2. APTA PR-CS-RP-003-98 Recommended Practice for Developing a Clearance Diagram for Passenger Equipment

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Abstract: This recommended practice provides a guide for passenger railroads to determine their particular equipment clearance requirements and develop a clearance diagram sufficiently specific to allow equipment designers to develop designs that will conform to those requirements. It has two specific limitations:

1. It is not intended to lead to the development of a universal passenger equipment diagram, because such a diagram would be too restrictive in one way or another to most passenger railroads.

2. It is based on conventional types of trucks and does not consider tilt suspension systems. If an unconventional truck design or a tilt suspension is employed, these procedures may have to be modified to suit the particular vehicles.

Keywords: clearance diagrams.

Introduction

The Association of American Railroads (AAR) maintains clearance diagrams governing the interchange of freight cars among railroads. There are five such diagrams -- AAR Plates B, C, E, F, and H. Plate B is the oldest and least generous of the five, and there are no restrictions on the movement of cars meeting its requirements. The other four diagrams have been developed in response to new types of freight cars. Cars designed to the requirements of these diagrams are restricted from certain portions of the railroad network.

AAR also developed a clearance diagram for unrestricted interchange of passenger cars. It was adopted as Standard S-035 in 1952 and was revised in 1953. It appears on page A-III-10 of AAR's **Manual of Standards and Recommended Practices**, Section A, Part III. Section A is out of print and no longer maintained by AAR. Many passenger cars not meeting the requirements of Standard S-035 have been built, but each such design had to be specially cleared for the routes over which it was to operate.

There are many differences between the passenger car clearance diagram and the various freight car clearance diagrams. The passenger car clearance diagram is more restrictive in height. It is also more restrictive with respect to maximum car width, although it allows greater overhang on curves. There are also some differences in the shapes of the diagrams at the top and at the bottom, presumably because of restrictions such as station platforms, platform canopies, and third rails that occur only in passenger facilities or on passenger tracks.

Since Amtrak was created in 1971, it has developed its own clearance diagrams (although Amtrak regularly operates equipment not meeting all of the requirements of these diagrams). Since Amtrak operates all intercity passenger service in the continental United States, it has not been faced with the same concern over interchangeability that existed when such services were operated by a multiplicity of railroads. Amtrak has generally required that new commuter equipment to be operated on its track must meet the provisions of its clearance diagrams. This restriction does not exist if the equipment is to be operated on a freight railroad or on a commuter railroad's own track.

In summary, there is little standardization of passenger car clearance requirements. Passenger cars constructed to AAR Standard S-035 may not meet the requirements of Amtrak's clearance diagrams. This is also true of much commuter equipment. Consequently, each passenger railroad is faced with the task of determining its particular clearance requirements.

During the investigation into passenger car clearance diagrams, APTA concluded that one or more universal passenger car clearance diagrams would not be feasible, because a diagram containing the most restrictive conditions of each passenger railroad would probably not be acceptable to any of them. Consequently, APTA opted to produce a procedure that could be followed by individual passenger railroads to develop their own clearance diagrams. This procedure identifies the various factors that should be taken into account and explains how they affect the final diagram.

Participants

The American Public Transportation Association greatly appreciates the contributions of the following individual(s), who provided the primary effort in the drafting of the *Recommended Practice for Developing a Clearance Diagram for Passenger Equipment.*

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1. Overview

Sections 1.1 and 1.2 define this recommended practice's scope and purpose. Sections 2 and 3 provide reference information, section 4 guides the user to the appropriate subsequent sections based on the passenger railroad's track ownership. Section 5 provides a checklist of steps to take in defining the clearance requirements for equipment (locomotives and cars) to be operated on a passenger railroad's own track, together with some specific recommendations. Section 6 describes the steps to take in defining the clearance requirements for equipment to be operated only on another railroad's track. Section 7 describes the steps to take in combining the clearance requirements for a passenger railroad's own track with those for another railroad's track.

1.1 Scope

This recommended practice provides a guide for passenger railroads to (1) determine their particular equipment clearance requirements and (2) develop a clearance diagram sufficiently specific to allow equipment designers to develop designs that will conform to those requirements. It has two specific limitations:

– It is not intended to lead to the development of a universal passenger equipment diagram, because such a diagram would be too restrictive in one way or another to most passenger railroads.

– It is based on conventional types of trucks and does not consider tilt suspension systems. If an unconventional truck design or a tilt suspension is employed, these procedures may have to be modified to suit the particular vehicles.

The procedure outlined in this recommended practice is based on facts and principles that are well understood in the railroad industry. However, it has not been tested as a comprehensive procedure. Therefore, it is the responsibility of the railroad to validate the results prior to implementation.

1.2 Purpose

Sections 4-6 of this recommended practice help the user through the process of developing the information necessary to establish an equipment clearance diagram, as follows:

Section 4 guides the user to either Section 5 or Section 6 based on the ownership of the track over which the passenger railroad operates.

Section 5 provides a checklist of steps to take in defining the clearance requirements for equipment (locomotives and cars) to be operated on a passenger railroad's own track, together with some specific recommendations. It is broken down into fixed obstructions along the right of way (Section 5.1), legal clearance restrictions (Section 5.2), equipment characteristics (Section 5.3), and track irregularities (Section 5.4).

Section 6 describes the steps to take in defining the clearance requirements for equipment to be operated on another railroad's track.

If the particular passenger railroad's equipment is operated both on its own and other railroad's tracks, the steps in both Sections 5 and 6 apply. The final clearance diagram should take into consideration the most restrictive conditions that exist on any of the lines over which the equipment will be operated, as described in Section 7.

2. References

2.1 Publications

"Clearances"; *Manual for Railway Engineering* (latest revision), Chapter 28; American Railway Engineering and Maintenance-of-Way Association (formerly American Railway Engineering Association).

Standard S-2026-88, "Equipment Diagram for Unrestricted Interchange Service, Plate B"; *Manual of Standards and Recommended Practices*, Section C, Part I (latest revision); Association of American Railroads.

Standard S-2028-91, "Equipment Diagram for Limited Interchange Service, Plate C"; *Manual of Standards and Recommended Practices,* Section C, Part I (latest revision); Association of American Railroads.

Standard S-2031-74, "Equipment Diagram for Limited Interchange Service, Plate E; *Manual of Standards and Recommended Practices*, Section C, Part I (latest revision); Association of American Railroads.

Standard S-2032-74, Equipment Diagram for Limited Interchange Service, Plate F"; *Manual of Standards and Recommended Practices*, Section C, Part I (latest revision); Association of American Railroads.

Standard S-2040-93, 2032-74, "Equipment Diagram for Double-Stack Container CarsLimited Interchange Service, Plate HF"; *Manual of Standards and Recommended Practices,* Section C, Part I (latest revision); Association of American Railroads.

Standard S-2040-93, "Equipment Diagram for Double-Stack Container Cars, Plate H"; *Manual of Standards and Recommended Practices*, Section C, Part I (latest revision); Association of American Railroads.

Standard S-035-53, "Passenger Equipment Diagram Unrestricted for Interchange Service"; *Manual of Standards and Recommended Practices*, Section A (obsolete), Part III (1953), p. A-III-12; Association of American Railroads.

2.2 Software

PASCLEAR, American Public Transportation Association, a Lotus 1-2-3 spread sheet for calculating clearance diagrams. This spreadsheet is included as a separate file on the CD-Rom that contains all six volumes of this Manual.

3. Definitions, abbreviations and acronyms

3.1 Definitions

3.1.1 Amtrak: National Railroad Passenger Corporation

3.1.2 c. g.: Height of center of gravity of vehicle above top of rail.

3.1.3 clearance diagram: As used in this document, this term means a cross-sectional drawing showing the limiting dimensions to which railroad equipment may be constructed. It is normally qualified in two ways. First, it specifies that the overhang of the equipment on a curve of specified radius may not exceed the overhang on the same curve of a piece of equipment with a specified length between truck centers and built to the full diagram width. Second, it usually specifies some body deflection conditions under which the requirements of the diagram must still be met.[1]

3.1.4 curvature: The severity of a track curve expressed in degrees and minutes.

3.1.5 equipment: Locomotives and cars.

3.1.6 right of way: The land on which the railroad track and associated structures (bridges, tunnels, signals, platforms, etc.) are located.

3.1.7 elevation: The difference in height between the outside and inside rails on a curve to compensate (at least partially) for the centrifugal force of a train going around the curve.

3.1.8 tangent: Straight; without curvature.

3.2 Acronyms

AAR	Association of American Railroads
AREA	American Railway Engineering Association[2]
AREMA	American Railway Engineering and Maintenance-of-Way Association[3]

4. General approach to establishing a clearance diagram

(Note: Bullet items in bold print throughout Sections 4-7 provide a checklist of actions to be taken in developing a clearance diagram.)

[1] Strictly speaking, the term "clearance diagram" refers to a diagram based on fixed obstructions along the right of way which must be cleared by passing trains; this is the sense in which the term is used by AREA. The diagram whose development is described in this recommended practice is called an "equipment diagram" by AREA. It would be described more completely as an "equipment construction limit diagram", but this term is cumbersome. Thus, this recommended practice follows the common practice of referring to this diagram as a "clearance diagram".

[2] On January 1, 1998, the name of this organization was changed to American Railway Engineering and Maintenance-of-Way Association.

[3] The new name of the American Railway Engineering Association as of January 1, 1998.

The approach to be followed in establishing a clearance diagram for a passenger railroad's equipment will vary depending on whether the equipment is to be operated:

– Only on track owned by the passenger railroad.

– Both on track owned by the passenger railroad and on track owned by another railroad.

– Only on track owned by another railroad.

Therefore, the following steps are necessary:

- **Identify ownership of the track over which the equipment will operate.**

- **If the particular passenger railroad's equipment is to be operated:**

  - **Only on its own tracks, go to section 5.0.**

  - **Both on its own and another railroads tracks, go to section 5.0.**

  - **Only on another railroad's tracks, go to section 6.0.**

Each of the subsections in Sections 5 and 6 contain a list of steps to be followed to develop sufficient information on the particular topic.

5. Clearance diagram for track owned by the passenger railroad

The following four separate sets of factors must be considered when developing a clearance diagram for track owned by the passenger railroad:

– Fixed obstructions along the right of way.

– Legal restrictions within the states in which trains will be operated.

– Physical characteristics of the equipment to be operated.

– Track irregularities

These are covered in Sections 5.1, 5.2, 5.3, and 5.4 respectively. The steps to be followed in combining them into a single clearance diagram are described in Section 5.5.

- **Go to Section 5.1.**

5.1 Fixed obstructions along track owned by the passenger railroad

- **Develop a composite diagram of the most limiting conditions along the right of way.**

A suggested method for charting all obstructions along the right of way is presented in Chapter 28, Section 3.3, of the AREMA (formerly AREA) ***Manual for Railway Engineering***. It consists of developing a composite diagram in a plane transverse to the track on which are drawn the most limiting obstructions around the complete perimeter of the space through which the equipment will operate. The location of each obstruction is also recorded. When an obstruction is not on tangent track, the track curvature and elevation at that point are also recorded.

As explained in Section 5.4, it is also important to know the authorized train speed at each obstruction. Knowing the location of an obstruction, the authorized speed at that location can be determined from the railroad's operating timetable.

- **Go to Section 5.2.**

5.2 Legal clearance restrictions

- **Review legal clearance requirements for the states in which the equipment will operate.**

Legal clearance requirements for the various states and the District of Columbia are summarized in simplified form in the table in Chapter 28, Section 3.6, of the AREMA Manual for Railway Engineering. The limiting dimensions for platforms shown in columns 24-29 are of particular concern.

Since this table is merely a summary, the full text of an individual state's clearance regulation should be reviewed if there is a question about any of the limiting dimensions shown.

- **Add to the composite diagram any legal requirements that are more limiting than the restrictions already identified.**

Any clearance limitations from the table in Chapter 28, Section 3.6, of the "AREMA Manual for Railway Engineering" that are more restrictive than the limitations identified in Section 5.1 should be added to the right-of-way restriction diagram developed in that section.

At this point the composite diagram will contain all of the most restrictive physical and legal limitations. However, this diagram is not adequate as an equipment clearance diagram for the following reasons:

- The effect of track curvature at the point of obstruction has not yet been evaluated.
- Lateral displacement of equipment permitted by design tolerances and by equipment and track component wear must be considered.
- Vertical and angular body displacement caused by spring deflection must be considered.
- This diagram is based on track which has a defined curvature and elevation. Therefore, a safety factor must be incorporated to allow for further deflections caused by track variations from the standard (defined) condition.

- **Go to Section 5.3.**

5.3 Equipment characteristics

Equipment characteristics pertinent to the development of a clearance diagram fall into two general categories. The first category consists of fixed dimensions or dimensional limitations that may be defined in advance for all equipment and are discussed in Section 5.3.1. The second category consists of factors that cannot be defined with fixed values because they vary with the type of equipment and are discussed in Section 5.3.2.

- **Go to Section 5.3.1.**

5.3.1 Fixed equipment dimensions and dimensional limitations

Certain basic equipment dimensions can be either defined or limited in advance to simplify the process of constructing an equipment clearance diagram. These include the distance between truck centers, the extreme width, and the minimum clearance above the top of the rail. These three dimensions are discussed in Sections 5.3.1.1, 5.3.1.2, and 5.3.1.3, respectively.

- **Go to Section 5.3.1.1.**

5.3.1.1 Truck centers

- **Select the distance between truck centers on which the equipment clearance diagram is to be based.**

  The center and end overhang of equipment on curves must both be considered in determining clearances. Since the amount of overhang at both the center and the ends of the vehicle varies with the distance between truck centers, it is necessary to specify a distance between truck centers as the basis for the clearance diagram. Passenger cars are longer than passenger locomotives, so it is the cars that govern in selecting this dimension.

  The end overhang of a railroad car is a function of both the distance between truck centers and the overall length of the car. As a general rule, the car designer prefers to select a distance between truck centers that will equalize the center and end overhang as much as possible, thereby optimizing the car width. In practice, however, there may be other design considerations that affect the truck placement. It is recommended that a distance between truck centers of 59'-6" (18.13 m) be used as the basis of the clearance diagram unless the equipment being operated by a particular passenger railroad is constructed to a different dimension.

- **Go to Section 5.3.1.2.**

5.3.1.2 Extreme width

- **Establish the extreme width permissible at any point throughout the height of the equipment.**

  It is recommended that the extreme width not exceed 10'-6" (3.20 m) at any point throughout its height regardless of right-of-way obstructions. In no case should the extreme width exceed 10'-8"(3.25 m).

- **Go to Section 5.3.1.3.**

5.3.1.3 Clearance above top of rail

- **Establish the minimum acceptable clearance above the top of the rail under the most severe conditions of wear and spring deflection.**

  It is recommended that the minimum clearance above the top of the rail for all parts of the car except the wheels be 2" (5 cm). This limitation should apply under the most severe conditions of wear and dynamic spring deflection. In the case of air springs, the most severe deflection occurs with fully deflated springs.

- **Go to Section 5.3.2.**

5.3.2 Variable equipment characteristics

(Note: The following discussion is based on the use of conventional types of trucks and does not consider tilt suspension systems. If an unconventional truck design or a tilt suspension is employed, these procedures may have to be modified to suit the particular vehicles.)

The extreme lateral and vertical displacement of the vehicle body from its normal position is affected by various design tolerances, wear limits, suspension characteristics, and track irregularities. There are two ways to deal with these factors.

The first way is to analyze each individually and combine the results. Tolerances are discussed in Section 5.3.2.1, wear limits in Section 5.3.2.2, suspension characteristics in Section 5.3.2.3, and track irregularities in Section 5.3.2.4.

- **If this approach is to be followed, go to Section 5.3.2.1.**

The alternative is to perform a static test and apply appropriate correction factors in a procedure outlined by AREMA. This is discussed in Section 5.3.2.3.

- **If this approach is to be followed, go to Section 5.3.2.3.**

5.3.2.1 Design tolerances

Design tolerances that affect the lateral displacement of the body include the following:

1. **Lateral tolerance between wheels and rails**

   Two types of flanges are permitted on railroad wheels - narrow and wide. The maximum lateral movement $\mathbf{T_1}$ possible for a new wheel set centered on in-gage track is a function of the flange type and is determined by the following formula:

   CAUTION: Use only English Units in Formulas in this Recommended Practice

   $\mathbf{T_1 = .5[g_t-(g_w+2f_n)]}$
   = .59375" for narrow-flange wheels
   = .375" for wide-flange wheels

   Where: g_t = standard track gage at a point "5/8" below top of rail = 56.5"

g_w = minimum gage of wheel set between backs of flanges = 53”
f_n = minimum thickness of new wheel flange = 1.15625” for narrow flange or = 1.375" for wide flange

2. Tolerance between center plate and center bowl

The manufacturers’ drawings will show the exterior diameter of the center plate and the interior diameter of the center bowl. The maximum lateral movement $\mathbf{T_2}$ possible for a new center plate centered in the center bowl is:

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$\mathbf{T_2 = .5(d_b - d_p)}$$

Where: d_b= center bowl diameter
d_p = center plate diameter

3. Side bearing clearance

If the side bearings are not of the constant-contact type, there is a nominal design clearance between the body side bearing and the truck side bearing. Rocking of the body on the center plates will allow the body and truck side bearings to contact. Since the static lean test described in Section 5.3.2.3 includes the effect of side bearing clearance, it need not be calculated separately.

4. Relative motion between truck bolster and frame

On trucks where the bolster is not part of the truck frame and is supported by swing hangers, relative lateral movement occurs between the bolster and frame. The manufacturer’s drawings must be consulted to determine the maximum lateral movement $\mathbf{T_3}$ of the bolster from its neutral position.

This item does not apply if the truck bolster is an integral part of the truck frame.

5. Relative motion between floating bolster and body

Where a floating bolster is used between the truck and the body (to accommodate air springs or a combination of air and coil springs), the manufacturer’s drawings must be consulted to determine the maximum lateral movement $\mathbf{T_4}$ of the floating bolster from its neutral (centered) position.

This item does not apply if there is no floating bolster.

6. Relative motion of roller bearing with respect to adapter and truck frame

Manufacturers’ drawings for the roller bearing, adapter, and truck frame must be consulted to determine the maximum possible lateral movement between the roller bearing and the adapter and between the adapter and the truck frame. The maximum lateral movement $\mathbf{T_5}$ between the truck frame and the roller bearing in its neutral (centered) position is then determined by the formula:

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$T_5 = .5(t_{ba}+t_{af})$$

Where: t_{ba} = maximum design lateral movement between roller bearing and adapter
t_{af} = maximum design lateral movement between adapter and truck frame

Determine the maximum total lateral movement of the body with respect to the track resulting from design tolerances by the formula $T_{tot} = T_1 + T_2 + T_3 + T_4 + T_5$ using the values determined in 1., 2., 4., 5., and 6. above.

5.3.2.2 Wear limits

Wear that affects the lateral displacement of the body includes the following:

1. **Wheels**

The minimum allowable thickness of a wheel flange (under AAR rules) is 15/16" (2.38 cm). Flange wear translates directly into increased lateral displacement. The maximum permissible reduction in flange thickness $\mathbf{W_1}$ is:

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$W_1 = f_n - f_c$$

Where: f_n = minimum thickness of new wheel flange = 1.15625” for narrow flange or 1.375" for wide flange
f_c = condemning thickness of wheel flange = .9375”

Using AAR limits, therefore, $\mathbf{W_1}$ = 1.15625" - .9375" = .625" for narrow-flange wheels, and $\mathbf{W_1}$ = 1.375" - .9375" = .4375" for wide-flange wheels. If the passenger railroad uses a different condemning limit for flange thickness, these calculations must be adjusted accordingly.

2. **Rail**

Wear of the inside of the rail head translates directly into increased track gage. Track gage is one of the factors considered by the Federal Railroad Administration (FRA) in determining track class; track class, in turn, determines the maximum speed at which trains are allowed to operate. If wear on the inside of the rail head $\mathbf{W_2}$ is assumed to be one-half of the increase in track gage, then it is determined by the following formula:

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$W_2 = .5(g_m - g_t)$$

Where: g_m = maximum track gage for class of track over which trains are operated
g_t = standard track gage at a point below top of rail = 56.5”

The values of $\mathbf{g_m}$ and $\mathbf{W_2}$ for various FRA classes of track over which passenger trains are likely to operate are:

FRA Track Class	Maximum Passenger Train Speed	Maximum Track Gage $\mathbf{g_m}$	Rail Head Wear $\mathbf{W_2}$
3	60 mph	57.75"	.625"
4	80 mph	57.50"	.50"
5	90 mph	57.50"	.50"
6	110 mph	57.25"	.375"

3. Center plates and center bowls

Wear limits for center plates and center bowls are at the discretion of the individual passenger railroad. The AAR limit for the difference between the center bowl diameter and the center plate diameter on freight cars is 1” (2.54 cm). It is recommended that this limit not be exceeded on passenger cars.

The maximum lateral displacement $\mathbf{W_3}$ of the car body resulting from wear of the center plate and center bowl is determined by the following formula:

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$\mathbf{W_3 = .5d_\Delta - T_2}$$

Where: $\mathbf{d_\Delta}$ = maximum permissible difference in diameters of center plate and center bowl
$\mathbf{T_2}$ = maximum lateral movement of new center plate centered in center bowl (see Section 5.3.2.1, Item 2)

- **Determine the maximum total lateral movement of the body with respect to the track** resulting from wear by the formula $W_{tot} = W_1 + W_2 + W_3$ using the values calculated in 1.-3. above.

- **Go to Section 5.3.2.3.**

5.3.2.3 Suspension Characteristics

The following equipment characteristics related to the suspension system affect the amount of static lean of the vehicle on elevated track:

1. Height of center of gravity of body above top of rail

When the center of gravity (c.g.) of the vehicle body is offset from the center of the center plate, it applies a moment to the trucks which will increase the load on the springs (and, therefore, the spring compression) on the side toward which the offset occurs and decrease it on the other side.

For new vehicles, the body c.g. height should be available from the manufacturer. Since the worst case of body lean needs to be identified, this c.g. should be for the fully loaded vehicle. If only the empty-vehicle c.g. is available, it will need to be modified to reflect the loaded condition.

2. Height of center plate bearing surface above top of rail

The center plate is the point about which the body rotates on the trucks. The moment arm through which the center of gravity operates when the vehicle is on elevated track is a function of the center plate height, the c.g. height, and the amount of elevation.

3. Spring rate

The compressive force on a spring per unit of deflection is the spring rate (usually expressed in pounds per inch). Some types of springs (e.g., conventional steel coil springs) have a relatively constant spring rate throughout their normal range of deflection. Others (e.g., inclined rubber chevron springs) have a spring rate that increases with deflection. The spring rates can be supplied by either the spring manufacturers or the truck manufacturers.

There are suspension designs in which two different kinds of springs are stacked (e.g., a steel coil spring on top of an air spring). In such a case, the composite spring rate must be calculated.

4. Lateral Distance between Center of Spring(s) and Longitudinal Center Line of Vehicle

The lateral distance between the center of the spring(s) and the center line of the vehicle is the moment arm that determines the compressive force on the spring(s) resulting from the moment created by the offset of the body c.g.

In the simplest suspension designs, this is a single dimension. There are many passenger car suspensions, however, that employ primary and secondary suspensions whose springs are not in vertical alignment. This is especially common where air springs are located between a floating bolster and the vehicle body, while mechanical springs are located at, or in line with, the journal box.

5. Side Bearing Clearance

Side bearing clearance will allow the vehicle body to roll freely until contact is made, at which point the load on the springs on that side of the vehicle will start to increase. With constant-contact side bearings, there is no clearance, so any body roll is translated immediately into increased spring loading.

6. Lateral Distance between Center of Side Bearing and Longitudinal Center Line of Vehicle

The lateral distance between the center of the side bearing and the center line of the vehicle, together with the side bearing clearance, determines the angle through which the vehicle body can roll before side bearing contact occurs.

Although the six parameters described above, together with the amount of elevation, are sufficient to calculate body lean on elevated track, the calculation is not simple, because it involves several equations and an iterative solution process. A more practical alternative is to conduct a static lean test of an actual vehicle.

The AREMA *Manual for Railway Engineering*, Chapter 28, Part 3, contains a procedure for conducting such a test. The AREMA procedure determines the combined lateral displacement caused both by leaning and by lateral displacement due to tolerances and wear. In order to use this procedure as written to obtain the maximum lateral displacement, it would be necessary to conduct the test on a car in which all of the pertinent truck and suspension components were worn to their limits.

Because of the cost and difficulty involved in preparing such a car for testing, it is recommended that the relative lateral shift of the various test car components mentioned in Sections 5.3.2.1 and 5.3.2.2 should be measured during the test, and these shifts should be subtracted from the test results so that the test results represent only the lateral displacement resulting from vehicle lean. Since the potential lateral displacements due to design tolerances and wear were already calculated in Sections 5.3.2.1 and 5.3.2.2, they can be added in as needed.

If it is not feasible to obtain lean data from an equipment lean test**,** the data must be estimated for various levels of elevation by means of the series of calculations described in Section 5.3.2.3 based on anticipated suspension characteristics.

- **Develop static lean data for various amounts of elevation either by calculation or by conducting a static lean test as described above. If a static lean test is conducted, the side bearings should be adjusted to their maximum permissible clearance, and the total lateral displacement of the body should be measured for each case.**

- **If a static lean test is conducted, adjust the results by subtracting relative lateral displacements (corrected for lean angle) of the various components itemized in Sections 5.3.2.1 and 5.3.2.2 to obtain lateral displacements due to lean only.**

- **Whether the static lean data are developed by calculation or by test, add to the lean-induced lateral displacements the maximum lateral displacements (adjusted for lean angle) due to design tolerances and wear as determined in Sections 5.3.2.1. and 5.3.2.2. Plot data in a graph similar to Figure 3 in AREMA *Manual for Railway Engineering*, Chapter 28, Part 3.**[4]

This graph presents static lean data. The next step is to determine the lean of a moving vehicle. In order to do this, the unbalanced elevation must be calculated at each obstruction located on a curve.

[4] This procedure adds the maximum component displacements to the lateral lean-induced displacement for all levels of elevation. In reality, the component displacements will be somewhat affected by the amount of elevation. Therefore, a straight line drawn through all of the plotted points will probably not pass through the zero of coordinates. It is recommended that a straight line be drawn through the zero of coordinates from the point representing the highest test elevation.

The first step in doing this is to calculate the equilibrium elevation[5] corresponding to each obstruction using the formula:[6]

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$\mathbf{E_r = 0.0007V^2D}$$

Where: $\mathbf{E_r}$ = elevation required for equilibrium (inches)
$\mathbf{V}$ = vehicle speed (mph)
$\mathbf{D}$ = curvature (degrees)

The next step is to calculate the unbalanced elevation corresponding to each of these obstructions using the formula:[7]

$$\mathbf{E_u = E_r - E_a}$$

Where: $\mathbf{E_u}$ = unbalanced elevation
$\mathbf{E_a}$ = actual elevation

The lateral displacement corresponding to the unbalanced elevation at each obstruction located on a curve can then be determined from the graph plotted as described above.

- **Determine equilibrium elevation corresponding to each wayside obstruction located on a curve as explained above.**
- **Determine unbalanced elevation corresponding to each wayside obstruction located on a curve as explained above.**
- **Determine lateral displacement of vehicle body at location of each wayside obstruction on a curve using graph plotted above.**

The other suspension characteristics that need to be examined are the spring deflection limits. It is necessary to refer to the truck manufacturer's drawings to determine these limits.

The total downward spring deflection possible from the normal empty-car position when under maximum load (including full deflated air springs, if used) will affect the location of appurtenances on the underside of the body, because these appurtenances must comply with the minimum clearance specified above the top of rail (see Section 5.3.1.3).

The total upward spring deflection possible from the normal empty-car position until the springs reach their limit of travel can be assumed to represent the extreme condition for upward bounce of the body. Greater upward movement of the body would result in center plate lift, which cannot be

5 The equilibrium elevation is the elevation at a given speed where the resultant of the vehicle weight and centrifugal force is perpendicular to the plane of the track.

6 Reference AREMA *Manual for Railway Engineering*, Chapter 5, Part 3, "Elevations and Speeds for Curves".

7 Reference AREMA *Manual for Railway Engineering*, Chapter 28, Part 3, Section 3.1.

tolerated, and bounce can be limited by controlling speed.

- **Determine upper and lower limits on vertical body motion as determined by spring deflection limits.**

- **Go to Section 5.4.**

5.4 Track irregularities

Track irregularities are difficult to take into account in a meaningful way, because statically measured irregularities usually change under dynamic load. Even if these irregularities could be defined precisely, their effect on vehicle dynamic behavior varies as a function of all the suspension characteristics defined in 5.3.2.3 plus vehicle speed and distance between truck centers.

There is a simpler way to approximate the effect of track irregularities. Figure 4 in the AREMA *Manual for Railway Engineering*, Chapter 28, Part 3, presents adjustment factors to be applied to the lateral displacements determined from the graph plotted in Section 5.3.2.3 to account for the dynamic behavior of passenger cars over track irregularities. Figure 4 provides these adjustment factors for all speeds up to approximately 93 mph (151.8 km/hr) based on actual measurements of the lean of eight passenger cars with different types of trucks when operated over high-speed track.

- **Determine adjustment factors from Figure 4 in AREMA *Manual for Railway Engineering*, Chapter 28, Part 3, to compensate for the dynamic behavior of equipment operating over track irregularities at the various authorized train speeds.**

- **Apply these factors to the lateral displacements determined in Section 5.3.2.3.**

5.5 Combining information on fixed obstructions, legal requirements, equipment characteristics, and track irregularities into a single diagram

Fixed obstructions along the track were identified and plotted in Section 5.1. Legal clearance requirements were identified in Section 5.2 and were incorporated into the diagram developed in Section 5.1.

Wherever a fixed obstruction occurs on a curve, it can be converted into an equivalent obstruction along tangent track by moving it toward the center line of the track by an amount equal to the offset of the longitudinal center line of the vehicle from the track center line.

If the fixed obstruction is on the inside of the curve, it should be moved toward the center line of the track by an amount equal to the offset of the longitudinal center line of the vehicle from the track center line at a point midway between the truck centers. This offset can be calculated using the equation:

CAUTION: Use only English Units in Formulas in this Recommended Practice

$$\mathbf{L = R-(R^2-T^2/4)^{1/2}}$$

Where: **L** = offset of vehicle center line from track center line at middle of vehicle

R = radius of curve[8]
T = distance between vehicle truck centers on which clearance diagram is to be based (see Section 5.3.1.1)

If the fixed obstruction is on the outside of the curve, it should be moved toward the center line of the track by an amount equal to the offset of the longitudinal center line of the vehicle from the track center line at the end of the vehicle.[9.] This offset can be calculated using the equation:

$$\mathbf{L' = (R^2 - T^2/4)^{1/2} - (R^2 - T'^2/4)^{1/2}}$$

Where: **L'** = offset of vehicle center line from track center line at end of vehicle
R = radius of curve
T=distance between vehicle truck centers on which clearance diagram is to be based (see Section 5.3.1.1.)
T' = overall length of vehicle body (see Section 5.3.1.1.)

The logical next step is to determine the minimum clearance desired between the equipment and the adjusted obstructions in the composite diagram under the most severe conditions of body movement. The composite diagram should then be further modified by moving all fixed obstructions on either side of the track laterally toward the track and all fixed obstructions above the track downward by the amount of minimum clearance desired. At this point the modified composite diagram represents the envelope through which the equipment should be able to operate without violation.

- **Modify the composite diagram developed in Sections 5.1 and 5.2 by:**

  Converting lateral obstructions on curves to equivalent tangent-track obstructions.

  Moving all charted obstructions inward by the amount chosen as the minimum clearance under worst-case conditions.

This modified composite diagram can now be used as the foundation for developing the equipment clearance diagram based on the various factors discussed in Sections 5.3 and 5.4. Each of these factors is discussed below.

1. **Truck Centers (Section 5.3.1.1)**

   At this point, the truck center length has already been taken into account, because it was used when modifying the composite diagram to convert right-of-way obstructions on curves into equivalent obstructions on tangent track.

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[8] If only the curvature in degrees is known, **R** (in feet) may be calculated using the formula **R = 5,729.65/C** where **C** is the curvature in degrees.

[9] Strictly speaking, the offset at the end should be calculated in a radial direction. However, the mathematics are more complex, the difference is very small for typical vehicle lengths and track curvature, and the slight error is in a conservative direction. For example, for an 85" car with a distance between track centers of 59'-6", the difference in the results obtained by the simplified method and the more rigorous method is approximately ¼".

2. **Extreme Width (Section 5.3.1.2)**

Two vertical lines tentatively representing the extreme equipment width should be drawn on the composite diagram. **(Note: 10'-6" (3.20 m) is the recommended maximum dimension under any circumstances.)**

3. **Clearance Above Top of Rail (Section 5.3.1.3)**

A horizontal line representing the minimum clearance above the top of the rail should be drawn on the composite diagram at the proper height. **(Note: The recommended dimension is 2" (5 cm).)**

4. **Design Tolerances (Section 5.3.2.1)**
Wear Limits (Section 5.3.2.2)

The two vertical lines representing the extreme equipment width must be relocated to account for the lateral design tolerances and the maximum permissible lateral wear of both track and equipment suspension components. Each vertical line must be moved outward by an amount equal to $\mathbf{T_{tot}} + \mathbf{W_{tot}}$. ($\mathbf{T_{to}}$ was calculated in Section 5.3.2.1, and $\mathbf{W_{to}}$ was calculated in Section 5.3.2.2.)

5. **Suspension Characteristics (Section 5.3.2.3)**
Track Irregularities (Section 5.3.2.4)

In order to compensate for vertical bounce of the vehicle, the adjusted locations of fixed obstructions over the track that were previously plotted should be moved downward by the amount of the maximum upward spring deflection determined in Section 5.3.2.3.

The vertical lines drawn on the composite diagram in 4. above should be rotated about the body pivot point (usually the center plate) to reflect the dynamic lean at each wayside obstruction located on a curve. This is done by referring to the elevation and authorized train speed corresponding to each obstruction and using the corresponding dynamic lean data from the graph plotted in Sections 5.3.2.3 and 5.4.

The lateral body displacement due to authorized speed in excess of equilibrium speed was determined in Section 5.3.2.3. at each wayside obstruction located on the outside of a curve. These displacements must be adjusted by the appropriate dynamic allowance factors from Table 4 in the AREMA *Manual for Railway Engineering*, Chapter 28, Part 3. The vertical lines drawn on the composite diagram in 4 above should then be rotated about the body pivot point (usually the center plate) to reflect the outward lean at each of these locations; this is done by referring to the authorized maximum train speed corresponding to each obstruction and applying the corresponding adjustment factor.

- **Refine the composite diagram by following steps 2.-5. above.**

At this point, the composite diagram contains the following:

1. An envelope defining the space through which the equipment should operate without violation.

2. A line parallel to the plane of the track defining the minimum clearance above the top of the rails.
3. Two lines representing the sides of the vehicle under the worst conditions of lean and lateral displacement if the vehicle is constructed to the extreme width selected in Section 5.3.1.2.

- **Define the extreme vehicle height as explained above.**

  The extreme height of the vehicle is defined based on Items 1 and 3 immediately above. It is not necessary that this extreme height be achievable over the full width of the vehicle; in fact, it usually is not. Passenger equipment is commonly constructed with a convex roof, in which case the vehicle body only approaches the extreme height at the center.

- **Plot the limits of vehicle width throughout its height as a function of the predefined maximum width (Section 5.3.1.2) and the clearance envelope through which the vehicle must operate.**

  Since the vehicle body must remain within the envelope defined in Item 1 immediately above, the body width must be reduced wherever the two lines in Item 3 above cross over this envelope. This can be done in steps, or the limiting equipment outline can be tapered.

- **Complete the limiting equipment outline as described above.**

  The shape of the limiting equipment outline connecting the sides and the top must be determined. Depending on the shape of the envelope, it may be sloped or curved.

- **Examine the limiting equipment outline thoroughly to determine whether it is realistic or needs to be modified in some way. If modifications are needed, follow any or all of the three steps outlined below to arrive at the final outline (or equipment clearance diagram).**

  This may be done by comparing it with existing passenger clearance diagrams such as AAR Standard S-035 or the Amtrak diagram for comparable (single-level or bi-level) equipment, as well as by determining whether equipment already owned or contemplated for acquisition by the passenger railroad will comply with it. If this outline is acceptable, it may be adopted as the passenger railroad's equipment clearance diagram. If there are portions of the outline that are too restrictive, there are three principal possibilities for reducing or eliminating these restrictions. They are discussed in priority order below:

  1. The obstructions responsible for these restrictions should be identified, and the possibility of eliminating them should be evaluated. The outline should be adjusted to reflect the elimination of any limiting obstructions.

  2. The characteristics of the vehicle suspension system should be analyzed to determine whether the desired suspension performance can still be achieved with a design that reduces body roll sufficiently to eliminate the problem. If so, the change in displacement due to body lean should be determined, and the outline should be adjusted to reflect this.

4. The authorized train speed in the vicinity of the obstruction should be examined to see if a speed reduction would reduce the potential body displacement sufficiently to eliminate the problem. As in 2 above, the change in displacement due to body lean should be determined, and the outline should be adjusted to reflect this. Operating considerations, of course, would also enter into any decision on speed reduction.

- **Evaluate vehicles constructed to the limiting equipment outline to ensure that there is no conflict between passing trains on the most critical curves in multiple track territory.**

  Use the Lotus 1-2-3 program PASCLEAR described in Appendix 1 to evaluate the overhand on multiple-track curves of passing vehicles designed to the limiting equipment outline developed. The end overhang of the vehicle on the inner track and the center overhang of the vehicle on the outer track need to be compared with the track center distance to ensure adequate clearance between passing trains.

  If the clearance is not obviously adequate, a more careful examination needs to be made. The most critical condition on a curve is a standing train on the outer track and a train operating at maximum authorized speed on the inner track.

  If any conflict exists, the limiting equipment outline must be modified. Alternatively, operating restrictions could be imposed or the distance between track centers could be increased at the critical locations.

- **If the particular passenger railroad's equipment is to be operated:**

  - Only on its own tracks, the equipment clearance diagram is complete.

  - Both on its own and another railroad's tracks, go to Section 6.0

6. Clearance diagram for track owned by another railroad

When a passenger railroad's trains are operated on another railroad's tracks, questions relating to clearances are much simpler to resolve, because the railroad owning the tracks will already have investigated its clearances.

- **Obtain a clearance diagram from the railroad involved.**

  The railroad over which the equipment will be operated will usually not be able to supply a composite diagram of right-of-way restrictions for the line(s) involved as described in Section 5.1. However, the railroad's clearance engineer should be asked to supply a clearance diagram showing the maximum acceptable equipment dimensions for operation over these lines. Vehicle body displacement due to design tolerances, wear, and spring deflection is typically taken into account to arrive at the maximum permissible dimensions for inclusion in such diagrams.

- **Review railroad clearance diagram for limitations that may present problems.**

  Height restrictions will be identical for all equipment on a given route. Equipment width restrictions at any height may be evaluated with the Lotus 1-2-3 program PASCLEAR described in Annex A.[10]

- **Review problem areas with railroad's clearance engineer.**

  Certain clearance limitations may sometimes be eliminated at little expense. This may be preferable to constructing new equipment to dimensions that are less than ideal.

- **If clearance diagram changes are agreed upon with the railroad, obtain a revised clearance diagram.**

- **Evaluate vehicles constructed to the limiting equipment outline to ensure that there is no conflict between passing trains on the most critical curves in multiple track territory.**

  Use the Lotus 1-2-3 program PASCLEAR[10] described in Annex A to evaluate the overhang on multiple track curves of passing vehicles designed to the limiting equipment outline developed. The overhang of the vehicle on the inner track and the center overhang of the vehicle on theouter track need to be compared with the track center distance to ensure adequate clearance between passing trains.

  If the clearance is not obviously adequate, a more careful examination needs to be made. The most critical condition on a curve is a standing train on the outer track and a train operating at maximum authorized speed on the inner track.

  If any conflict exists, the limiting equipment outline must be modified. Alternatively, operating restrictions could be imposed or the distance between track centers could be increased at critical locations.

- **If the particular passenger railroad's equipment is to be operated:**

  - Only on another railroad's tracks, the equipment clearance diagram is complete.

  - Both on its own and another railroad's tracks, go to Section 7.

7. Combined clearance diagram both for track owned by the passenger railroad and for track owned by another railroad

- **Perform a detailed comparison of the equipment clearance diagram developed in Section 5.0 and the clearance diagram obtained from the other railroad in Section 6.0**

[10] This program is a separate file on the CD Rom that contains all six volumes of the APTA Manual of Standards ans Recommended Practices for Rail Passenger Equipment

The Lotus 1-2-3 program PASCLEAR described in Annex A may be useful in conducting this comparison, particularly if the two diagrams are based on a different distance between truck centers.

- **Reconcile the two clearance diagrams to arrive at a final equipment clearance diagram for the passenger railroad.**

If the other railroad's clearance diagram is more restrictive in any respect, that restriction should be added to the passenger railroad's clearance diagram unless further discussion with the other railroad's clearance engineer determines that this restriction can be lifted.

Annex A

PROGRAM FOR DETERMINING MAXIMUM WIDTH OF TWO-TRUCK RAILROAD PASSENGER VEHICLE AT ANY POINT ALONG ITS LENGTH

A program to determine the maximum width of a two-truck railroad passenger vehicle at any point along its length is included as a file on the CD Rom containing this manual.

It is written in Lotus 1-2-3 but may also be brought up and used in Microsoft Excel.

When the program is brought up, the screen appears as shown in the box below. Actual numbers are shown for one example condition.

MAXIMUM WIDTH OF TWO-TRUCK RAILROAD PASSENGER VEHICLE AT ANY POINT ALONG ITS LENGTH

Definitions of Variables:

C = curvature (deg and min) on which clearance diagram is based
T = distance between truck centers (ft and in) on which clearance diagram is based
T' = actual distance between truck centers (ft and in)
W = maximum width permitted by clearance diagram (ft and in) at a given height
W' = permissible width of vehicle (ft, in, or mm) at center at height corresponding to W
W" = permissible width of vehicle (ft, in, or mm) at specified point along its length at height corresponding to W
X = distance from transverse center line of vehicle (ft and in) at which W" is being determined

Assigned Values:					**Calculated Values of W' and W":**		
C	= 13 deg	0 min			**W'**	=	9.870 ft
T	= 46 ft	3 in	(	14,097 mm)		=	118.45 in
T'	= 59 ft	6 in	(	18,136 mm)		=	3,009 mm
W	= 10 ft	8 in	(	3,251 mm)	**W"**	=	10.381 ft
X	= 15 ft	0 in	(	4,572 mm)		=	124.57 in
						=	3,164 mm

Discussion of Assigned Values

For internal calculation purposes, the program converts the value of **C** into a curve radius **R** using the simplified formula **R = 5729.65/C**.[1] The radius calculated by this formula is correct to within less than one foot for all curves up to 13° 48'. Thus, the error introduced by this simplified formula is very small for curves on which passenger equipment operates.

The value of **T** is whatever distance between truck centers is used as the basis for the clearance diagram. The *de facto* standard for passenger cars in North America has long been 59' 6". This is the value of **T** for both the old AAR passenger clearance diagram[2] and the Amtrak clearance diagram.

[1] ***The Economic Theory of the Location of Railways***, sixth edition, corrected, page 266; A. M. Wellington; John Wiley & Sons, Inc.; 1914.

[2] **"**Passenger Equipment Diagram Unrestricted for Interchange Service**"**, Standard S-035-53; *Manual of Standards and Recommended Practices*, Section A (obsolete), Part III, p. A-III-12; Association of American Railroads; 1953.

American passenger cars have been constructed with a distance between truck centers of 59' 6". The primary exception to this has been some multilevel commuter cars in which **T'** has been increased in order to lengthen the two-level portion of the body.

W is the maximum width of the body permitted by the clearance diagram under any conditions. For typical clearance diagrams, the value of **W** varies with the height above the top of the rail. Using the program, **W** may be varied in accordance with the various parts of the clearance diagram to determine **W'** and **W"** at any height.

X defines the longitudinal point at which **W"** is being determined. (**W'** is the value of **W"** when **X** = 0.) **X** is measured from the transverse center line of the vehicle, so its maximum value is one-half of the length of the vehicle. For any given value of **X**, the program determines whether the point being examined is inboard or outboard of the bolster and automatically applies the correct equation. If the calculated value of **W'** or **W"** is greater than the value of **W**. it is limited to the value of **W**.

Use of Program

As the program is delivered, all cells except the 10 cells in which data are to be entered are protected so that existing information will not be inadvertently overwritten.

The program is very simple to use. When the appropriate values for the variables listed under **ASSIGNED VALUES** are entered in feet and inches[3], the corresponding values of **W'** and **W"** will automatically be shown under **Calculated Values of W' and W"** in feet, in the equivalent number of inches, and in the equivalent number of millimeters.

Note that the assigned dimensional values may not be entered directly in millimeters, but the equivalent values in millimeters are automatically shown when an entry is made. Therefore, a metric value may be entered indirectly by adjusting the value in feet and inches to achieve the desired number in millimeters.

If several cases are to be examined in one sitting, invoking /**Range Input** for cells **C13..E17** will allow the cursor to move only among the 10 cells in which data are to be entered, thereby speeding data entry.

[3]Common fractions may not be used. Decimal fractions may be used in the **minutes** or **inches** entries. Alternatively, **degrees** or **feet** may be expressed using decimal fractions.

[1]*The Economic Theory of the Location of Railways*, sixth edition, corrected, page 266; A. M. Wellington; John Wiley & Sons, Inc.; 1914.

[2] "Passenger Equipment Diagram Unrestricted for Interchange Service", Standard S-035-53; *Manual of Standards and Recommended Practices*, Section A (obsolete), Part III, p. A-III-12; Association of American Railroads; 1953.

[3]Common fractions may not be used. Decimal fractions may be used in the **minutes** or **inches** entries. Alternatively, **degrees** or **feet** may be expressed using decimal fractions.