The impact of how
“Wheels interface with Rail”

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The LA Metro Underground Background

Metro™

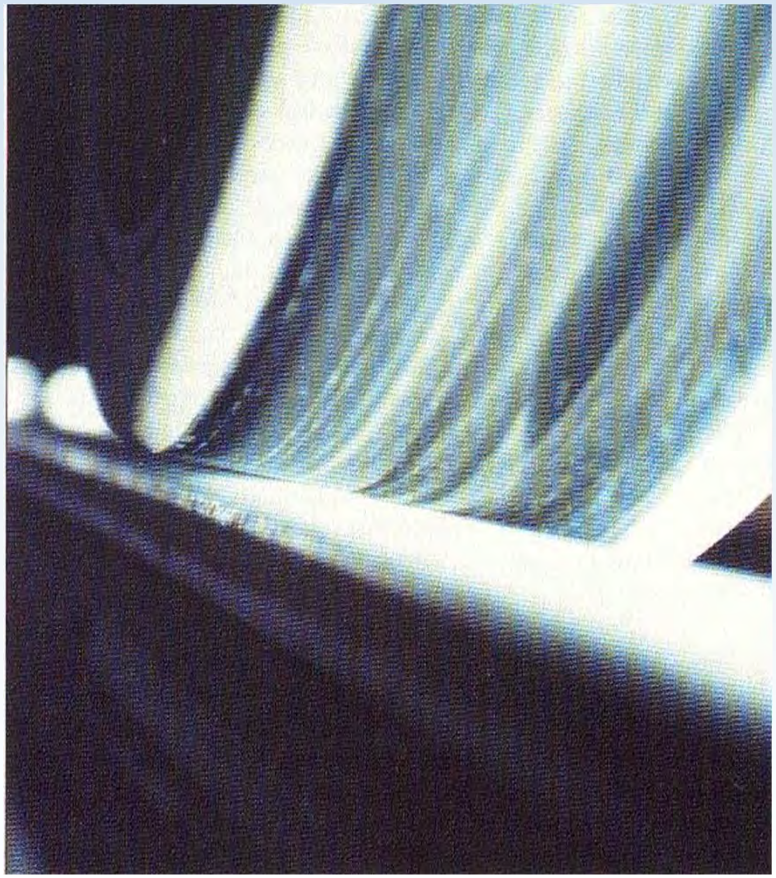
The LA Metro Subway Line

- Began as a “State-of-the Art” for the Heavy Rail Transit.
- Instead, it became a “Work in Progress”
  - Within a few months of rail operation,
  - Fewer than 20,000 miles of revenue service,
  - Switch Points and Wheels were so badly worn,
  - This rail equipment required replacement.

Wheel / Rail Compatibility

- Many articles and questions arose about our new Heavy Rail Transit System that was having fundamental Wheel / Rail Issues.

Los Angeles' Wheel Problem

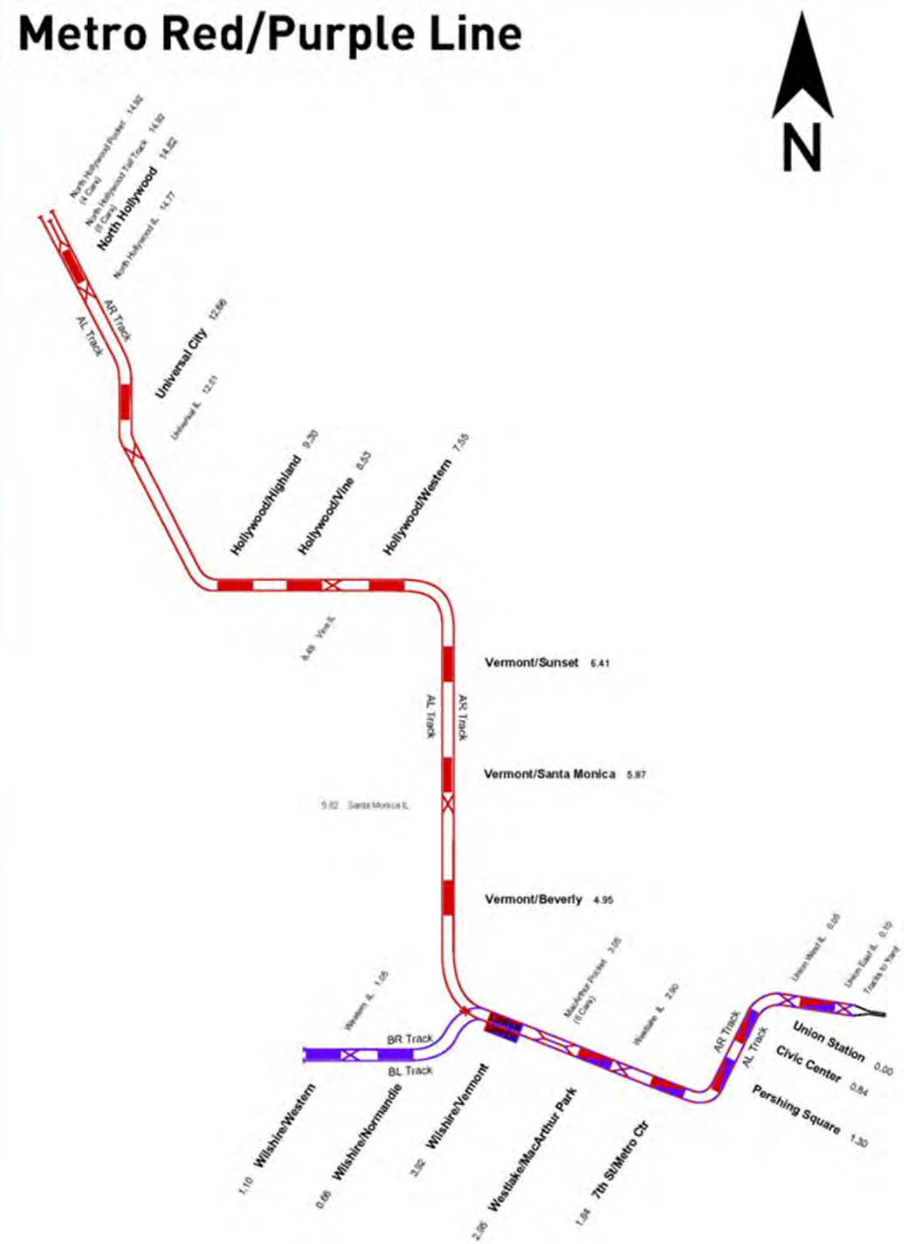


- The problem wheel life on the Metro RED Line stemmed primarily from the poor curving ability of their stiff trucks, large diameter wheels, and long 90.5-inch wheel base trucks that were allowed by the specifications for rail cars on the line.

LA Underground Rail System

- The physical plant (alignment, stations, crossovers, ventilation, etc.) design was based on an underground rail system that would be operated at speeds up to 75 mph and support service headways of 2 minutes from Downtown LA – Union Station to North Hollywood to offset the traffic congestion associated on the #101 Freeway during peak service hours with expansion westward.

Metro Red/Purple Line



Why the Mismatch???

- It was said by Construction Staff:
  - “The people who designed the vehicles didn’t talk to the people who designed the track”
- The basic system objective for the long term was to design a High Speed Underground Rail System to connect Downtown Los Angeles with North Hollywood and ultimately west to Santa Monica so that rapid rail service could be provided to the people of Los Angeles County.

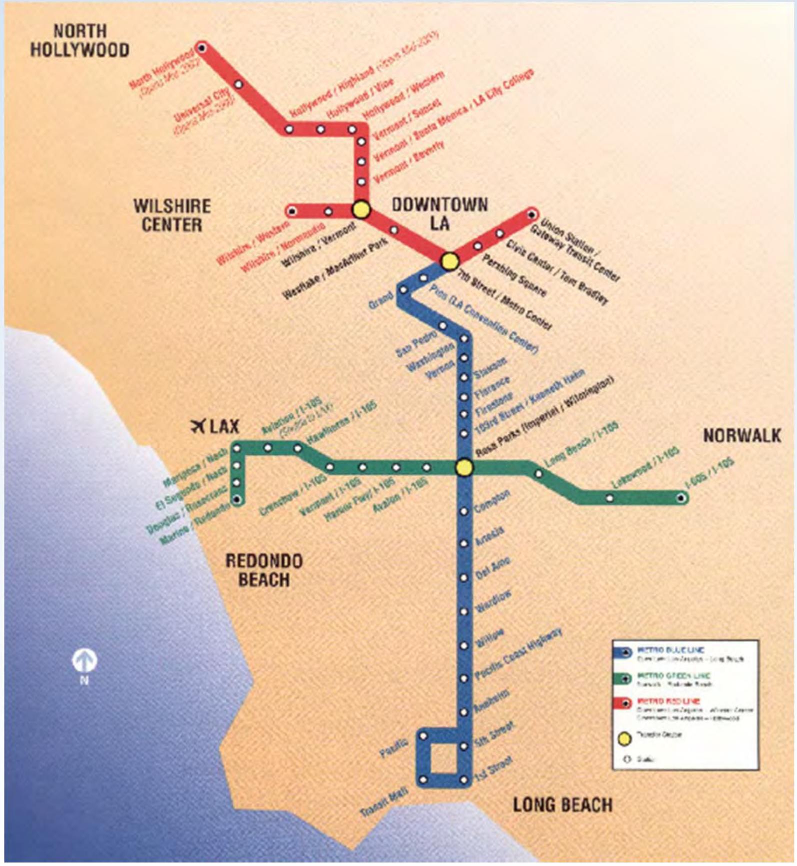
Los Angeles – Not New to Rail Transit

- The Los Angeles Area had extensive rail service throughout the county servicing all areas in the 1940’s and 50’s by Pacific Electric Railway using the old “RED” Cars.
- However, the change to private automobiles and road construction saw the end of public rail transportation to the area.
- In 1990 the first re-introduction of rail service was operated from Los Angeles to Long Beach.

Metro Rail in the 1990's

- The Los Angeles Area had seen public rail transit grow with various New Rail Lines being designed and constructed:
  - The Metro BLUE Line to Long Beach - 1990
  - The Metro RED Line to Wilshire Western and North Hollywood – 1993 to 2000
  - The Metro GREEN line from Redondo Beach to Norwalk - 1995

LA Metro 1990's Rail System



- The Metro Blue Line, 22 miles and The Metro Green Line, 20 miles, both double track overhead cantenary, Light Rail. The Metro Red Line, twin tunnel subway, 17.4 miles, Heavy Rail with 3rd Rail.

Rail Operating Experience

- With the growing rail systems, rail operating and maintenance staff were acquired to ensure that a safe, reliable, and efficient rail service would be provided to the LA Area.
- For rail system efficiency, proper equipment would be needed for maintenance.

- LA Metro purchased a specially designed 16-stone Fairmont grinder for ongoing rail maintenance.

Rail System Compatibility Issues

- The alignment and track system was designed to modern Rail Transit Standards as defined by the TCRP (Transit Cooperative Research Program), TRB (Transit Research Board) Special Report, etc. for typical rail transit vehicles with wheel diameters between 26” and 28”.
- However, the Rail Subway Vehicles acquired were designed for high speed stability and used conventional rail truck designs using commuter or commercial wheels with diameters of 32” to 36”.

Missing the Key Elements

- The Wheel / Rail Interface remains the key to an efficient, reliable, and safe rail system; however, despite such importance it somehow is the system that too often gets ignored.
- The reason this key element gets ignored is because it is not “sexy”, it does not usually carry such words as “high-tech”, “state of the art”, tera-bytes” or “giga-hertz”, and it involves two parties that often have quite different views of each other.

Differing Views

- The two parties that have differing views of each other are the fixed track infrastructure and the moving rolling stock provided.
- If these parties can even see or speak to each other is rare and yet they have the potential to bring any rail operation to its knees, if not in seconds, in hours and the resulting cost can be in the mega-millions.
- It is this phenomenon that occurred in Los Angeles with the underground subway.

Rail System Design Components

- The track design had used Modified AREMA turnouts with extended Simple Circular Curves or Custom Simple Circular Turnouts in the alignment for terminal and failure management diamond crossovers to minimize the open box areas and reduce initial capital construction costs.
- The vehicle truck design was for high speed 70 mph operation with 34½" Diameter Wheels and a truck axle spacing of 7'-7".

New Vehicle Commissioning

New LA Heavy Rail Transit Vehicle

Metro Heavy Rail Vehicle Testing

- With the introduction of the Metro New Heavy Rail Vehicles onto this 3.5 mile MOS-1 Section and the Yard operation; in-house training, vehicle familiarization, and vehicle performance issues reduced any ultimate system testing.
- During this new Vehicle Commissioning process, it was noticed that a number of performance issues were not consistent with those experienced on the borrowed rail transit vehicles.

Dissimilar Operational Issues

- Excessive noise was heard through these tight diamond crossovers even at low speeds.
- Excessive wheel and rail wear was beginning to show on the new equipment and rails.
- Flange climb was experienced at speeds well below design operational speeds.
- Truck "nosing" was detected and stiffness to ease of rotation was apparent.

Compatibility Issues

- Excessive wheel wear – metal shavings in curves and switch areas.
- The definite proof lay in the scrap piles where wheels were tossed after only 19,000 miles of service.
- Excessive rail wear – a 2,000-foot section of 115-pound, head hardened rail in a six-degree curve had to be replaced after fewer than two years of service.

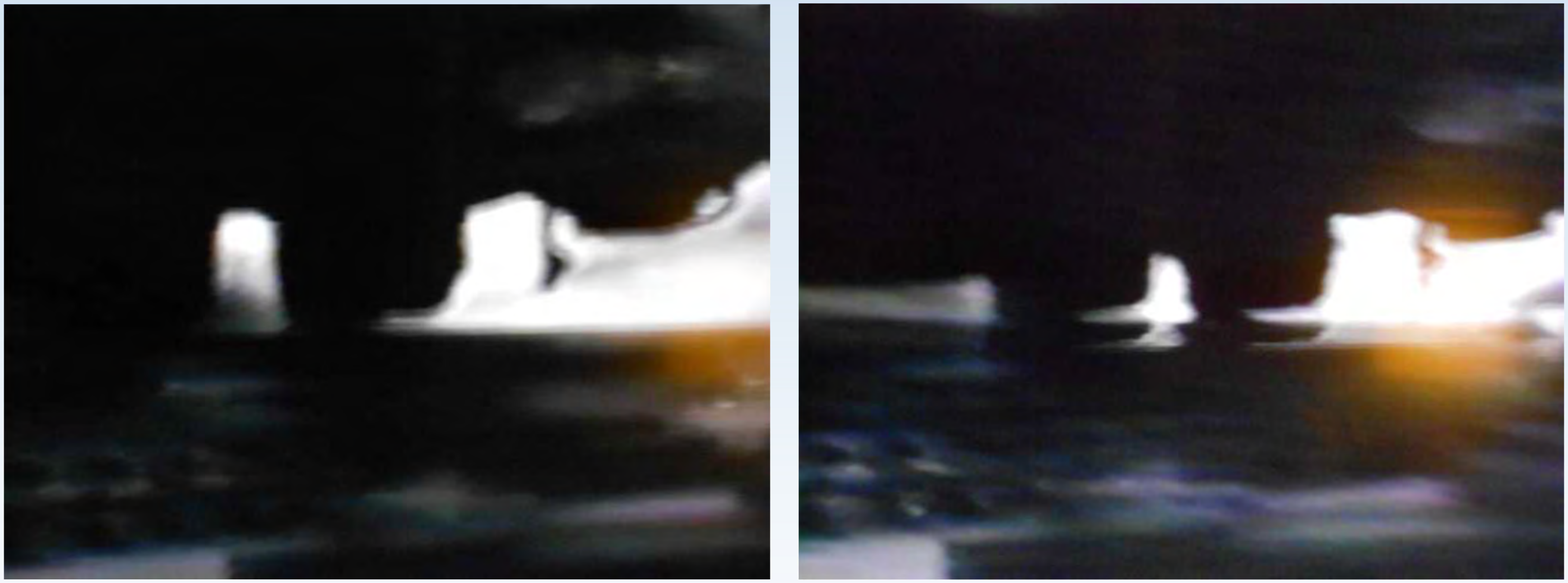
Metro Yard Derailment

- In 1994, a minor yard derailment occurred when entering the yard from the mainline through standard #8 crossovers in the yard.
- The cause of this slow speed derailment was investigated and determined to be due to Wheel Climb.
- This prompted a comprehensive investigation of all mainline crossover moves for possible similar Wheel Climb Derailments.

Mainline Crossover Risks

- Because of the low speed Standard AREMA #8 Yard Derailment, the Modified #10 Turnback Diamond Crossover at Union Station West Interlocking Plant was targeted to see if similar conditions or contributing factors could lead to a derailment while carrying passengers.
- To better determine the potential risks for a wheel climb mainline derailment, cameras were placed so that the wheel rail action could be observed.

Wheel Climb Issue at 12 mph



Original AAR Wheel Profile

Exposure to Mainline Risks

- The system had already been certified for operation including these crossover moves using borrowed Heavy Rail Transit Vehicles.
- Actual tests confirmed there was a realistic risk that the newly acquired Heavy Rail Transit Cars could be exposed to Wheel Flange Derailments at 12 mph – speeds far below the design speeds of 25 mph.

Mitigation of Mainline Risks

- The Rail Safety Engineer – Mr. Wyman Jones immediately Restricted all crossover moves to 10 mph and had the speed codes changed.
- Mr. Wyman Jones and the Superintendent of Rail Technical Support – Mr. Bud Moore arranged with the Vehicle Staff to change the Wheel Profile from the standard AAR 1:20 to the Worn Profile AAR-1B that most railroads had in an attempt to minimize wheel climb.

Change Wheel Hardness & Profile

- A class B hardness wheels were adopted in hopes of prolonging wheel life. Also the first profile change was made from a 1:20 AAR to the AAR 1B worn-wheel profile.

Mitigation of Mainline Risks

- The Wheel Profiles were changed to the AAR-1B and increased the wheel hardness to a “Class-B” and had a slight increase in Wheel Life. This proactive action moved the wheel life from 19,000 miles to something in the order between 25,000 and 30,000 miles – still not a economical wheel life.
- Mr. Wyman Jones and the Superintendent of Rail Technical Support – Mr. Bud Moore arranged for the agency to engage an outside consultant to confirm their internal findings associated with this new rail system.

Acquire Outside Consultants

- Due to the nature of the internal investigation and potential operating risks, the agency was suggested to hire Advance Rail Management (ARM) Consultants that specialized in Wheel Rail Interaction so that verification of the risks and possible solutions to the operating problems could be determined.
- In 1995, ARM Consulting was hired to assist SCRTD, the operating agent, in determining the interface problems and possible solutions to these problems.

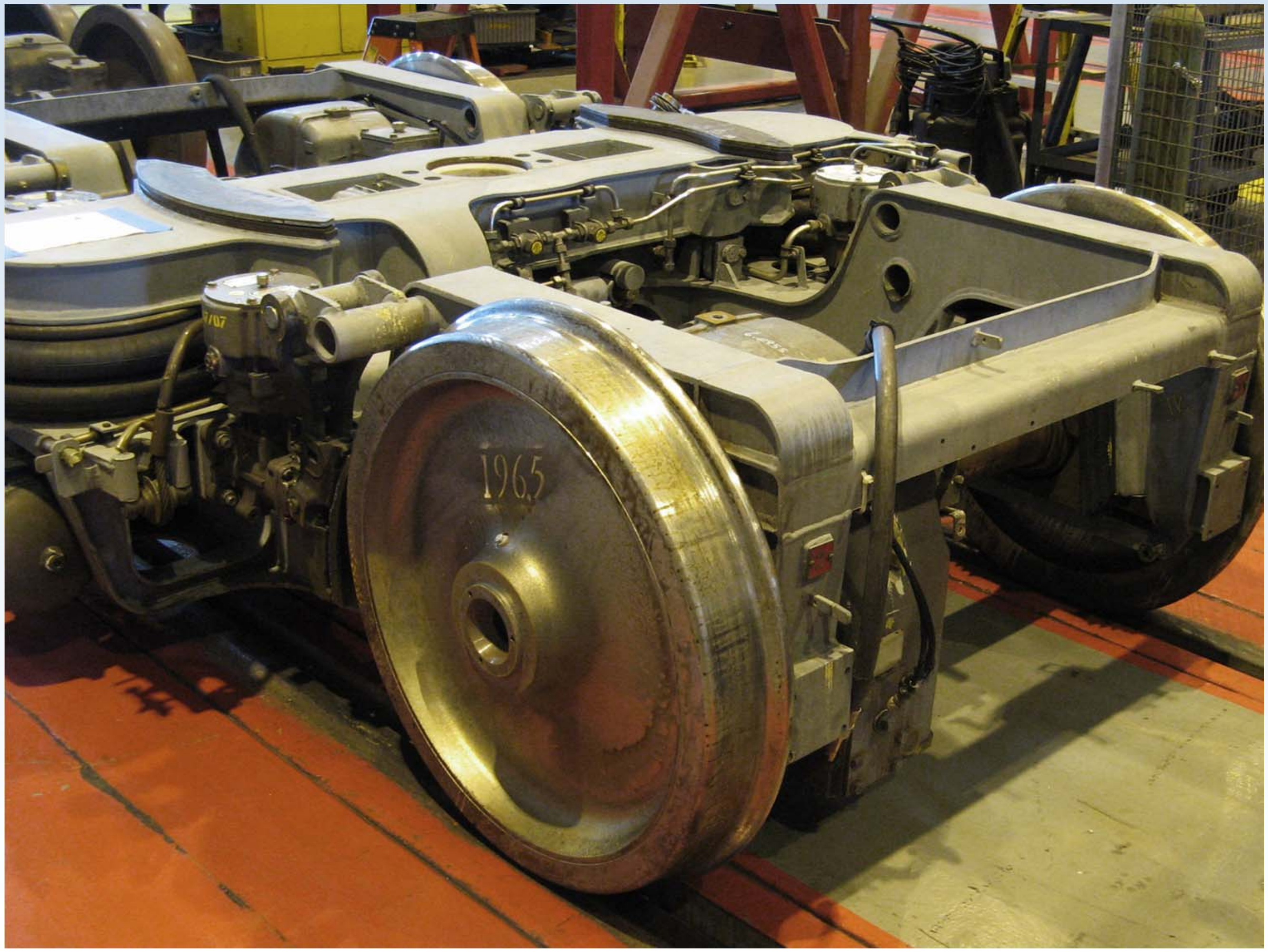
Original Response to Issues

- The consultant agreed that a key system compatibility issue was the primary cause in the yard derailment and that the internal safety's recommendation to limit and restrict any crossover movement to 10 mph or set mainline speed codes to 9 mph for any mainline Crossover Speeds until a long term solution to the track alignment and vehicle incompatibility could be addressed was appropriate.
- All Mainline Crossover Speed Codes were reset to reflect a 9 mph speed code.

Investigate System Modifications

- Since the underground alignment and Special Modified or Custom Turnout Designs were already constructed, the recommendations were concentrated on the New Rail Vehicle Trucks.
- Because the new Rail Vehicles were already showing signs of limited wheel life, it was perceived that this issue would be the most beneficial and assist in reducing the crossover risks for wheel climb derailments.

LA Metro High Speed Truck



Recommended Modifications

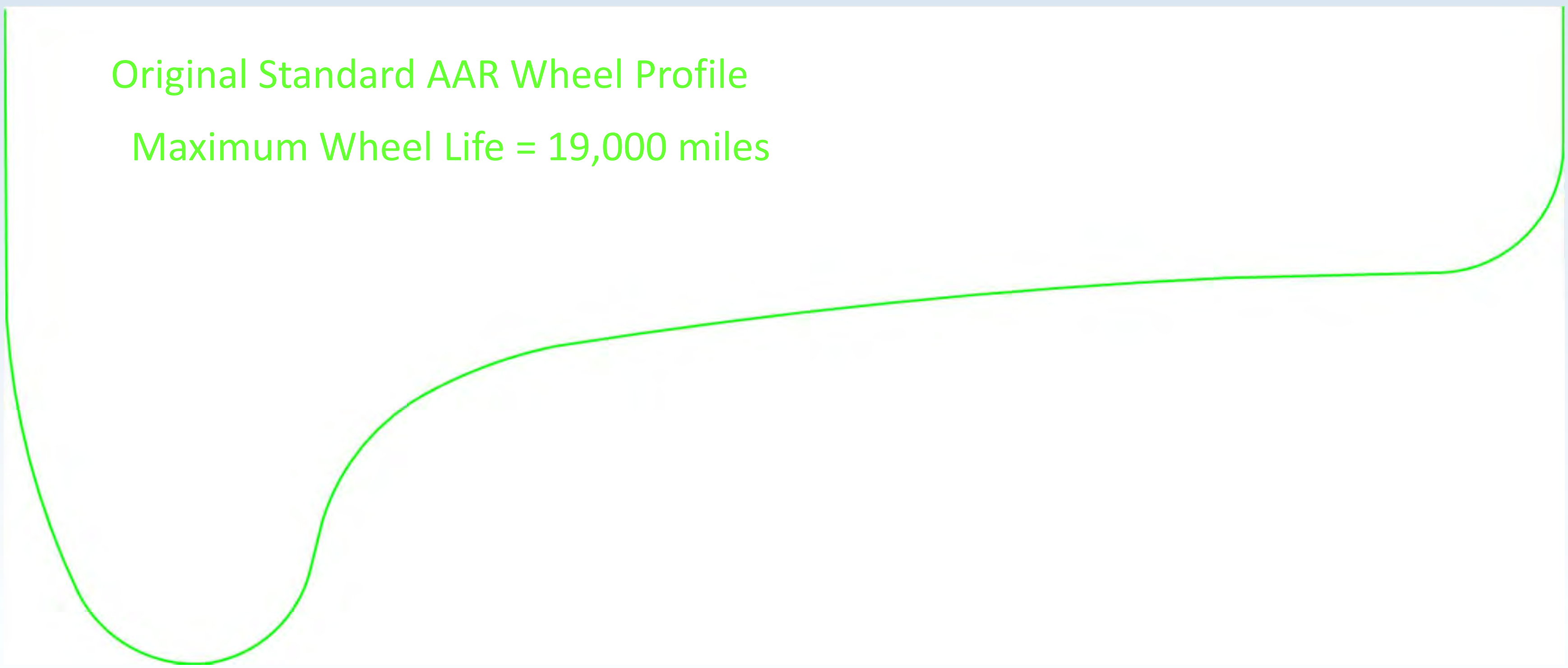
- The following immediate vehicle modifications were recommended to truck and wheels so that operating improvements when vehicles negotiating tight radius transit curves could be improved:
  1. Install Flange Lubricators on all wheels
  2. Change Side Bearing Plates to reduce friction
  3. Develop a Custom Wheel Profile Design
  4. Develop Custom Rail Grinding Profiles to optimize wheel rail performance through curves
  5. Explore changing the primary truck suspension

Added Flange Lubricators

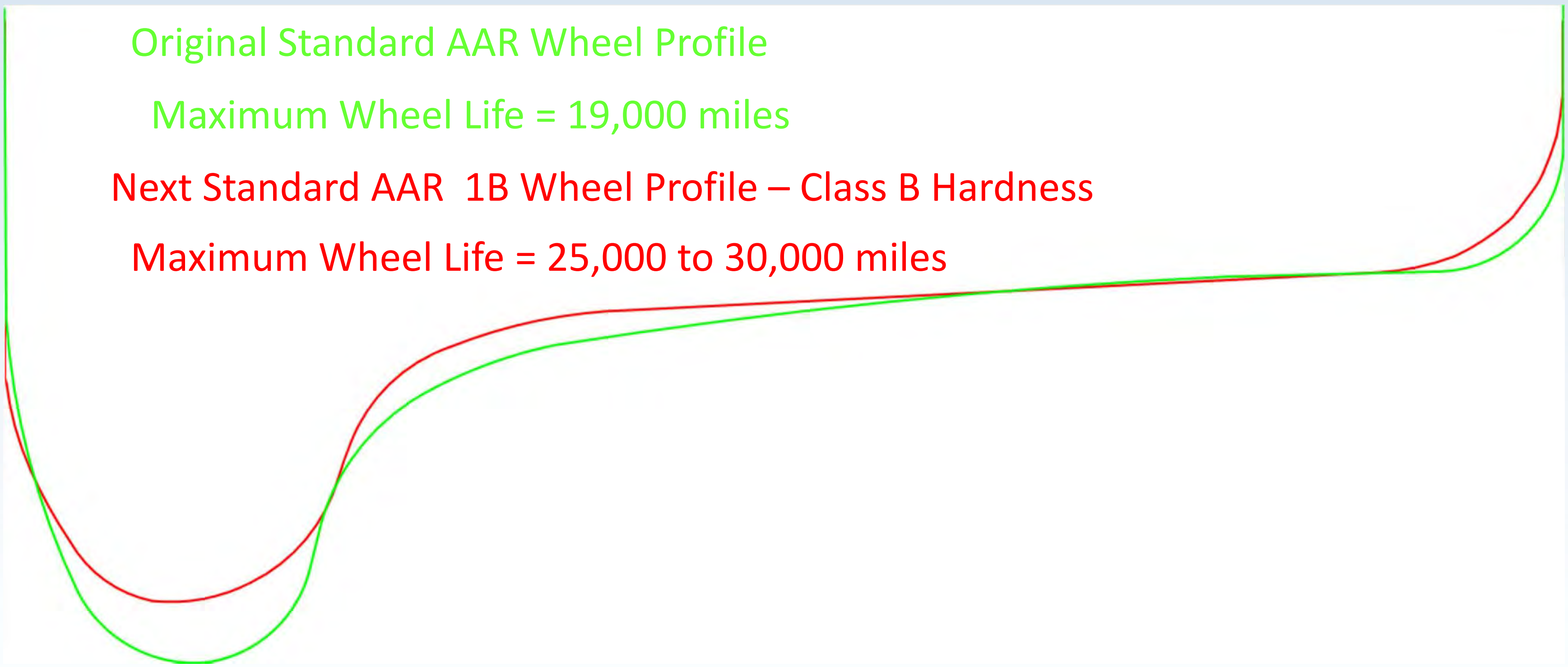
Modified Side Bearing Plates

Introduced New Custom Wheel Profile

LA Metro Progressive Wheel Profiles



LA Metro Progressive Wheel Profiles



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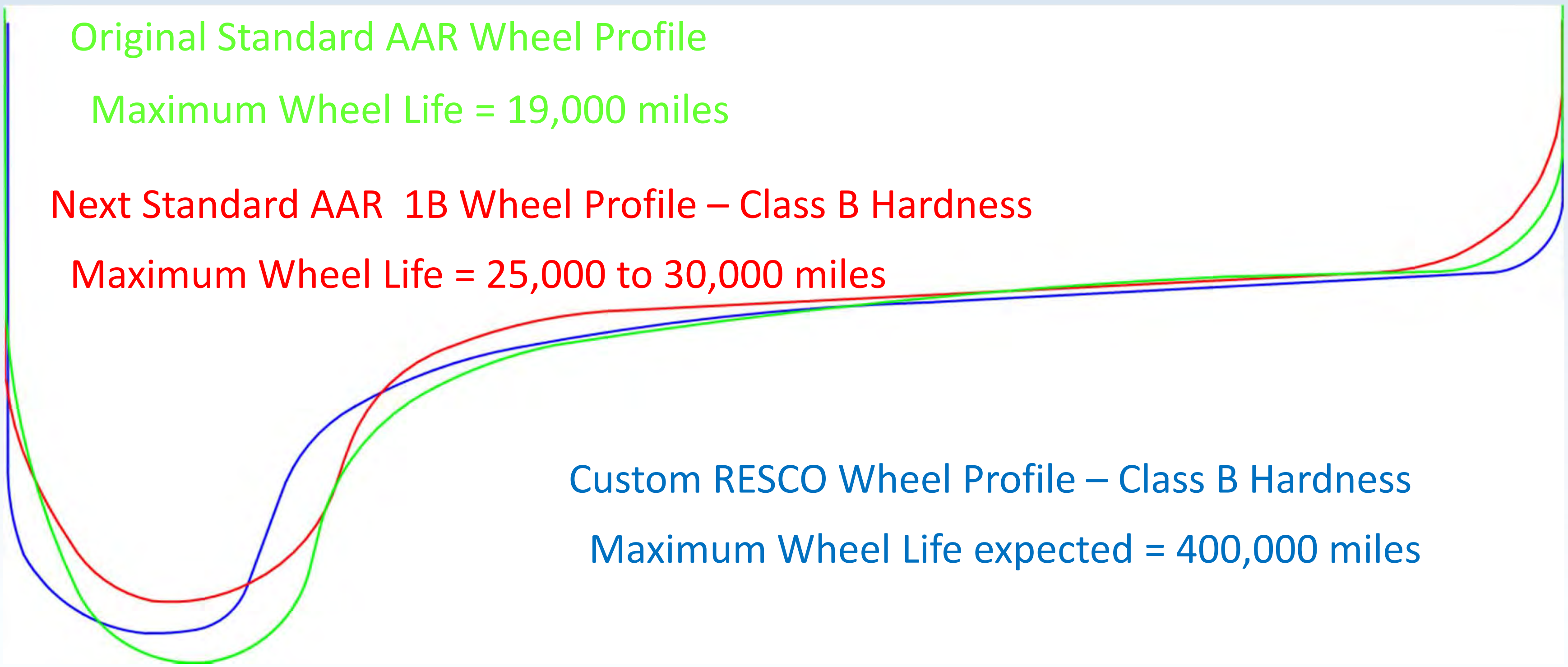
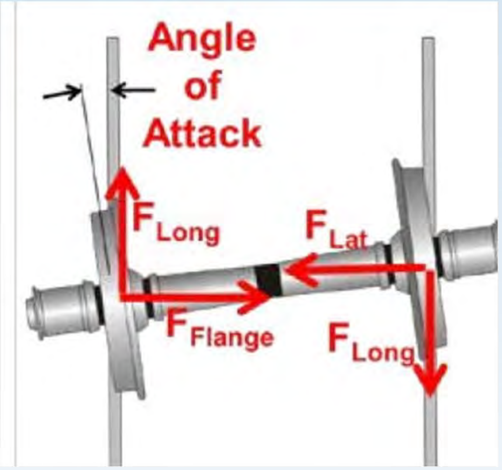
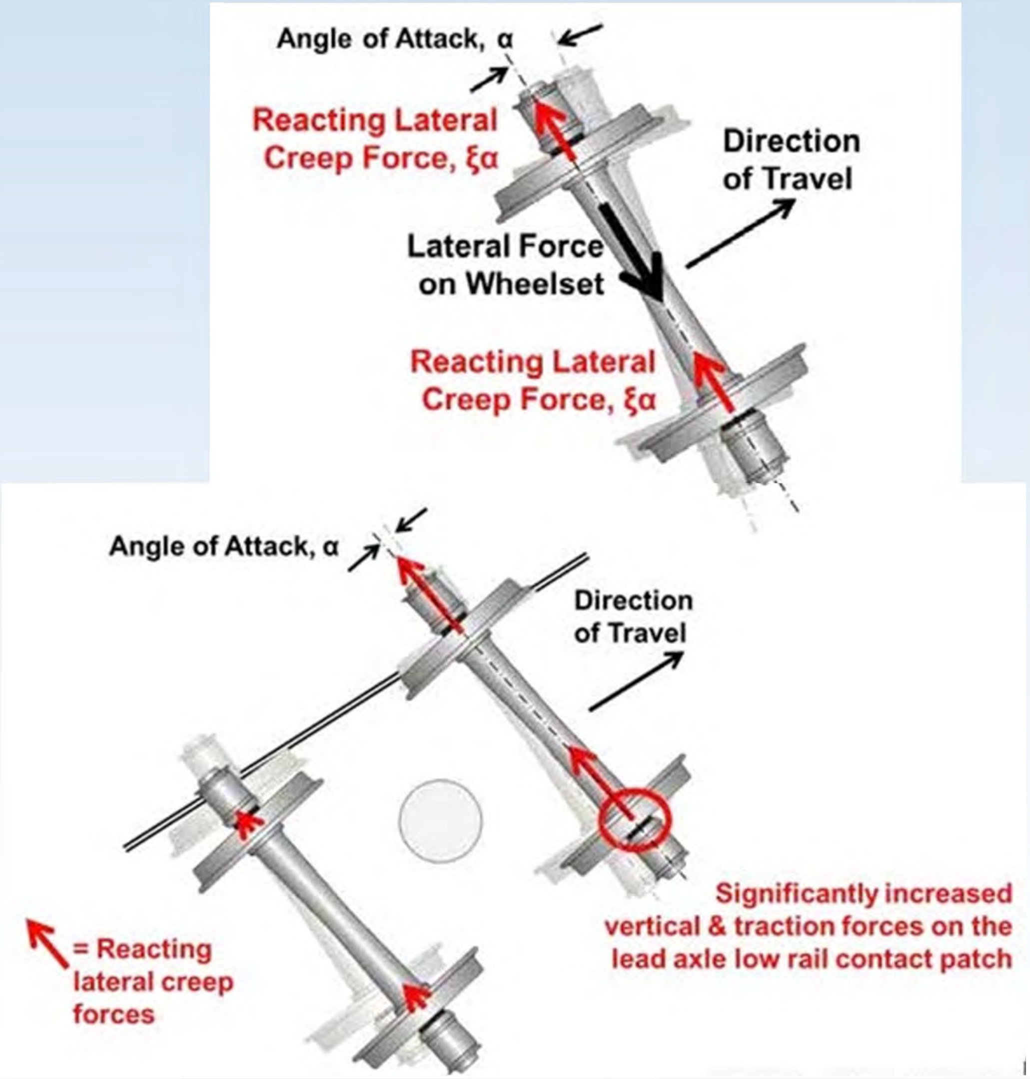
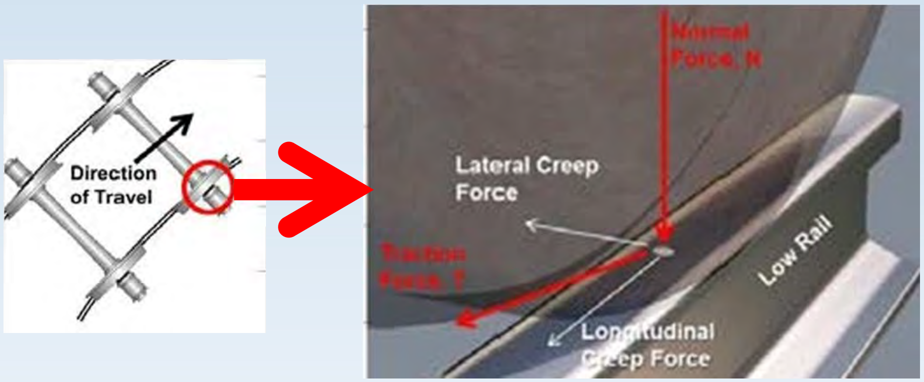


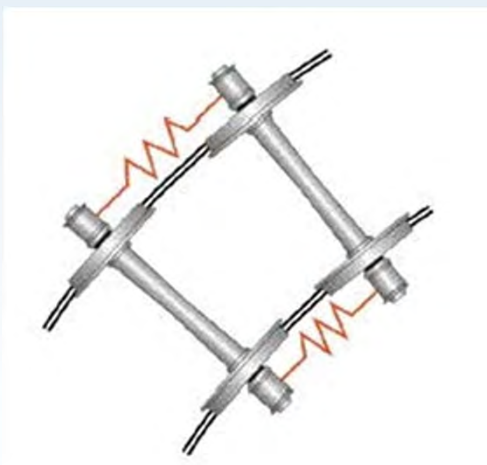
Why Question Primary Suspension?

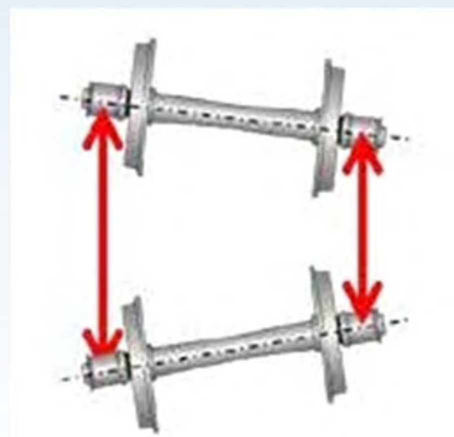




To Improve Truck Steering Ability







Radial Misalignment

Suggested Modification Acceptance

- After discussion with the Vehicle Manufacturer, all but the recommendation to explore the possibility of changing the truck's primary suspension was acceptable.
- The reason that any change to the truck's primary suspension by the vehicle manufacturer was unacceptable was due to the high speed performance requirements and any change would require additional vehicle testing and recertification.

Modification Implementation

- The System Crossover Speed Reduction in the interest of Rail Safety had and would continue to be set at a maximum of 10 mph for any crossover movements.
- While this speed reduction for crossover movements impacted Rail Operations' Failure Management Plans and Single Track Headways, it was better than the risk of Wheel Flange Climb Derailments.

Modification Implementation Cont'd

- While some of these vehicle recommendations could be implemented immediately, others took considerable time to change wheel truing equipment, design custom wheel profiles and corresponding rail grinding rail profiles.
- Once completed, the average wheel life had moved from the unacceptable 19,000 miles to over 200,000 miles and growing.
- Also, it would seem that the noise and rail wear were reduced.

Why Rail Design Issues???

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Design Compatibility Issues

- The System Transit Design for both the track and the vehicle specifications came from the Rail Construction Group for a high speed rail system.
- The Procurement Group put the Vehicle Spec out for industry review and discussed the request to open the truck tolerances and wheel sizes with construction.

Rail Knowledge & Experience

- The art and fundamental training in Rail Engineering is no longer provided in great detail to fully understand the art aspect.
- Designers claiming rail design experience generally are using Federal Rail Transit Guidelines and general Civil Engineering Techniques similar to High Transportation Design – Rail Transit is basically an Electric Bus running on Rails – no special design issues.

Rail Knowledge & Experience Cont'd

- Highway Designers use Universal Standards for the physical alignment that all road vehicle manufacturers must design their vehicles to operate over.
- However, motorized Rail Vehicles are designed for specific performance characteristics – Trolleys, Light Rail, Heavy Rail, Rapid Rail, etc.
- This requires that the Rail Physical Plant and the alignment must be designed as a total system.

Rail Knowledge & Experience Cont'd

- This total system design is similar to what the railroads designers did in years past.
- Special "Locomotives" were required for the track design so that an efficient, reliable, economical, and maintainable rail operating system would be assured.
- These special locomotives were specially designed and given name types such as Pacific, Northern, Mountain, etc.

Rail Knowledge & Experience Cont'd

- Even these Class 1 Railroads created system modifications to the plant to ensure long term maintainability and operational efficiency.
- With the movement into diesel electric systems, the locomotives became more standard in the power trucks so a cookie cutter approach to rail engineering could develop.
- This allowed general standards for alignment and plant for an acceptable maintenance practice.

Rail Knowledge & Experience Cont’d

- However, with the development of new specialized rolling stock for special customers, the Class 1 Railroads again began the art of railroad design to ensure a long term cost efficiency for Operations and Maintenance (O&M).
- General AREMA Standards for Special Trackwork were reviewed by experienced railroaders and modified to reduce long term maintenance or performance to improve profitability.

Rail Knowledge & Experience Cont'd

- Some Class 1 Railroads took the Standard AREMA Lateral (spiral) Turnout using offsets to define the curved closure rails and modify these to improve long term O&M efficiencies.

- For Example:

Standard AREMA Lateral #8

- Point Length = 13'-0"
- Actual Lead = 58'-11"
- #8 Frog = 7° 09' 19"
- Theoretical Curve = 10° 25'

Custom Improved Lateral #8

- Point Length = 16'-6"
- Actual Lead = 67'-11"
- #8 Frog = 7° 09' 19"
- Theoretical Curve = 9° 30'

Rail Knowledge & Experience Cont'd

- By extending the AREMA Lateral (spiral) offset designed actual lead with longer points and longer closure rails, the turnout performed better with less wear to wheels and rail.
- It is this rail design and experience that is missing in today's Rail Transit Designers.
- Without this understanding of the art of railroading system efficiencies and long term O&M issues the Wheel Rail Interaction is lost.

Rail Knowledge & Experience Cont'd

- How does this relate to Rail Transit Designers:
  - Most designers use the cookie cutter approach and have designed / built rail systems that utilize short, small wheel vehicles, operating at low speeds.
  - Most designers do not have O&M experience or see the long term problems that the standard cookie cutter approach has created.
  - When an organization sees the high speed long term efficient in the rail transit system is lacking, the designer is gone.

Rail Knowledge & Experience Cont'd

- Most Designers and Rail Transit Design Guidelines use the simple curve information and believe that if that radius is acceptable for a certain speed, then why is there an operating problem, if the vehicle has larger wheels or uses heavier trucks?
- The past rail transit systems that have been referenced in transit design guides indicate that simple curved turnouts can provide the same performance as AREMA and save capital costs.

Rail Knowledge & Experience Cont'd

- As a Rail Vehicle proceeds through a simple Curved Turnout or Modified Rail Transit Crossover, the speed and track train dynamics must be fully understood to effectively support the long term design O&M requirements.
- Lets look at how these Wheel Rail Interface issues relate when a Rail Vehicle proceeds through a Rail Transit Crossover.

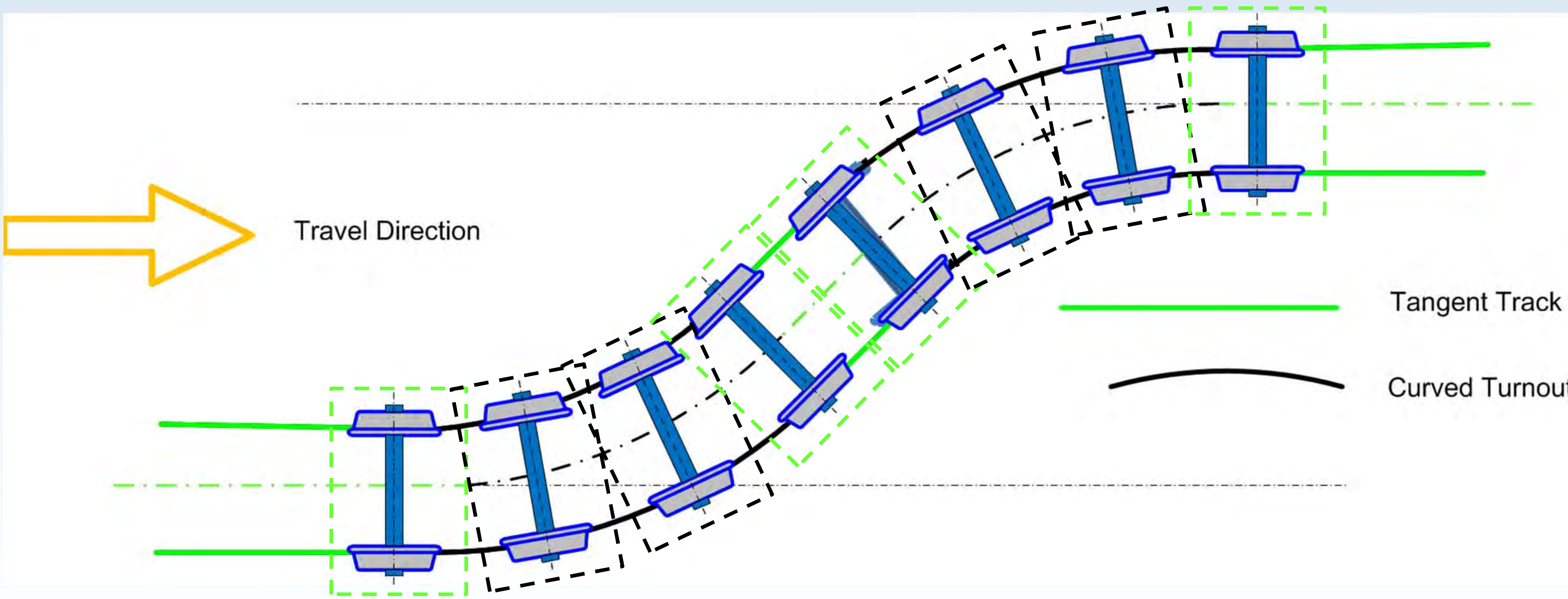
Wheel Rail Interface Through Crossover

Simple Curved Rail Transit

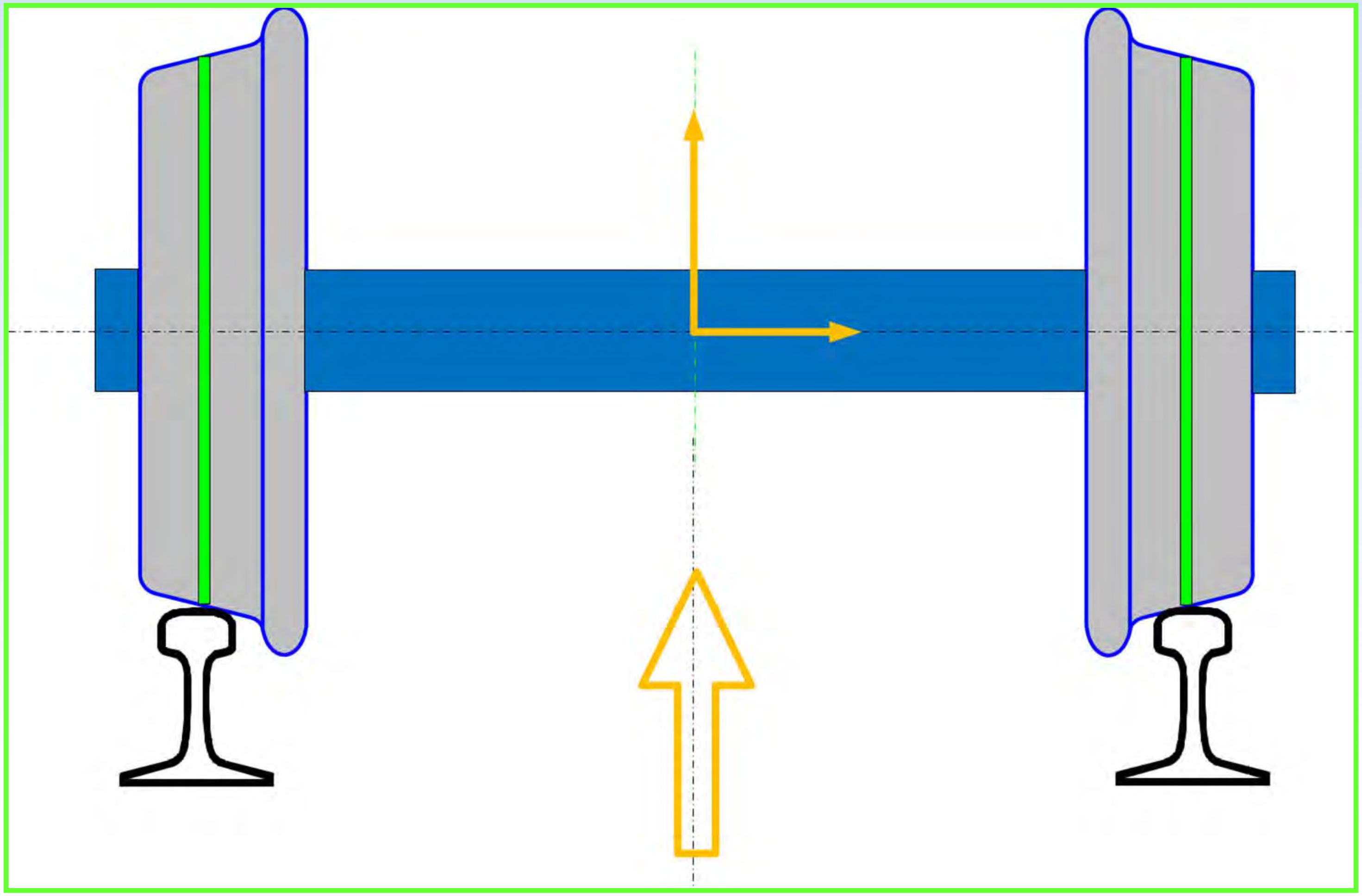
Diamond Crossover

Lead Wheel Progression

Using Standard TRANSIT (curved) Turnouts



Wheel Rail Interface



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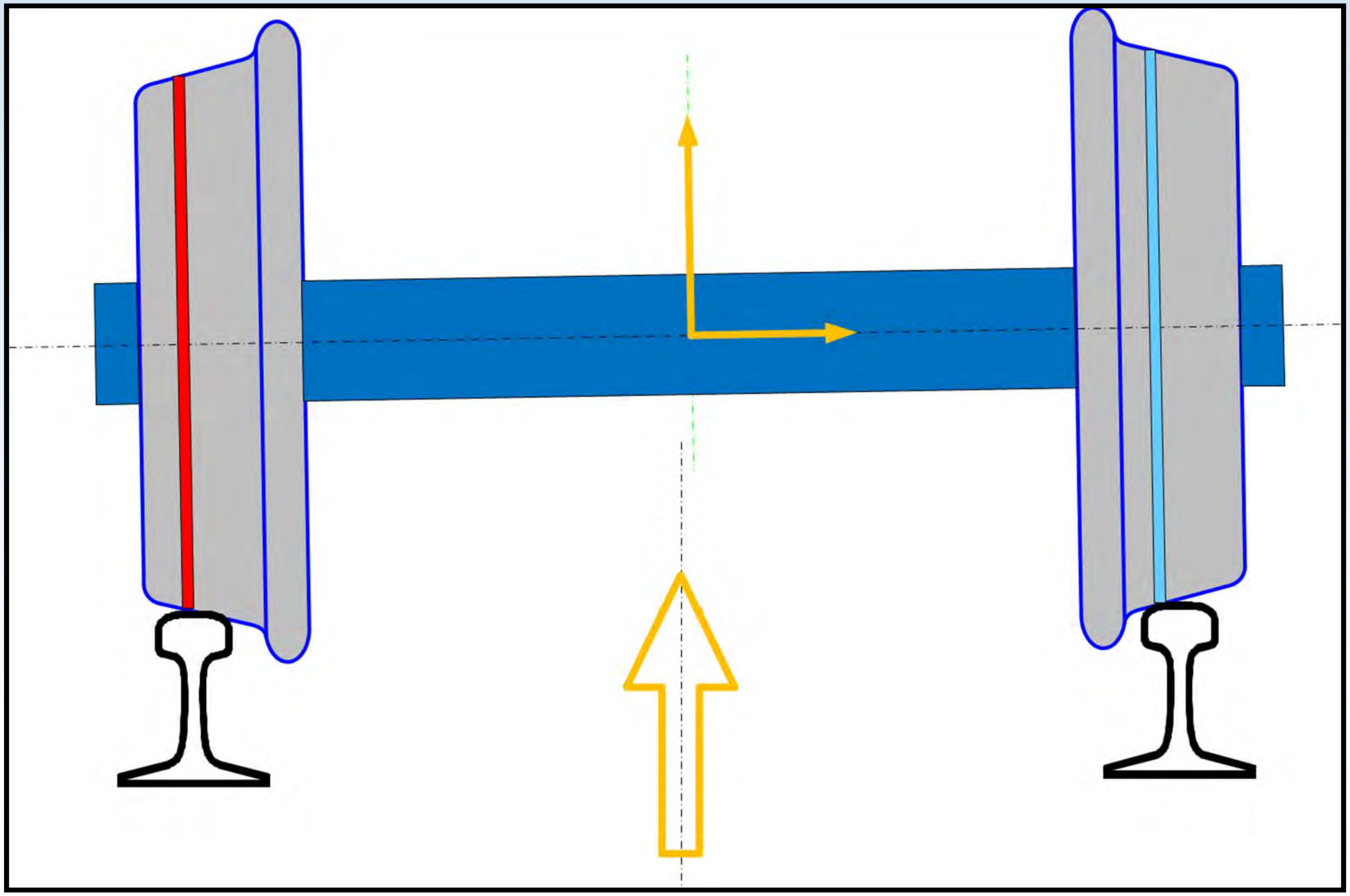

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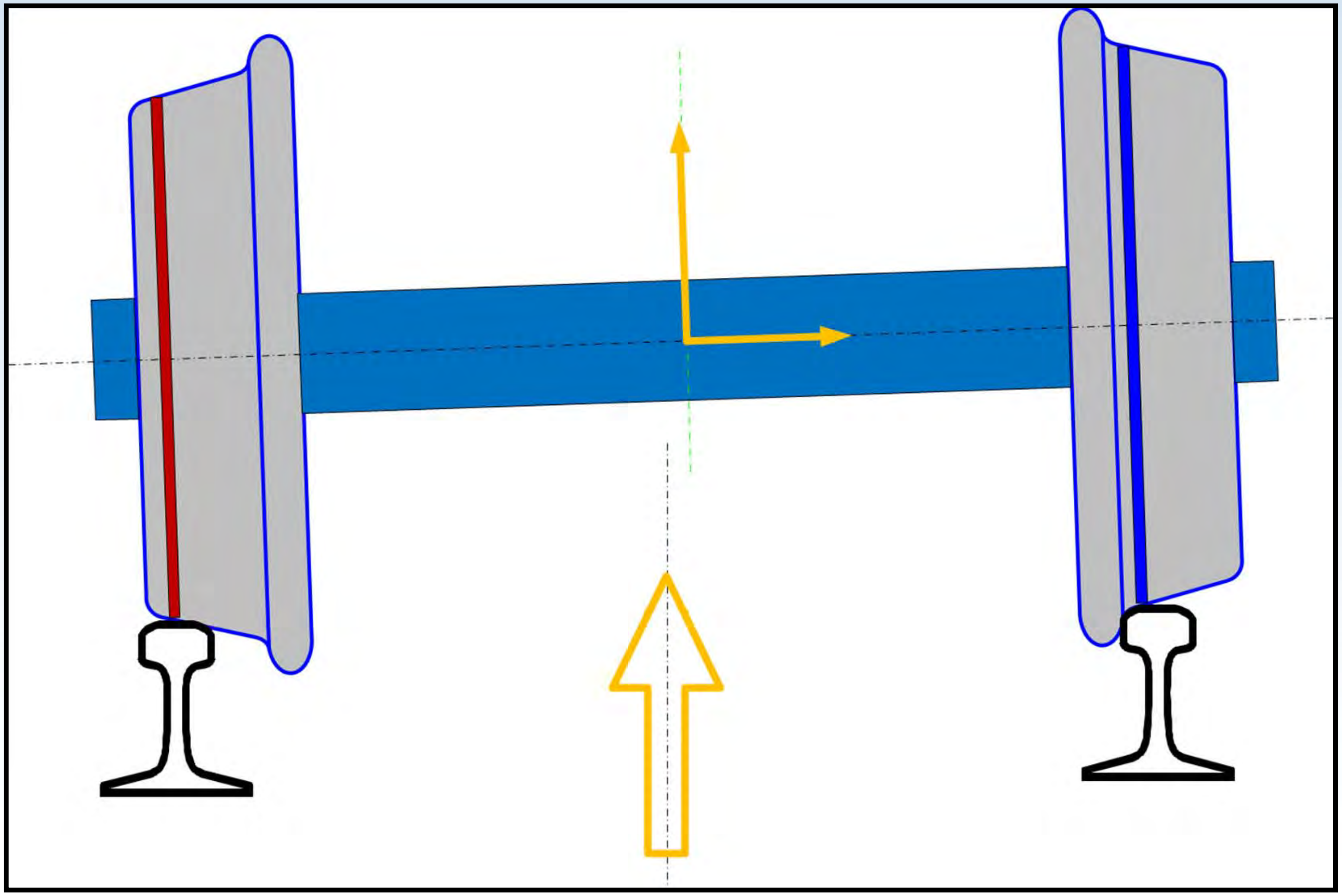

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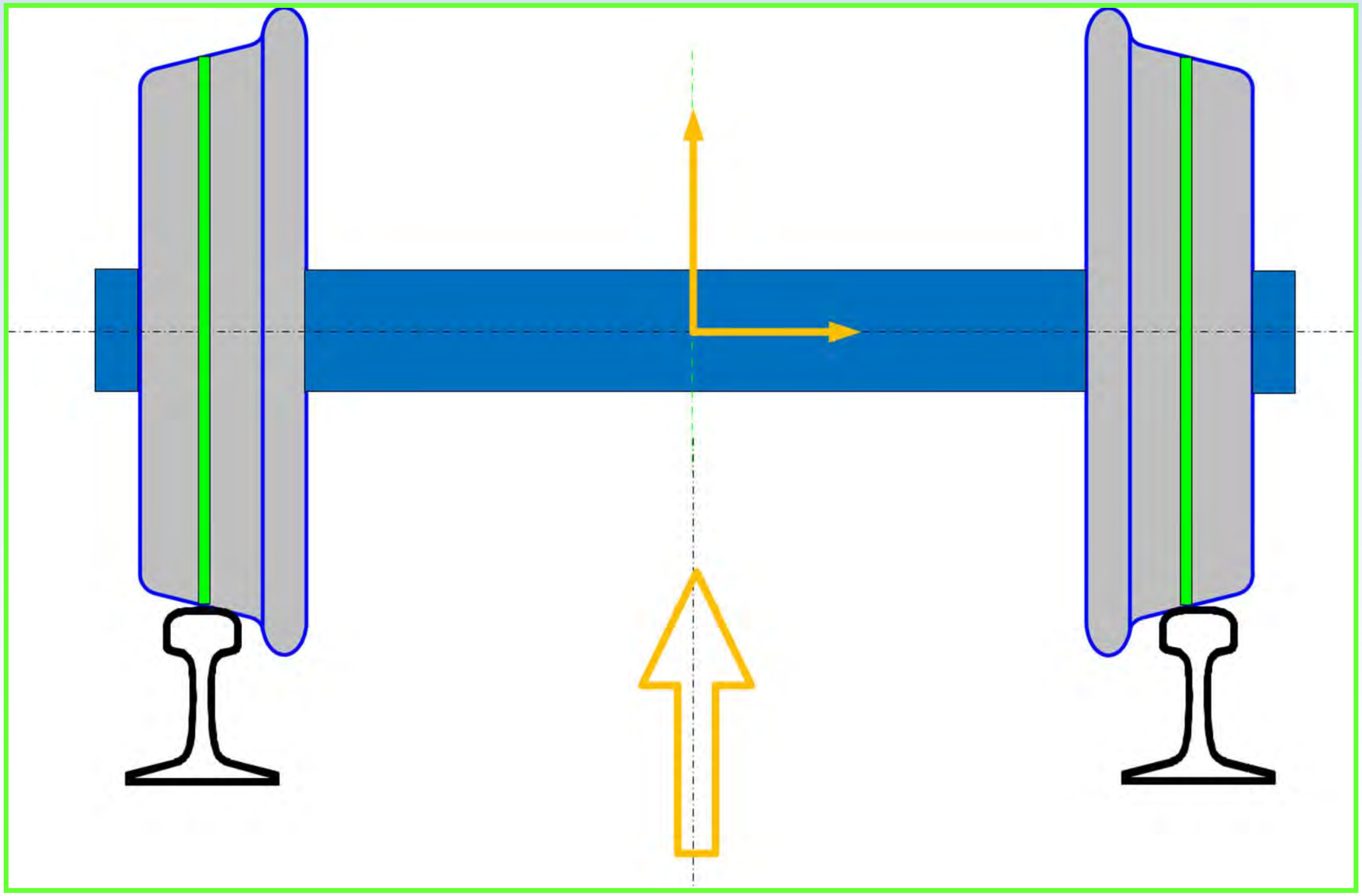

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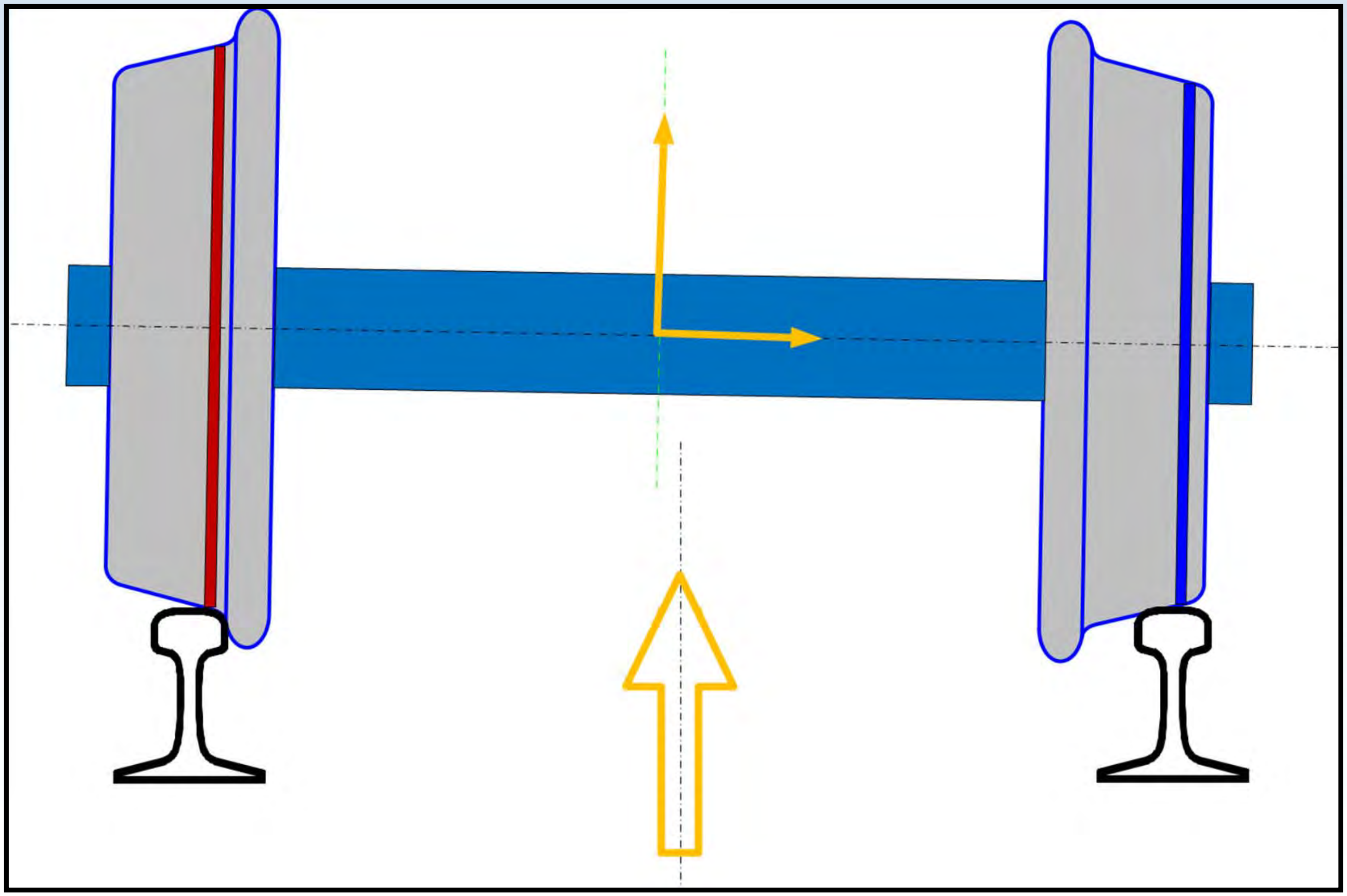

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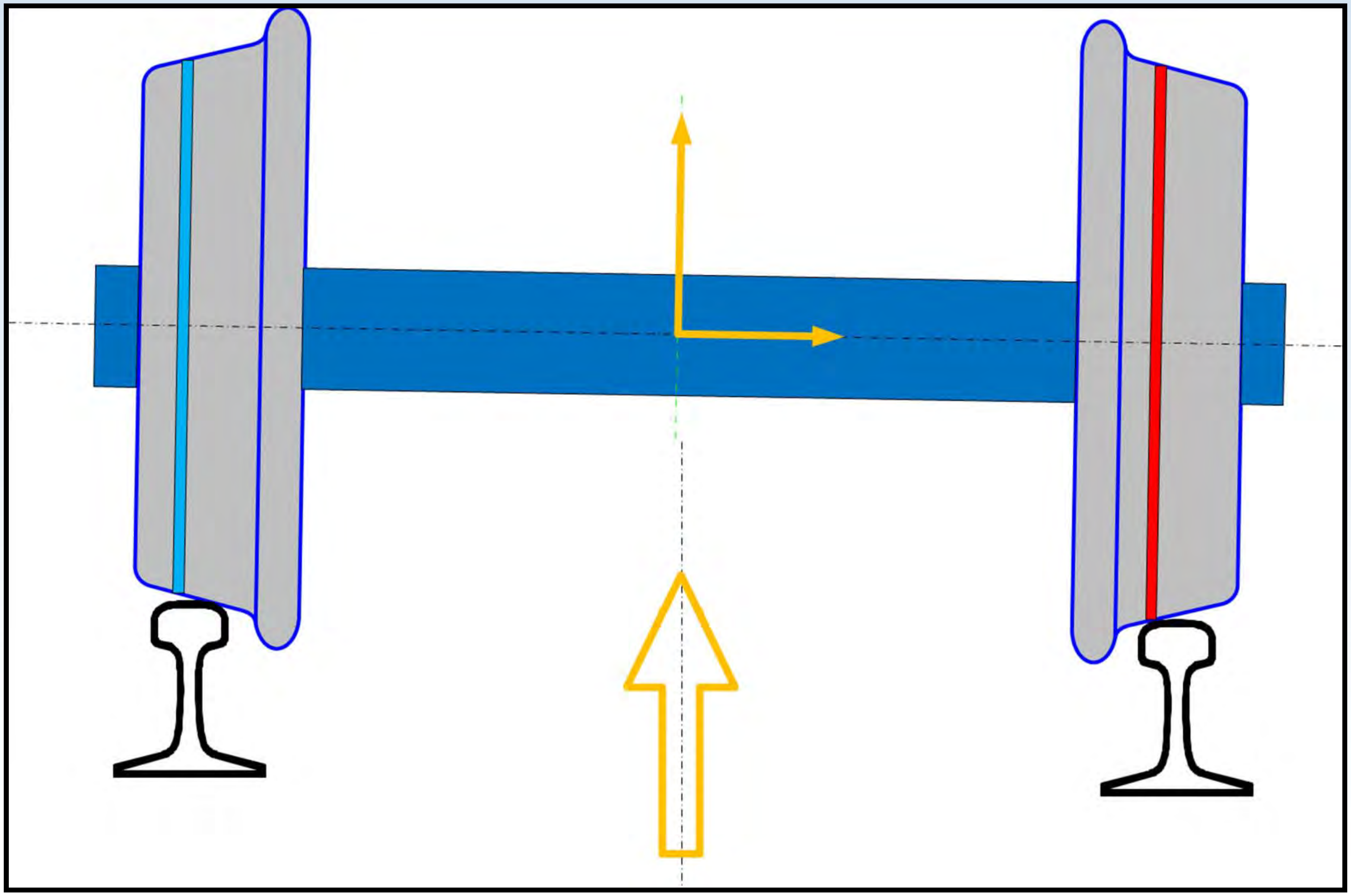

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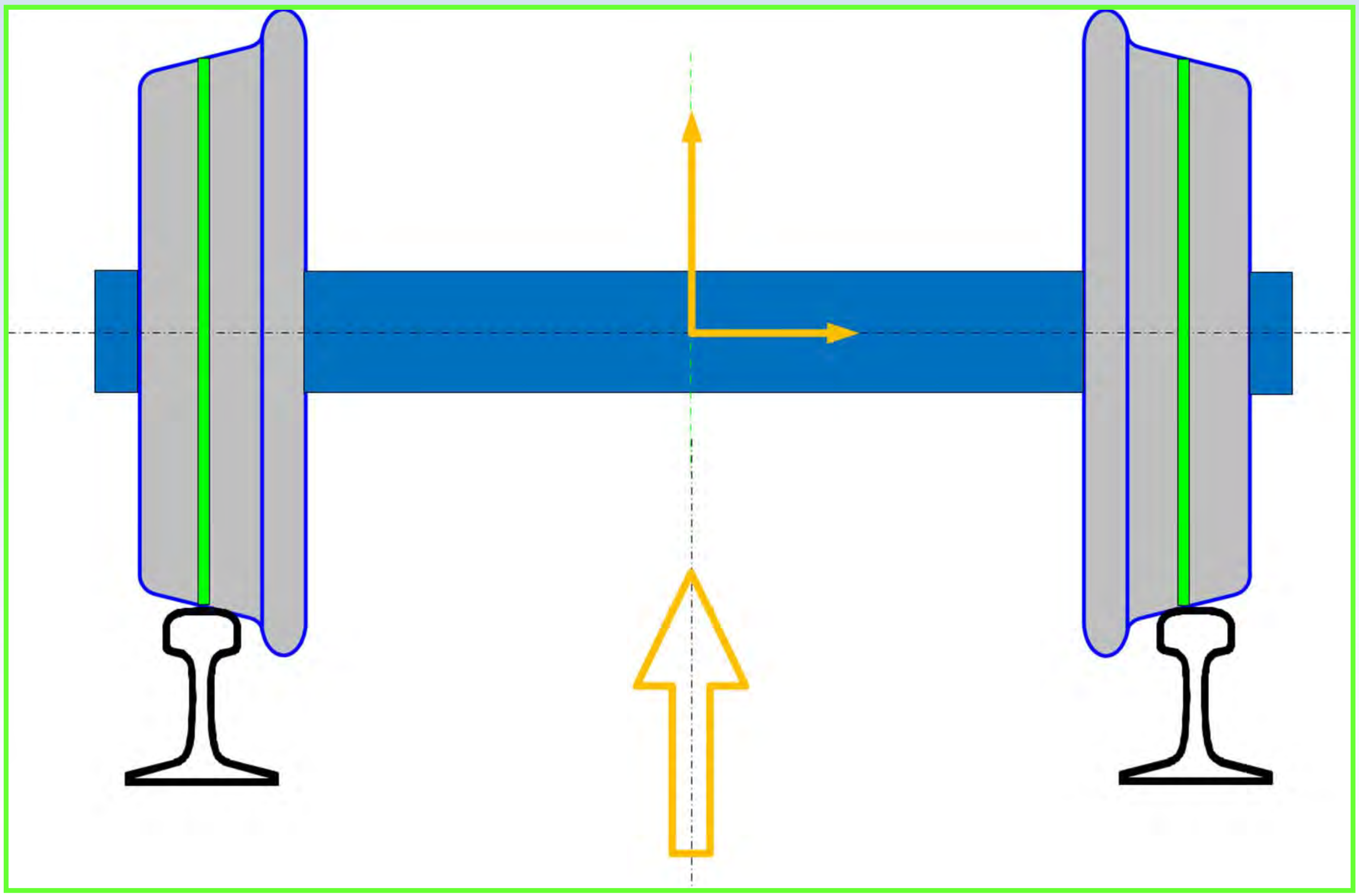
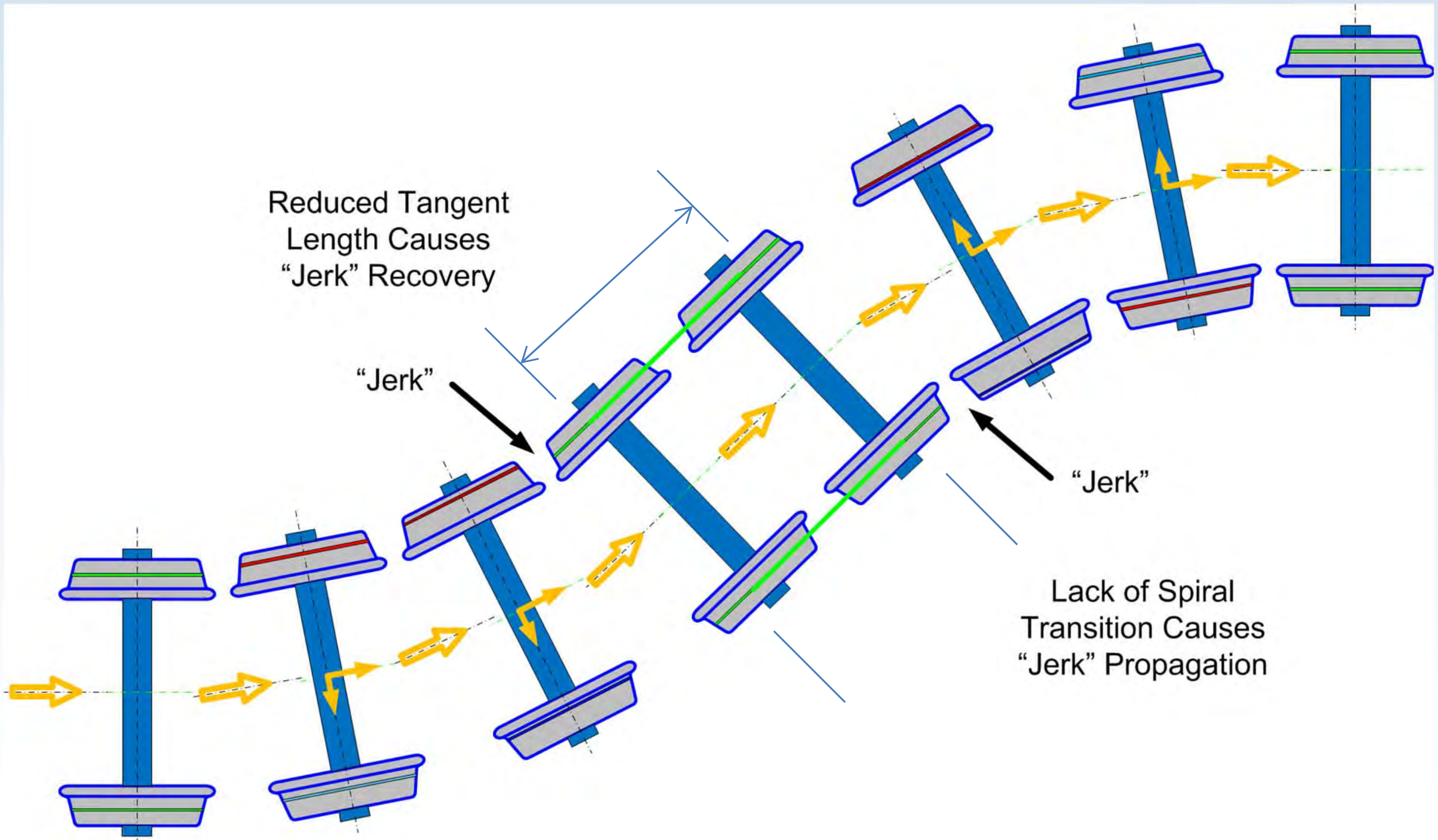


Wheel Progression



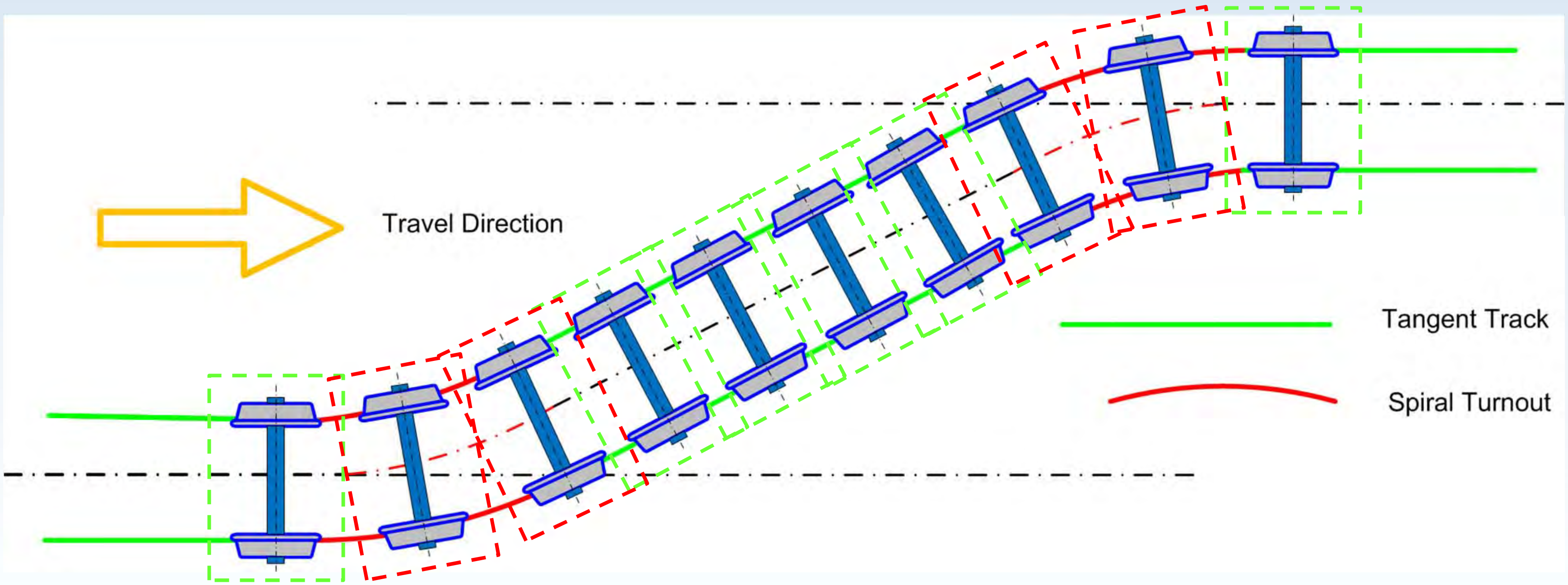
Wheel Rail Interface Through Crossover

Standard AREMA

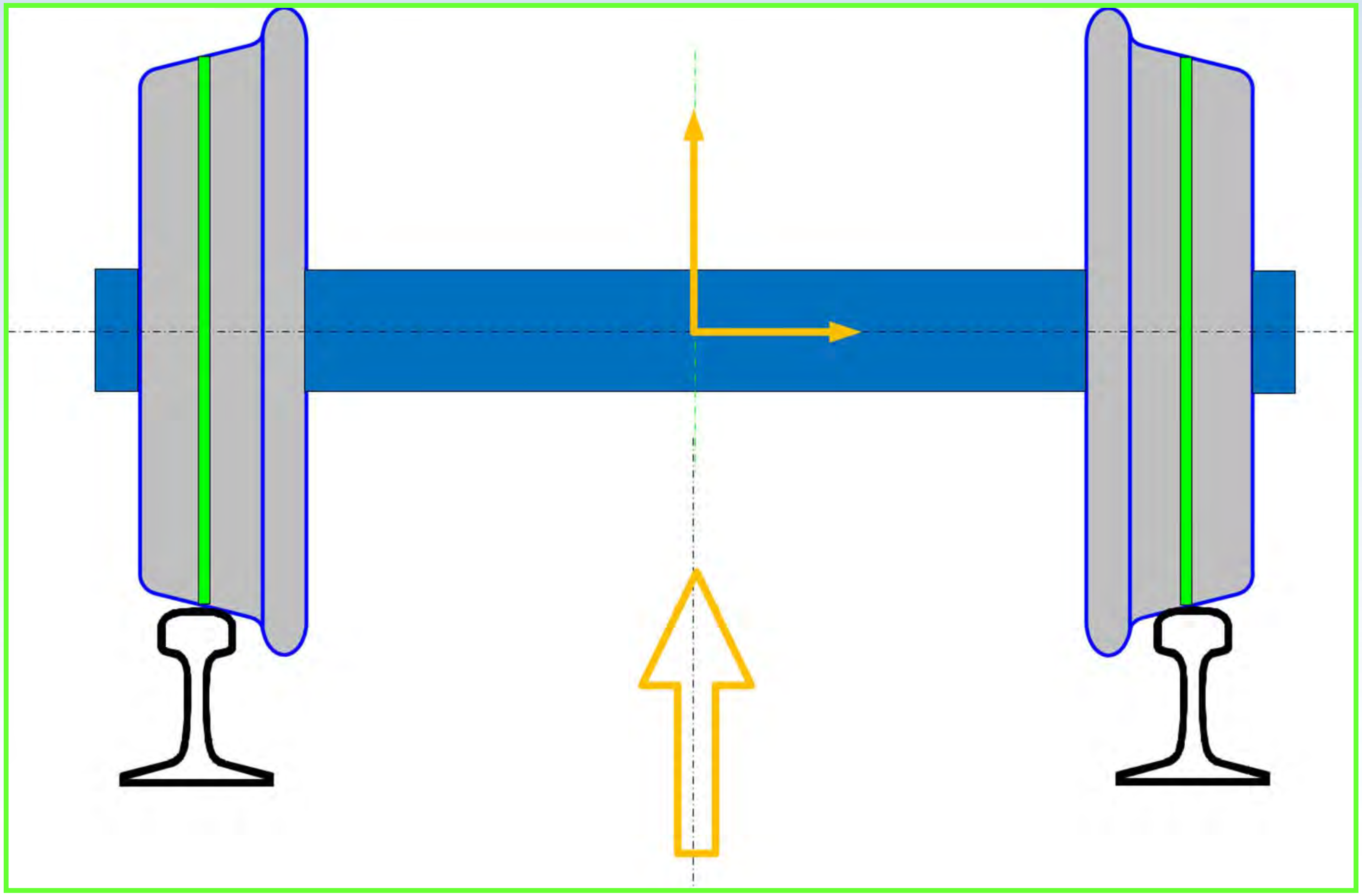
Diamond Crossover

Lead Wheel Progression

Using Standard AREMA (spiral) Turnouts



Wheel Rail Interface - AREMA



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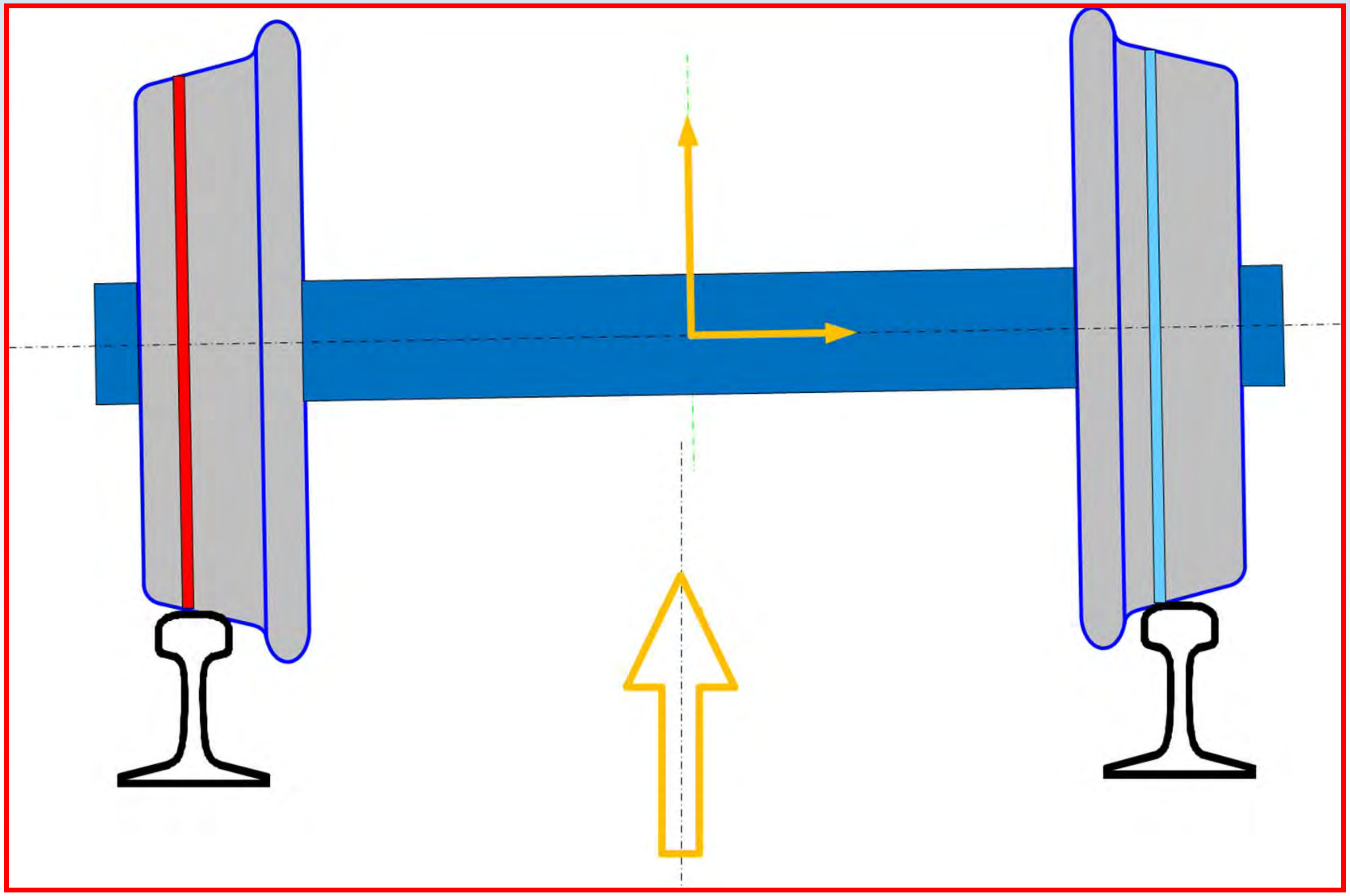

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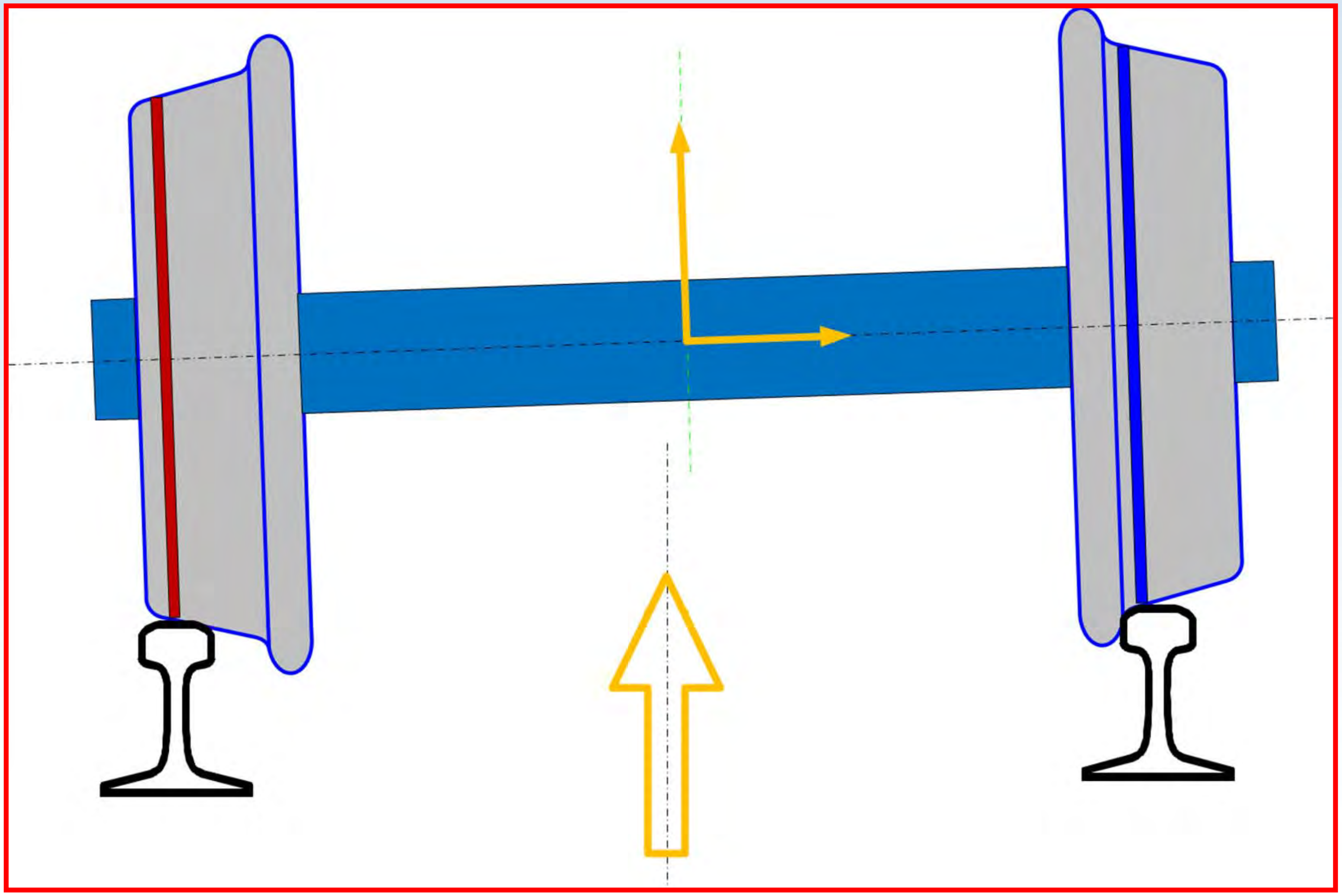

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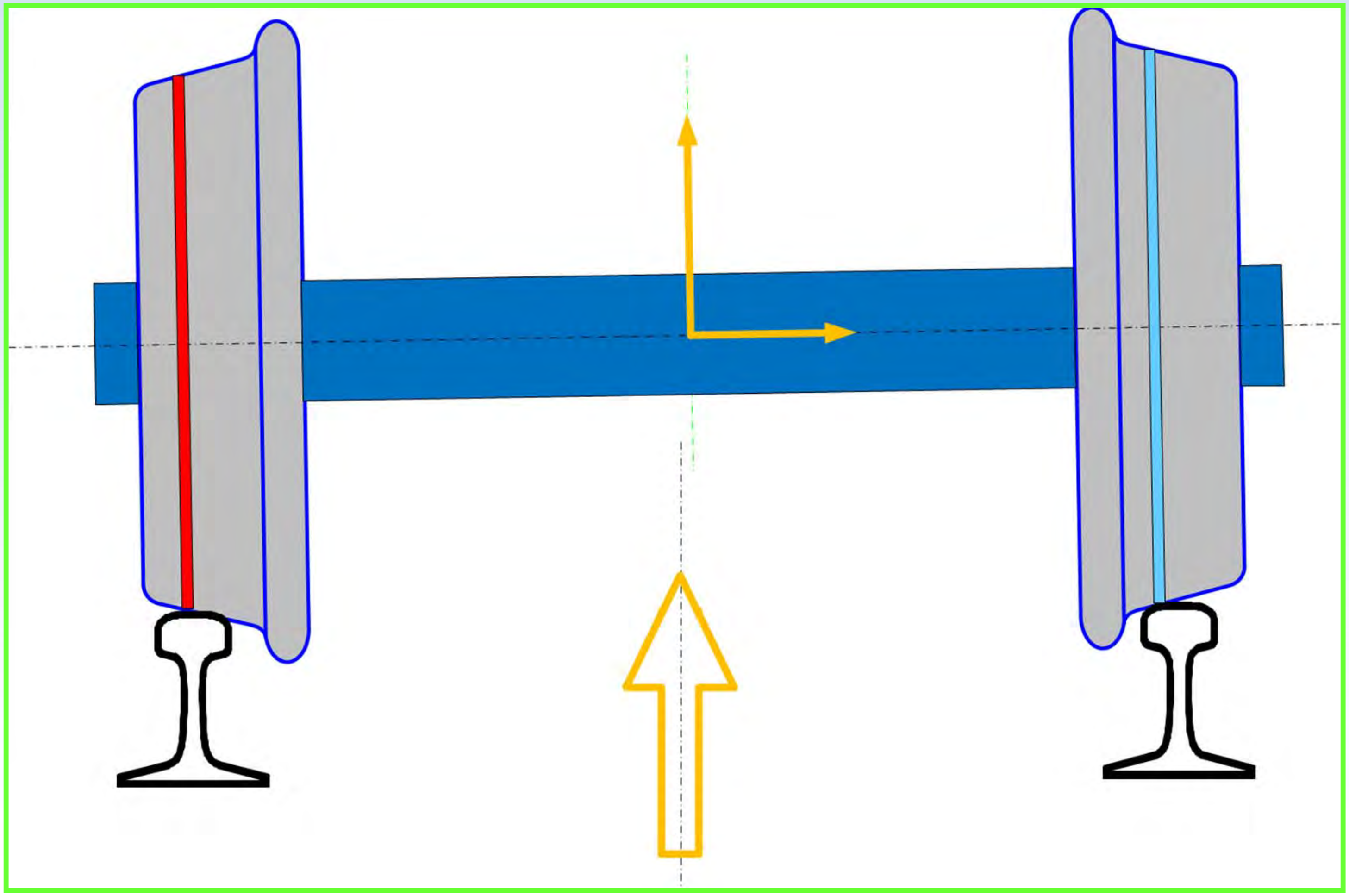

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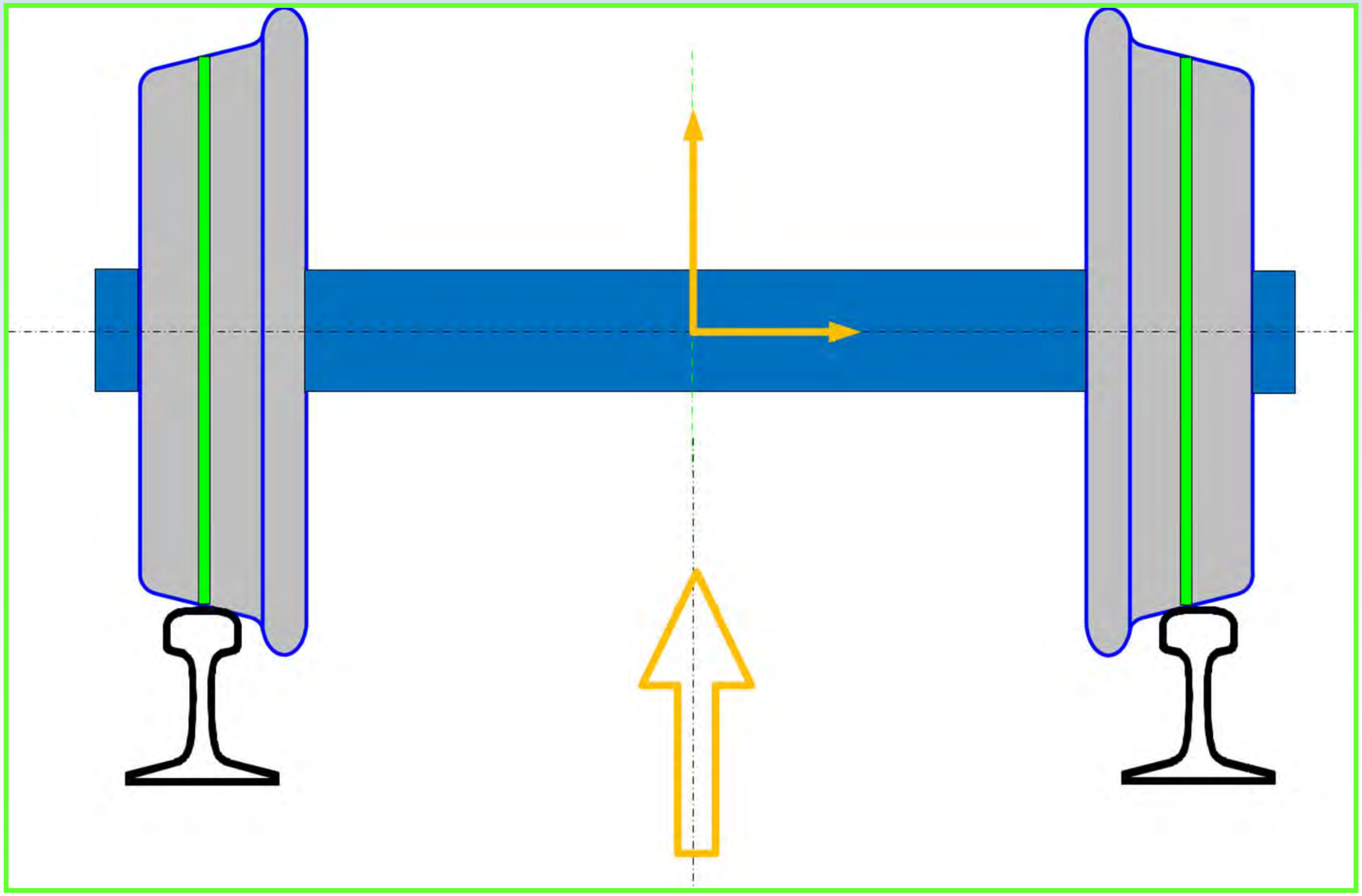

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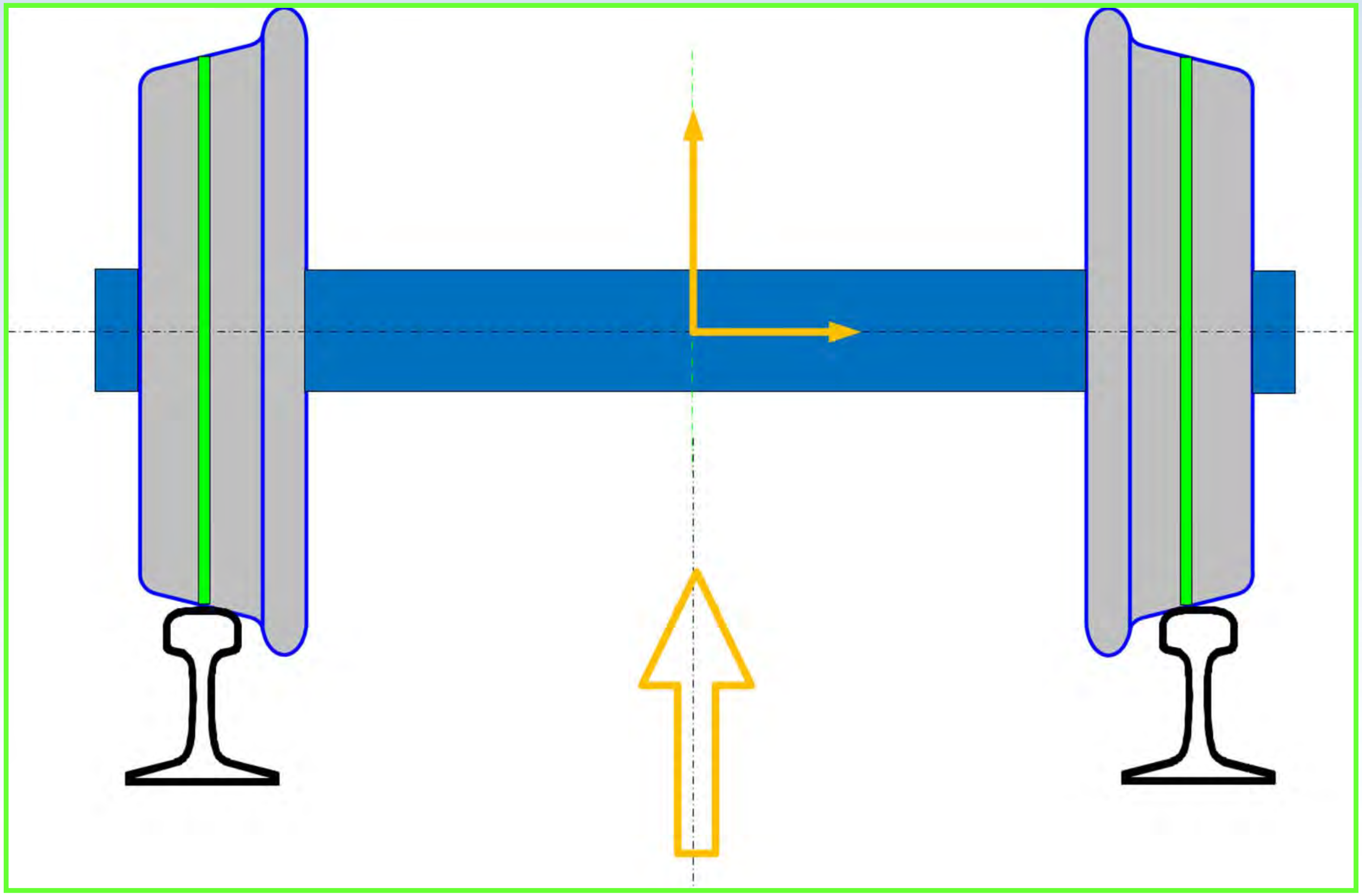

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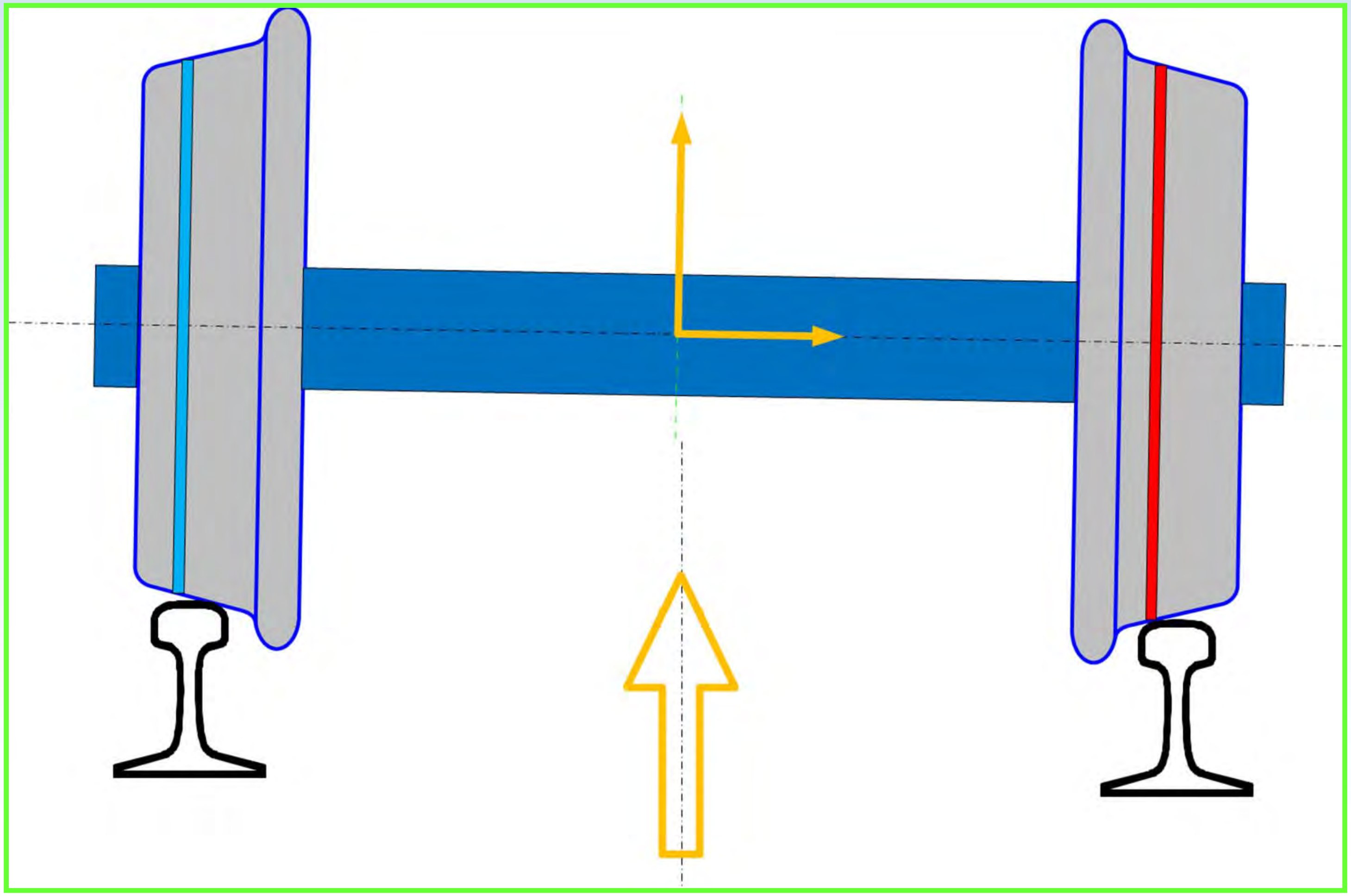

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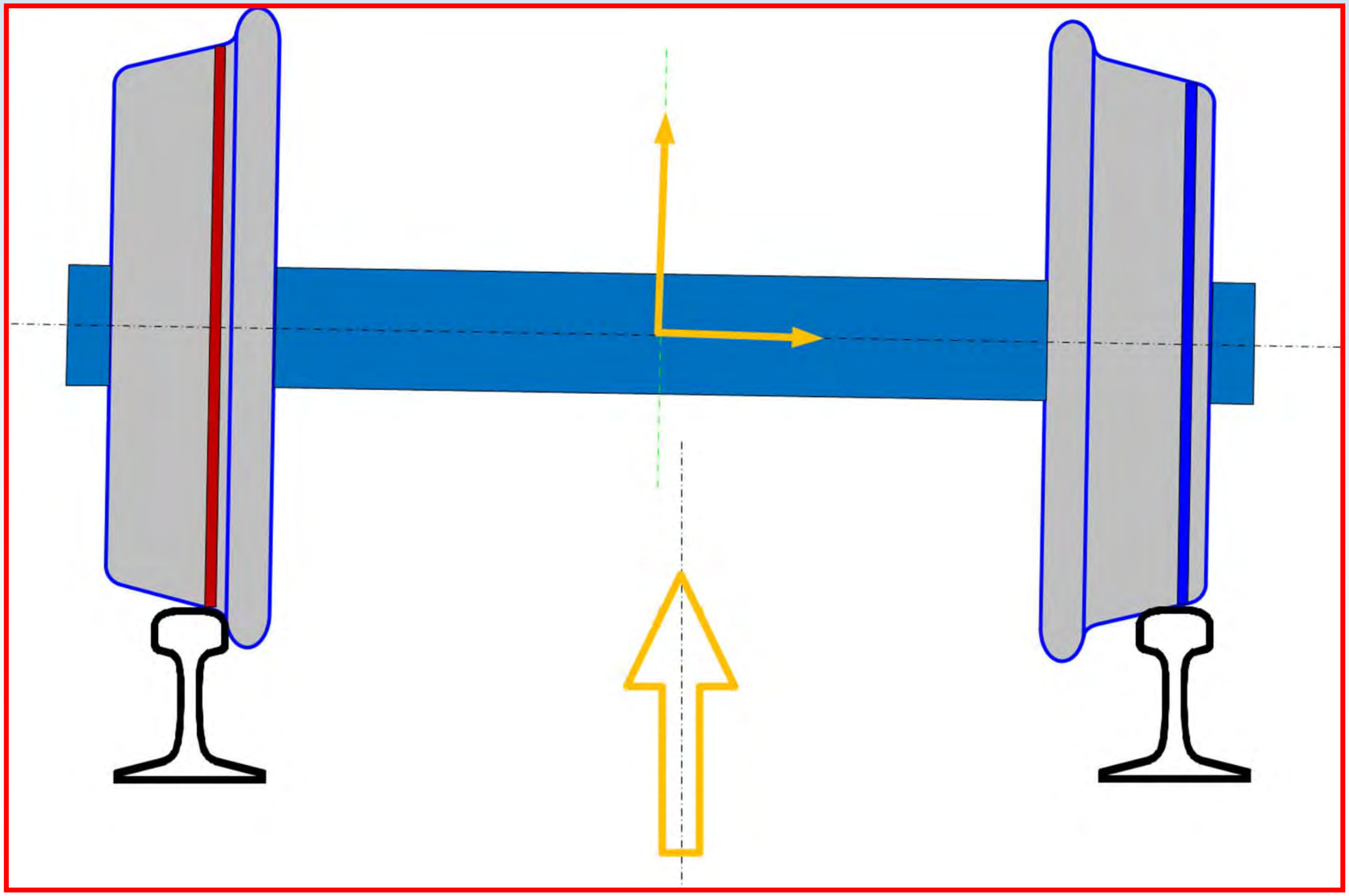

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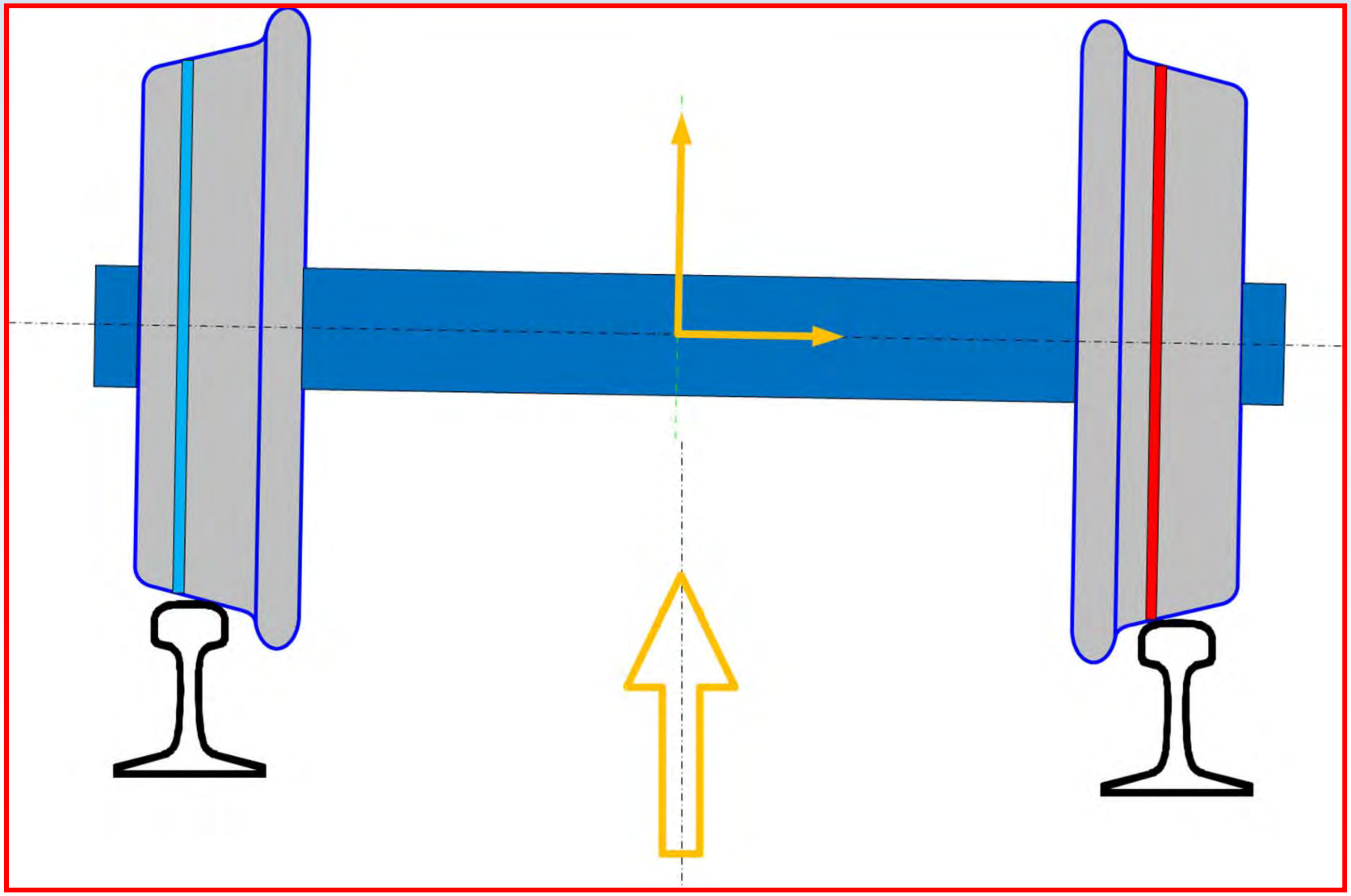

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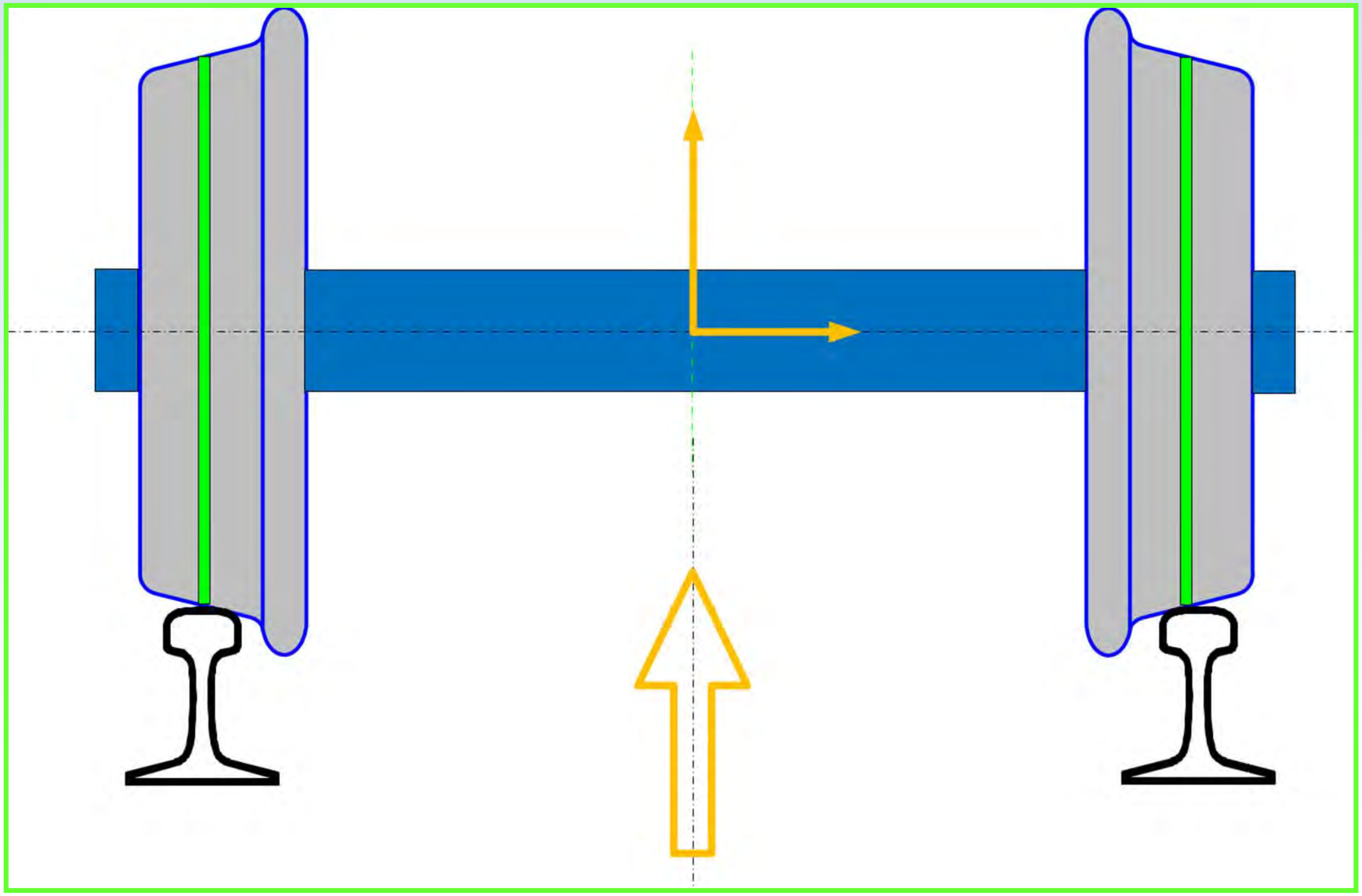
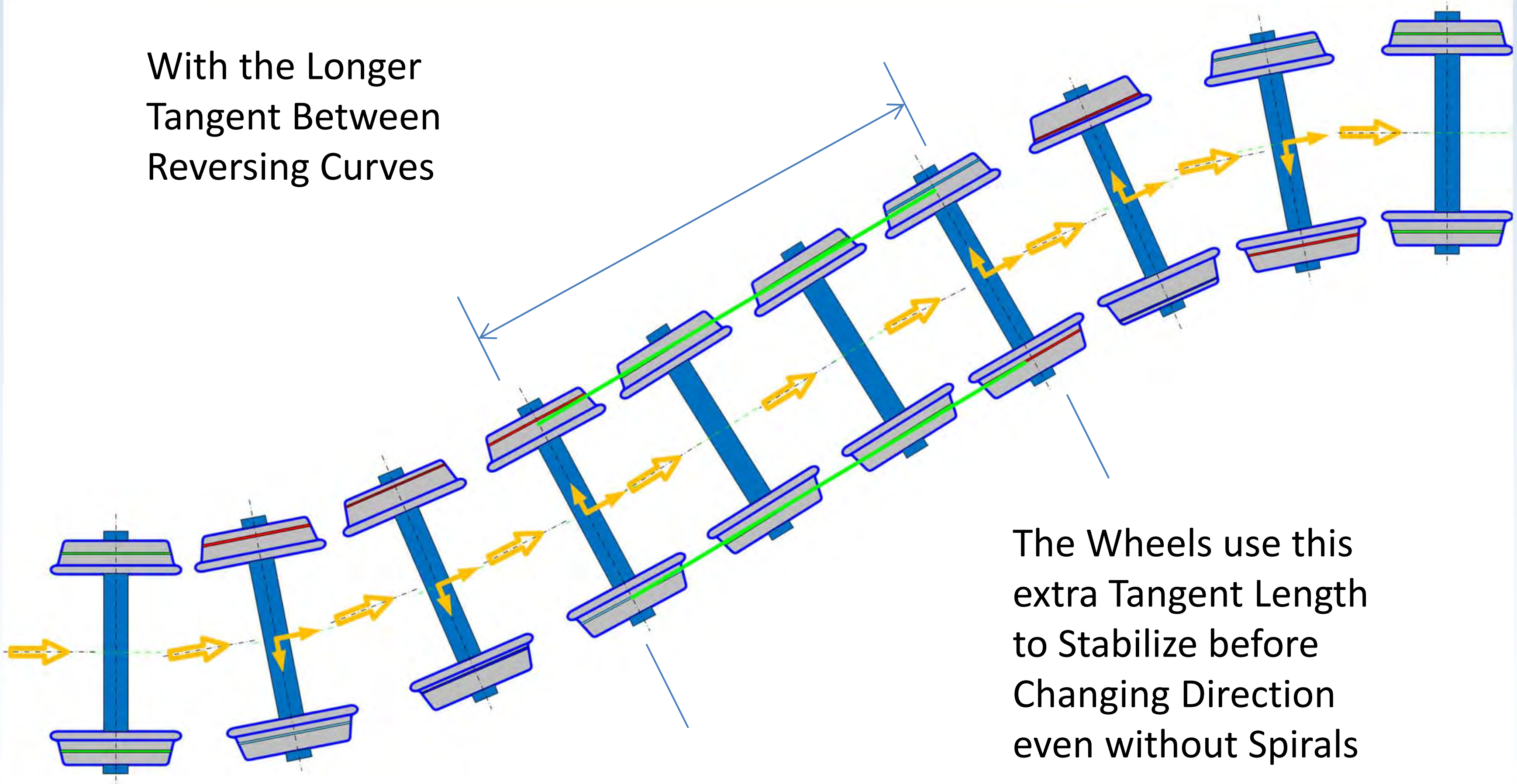


Wheel Progression

With the Longer Tangent Between Reversing Curves



The Wheels use this extra Tangent Length to Stabilize before Changing Direction even without Spirals

Rail Knowledge & Experience Cont'd

- When a vehicle manufacturer designs a high speed performance rail vehicle, the hunting and mainline stability are more important than speeds through special trackwork or when single track failure management is required for routine maintenance and repair issues.
- Therefore the individual designers for System Components have different objectives such as plant vs vehicles, and require an experienced Rail Design Engineer with O&M experience.

Underground Rail System
Purple Line Expansion

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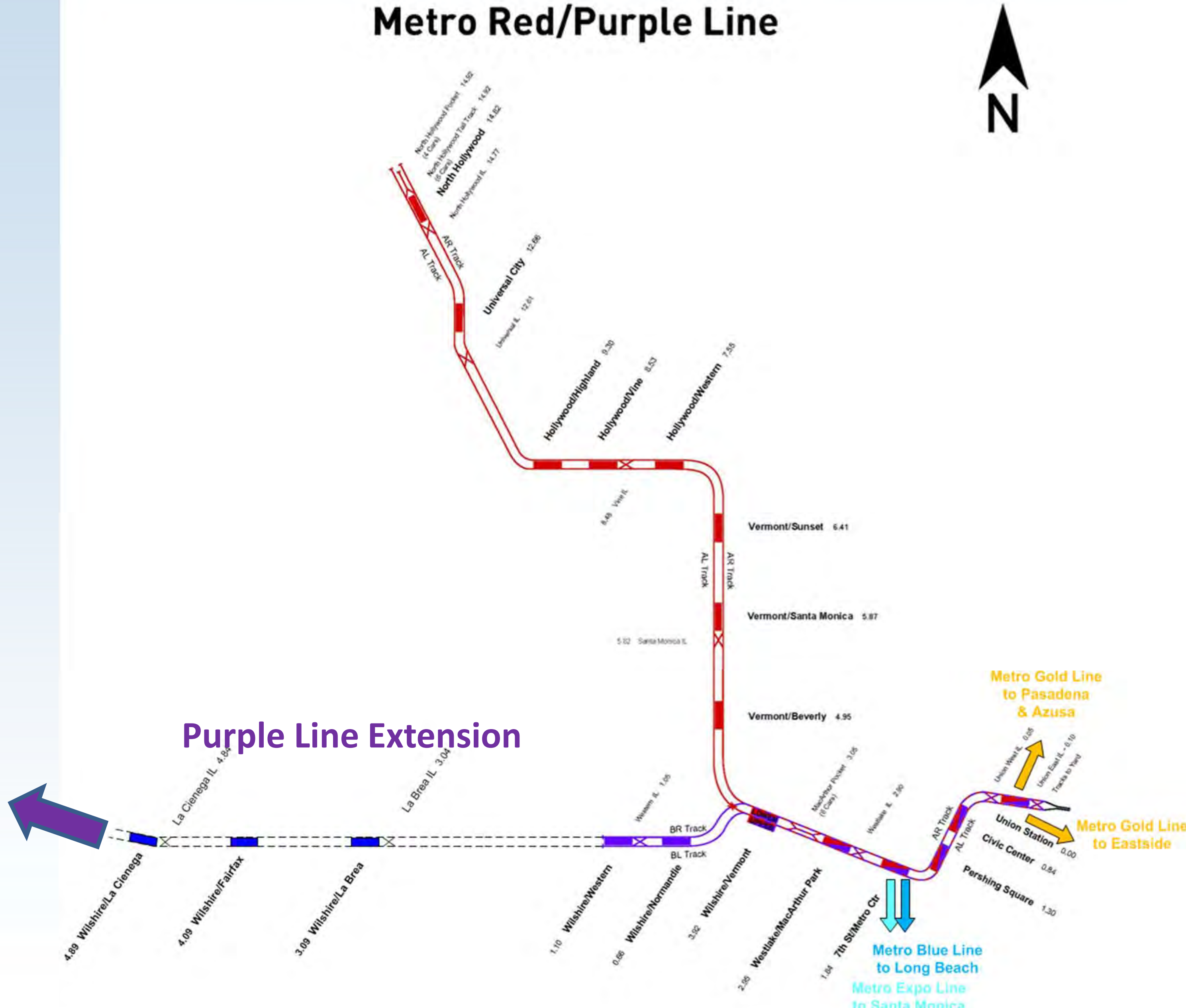
System Expansion

- With the increasing demand for more efficient and extended rail service, the LA Metro was moving into a major system expansion of their existing Heavy Rail Subway westward by constructing a Purple Line Extension (PLE) from Wilshire Western to Westwood / VA Hospital Station.
- The first portion of this underground PLE Expansion was from Wilshire Western Station to Wilshire La Cienega Station.

Metro Red/Purple Line



Subway Extension Issues

- With the System Design Issues associated with rail vehicle and transit system alignment, the movement to expand the underground system now needed to revisit the compatibility and key system design issues so that long term operating issues can be mitigated or improved in this new heavy rail construction project.
- The Alignment and Track Crossover Design can now be modified to assist in regaining operating compatibility between the High Speed Rail Vehicles and the operating needs of the system.

Underground Rail System Crossover Design Issues

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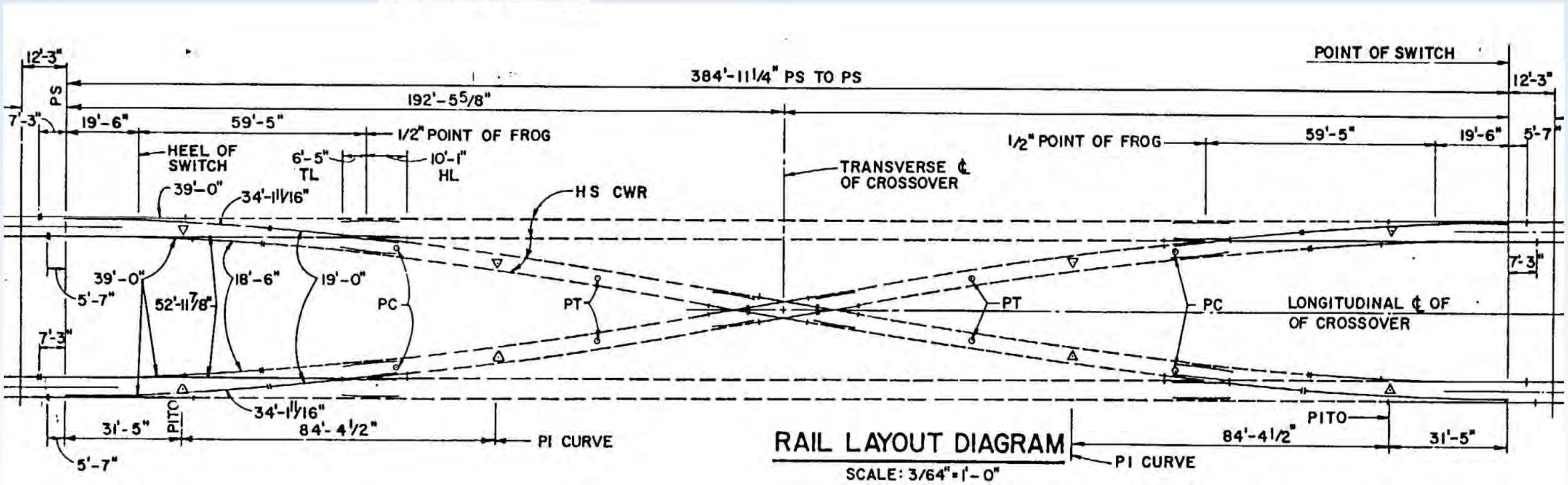
Existing Modified #10 Crossover

- Metro Modified #10 Diamond Crossover at 42' 10" track centers using:
  - the Standard AREMA #10 Turnout
  - with 19' 6" curved points, straight frog,
  - followed with a simple 806.09' Radius Curve
  - with a Center Diamond Tangent Length of 98 feet
  - that reverses to a simple 806.09' Radius Reverse Curve
  - then to a Standard AREMA #10 straight frog
  - and Reverse Turnout with 19' 6" curved points.

As-Built Metro Modified #10 X-Over

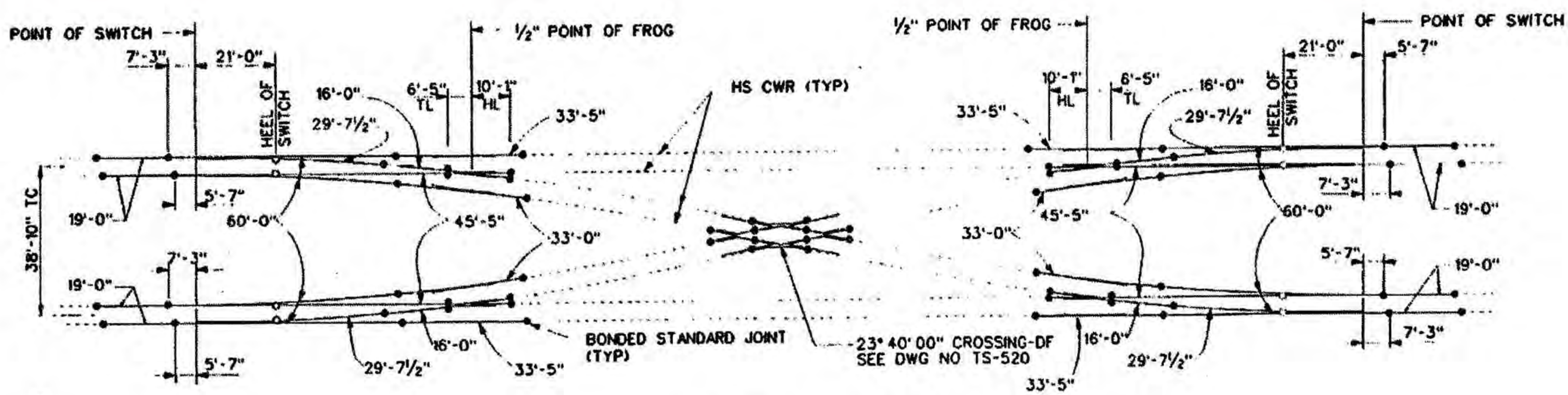
	CURVE DATA
Δ	3° 52' 01"
R	806.09'
T	27.21'
L	54.40'



Existing Custom 645’ R Crossover

- Metro Custom 645’ Radius Diamond Crossover at 38’ 10” track centers using:
  - the Custom Simple 645’ Radius Curve
  - with a 21’ Curved Switch Point
  - through a custom 645’ radius frog
  - and curve end some 20 feet from the Center Diamond
  - Center Diamond Tangent Length of 45 feet
  - that reverse to a simple 645’ Radius Reverse Curve
  - and Reverse Custom 645’ R Turnout with 21’ curved points.

As-Built Custom 645’ Radius X-Over



RAIL LAYOUT DIAGRAM
NO SCALE

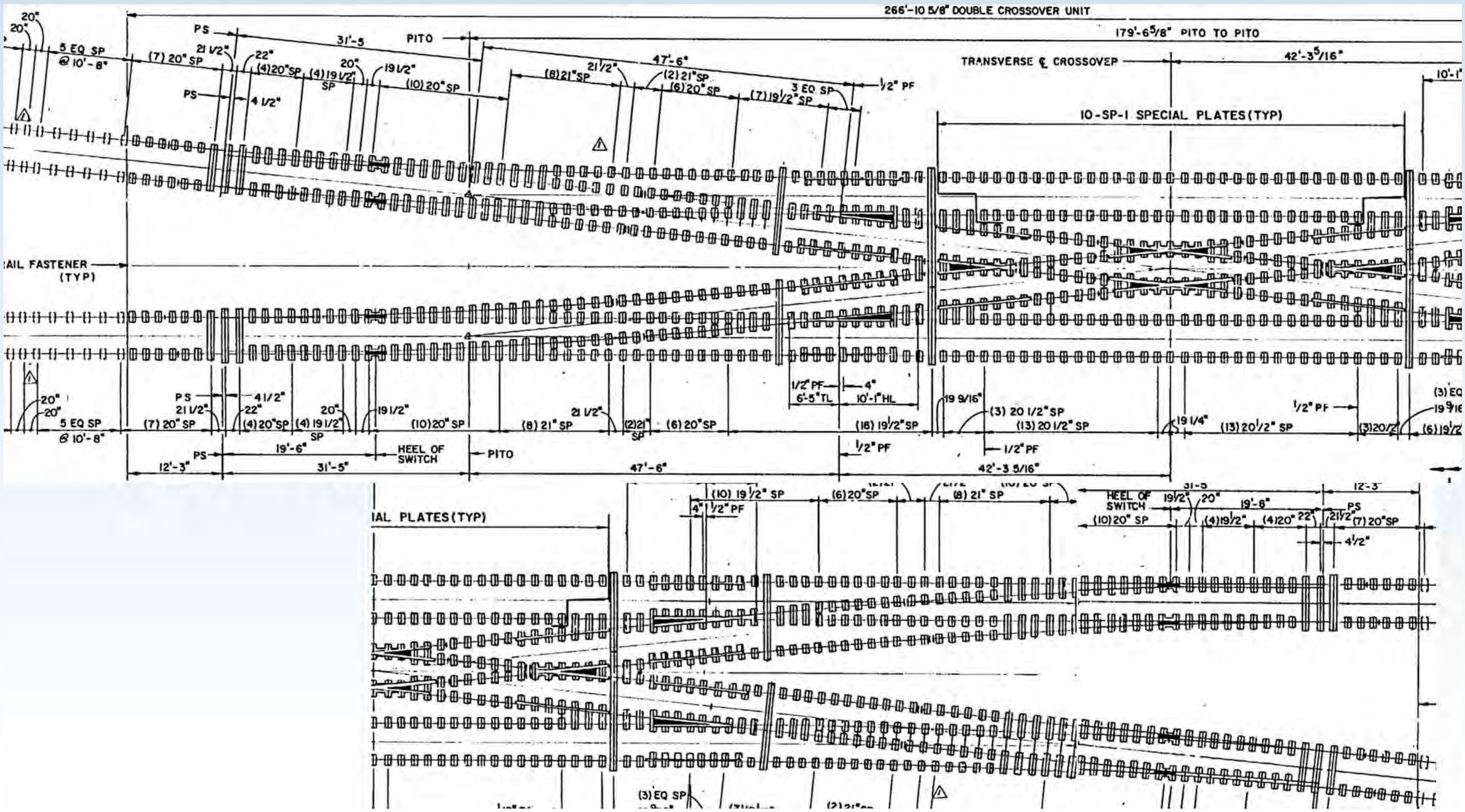
Standard AREMA #10 X-Over

- Since Metro only has one Standard # 10 Crossover, east of Union Station that could approximate the forces and design issues with a Standard AREMA #10 Diamond Crossover, this typical standard AREMA #10 Crossover with tangent track through the diamond crossover between the straight frogs of the AREMA #10 Turnouts was used for testing purposes.

Existing AREMA Std #10 Crossover

- Metro Standard AREMA #10 Diamond Crossover at 19’ 0” track centers using:
  - the Standard AREMA #10 Turnout
  - with 19’ 6” curved points with straight frogs
  - followed by standard tangent through diamond
  - with a Center Diamond Tangent Length of 98 feet
  - that reverses to a Standard AREMA #10 Reverse Turnout with straight frog and 19’ 6” curved points.

As-Built #10 Diamond Crossover



System Design Issues

- The existing Crossover Designs used typical rail transit standards associated with transit vehicle designs using 26” to 28” diameter wheels.
- However the High Speed Rail Vehicles purchased by LA Metro for their High Speed Underground Subway System have wheels (34½” dia.) and truck dimensions that are associated with commuter or commercial passenger vehicles using 32” to 36” diameter wheels.

Construction Design Issues

- The Metro Rail Design Criteria (MRDC) for the alignment requires that a minimum of 75 feet must be provided between reverse curves, but these standards are not applied to special trackwork or Diamond Crossover for failure management operation.
- The MRDC also requires that the single track design headway shall be no greater than 12 minutes.

Project Cost Issues

- As with any Underground Construction Project the amount of Open Box Area that support rail Special Trackwork or Diamond Crossovers associated with system failure management operations increases the cost of the overall project.
- The goal is to provide a realistic system design that can utilize the vehicle speed and still allow the underground alignment and crossover designs to be practical.

Project Cost Issues Cont'd

- The Operating Restriction for only 10 mph through Crossovers due to original Rail Vehicle design is unacceptable.

- Design Build Consultants and Construction questioned the original Rail Vehicle Design suitability for the 104 Heavy Rail Car Fleet.

- Since no actual vehicle performance had been done with the LA Metro Modified High Speed Vehicles, no performance data was available.

Project Cost Issues Cont'd

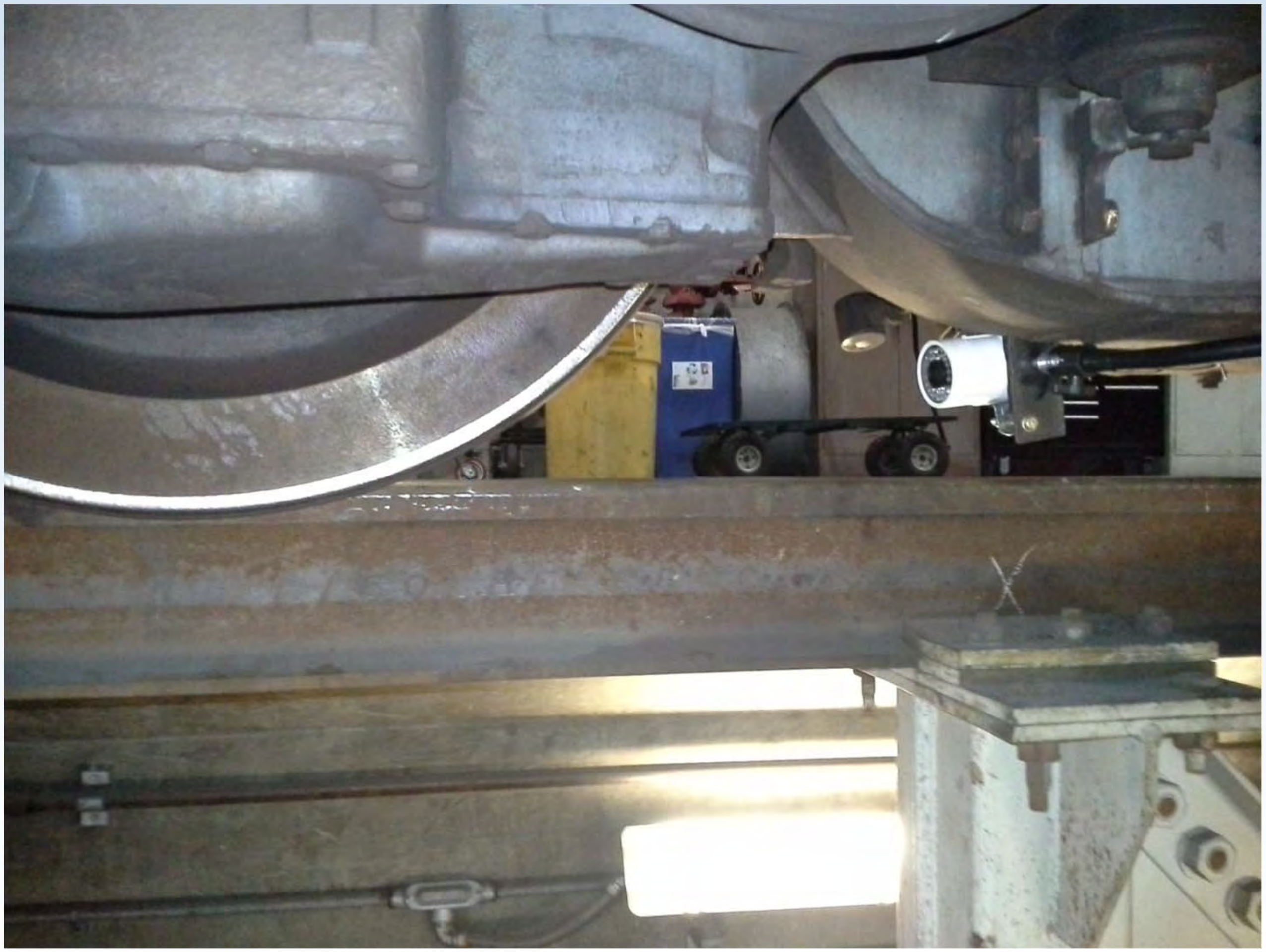
- Slower crossover speed, more crossovers required for Single Track Failure Management operation – increased up-front capital costs.
- With the increase Oversight Safety Restrictions for Wayside Worker Protection, the amount of Single Track operation has risen to 5 out of 7 nights per week just to comply with regulatory inspections and routine maintenance.
- Do existing modified rail vehicles perform, and can they operate faster through the Crossovers?

Underground Rail System Crossover Speed Validation Testing

Two Phases of Testing

- Phase 1:
  - Determine the safe operating speeds
    - Limits on Wheel / Rail System to control flange lift
    - Limit crossover speeds to prevent rail overturning
    - Limit crossover speeds to prevent wheel climb derailments
- Phase 2:
  - Determine Passenger Comfort and Personal Safety by removing the risks of onboard slips and falls

Test Equipment Placement



Test Equipment Placement Cont'd

Test Equipment Placement Cont'd

Railway Curve Effects

- To determine the Curve Effects, 6-car Test Trains with both New Wheels and Worn Wheels – as close to condemning limits as possible were used. The Test Car #555 for the New Wheel Analysis had an average wheel diameter of 34.452 inches while Test Car #531 for Worn Wheel Analysis had an average wheel diameter of 32.395 inches.
- Steady-State curving effects, and
- Transient effects as trains negotiate changes in degree and direction of curves

Typical Undercar Videotaping – 9 mph

Typical Undercar Videotaping – 15 mph

Typical Undercar Videotaping – 20 mph

Typical Undercar Videotaping – 25 mph

Railway Engineering & Metro Issues

- Developed through:
  - System Safety design
  - Practical experience
  - Empirical experience
  - Study of dynamics
  - Economical considerations
  - Maintenance considerations

Metro Design Issues

- The Metro Heavy Rail Vehicles with the long truck axle wheelbase, the large diameter wheels, and the medium to high speeds more closely resembles a conventional railroad than a light, rapid, or heavy rail transit system.
- Therefore, for these reasons the design should evolve around design criteria from the American Railway Engineering and Maintenance Association (AREMA) not Rail Transit standards.

Spiral Design Functions

- The spiral has two functions:
  - first is to provide a gradual increase in the curving force instead of a sudden "jerk" or sudden onset or peak of lateral acceleration as the car transitions to/from the curve.
  - second, serves as a "ramp" to gradually increase the super-elevation (if any) from zero on the tangent to the value in the body of the circular curve. Spirals are specified by their length.

Basic Curve Design Criteria

- Six Basics to control any risk of derailment and/or passenger comfort and safety:
  - Risk of flange climb / wheel lift derailment
  - Overturning moment on curving vehicles
  - Transitions between tangents and circular curves
  - Transitions between especially reversing curves
  - Transitions between grades (vertical curves)
  - Special considerations for low speed track

Metro Rail Design Criteria (MRDC)

- An example from conventional railways is to compute the reversing tangent length as the distance covered by two seconds at the design speed. The MRDC for reversing tangents of Heavy Rail Systems is 75 feet, and this appears to be a good choice for 25 mph crossover operation.
- This tangent to curve transition also applies to changes between curves of different radius in the same direction.

Design Issues with Large Trucks

- While the MRDC has indicated a minimum tangent between reverse curves of 75 feet and may be acceptable for Rail Transit Vehicles, the commercial railroads expect 2 seconds of vehicle stabilization before the car is exposed to a reversing curve.

- For operating speeds that may vary from 55 to 70 mph, then the minimum tangent lengths should be between 162 feet and 205 feet on the mainline.

Wheel Rail Design Implications

- Since these Crossovers are expected to operate at 25 mph, then using the commercial rail design for large heavy trucks, the expected minimum tangent length between reversing curves would need 2 seconds of stabilization time.
- Another issue associated with Crossover Designs to reduce jerk and excessive wear, is to utilize the equivalent length that a spiral would be needed to mitigate the Unbalanced Forces imposed.

Wheel Rail Design Implications Cont'd

- Therefore, the minimum length should be at least that defined by Speed in fps x 2 seconds for stabilization, or for 25 mph crossovers, this would require 36.67 fps x 2 sec. or **74 feet**.
- But the minimum length using the equivalent length to reduce Unbalanced Lateral Forces for Super Elevated Curves (1.18 x Eu x MPH) would imply that for a crossover speed of 25 mph, this tangent length between curves should be **89 feet**.

Basic Railway Engineering

- While not clearly defined in MRDC except on super elevated curves, the application for transitional spirals should be used to ease the more commercial larger heavier trucks with large wheels and longer axle spacing.
- This would eliminate “jerk” or issues related to passenger comfort and safety to reduce the risk of slips and falls from standing passengers common to rail transit operations.

Spiral Length to reduce "Jerk Rate"

- A commonly used AREMA design criteria is that the Ls (length of spiral) shall not exceed the product of the speed and unbalance elevation multiplied by a constant.
- One example for spiral length is 1.18 x Eu x MPH. This is referred to as the "jerk" rate.
- In practice, it is found that lateral acceleration impulses or jerks are more problematic than steady state lateral acceleration as in the body of curves.

LA Design Compatibility Issues

Mainline Performance

Los Angeles Compatibility Issues

- Has the Improved High Speed Rail Vehicle performed sufficiently well to continue with the truck design on new acquisitions and look at changes to the track geometry rather than a drastic change in the rail operating fleet?
- What performance documentation has been developed for the Improved Wheel / Rail interface of the existing car to determine its high speed performance?

Initial Overall System Findings

- The study found that the modifications to the wheel and rail profiles, and the modifications to the rail truck system were performing very well over the whole length of the Metro Red Line.
- There was no flange contact on most curves, and the cars tracked without hunting or other irregularities at all speeds on tangent track.
- There were almost no audio indications of rail corrugations or defects.

Improved Wheel Performance High Speed Tangent – Little to No Hunting

Improved Wheel Performance
High Speed Curves – Little to No Contact

Vehicle Design vs Track Design

- Metro Rail had decided not to incorporate a steerable articulated truck on the additional 50 new cars that BREDA was building to serve the Red Line Extensions, because the cost was prohibitive.
- The Wheel / Rail evidence substantiates that the Vehicle Improvements made support the intended performance on existing mainline, has reduced rail wear, and the test train worn wheels had operated for 545,913 miles and still have 0.9'"of the wheels 3" wear limit available before wheel replacement.

LA Design Compatibility Issues

Crossover Performance

Overall System Recommendation

- For a desired high speed underground rail system, the improved custom LA Heavy Rail Car supported by Conventional Passenger or Commuter Rail trucks using 34½” wheels is performing well.
- The Metro Track Design Geometry should be modified to allow the Operational Requirements to continue with refinements so that Increased Speeds through Failure Management Crossovers can be provided.

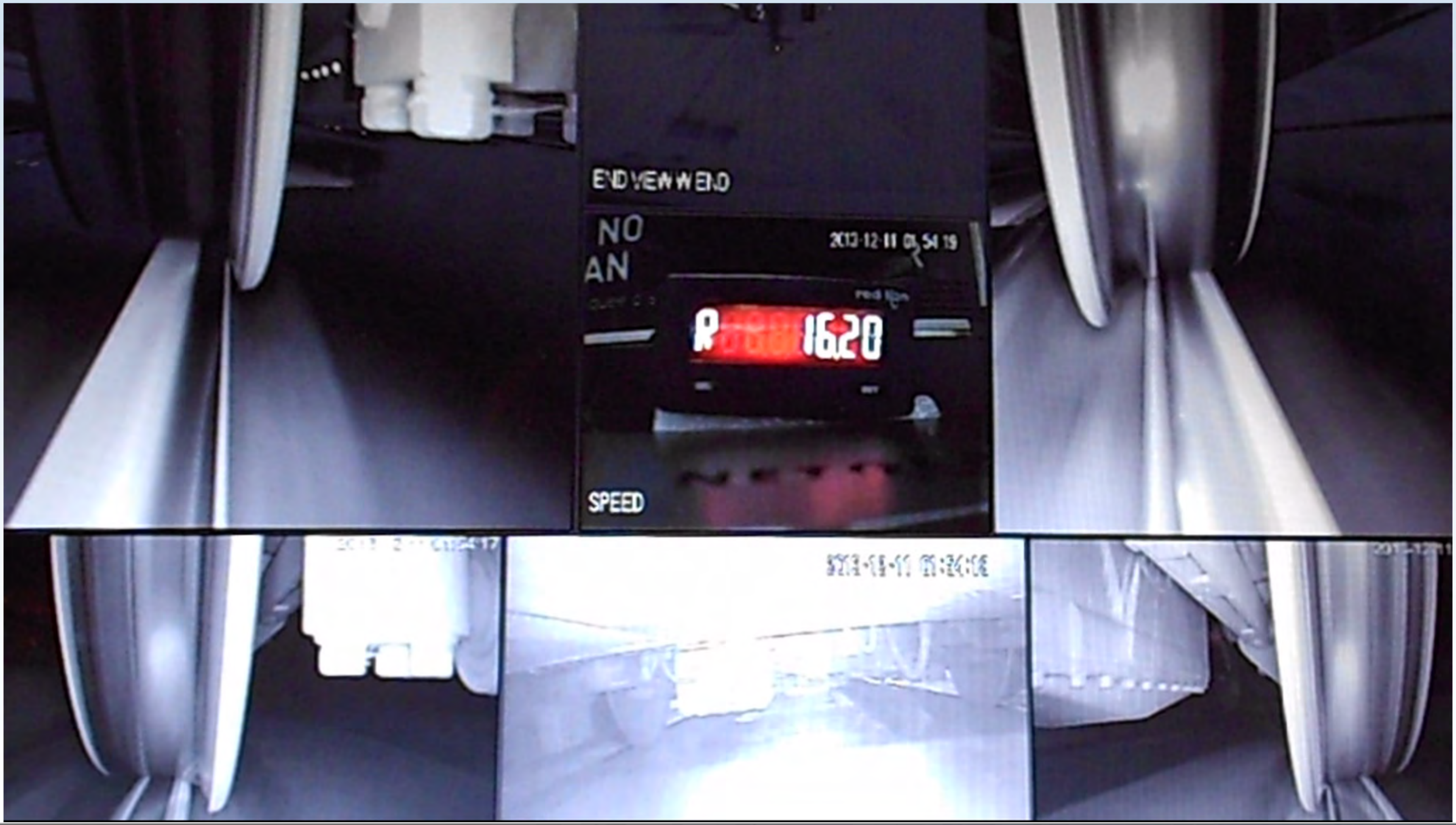
Crossover Validation Testing

- The study documented that Metro could now operate without the fear of derailment at the following maximum speeds:
  - No. 8 AREMA at 15-foot track centers (in the yard) 18 MPH
  - No. 10 AREMA at 19’ or greater track centers and no reverse curves 28 MPH
  - Metro Modified No. 10 Crossovers at 42’- 10” track centers and reverse curves 20 MPH
  - Metro Custom 645’ Radius Crossovers at 38’ 10” track centers 18 MPH

Improved Wheel Performance
Crossover Movements – Standard AREMA #10

Improved Wheel Performance
Crossover Movements – Modified #10

Improved Wheel Performance
Crossover Movements – Custom 645'R



Crossover Speed Testing Issues

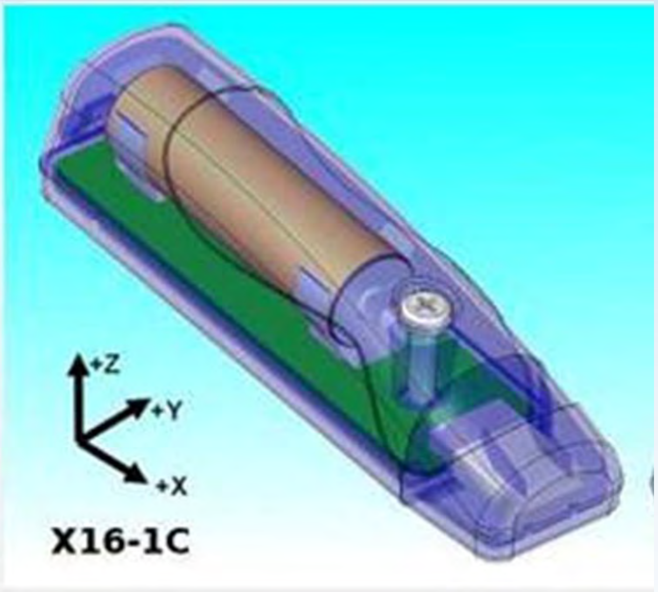
- While these Maximum Speeds can be operated through the various crossover movements with the modifications to wheel profile, lubrication, and custom rail grinding, but the actual recommended speeds must be adjusted downward due to Passenger Comfort and Safety consideration following the Phase Two Testing Analysis.
- Excessive “jerks” due to geometry issues would increase liability if these speeds were accepted.

Conclusion of Initial Findings

- The Original High Speed Truck Design using 34½" wheels similar to Commuter Rail or Commercial Passenger Rail designs with 32" to 36" Wheels together with the LA Metro system improvements such as customized wheel profiles, custom rail grinding, and changing the track design standards have provided a system performance that has not been seen in rail transit and should not be reversed.

Subsequent Analysis on Passenger Comfort & Safety

Phase 2 - Test Equipment Placement



Phase 2 - Test Equipment Placement Cont'd

“Jerk Rate” Issues

- Jerk rate for conventional railroads is generally considered as 0.5 g’s for seated passengers on long distance travel runs.
- Rail transit is designed for short distance travel between stations unlike conventional rail systems; therefore, the acceptable “Jerk Rate” needs to be reduced to account for standing rail passengers.

“Jerk Rate” Issues Cont’d

- Due to Extra Seats removed for greater capacity the “Jerk Rate” becomes of greater concern to risks of passenger slips and falls or liability.

"Jerk Rate" Issues Cont'd

- Metro has already removed seating in the cars to accommodate more open space for standing passengers and increasing passenger risks of slips and falls if "High Jerk Rates" are experienced.
- Therefore, increasing the operating speeds through these non standard AREMA crossovers must reduce "Jerk" to these standing passengers before a final operating speed can be designated for crossover moves.

“Jerk Rate” Issues Cont’d

- A general acceptance from modifying the conventional seated jerk rates of 0.5 g’s to simulate a reasonable jerk value for standing passengers is to reduce this exposure force by 50%.
- This would indicate that for Rail Transit Systems, the acceptable Jerk Rate for standing passengers would be some number below 0.25 g’s.

“Jerk Rate” Issues Cont’d

- Another issue related to higher “Jerk Rates” is the long term impacts on the track / truck maintenance components and long term serviceability.
- The car builder generally has indicated that the truck is designed to support a maximum jerk force of 2 g’s, but it is not a force that is to be considered routine or normal exposure, if the long term reliability of the truck components is to be maintained.

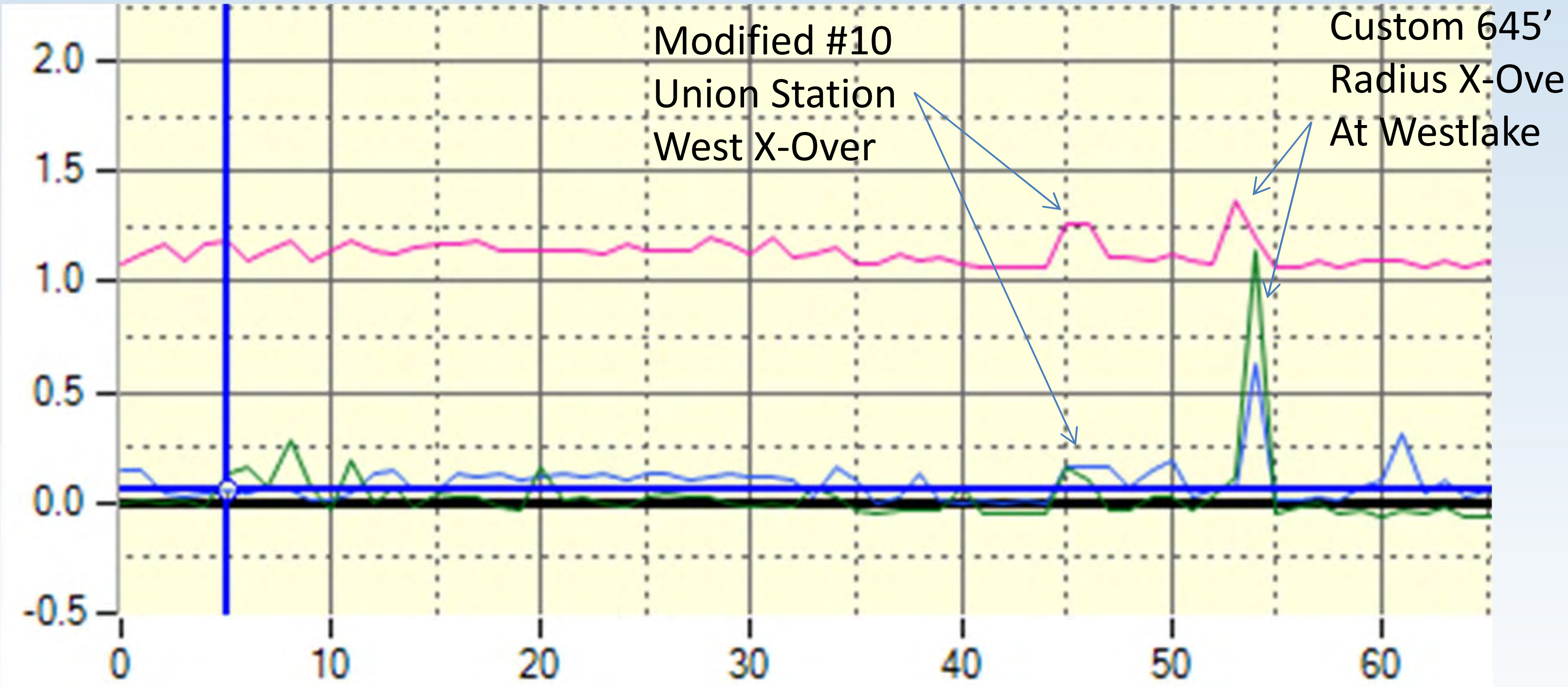
Car vs Truck Accelerometer

- To determine the actual Truck Lateral Forces, we looked at different options for determining a multiplier between the car vs. truck mounted accelerometers.
- The best method found was comparing peaks for the entire run on the most active channel of each.
- The truck mounted unit (XLR8R image) has about 6x higher readings than the car unit (Sensware image).

Truck "Jerk Rate" Issues

- The relationship from testing the car passenger "Jerk Rate" is seen as approximately 6 times less "g Forces" than those experienced on the trucks.
- The ultimate design speeds approved must be evaluated for the long term truck maintainability and system component longevity.
- Therefore, the maximum g-Force that the car passenger compartment should see, should be less than 0.33 g's or 0.25 g's for comfort.

Typical Car Accelerometer Data



Metro Red Line Feb 6 Test Routes operating at 25MPH start at 42 minute mark in EMO mode.

Crossover Speed Implications

- The Car Body Accelerations at 25 mph for the Modified #10 Diamond Crossover at Union West with simple 806’ radius curves separated by a 98’ tangent between reverse curves depicts considerably less jerk.
- The Car Body Accelerations at 25 mph for the Custom 645’ Radius Diamond Crossover at Westlake MacArthur Park that uses a simple 645’ Radius Curved Turnouts with only a 45’ tangent distance between reverse curves depicts unacceptable (0.6 lateral) jerk forces.

Crossover Speed Implications Cont'd

- This supports the commercial rail design that when the tangent between reverse curves becomes shorter, the ability for the truck to stabilize before changing direction is reduced and affects how a truck and train will react through a crossover move.

- Because of these Rail Vehicles used on the LA Metro Underground, it is important that the Track Alignment Design accommodate and support these long term performance improvements.

Crossover Speed Implications Cont'd

- When looking towards the proposed PLE Modified #10 Turnout with only 60' tangents when compared to the Existing Modified #10 with 98' tangents (a 39% reduction), it could imply that the shorter tangent could increase the jerk rates and may require additional speed restrictions through these intermediate Crossover Movements.

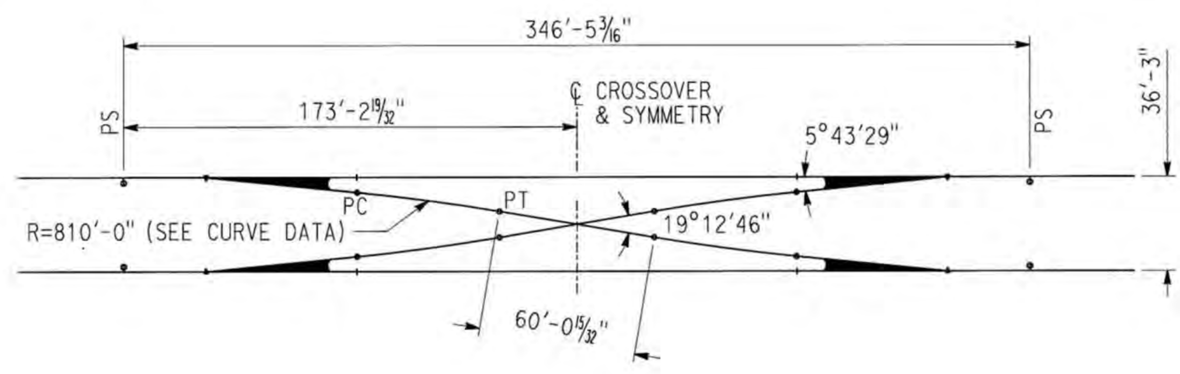
Design Improvements

- Due to Passenger Comfort and reduced risk of slips and falls, most Diamond Crossover designs in Europe and now in North America are being designed to have constant guarding from Frog to Frog even when simple curves are added after the frogs to limit “Jerk” effects and make the ride a more normal movement through these crossover alignments.

Required Design Improvements

Design Improvements Required

- It is recommended that all Rail Transit Curved Double Crossover Design be supported with continuous Guarding as shown above so that the potential for increased crossover speeds can be implemented.

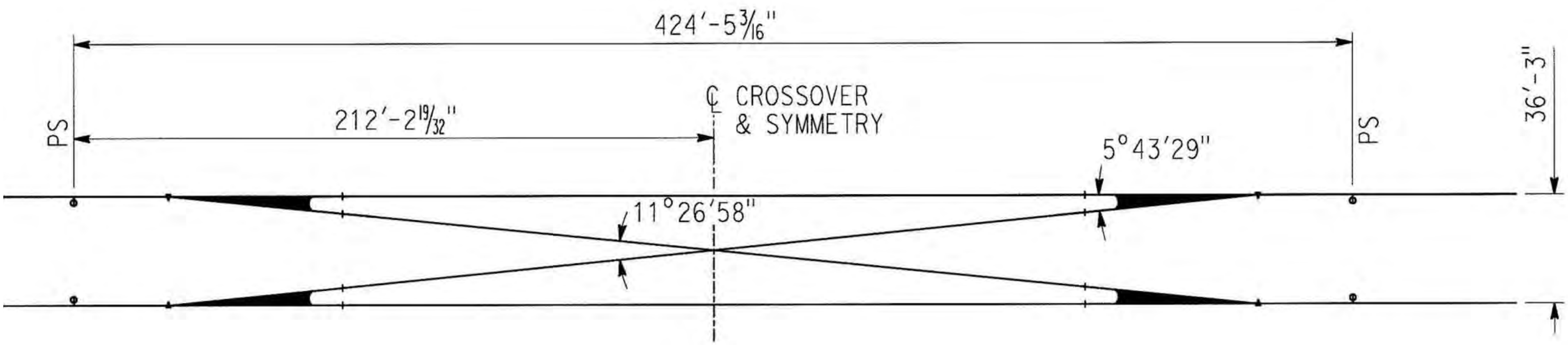


NO 10 CURVED DOUBLE CROSSOVER
36′-3″ TRACK CENTERS (CURVED)

Terminal Crossover Designs

- Due to the extensive use 24/7 of the Terminal Crossover Movements, it is desirable to have the fastest speed for incoming and outgoing trains to minimize terminal congestion.
- With 24/7 usage, it is also imperative that the forces and jerks to passengers be minimized due to the people moving about the cars in preparation for de-boarding or finding a seat.

Recommended Terminal X-Over



NO 10 CURVED DOUBLE CROSSOVER
36'-3" TRACK CENTERS (STRAIGHT)

Crossover Speed = 25 mph with minimum jerk

DESIGN RECOMMENDATIONS

Effect of Vehicle Modifications

- From the testing data and performance evaluations, it is found that the Metro Heavy Rail Vehicle modifications initially recommended and installed in 1996 are performing as expected and should become standard to ensure all new vehicles, rebuild truck assemblies, and the enhanced vehicle performance is maintained for the current rail underground system.

- The Worn Wheel on the Test Car was shown from maintenance records to have 545,913 miles and still not at the condemning limits.

Proposed Track Modifications

- From the testing data and performance evaluations, it was found that the Metro Heavy Rail Crossover Designs are not compatible with the High Speed Vehicles with the large truck design and 34½" diameter wheel.
- Modify the existing Terminal Crossovers as recommended and change the Metro Rail Design Criteria (MRDC) so that all Heavy Rail Extensions track designs can support the current high speed rail vehicle.

Effect of Track Modifications

- From the testing data and performance evaluations, it is found that the Metro Heavy Rail modifications initially recommended and installed in 1996 must be maintained for overall system long term efficiency.
- All new extensions should incorporate these improvements into these design build contracts including the Custom Rail Grinding to match the Custom Designed Wheel Profile

Possible Crossover Speeds

Location	Turnout Type	Track Centers	Tangent Length Between Curves	Crossover Speeds current	Crossover Speeds proposed	Modifications
Existing Rail Transit Metro RED Line & Metro PURPLE Line Crossovers:						
	Standard AREMA #8	15’-0”	45’	10 mph	15 mph	No Change
Union East	Standard AREMA #10	19’-6”	98’	10 mph	25 mph ?	Change Approach Trk
Union West	MRL Modified #10	42’-10”	98’	10 mph	25 mph	Guard Frog to Frog
Intermediate	Custom 645’ Radius	38’-10”	45’	10 mph	15 mph	Replaceable Pt Tips
Pocket	#10 & Eq. #8 AREMA	19’-6”	128’	10 mph	25 mph	No Change
Proposed Westside Expansion – Purple Line Extension (PLE)						
Intermediate	PLE Modified #10	36’-3”	60’	10 mph	15/20 mph	Guard Frog to Frog
Terminal	Standard AREMA #10	36’-3”	343’		25 mph	

L A Metro – Still Expanding

- This completes the presentation on how “Wheels interface with Rail” on the LA Metro Rail Transit System.