Design Vehicles: From Turning Templates to Smart Systems

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Abstract – "Design Vehicles: From Turning Templates to Smart Systems"

The application of a design vehicle as an integral part of highway geometric was formally establish by AASHO in 1940. This early AASHO documentation contained a set of four design vehicles, generally the largest in each category including an automobile, bus and two trucks. Swept paths for simple 90 degree turns for the single wheelbase vehicles were developed based on equations.

The 1954 AASHO "A Policy on Geometric Design of Rural Highways", was published and Mr. Jack Leisch, shortly thereafter developed the first set of plastic turning vehicle templates at a scale of 1"=50', 1"=40' and 1"=20' for the use of DeLeuw Cather staff and a limited number of others. Jack Leisch moved to Toronto, Canada in 1964 and CGRA under Mr. Leisch's direction, developed the second generation of turning vehicle templates which were sold by CGRA throughout Canada and the US beginning in 1969.

These plastic turning templates and their future generations became the standard approach to the design of any vehicle facility and is still used widely today.

The development of the computer led to several developments on mainframe computers that allowed the simulation of turning vehicles, however it wasn't until the early 1990s, with the dawn of the micro-computer that programs such as AutoTRACK, AutoPATH, and AutoTURN®, that operated directly within CAD, became a popular approach to designing for turning vehicles at intersections, roundabouts, parking facilities truck terminals and bus stations. These approaches provided designers with considerable flexibility and efficiency in a CAD environment over fixed plastic (mylar) turning templates.

One future direction is for design to be fully inclusive of vehicles turning requirements, such that it allows for a highly dynamic and integrated approach, eliminating the need to check for the required space after the fact. Coupled with expert systems capabilities, these programs will provide powerful and highly effective methods for providing for the spatial requirements for design vehicles, in all dimensions – horizontal and vertical, as well as speed.

This paper will chronicle the evolution of the application of design vehicles in geometric design from inception in the late 1930's to the present and provided insight into the future of this fundamental component of road and facility planning and design.

INTRODUCTION

Application of the design vehicle in highway geometric design began in the 1930's. It has continued to this day as one of several design dependent controls. The design vehicle has changed significantly as has their application in geometric design.

This paper will chronicle the history and evolution of the application of the design vehicle in highway geometric design from the 1930's to the present and into the future.

EVOLUTION OF AASHO/AASHTO/CGRA/TAC DESIGN VEHICLES

The American Association of State Highway Officials (AASHO) was founded in 1914, the same year as the Canadian Good Roads Association (CGRA). AASHO published eight (8) documents (paperback) from 1938 – 1945 covering different areas of geometric design including Interstate Highways (#8) in 1945. The two published in 1940, ***"A Policy on Highway Types"*** and ***"A Policy on Intersections At Grade"*** defined four (4) typical design vehicles: passenger car, single unit truck, bus and semi-trailer truck (see figure 1). Generally, these were the largest vehicle in each classification. Swept paths for the design passenger car and the design single unit truck (bus assumed the same) for a minimum radius turn and turn angle of 90 degrees was shown. These paths were plotted by hand applying an equation relating the track of the rear inside wheel of the vehicle to the outside front wheel of the vehicle. The minimum radius was based on data provided by manufacturers of the various vehicles. There was no swept path for the semi-trailer with a wheel base of 35 feet (front axle of the cab to the rear axle of the trailer).

These eight documents were published in one paperback volume in 1950, ***"Policies on Geometric Highway Design",*** with the same design vehicles.

The 1954 AASHO ***"A Policy on Geometric Design of Rural Highways"*** was an update and expansion of the eight individual policies developed from 1938-1945. It included a fifth design vehicle (semi-trailer) with a wheel base of 44 feet and overall length of 50 feet - referred to as a C50 design vehicle. Swept paths for all 5 vehicles were shown for both a 90 degree turn and a 180 degree turn with minimum radius (see figure 2). There is no mention of how these swept paths were derived. However, Jack Leisch, known as the author of the first AASHO Policies (actually, the Bureau of Public Roads liaison to AASHO responsible for "making investigations, compiling material and preparing drafts" for the AASHO Committee on Planning and Design Policies) told Joel Leisch in the 1970's that there were some tests made in parking lots with the various design vehicles using sand to define the vehicle paths.

The 1957 AASHO ***"A Policy on Arterial Highways in Urban Areas"*** contains the same 5 design vehicles as the 1954 Policy with the same swept paths and dimensions for minimum turning radius for each vehicle.

DEVELOPMENT OF TURNING VEHICLE TEMPLATES FOR GEOMETRIC DESIGN

The concept of the turning vehicle templates for geometric design was envisioned by Jack Leisch in 1956-7. Mr. Leisch had completed 20 years with the Bureau of Public Roads (now the Federal Highway Administration - FHWA) as Chief of Design Development. His responsibilities were not limited to, however, included: 1) Liaison with AASHO to finalize, edit and the Bureau print the first two AASHO Design Policies (1954 Blue Book and 1957 Red Book), 2) Review and approval of all freeway and interchange design projects in the US, whether developed by or for a State Highway Department, City or County. He was also a member of the Highway Capacity Committee of the Highway Research Board (now the Transportation Research Board - TRB) responsible for the development of the first (1950) Highway Capacity Manual. Consequently, Mr. Leisch's reputation as an expert in geometric design, traffic engineering and specifically for freeways and interchanges was well known. When President Eisenhower signed the Interstate and Defense Highway System Act in 1956 several consulting firms offered Mr. Leisch positions. DeLeuw Cather and Company made Mr. Leisch an offer he could not refuse as Chief Highway Engineer with a move from Washington, DC to Chicago. Once settled in Chicago in August 1956 Mr. Leisch understood that 90% of the interchanges on the Interstate System would have intersections (signalized or with stop control). To assist the engineers at DeLeuw Cather to design these intersections to accommodate the appropriate design vehicle he conceived of and developed the first set of plastic turning vehicle templates at a scale of 1"=50', 1"=40' and 1"=20'. All of the AASHO design vehicles in the first AASHO Design Policies were included. An instruction manual was also prepared to guide the designers in the use of the templates with an example intersection. These templates were only for the use of DeLeuw Cather staff and a limited number of others. A wooden, tiered case painted in gray and placed on the wall held the templates and the instruction manual.

CONTINUING EVOLUTION OF THE DESIGN VEHICLE AND DESIGN VEHICLE TEMPLATES

The 1965 AASHO, ***"A Policy on the Design of Rural Highways",*** contained significant changes in the design vehicles. The passenger car, single unit truck (SU) and bus remained the same. There were two semi-trailer combinations both larger than the one in the previous policies. The small semi-trailer is referred to as a WB-40 (wheel base of 40' and overall length of 50 feet). The larger semi-trailer is a WB-50 (wheel base of 50' and overall length of 55 feet). Scale models of the WB-40 and the WB-50 were developed and used to determine the minimum turning radius and the dimensions of the swept path. By this time there were a few "full trailer combinations" (double bottom or twin trailer) operating in western states. These were recognized in the 1965 AASHTO Policy that the swept path was slightly narrower than the WB-50 semi-trailer truck. These same vehicles were incorporated into the first CGRA, ***"Geometric Design Standards for Canadian Roads"*** in 1963 and 1967.

Jack Leisch moved to Toronto, Canada in 1964 to take the position of Vice President and Chief Highway Engineer for DeLeuw Cather of Canada, Ltd. (later called DelCan) and taught at Waterloo University (photo of Jack Leisch, Figure 3). DeLeuw Cather of Canada with the sponsorship of the Canadian Good Roads Association/CGRA (now Transportation Association of Canada - TAC), with Mr. Leisch's direction, developed the second generation of turning vehicle templates which included several additional design vehicles at the same scales as the original and two architectural scales with an instruction manual. These were contained in a yellow plastic binder and sold by CGRA throughout Canada and the US beginning in 1969. A list of the templates and scales, including architectural scales that were available are in figure 4 with the cover of the binder. An open view of the binder is shown in figure 5 and example templates are shown in figure 6. Note that there are “special radius templates” for buses operating on multiple radii utilized for the design of bus terminals. These could also be used for single unit trucks for the design of docking facilities for truck terminals. Most of the design vehicle templates came in three (3) radii of turn and were color coded; red for the minimum radius, blue for an intermediate radius and green for a large radius.

THE NEXT GENERATION – DESIGN VEHICLES AND TEMPLATES

The 1973 AASHO, ***“A Policy on Design of Urban Highways and Arterial Streets”,*** added a large bus and a semitrailer/full trailer combination to make 6 design vehicles. The passenger car, single unit truck, WB-40 and the WB-50 remained the same as in the 1965 Policy. The bus was increased in dimensions to reflect the larger buses now operating in many major cities. The wheel base was 25’ with an over-all length of 40’. The semitrailer/full trailer combination (WB-60, double bottom trailer) was added with a swept path design for minimum radius turn of 45’ and all dimensions for the swept path.

Late in 1968 Mr. Leisch moved back to the Chicago area teaching at Northwestern University, the Northwestern Traffic Institute and consulting. He built a vibrant consulting practice (Jack E. Leisch and Associates), eventually with a staff of 55 and offices in four states. In 1977 he developed the last version of the plastic turning vehicle templates in both the imperial system and metric (see figures 7, 8 and 9). Bar templates were developed for both the large bus and the single unit truck with multiple radii which could be used for the design of bus terminals and trucking facilities. Ten years later (1987) a larger semi-trailer truck was developed (WB-60) anticipating AASHTO adopting an additional larger semi-trailer than the WB-50 as a design vehicle. A WB-60 double bottom trailer, triple bottom trailer, or was any of the other AASHTO design vehicles developed as templates because the ones contained in the set were the ones that would always determine the design of an intersection. As with the previous generations of templates these had turning paths for degrees of turns at 30 degree increments from 30 degrees to 180 degrees and holes punched in the center of the radius turn and along the swept path for easy plotting of the swept path. The 1990 AASHTO Policy adopted a WB-62 and a WB-67 referred to as Interstate Semitrailer(s). Jack Leisch passed away in 1991 too late to incorporate them into the set of templates. The templates were contained in a 5-ring binder and sold by Jack E. Leisch and Associates directly or by consignment to the Institute of Transportation Engineers. The instruction manual not only demonstrated the use of the templates for design but included an intersection project demonstrating a pro-active application of the turning vehicle templates in channelization design of an intersection as well as the use of the bus bar template in the design of a bus terminal. The instruction manual that accompanied the templates remained the same from the 1950’s to the 1980’s. Figure 10 shows the 3-leg intersection project in the instruction manual used to demonstrate the application of the design vehicle templates in proactively developing the channelization design of an intersection. Figure 11, from the manual shows an engineer utilizing the templates in developing the swept path for the design vehicle.

THE ADVENT OF THE COMPUTER AND COMPUTER-AIDED-DRAFTING DESIGN

The use of the computer for highway engineering through the 1960s and 1970s, provided an opportunity to assess off-tracking and swept path analysis, particularly to comprehend the impact of newer vehicle types and configurations. The some of the better known earlier developments were mainframe programs such as CALTRAN's TOM program, as well as numerous other standalone PC based programs such as VEHICLE/PATH (Queensland Main Roads Department), PathTracker (Ministry of Transportation BC) all of which produced off-tracking analysis, while later developments such as programs developed by the Ministry of Transportation (Ontario), and TRL's TRACK produced full swept path analysis output. These programs were based on different algorithms but essentially involved defining the vehicle's critical dimensions and a path, which consisted of an entry tangent, a circular path and an exit tangent. A popular algorithm used in such programs is called the constant pursuit method, also referred to 'incremental method of analyses'. Figure 12a and 12b illustrate the constant pursuit approach in a conceptual manner.

As computer-aided-drafting and design (CADD) became popular in the mid-80s, designers resorted to scanning (albeit infringing on copyrights) plastic turning templates and using these images to check their designs.

The Launch of Disruptive CADD based programs

Two factors brought about enhanced swept path analysis; the significant advancements of the CADD systems, namely AutoCAD and Microstation, and the inherent need to assess complex turns or to simulate non-standard vehicles. In such cases single turn simulations or scanned turning templates were of limited use.

The early 1990s saw the launch of disruption technologies, where software such as AutoTRACK, AutoPATH and AutoTURN®, three of the most widely used programs in recent years, were launched for the PC and Unix workstations. A huge benefit was being able to output simulation results directly into the user's drawings. Over the next two decades these programs evolved in significant ways:

- Initially, they worked with predefined paths consisting of lines and arcs and later more complex line types
- The software allowed for the definition and simulation of non-standard or customized vehicles. This was particularly useful for specific projects where the design vehicle was not of relevance.
- As the development of these tools continued, new powerful and dynamic tools emerged. These 'Smartpath' tools provided designers with much simpler swept path capabilities. For example, the user could 'virtually' drive their vehicles in their design or easily generate complex or forward and reverse turns
- Further evolution included complete 3D analysis and simulations to check for horizontal, vertical overhead and underside clearances. Figure 13 shows a perspective view of a 3D swept path.

- Simulations of highly complex vehicles (see Fig. 14 for an example of such a vehicle), including vehicles with linked and self-steered rear axles such as those used for wind farm equipment, large electrical transformers, oil refinery parts etc.

THE FUTURE OF SWEPT PATH ANALYSIS

The future of swept path analysis to some degree will be based on highly desired and currently undeveloped capability. There are several ideas that are both feasible and likely to be realized, given current trends and logical advancements. The following highlights possible future visions for the evolution of swept path analysis, which will always be an important component of road and facility design.

Integrated Swept Path Design Approach:

The direct integration of design vehicle turning performances and their swept paths is one obvious future direction. The term direct integration in its simplified form means that the design software incorporates the design vehicles' turning performance and automatically accommodates it and the resulting swept path as the design is developed. In such cases the need to verify that the design can accommodate the design vehicle, i.e. run a design check with a turning template or run a vehicle simulation is no longer necessary. Examples of this direct integration can be seen in TORUS® and NEXUS®, a roundabout and intersection design software respectively, where the design vehicles can used to define the various geometric design features, Figure 15a and 15b attempt to illustrate how design components of an intersection and roundabout are automatically developed to accommodate the swept path of a design vehicle. In the case of an intersection, the designer defines the governing design vehicle that is to establish a given turn movement , example a WB 20 defining the left turns, while a BUS12 defines the right turns. In developing the design, the software automatically accounts for the turn radius and the resulting swept path, from which the designer can then sets channelization details such as median nosing, in the case of a left turns, or as in the case of right-turns, the shape and size of the islands or curb returns geometry. If the designer prefers to increase or decrease the turn, the designer simply readjusts the simulation, and to some extent the design automatically updates to account for the changes.

Direct integration with with LiDAR data:

There will always be a need to complete vehicle turn checks on existing infrastructure. Today, this work process includes a typical survey of the project site, uploading the survey data into CAD, then generating the CAD drawing and /or surface of the survey, before applying turn simulation programs.

LiDAR surveying is fast catching and is likely to be a common and efficient survey approach for all types of civil engineering projects. Being able to directly work within a LiDAR output environment would reduce the need for the CAD production activity. To be able to work directly within LiDAR data, the vehicle simulation programs will have to be able to intelligently distinguish the travel surface from the non-traversable areas. While it may require some specialized algorithms, it is not impossible to imainge such a capability in the future.

Incorporate intelligent path algorithms

The intelligent path finding, to some degree, incorporates artificial intelligence programming. It also requires either the designer to define the constraints or the program to be able to recognize constraints in a design drawing. Based on the desired outcome, the program will be able to select the optimal path through the subject design layout and accordingly generate the swept paths.

With such a tool, the designer, would select the design vehicle, its start position and ending position, leaving the program to find the optimal path (see Fig. 16 for a simple example). This capability will reduce the need to define a path, but let the program generate one or more possible paths, leaving it to the designer to decide on the preferred solution.

It is unknown to what extent such a solution would be beneficial, particularly as most design challenges/projects are somewhat small in scale.   But an example for such an application may be in the case of a delivery vehicle where the simulation may begin on the adjacent roadway and extend to the loading area/bays, including reversing into the loading bay.

Automated solution for multiple design vehicles

Some projects require designers to test for more than a single design vehicle. For example, it is not always easy to determine whether a WB 20 or a BUS 12, will be more demanding on a right turn design at an intersection. If both these vehicles will be using this turn, one may control the width of the turning roadway, while the other may control the inside turn radius. The ability to automatically develop a design (as with the 'integrated swept path design' approach) that satisfies the requirements of all critical vehicles using the facility will result in a more comprehensive and accommodating design.

Future development in this area is inevitable and very likely as it is an incremental development over the direct integrated function. Such capability will remove the need to do several design checks for each of the vehicle types.

Platform based enhancements for the future:

Two other future developments are possible extensions to the current methods for accommodating swept paths for turning vehicles. These developments relate more to the operating platform vs the functional aspects of swept paths in road and facility design. The first relates to the 'Cloud', whereby the delivery swept paths analysis will be available on an 'as you need it, when you need it' basis and provide easy access to swept paths analyses to a much wider audience. This, of course, raises the issue of training in the proper use of this key transportation engineering knowledge.

Another future possibility is for software to operate in any and all environments, in other words the software is CAD agnostic. In such situations, designer s would have the ability to work in any environment via some data exchange model without the fear of being captive to a single CAD platform.

BEYOND TURNING TEMPLATES AND SWEPT PATHS

The fact that technology is evolving at a fast pace, an area for future consideration is for the design vehicles to be more comprehensively defined. For example, the design vehicles could be more complete in critical design related components, including their height, underside clearances, weight, power, acceleration and deceleration performance, braking performance, and so on, in addition to the current turning and plan dimension data. With these defined components, and driven by a database approach, the ability to seamlessly incorporate the design vehicle and its performance can significantly enhance the entire road design approach, not just in the area of turning and swept paths.

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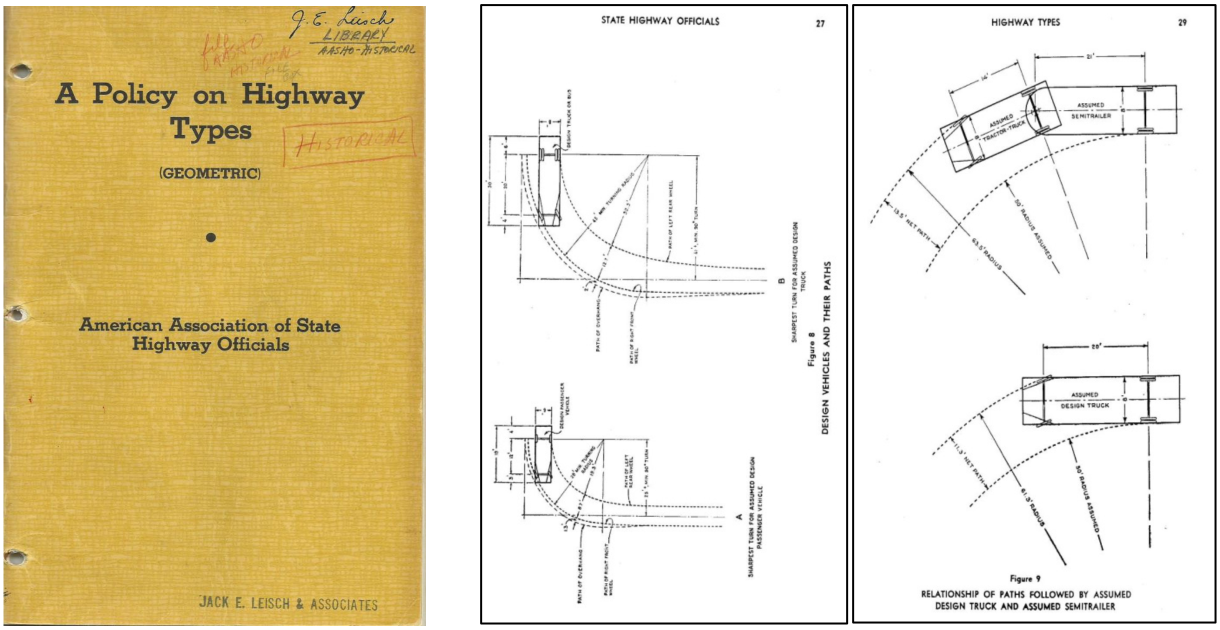


Figure 1 – AASHO Design Policy/Design Vehicles , 1940

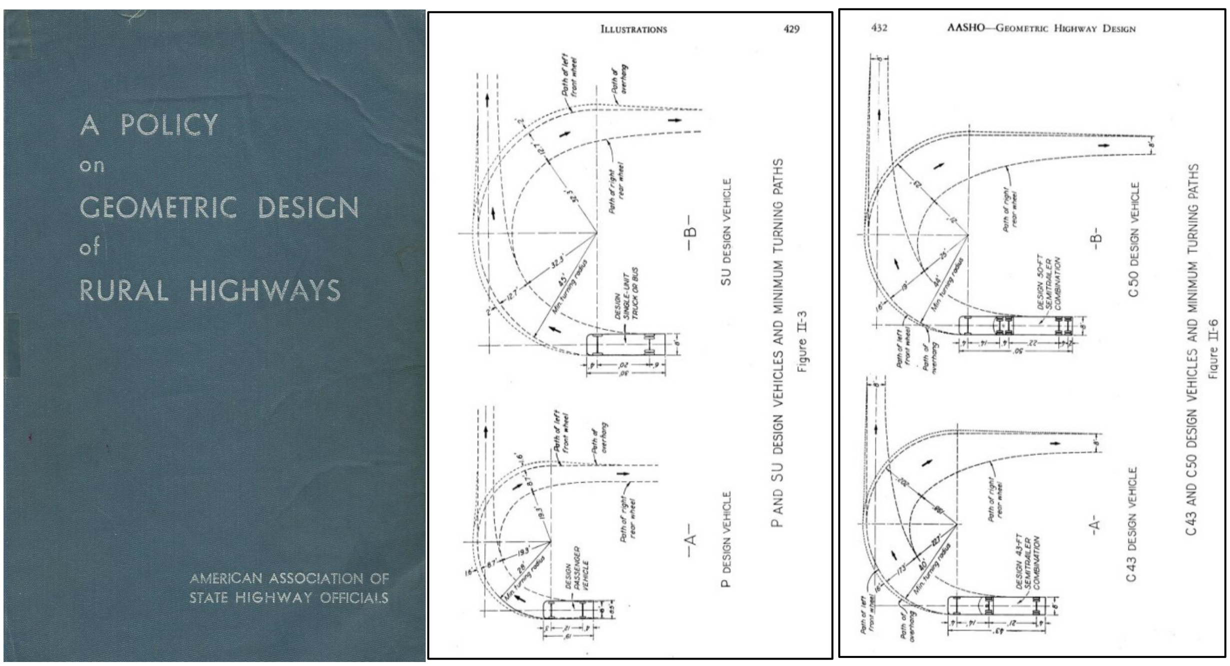


Figure 2 – AASHO Design Policy/Design Vehicles, 1954

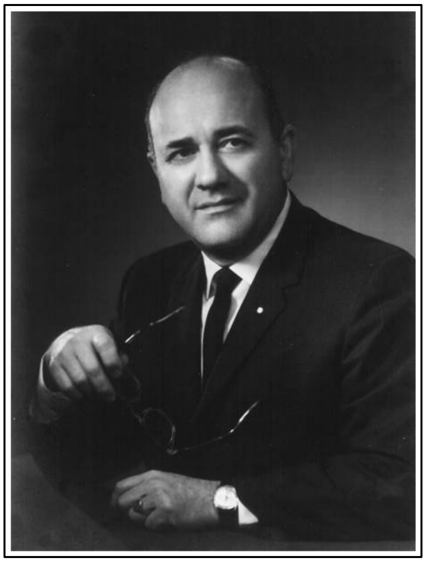
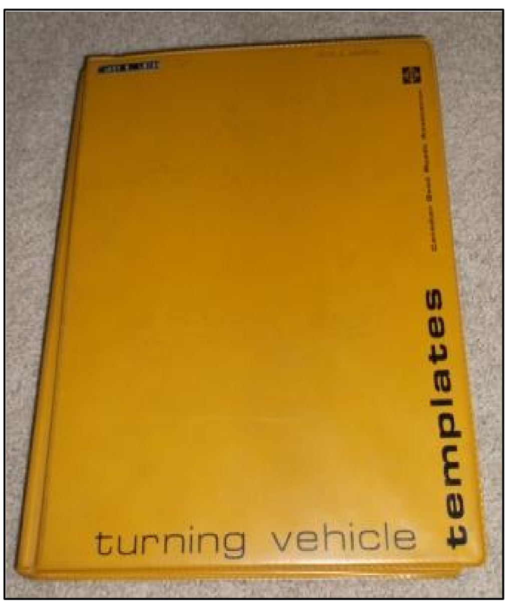


Figure 3 – Jack Leisch, Toronto, CA, 1966

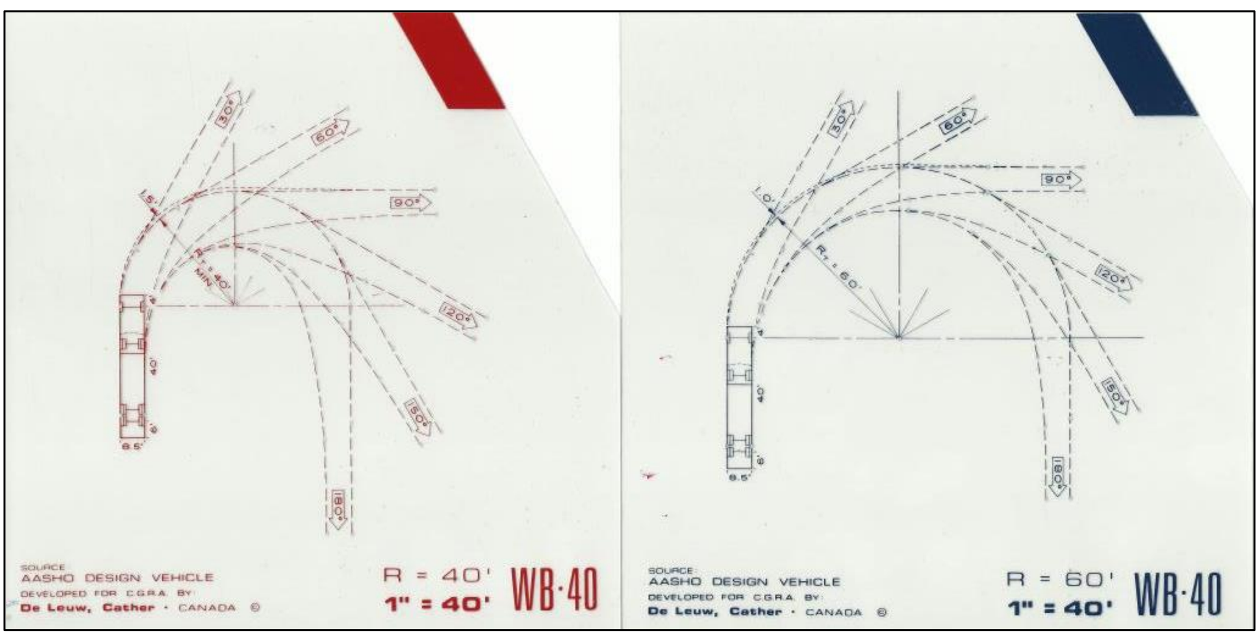


VEHICLE TYPE	VEHICLE DESIGNATION	TURNING RADIUS	SCALE: 1/16"=1'0" or 1"=16'	1"=20'	1/32"=1'0" or 1"=32'	1"=40'	1"=50'
Semitrailer Combination	WB-50	45' min.	x	x	x	x	x
		60'	x	x	x	x	x
		75'		x		x	x
	WB-40	40' min.	x	x	x	x	x
		60'	x	x	x	x	x
		75'		x		x	x
Highway Bus	B-40R	50' min.	x	x	x	x	x
		65'	x	x	x	x	x
City Bus	B-40	40' min.	x	x	x	x	x
		55'	x	x	x	x	x
	B-35	35' min.	x	x	x	x	x
		50'	x	x	x	x	x
Single Unit Truck or Bus	SU-30	42' min.	x	x	x	x	x
		60'	x	x	x	x	x
Buses (Special Radius Templates)	B-40R	Min. Radius to 150'	x		x	x	
	B-40		x		x	x	
	B-35		x		x	x	
Passenger Vehicle	P	24' min.	x	x	x	x	
	Ps	21' min.	x	x	x	x	

Summary of Design Vehicles, Scales and Turning Radii Represented by Templates

Figure 4 – CGRA/DeLeuw Cather of Canada Turning Vehicle Templates, 1969

Figure 5 – CGRA / DeLeuw Cather of Canada Binder



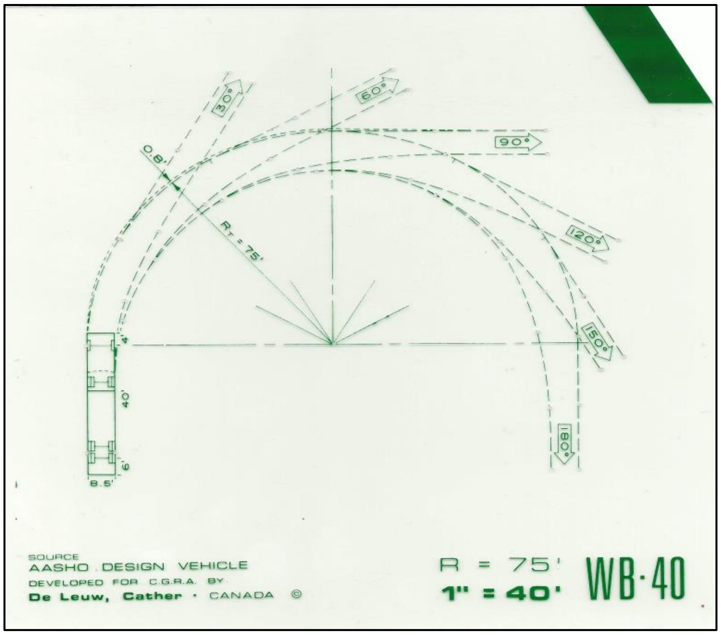
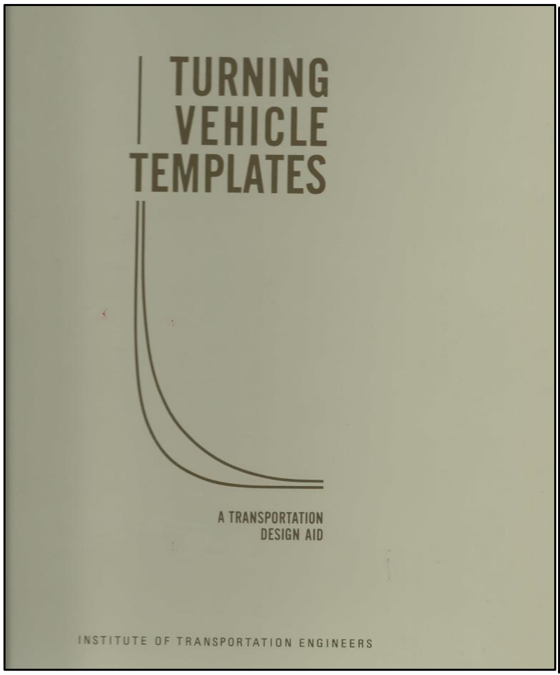


Figure 6 – Example CGRA Templates, WB-40, 1”=40‘, Turn Radii = 40’, 60’, 75’



LIST OF TEMPLATES

VEHICLE TYPE	SCALES	TURNING RADIUS - ft.	AVERAGE SIZE - in.	NUMBER OF TEMPLATES
LARGE SEMITRAILER WB-50	1" = 20' 1" = 40' 1" = 50'	R = 45, 60 & 75 " " " " " "	8 X 10 7 X 7 7 X 7	3 3 3
SMALL SEMITRAILER WB-40	1" = 20' 1" = 40' 1" = 50'	R = 40, 60 & 75 " " " " " "	8 X 10 7 X 7 7 X 7	3 3 3
BUS B-40	1" = 20' 1" = 40' 1" = 50' 1" = 20'	R = 42 & 60 " " " " R = 42 to 150 Bar Template	8 X 10 7 X 7 7 X 7 8 X 10	2 2 2 1
SINGLE UNIT TRUCK SU-30	1" = 20' 1" = 40' 1" = 50' 1" = 20'	R = 42 & 60 " " " " R = 42 to 150 Bar Template	8 X 10 7 X 7 7 X 7 8 X 10	2 2 2 1
PASS. CARS Large - P Medium - P_m	 1" = 20' 1" = 20'	 R = 24 R = 21	 7 X 7 7 X 7	 1 1
EXTRA LARGE SEMITRAILER WB-60	1" = 20' 1" = 40' 1" = 50'	R = 45, 60 & 75 " " " " " "	8 X 10 7 X 7 7 X 7	3 3 3

Figure 7 – 1977-1987 Imperial System Templates, Jack E. Leisch & Associates

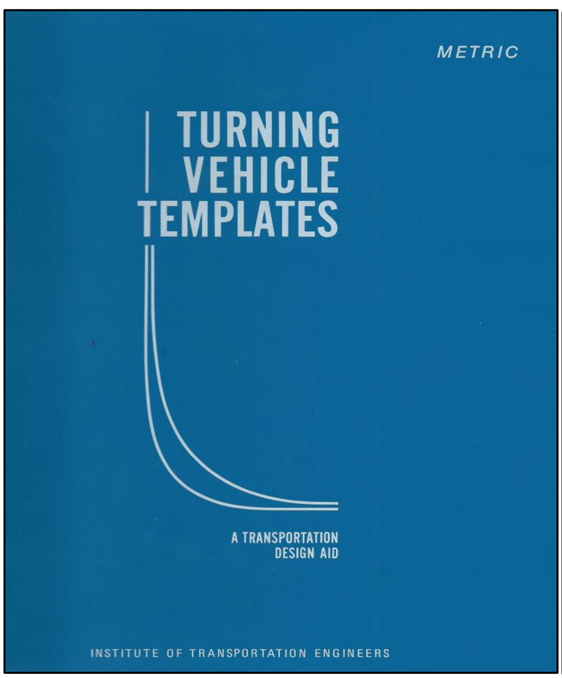


Table 2
List of Templates

VEHICLE TYPE	SCALES	TURNING RADIUS – m.	AVERAGE SIZE – cm.	NUMBER OF TEMPLATES
LARGE SEMITRAILER WB-15	1:250 1:500	R = 14, 18 & 23 " " "	20 X 25 18 X 18	3 3
SMALL SEMITRAILER WB-12	1:250 1:500	R = 12, 18 & 23 " " "	20 X 25 18 X 18	3 3
BUS B-12	1:250 1:500 1:250	R = 13 & 18 " " R = 13 to 50 Bar Template	20 X 25 18 X 18 20 X 25	2 2 1
SINGLE UNIT TRUCK SU-9	1:250 1:500 1:250	R = 13 & 18 " " R = 13 to 50 Bar Template	20 X 25 18 X 18 20 X 25	2 2 1
PASS. CARS Large P	1:250 1:250	R = 7.5 R = 7.5 to 30 Bar Template	18 X 18 18 X 18	1 1
Medium P_m	1:250 1:250	R = 6.5 R = 6.5 to 30 Bar Template	18 X 18 18 X 18	1 1
Small P_s	1:250 1:250	R = 5.5 R = 5.5 to 30 Bar Template	18 X 18 18 X 18	1 1
EXTRA LARGE SEMITRAILER WB-18	1:250 1:500	R = 14, 18 & 23 " " "	20 X 27 18 X 19	3 3

Figure 8 – 1977-1987 Metric Templates, Jack E. Leisch & Associates

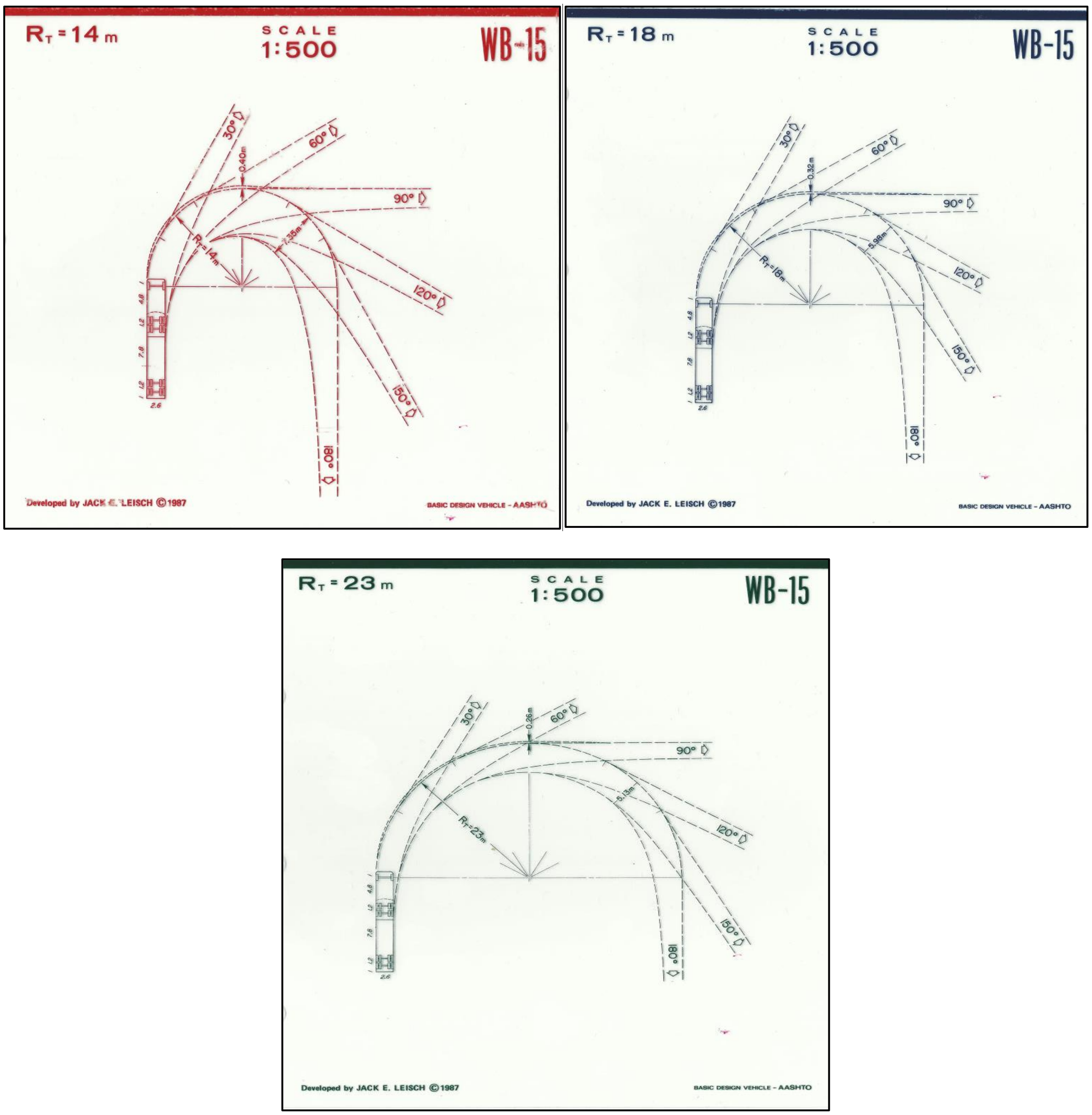


Figure 9 -- Example Jack E. Leisch Templates, Metric, WB-15, 1:500, Turn Radii = 14m, 18m, 23m

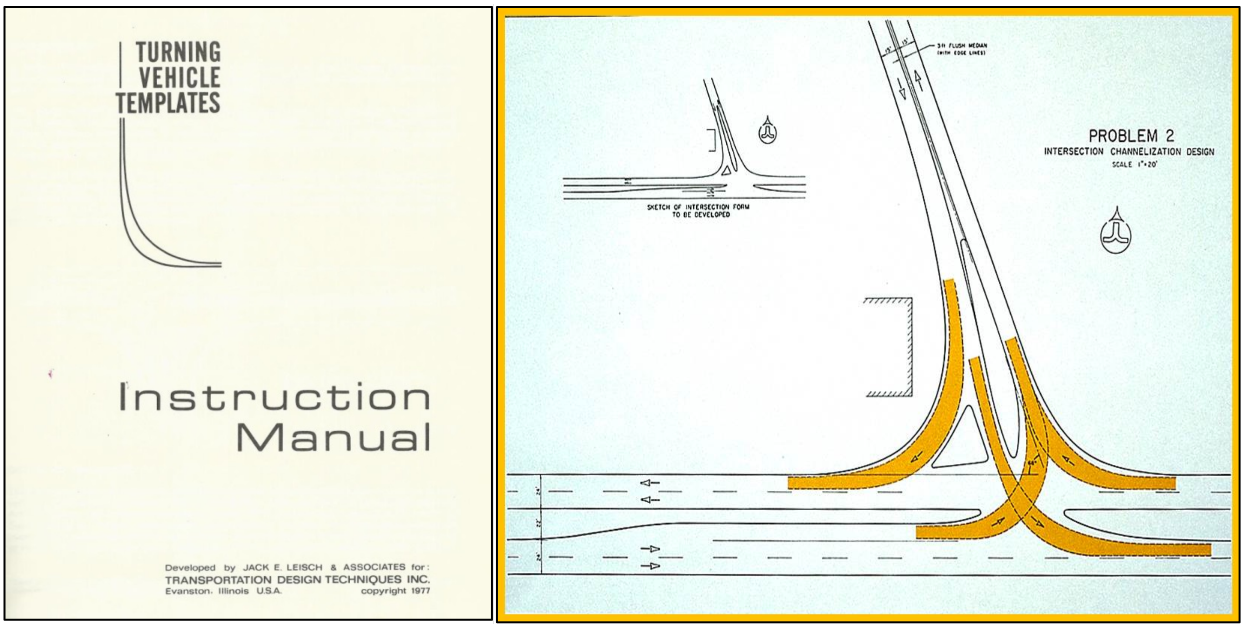


Figure 10 – Instruction Manual and Example Intersection

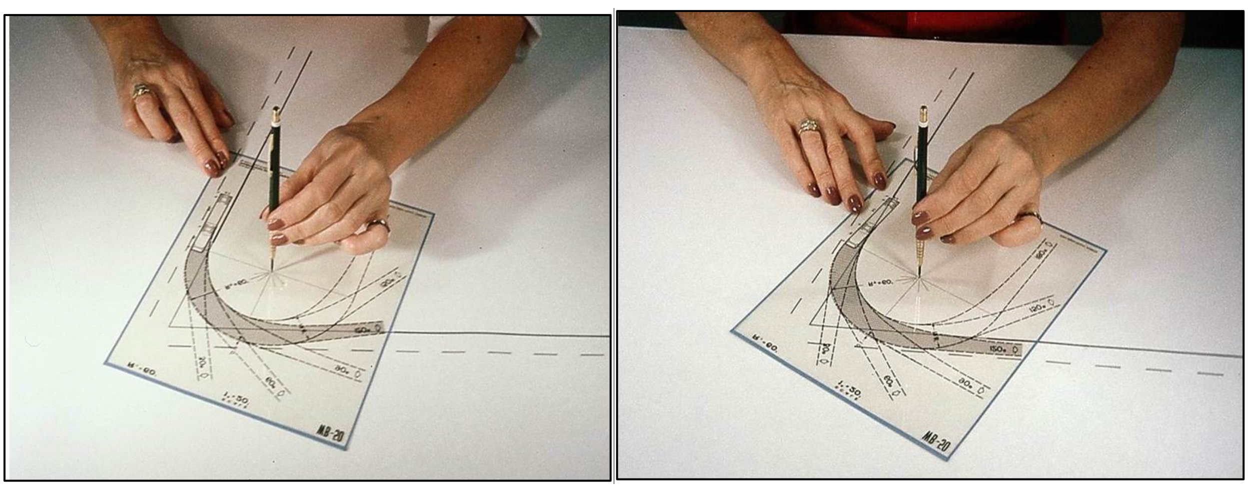


Figure 11 – Demonstration of Template Swept Path Design in Manual

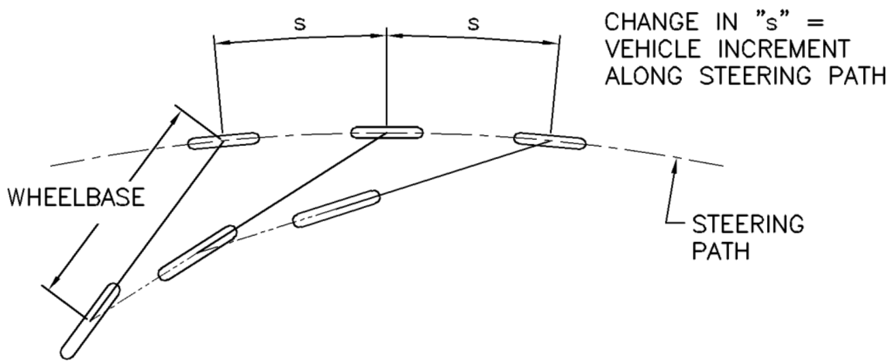


Figure 12a – Bicycle Model Concept

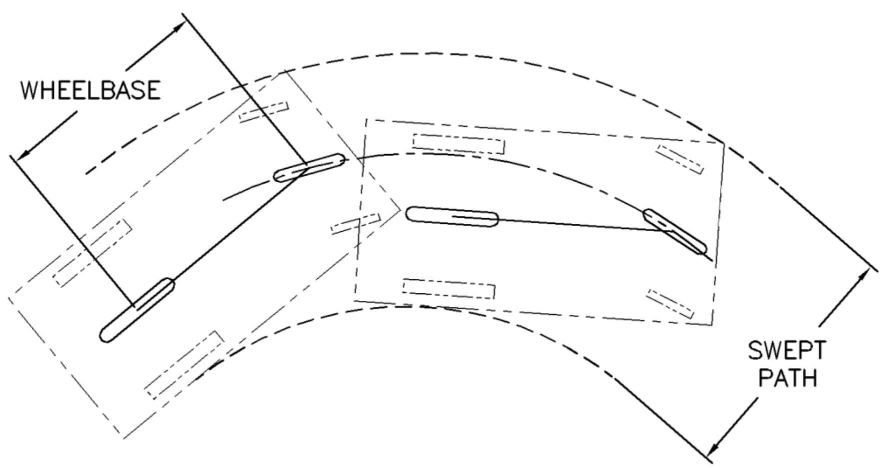


Figure 12b – Illustration Showing how Simulation and Swept Path is derived from Bicycle Model

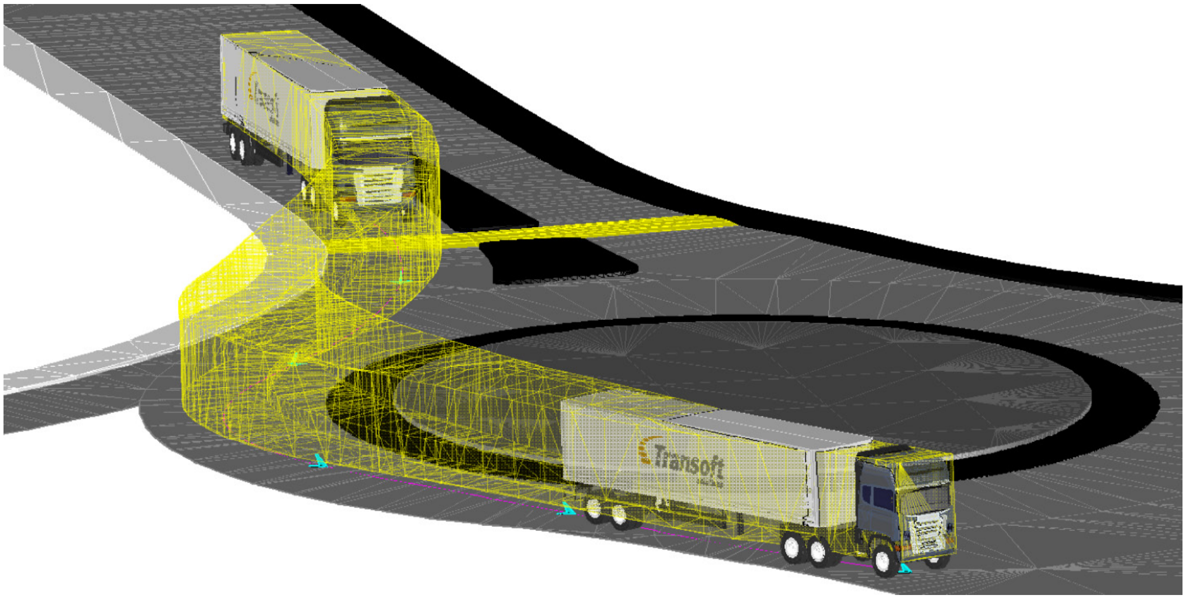


Figure 13 – Perspective of 3D Simulation

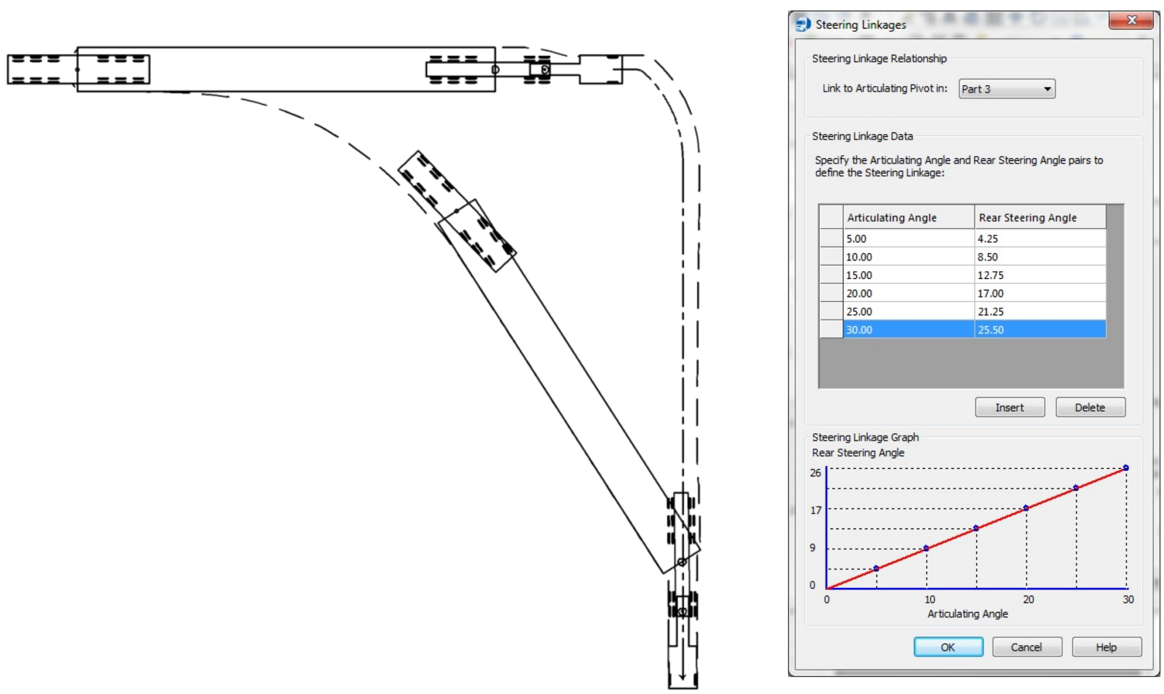


Figure 14– Example of a Special Transport Vehicle with Steering Linkage

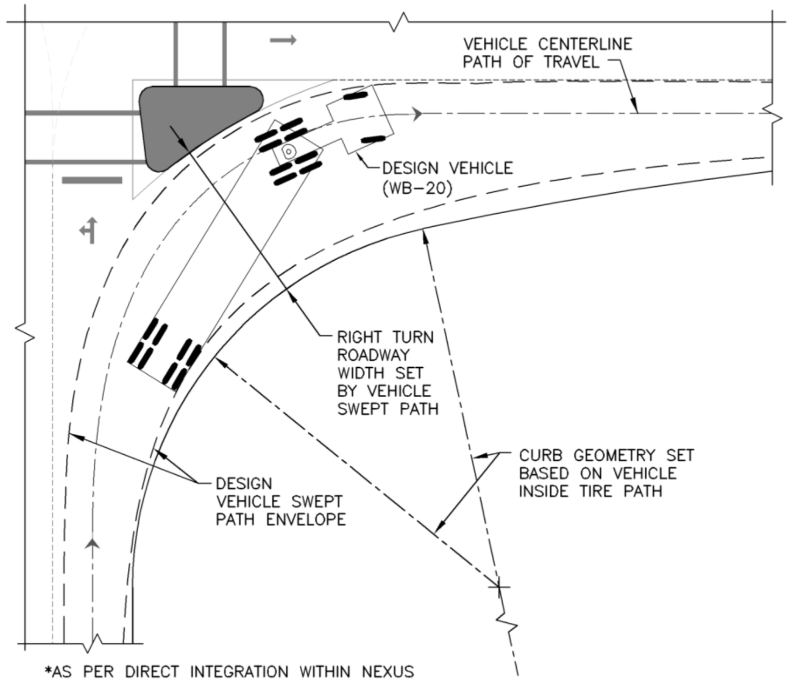


Figure 15a – Example of Direct Integrated Swept path – Intersection Right Turn

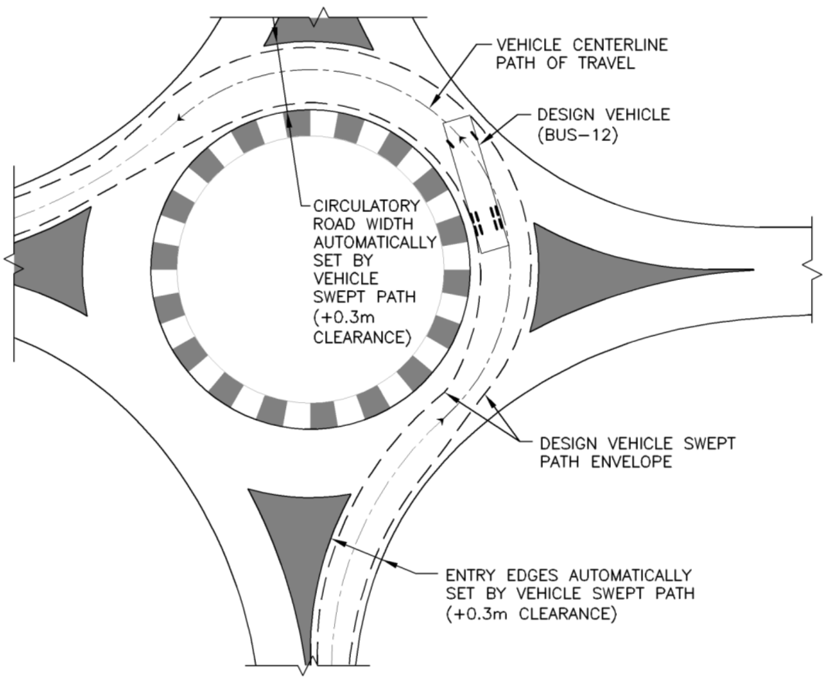


Figure 15b – Example of Direct Integrated Swept path – Roundabout

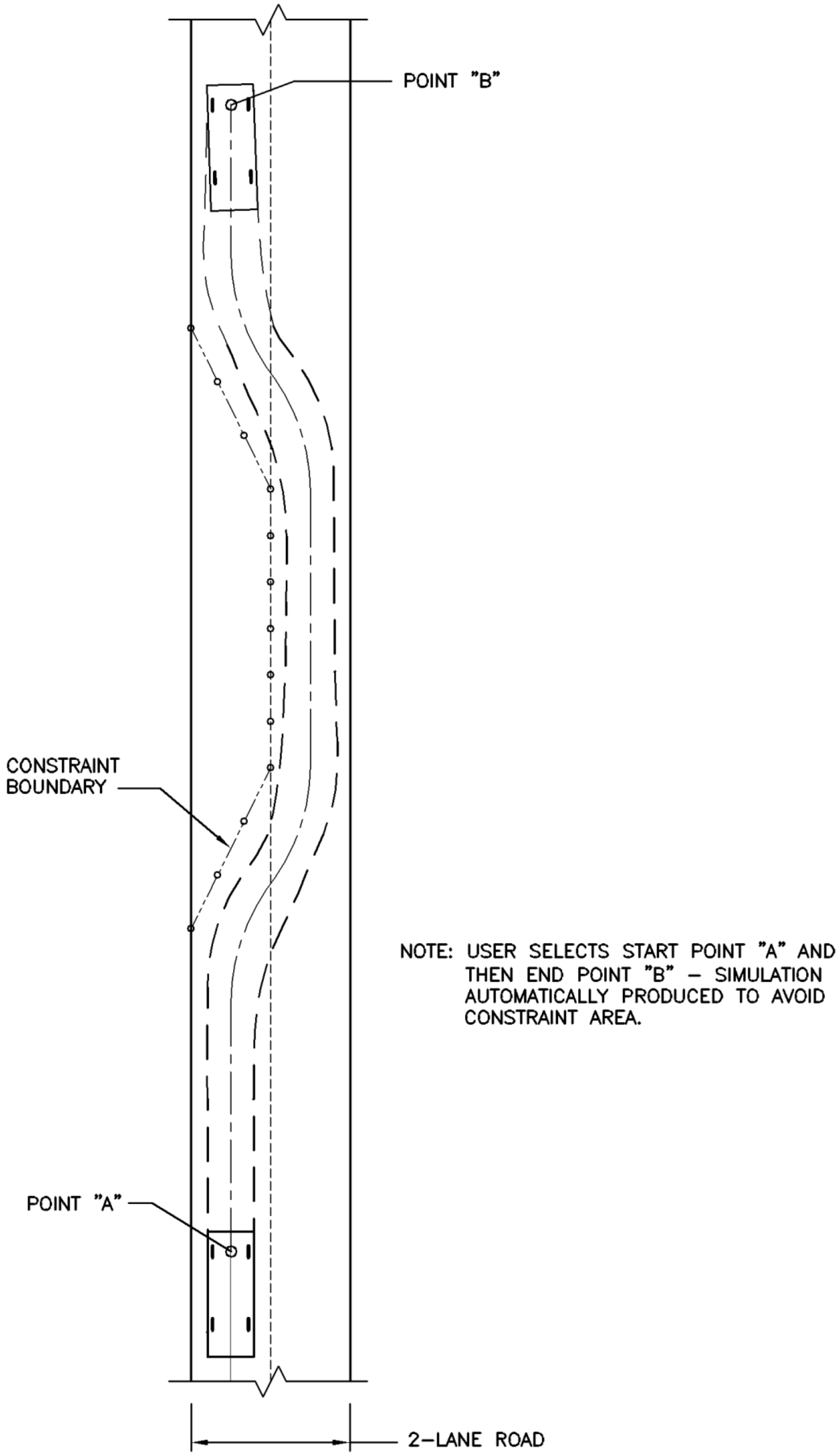


Figure 16 – Intelligent Path Concept