time	:	1.5	seconds
Deceleration rate	:	-1.8	m/s^2
Design speed	:	16.7	m/s
85 % Design speed	:	14.2	m/s

Time 1	**:**	**1.5**	perception-reaction time
Time 2	**:**	**1.389**	t=v-u/a (time during decelerating @ $-1.8m/s^2$ from design speed to 85% of design speed)
Time 3	**:**	**20.7**	time travelling at 85% of design speed

Distance 1	**:**	**25.00**	$s=ut+0.5at^2$	with a = 0
Distance 2	**:**	**21.412**	$s=ut+0.5at^2$	with a = -1.8
Distance 3	**:**	**293.565**	$s=ut+0.5at^2$	with a =0
Distance	**:**	**339.98**	m	
Spacing	**:**	**173**	**m**	

$S_{overlap3.1}$: Spacing required for vehicle A travelling along the main road maintaining design speed and not colliding with Vehicle B which accelerates at 0.9 m/s²

Vehicle B

Vehicle B accelerating from rest at 0.6m/s² to reach design speed 60 km/h

Acceleration rate	:	0.9	m/s²
Design speed	:	16.667	m/s
Time 1	**:**	18.5	t=v-u/a
Distance 1	**:**	154.32	s=v²-u²/2a

Vehicle A

Vehicle A does not decelerate and remains at design speed 60km/h

Distance 2	**:**	308.64	m	s=ut+0.5at² (distance travelled in 18.5 seconds)
Spacing	**:**	**154**	**m**	

$S_{overlap3.2}$: Spacing required for vehicle A travelling along the main road reducing speed after a 1.5s perception reaction time at 1.8 m/s² until reaching a speed of 85% of the design speed and not colliding with Vehicle B which accelerates at 0.9 m/s²

Vehicle B

Vehicle B accelerates at 0.9m/s² up to 85% of design speed and remains at that speed

Design speed	:	60	km/h	
Acceleration rate	:	0.9	m/s²	
85 % Design speed	:	14.2	m/s	
Distance B	**:**	**111.50**	m	$s=v^2-u^2/2a$
Time B	**:**	**15.7**	seconds	$t=v-u/a$

Vehicle A

Vehicle A decelerates at 1.8m/s² to reach 85% of design speed and remains at that speed 51 km/h

Percep reaction time	:	1.5	seconds
Deceleration rate	:	-1.8	m/s2
Design speed	:	16.7	m/s
85 % Design speed	:	14.2	m/s

Time 1	**:**	**1.5**	s	perception-reaction time
Time 2	**:**	**1.389**	s	t=v-u/a (time during decelerating @ -1.8m/s² from design speed to 85% of design speed)
Time 3	**:**	**12.9**	s	time travelling at 85% of design speed
Distance 1	**:**	**25.00**	m	$s=ut+0.5at^2$ with a = 0
Distance 2	**:**	**21.412**	m	$s=ut+0.5at^2$ with a = -1.8
Distance 3	**:**	**182.068**	m	$s=ut+0.5at^2$ with a =0
Distance	**:**	**228.5**	m	
Spacing	**:**	**117**	**m**	

$S_{overlap4.1}$: Critical spacing required for vehicle A travelling along the main road reducing speed after a 1.5s perception-reaction time at 1.8 m/s² and not colliding with Vehicle B which accelerates at 0.6 m/s²

<u>Vehicle A</u>

Acceleration	:	0.6	m/s²
Deceleration	:	1.8	m/s²
Percep-reaction time	:	1.5	seconds

<u>Vehicle B</u>

Vehicle B accelerating from rest to reach design speed 60 km/h

Design speed	:	16.67	m/s	
Time	**:**	8.1	s	t=(u+4.5a)/4a
Speed	**:**	4.84	m/s	v=u-3a(t-1.5)
Spacing	**:**	**76**	m	$S=[V_{ec}((V_{ec}+4.5a)/4a)]-3(u-1.5a)^2/32a-(u+4.5a)^2/32a$