2011 AREMA CONFERENCE

Turnout Design: Higher Diverging Speed in The Same Footprint

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ABSTRACT

TURNOUT DESIGN: HIGH DIVERGING SPEED IN THE SAME FOOTPRINT

A turnout is defined as an arrangement of a switch and a frog connected by closure rails, by means of which rolling stock may be diverted among different tracks (AREMA Turnout Terminology- 101-08). A turnout could produce high lateral forces and accelerations, which require slower operating speeds and can have adverse effects on ride quality and component life.

The author’s Objective Function is Low Cost Modification of Existing Turnouts for Higher Diverging Speed in the same Footprint. The main Constraints are to keep the certain parameters as fixed e.g. Lead Distance (distance between the point of switch and point of Frog), Interlocking Footprint, Location of P.S. (Point of Switch) and P.F. (Point of Frog), Frog Angle. Commercial Field tests were not within the scope of this paper, but the recommendations were proposed, based on author’s proposed hypothesis and the existing techniques thorough literature review. Also, a rehabilitated MNRR (Metro-North Railroad) high speed AREMA no. 20 turnouts at Scarsdale on the Harlem line in New York State is illustrated as an example of implementation of various recommendations.

When a railroad vehicle negotiates a diverging portion of turnout, the lateral force is generated due to centrifugal action and varies due to inherent geometry of the turnout. The author proposes to use concept of same amount of work done in moving of a railroad vehicle from P.S. (Point of Switch) to P.F. (Point of Frog) through various diverging routes. Here the author is concentrated on lateral force variation by optimal geometric design of diverging portion of the track. The author proposes some constraints in this analysis like 1. Frog angle; Lead distance remains same through various diverging routes; 2. Energy lost in heat, sound, etc. is negligible or constant through different diverging routes; 3. Longitudinal force is constant throughout the turnout move of railroad vehicle.

Mathematically, \[ \sum [(\text{Force Exerted by Railroad Vehicle to the Rail}) X (\text{Differential Distance along the Path of Various Diverging Route})] = [(\text{Average Lateral Force}) X (\text{Lateral Displacement between P.S. And P.F})] + [(\text{Average Longitudinal Force}) X (\text{Longitudinal Displacement between P.S. and P.F.})] \]

Applying The Assumptions mentioned above,

Hence; \[ \sum [ (\text{Instantaneous Lateral Force}) X (\text{Differential Lateral Displacement between P.S. And P.F.}) ] \] is same for All Diverging Routes. The proposed solution is to redesign the diverging track alignment between P.S. and P.F. so that average lateral force remains within the optimum level.

The author has done a detailed feasibility study of implementation of various techniques for higher diverging speed over turnout in same footprint with reduced lateral forces and accelerations, thus improving ride quality and potentially

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decreasing component wear. The author basically implies “same footprint” to “Same interlocking footprint”. Future challenges are to extend the study even to commercial level by using different methodologies. As such the Turnout design methods & techniques (for higher diverging speed in the same footprint) discussed here should be regarded as “work-in-progress” rather than a conventional theory. The paper concludes with the latest accomplishments of turnout design and opportunities of future work which leads to higher diverging speed in the same footprint without changing the basic track infrastructure.

INTRODUCTION/BACKGROUND:

Turnouts are essential parts of track work, but could be a trouble maker if not done properly (Rich Kohm, 2008). Turnout is the inherent weaker portion of the track work and thus the most sensitive to improper design, construction and maintenance. The diverging route of turnout could produce high lateral forces and accelerations due to centrifugal and unbalanced forces. If proper design of diverging portion of turnout is not done, it will lead to reduced operating speed in order to maintain good ride quality and component life. The diverging route of turnout has lower speed capacity, compared to mainline track. This given situation reduces the high speed potential of railroad vehicle negotiating the turnouts. These above factors contribute to reduced speed over turnouts which in turn reduce the line capacity of a track section.

The author would like to mention about the necessity for low cost modification of existing turnouts design for higher diverging speed in same footprint. Railroad companies around the world utilize a large number of turnouts. Only small percentage of existing turnout is rehabilitated as a whole. Majority of turnouts are rehabilitated with second hand materials or component wise replacement. (e.g. Freight railroads in North America has 280,000 turnout of which only about 25% are ever replaced entirely (“Bonaventura, C.S., Holfeld, D.R., Zarembski, A.M., Palese, J.P., 2005).

Trackwork systems consisting of various types of turnouts with higher diverging speed can increase higher line capacity & better dynamics /mobility of the railroad system. The procurement of new high speed turnout with change in existing infrastructure is a costly proposition and it needs huge upfront funding which many railroad companies cannot afford. Keeping above facts in view; the author proposes the necessity for turnout design-higher diverging speed in same footprint with low cost modification of existing turnouts.

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The author would like to quote a simple example to illustrate his views. It is interesting to note that changing Turnout in isolation does not help in increasing the line capacity. This does not increase the overall speed of the section. It is better to do low cost modification of all turnouts so that overall sectional speed of the railroad vehicles can be increased over the section. This helps in increasing the line capacity of the section. It is to be noted that it takes lots of time to replace the turnouts as it is not easy to get traffic interruption blocks to do the turnout renewal works. “For example, Amtrak has committed to upgrade most turnouts on the Northeast Corridor to a tangential geometry design. While this will increase speed as well as greatly improve ride quality, safety, and maintainability, Amtrak estimates that 25 years will be required to achieve a complete replacement.” (“Bonaventura, C.S., Holfeld, D.R., Zarembski, A.M., Palese, J.P., 2005). Other railroad companies around the world are facing the similar problem in dealing with replacement/ maintenance of aging turnout system which is leading to service disruptions and accidents. This problem is more acute for developing as well as underdeveloped countries due to funding constraints. Even in developed countries which are going through the recession period, have not sufficient funding for upgrading the existing turnout system. This shows the necessity of using the concept Turnout Design: Higher Diverging speed in same interlocking footprint. Field tests were not within the scope of this paper, but the recommendations were proposed, based on author’s proposed hypothesis and the existing techniques thorough literature review. The Author has referred to the field tests done(Reference# 32 to 34) to correlate his recommendations with the test results on AREMA#20 conventional turnout to the modified track geometry for higher diverging speed on the same interlocking footprint maintaining the safety standards. Also, the author has mentioned of a rehabilitated MNRR (Metro-North Railroad) high speed turnout no. 20 at Scarsdale on the Harlem line in NY State as an illustration of higher diverging speed of a rehabilitated turnout. The author would like to mention the feasibility study as well as analysis of various Field tests (Reference 33-34) that were conducted in the past to develop Low Cost modification of existing turnout which can lead to higher diverging speed in the same footprint. The basic aim is to provide the low cost up-gradation of existing turnout for higher diverging speed of various rail road companies throughout the world with less life cycle cost.
TYPES OF SPECIAL TRACKWORKS (Reference #35).

1. Conventional [mainline & diverging tracks are straight & curved respectively]
2. Curved [mainline (higher radius) & diverging tracks (lower radius) curved in same side]
3. WYE [mainline (higher radius) & diverging tracks (lower radius) curved in opposite side], special case WYE turnout is equilateral
4. Single and double crossover
5. Single and double slips
6. Crossover- Crescent Universal no. 20 Interlocking (Non Transit)[ Ref: Amtrak- FRA Plan T-4]

SKETCHES OF VARIOUS TYPES OF SPECIAL TRACKWORKS; (FIGURE-F1)

Standard Turnout

WYE Turnout (Special Case- Equilateral)

Crossover- Crescent Universal No. 20 Interlocking (Non Transit)
The following locations of a typical Turnout provide restriction on speed over Turnouts. The possible solution is also suggested to counter these bottlenecks in the turnout. (Reference #37)

A- TTS (Toe of Switch): Kink in Alignment
B- TTS (Toe of Switch): Change in curvature
C- Heel of Switch: Change in curvature
D, E. Toe of Frog: Change in curvature & Heel of Frog: Change in Curvature
F- Gap at the “V” of crossing
G- Lead curve without Cant/ super-elevation

**FIGURE F2: GENERAL TURNOUT CONFIGURATION AFFECTING DIVERGING SPEED AND UNBALANCED FORCE VISUALIZATION**

![Diagram of general turnout configuration affecting diverging speed and unbalanced force visualization.](image)

*NOTE:* R, R1, R2, R3, R4, R5, R6 are radius of turnout at various locations as mentioned in the sketch. General turnout configuration: Unbalanced force visualization

A- TTS (Toe of Switch): Kink in Alignment
Near point of Switch in Diverging Track, switch rail creates Kink in the alignment. Due to sudden change in direction of alignment, lateral force/acceleration is introduced. In order to mitigate or minimize the lateral force/ lateral acceleration, smaller entry angle is recommended. The value of the following parameters (Bend in stock rail, Switch vertex location, Switch entry angle etc) can be adjusted for higher Diverging speed in the same footprint.

**B- TTS (Toe of Switch): Change in curvature**
The switch rail can be straight as well as curved. If switch rail is straight, the curvature in alignment is only introduced at start and end of the switch rail. If switch rail is curved, then curvature starts at the switch entry point and ends at switch rail end before the closure rail. Normally, there is no provision of transition in switch rail, which leads to unbalance force at entry and exit of the switch rail.

**C- Heel of Switch: Change in curvature**
Normally turnout diverging lead curve is not provided with transition curve after the switch rail and before the crossing in conventional crossings. This will lead to unbalance forces. Proper transition curve is required to take care of this situation.

**D, E. Straight Leg of Crossing: Toe of Frog: Change in curvature, Heel of Frog: Change in Curvature**
Normally, the lead curve ends at the toe of the crossing. Curved leg in Crossing can be provided to take care of this problem. But this lead to complexity in the geometric design and dynamic nature of turnout components.

**F- Gap at the V of crossing**
The gaps in the running rail at the nose of crossing are there in conventional frogs. Due to this gap at the V of the crossing, there is vertical impact the crossing nose as well as high lateral forces at the Wing and check rails near the crossing. Gap in the crossing can be avoided through various techniques like use of spring or movable point frogs, etc..

**G- Lead curve without Cant/ super-elevation**
Due to lead curve radius, there is centrifugal force acting on the diverging portion of track if suitable super elevation / cant are not provided.

This is important to consider above mentioned SEVEN factors which control speed over turnout. In Proposed Turnout design modification, the author will consider above mentioned factors and propose recommendations to counteract these factors to achieve higher diverging speed in the same footprint.

**PROPOSED HYPOTHESIS FOR TURNOUT DESIGN-CONCEPT OF OPTIMAL LATERAL FORCE**
When a railroad vehicle negotiates a diverging portion of turnout, the lateral force is generated due to centrifugal action and varies due to unbalanced forces throughout the length of the turnout. It is desirable to keep average lateral force exerted on the Track Infrastructure (Turnout components) is within the optimal range. In conventional turnouts, the lateral force is very high near the switch and frog area, which normally exceeds the optimal force. In redesigning the turnout for higher diverging speed in same interlocking footprint, the turnout geometry is to be redesigned so that average lateral force throughout the turnout portion remains within the optimal force.

The title “Turnout Design- higher diverging speed in the same footprint” has a very subjective meaning. There are two extremes of Replacement/ rehabilitation of existing Turnout. One is the Replacement in Kind (No Change) and another is Complete Rehabilitation including change in Infrastructure. There may be lots of combinations where we can optimize the design of existing turnout and make Low cost modifications where higher diverging speed can be achieved. The author has done a detailed feasibility study of the implementation of various techniques for higher diverging speed over turnout with reduced lateral forces and accelerations to improve ride quality and decrease track/infrastructure component wear. Higher diverging speed in the same interlocking footprint requires modification to some geometrical parameters within the existing constraints.

When a railroad vehicle negotiates a diverging portion of turnout, the lateral force is generated due to centrifugal action and varies due to unbalanced forces throughout the length of the turnout.

The following assumptions are made in analysis e.g.

1. Frog angle, lead distance (distance between point of switch (P.S.) & point of frog (P.F.)) remains same through various diverging routes.

2. Energy lost in heat, sound, etc. is negligible or constant through different diverging routes.

3. Longitudinal force is constant throughout the turnout move of railroad vehicle.

The author proposes to use concept of same amount of work done in moving of a railroad vehicle from P.S. (point of switch) to P.F. (point of frog) through various diverging routes. Here the author is concentrated on lateral force variation by optimal geometric design of diverging portion of the track.

Mathematically,
\[ \sum ((\text{Force Exerted By Railroad Vehicle to the Rail}) \times (\text{Differential Distance along the Path of Various Diverging Route})) = [(\text{Average Lateral Force}) \times (\text{Lateral Displacement between P.S. And P.F.})] +[(\text{Average Longitudinal Force}) \times (\text{Longitudinal Displacement between P.S. And P.F.})] \]

Applying the Assumptions Mentioned Above, First Part Is Analyzed In Detail due To Lateral Force Variation

Hence: \( \sum (\text{Instantaneous Lateral Force} \times \text{Differential Lateral Displacement between P.S. And P.F.} ) \), is same for all proposed Diverging routes.

The only option is to redesign the alignment between P.S. and P.F. so that average lateral force remains within the optimum level.

ILLUSTRATIONN OF CONCEPT OF OPTIMAL LATERAL FORCE FOR TURNOUT DESIGN (FIGURE- F3)

For a given Turnout geometry and Speed, there is Equilibrium Cant. If the super elevation provided is excess than the equilibrium super elevation, then Excess cant exists. On the other Hand, if provided super elevation is less than equilibrium super elevation, then Cant Deficiency exists.

Reference: AREMA- Section 3.3.: Elevations and Speeds for Curves (1962).

[Speeds through turnouts with either straight or curved switch points are calculated from the equations]
$E = [0.0007 (V^2) (D)]^{-3}$; or $V = \text{Square Root } [(E + 3)/ (0.0007*D)]$ or

**Cant Deficiency** $(Eu) = [(0.0007*D) (V^2)] - E$

Where

- $E$ = Equilibrium elevation in inches of the outer rail (center to center of rails)
- $D$ = Degree of curve
- $V$ = Speed in miles per hour
- $R$ = Radius of curve in feet

The Cant Deficiency $(Eu)$ is taken “3” inches in above formulation. The number of inches of “unbalance” allowed, Where D equals the degree of curvature of the closure curve or the switch curve, whichever is sharper?

**Keeping the above mentioned formulation, the following considerations can be made in regarding Cant Deficiency which can contribute to increase the diverging Speed over Turnout:**

1. The proper design of Diverging track alignment so that the lateral force variation is minimum throughout the turnout and is close to optimum force
2. Increase the Track Stability i.e.
   a. Higher Unit strength of Rail,
   b. Turnout rigidity fasteners
   c. Stronger plates connecting Rails and Ties,
   d. Ties with higher lateral strength,
   e. Ties are properly secured to the Track base depending upon various types of Construction.
3. Flatten the degree of curvature of Diverging portion of the Track
4. Provide suitable super elevation to reduce the value of Cant Deficiency

**OBJECTIVE FUNCTION:**

Low Cost Modification of Existing Turnouts for Higher Diverging Speed in the same footprint satisfying the Given Constraint and able to achieve Desirable Results as mentioned in subsequent slides.

**CONSTRAINTS:**

The following parameters are considered as fixed in optimization of above mentioned objective function:

1. Lead Distance (Horizontal distance between the point of switch and point of Frog)
2. Interlocking Footprint
3. Frog Angle,
4. Location of P.S. (Point of Switch) and P.F. (Point of Frog),

JUSTIFICATION FOR THE PROPOSED CONSTRAINTS.

1. There are two extreme cases of turnout rehabilitation
   a. Replacement in-kind
   b. New high speed turnout design with advanced features with change in
      Track infrastructure.

2. Changing turnout lead length and/or frog angle and/or footprint may require change in basic
   track infrastructure, which is a very costly proposition in this poor economy.

3. It is to be noted that above constraints can be relaxed depending upon special requirement.

DESIRABLE RESULTS OF MODIFICATION OF EXISTING TURNOUTS FOR HIGHER
DIVERGING SPEED

a. Turnouts /crossovers with higher diverging speed can provide higher line capacity & better dynamics
   /mobility of the railroad system.

b. Better Ride Quality, Comfort

c. Reduced Lateral Wheel forces and Acceleration

d. Reduced [L(Lateral Force) / V (Vertical Force)] ratio

e. Predicted Rail Wear Rates

f. Longer service life

g. Minimum life cycle cost- Least life cycle cost with minimum traffic interruption for repairing and
   reconditioning

h. Safety: The modifications made in the track should comply with safety requirements.

i. Maintainability- Planned maintenance without emergencies, Track geometry maintainability
   comparable with the normal track

j. Minimize wheel drag and flange wear,

k. Warning before failure
The author wants to refer to the FIELD TESTS as mentioned below in order to emphasize his recommendations for Higher Diverging speed in same footprint of the Turnout. The following agencies did the field tests on AREMA#20 conventional as well as optimized AREMA#20 turnout for illustration of Turnout geometry optimization.

<table>
<thead>
<tr>
<th>FROG NO.</th>
<th>20</th>
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1. VAE Aketiengesellschaft of Zeltweg, Austria concept of Turnout Geometry optimization.

2. Butzbacher Weichenbau GesmbH (a company of VAE) concept of Turnout Geometry optimization.

In railroad Industry, the AREMA No. 20 turnout with straight switch points are more commonly used for geometry optimization? The above mentioned agencies have done Field tests (mentioned in the following sections) for Optimization of AREMA#20 Turnouts. The author recommends that more tests is to be done on other AREMA Turnouts to check the suitably for different requirements.

Details of AREMA #20 Conventional Turnouts
(Source: Plan No 910-41; Plan No 20-71 AREMA Portfolio of Track Work Plans-2010 Edition)

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In this paper, Field tests referred were done on AREMA#20 Conventional Turnout. The author has mentioned some of the geometrical parameters of this turnout in the above mentioned table to give readers an idea. The other geometric features can be referenced from Plan No 910-41; Plan No 20-71 - AREMA Portfolio of Track Work Plans-2010 Edition.
FIELD TEST – I ANALYSIS
(Source: VAE Aketengesellschaft of Zeltweg, Austria concept of Turnout Geometry optimization)

The following results are shown to illustrate the findings:

The author like to present views of paper “Turnout Geometry optimization with dynamic simulation of track and vehicle” by Author “J. Rainer Oswald” which talk about various track geometry optimization based on field test done on Standard AREMA#20 as well as Optimized #20 geometry (which results are based on simulation). The following figures shows lateral forces through the turnout for a loaded coal hopper car at a running speed of 40 mph for the left and right wheel of the first axle.

The Figure A illustrates AREMA#20 Turnout response i.e. the variation of Lateral forces (Pounds) along the Distance from turnout start (feet).

FIGURE- A: Leading Axle Wheel/Rail Forces in a Standard #20 Turnout
(Turnout Geometry optimization with dynamic simulation of track and vehicle by Author “J. Rainer Oswald”)

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The Figure B illustrates Modified AREMA#20 Turnout response i.e. the variation of Lateral forces along the distance from turnout start. For Optimized #20, consists of a back to back spirals having following parameters (initial radius, beginning radius of second spiral, final radius as well as the distance between the two spirals, location of the minimum radius i.e. vertex location in the body of the turnout) (J Rainer Oswald, VAE Aktiengesellschaft of Zeltweg, Austria). It was noticed that for Optimized #20, the same lead length and turnout angle of a standard AREMA #20 turnout is taken. The optimized turnout curve consists of two back to back clothoids (spirals) with the initial bigger radius of 4000’ at the entry of the turnout, a smaller radius of 2100’ in the body of the turnout and a final bigger radius of 4200’ at the heel end of the turnout. It is interesting to note that changing the internal geometry of the turnout can without changing the length or turnout angle, a reduction in lateral forces of approximately 40% is possible (J Rainer Oswald, VAE Aktiengesellschaft of Zeltweg, Austria).

![Leading Axle Wheel/Rail Forces in an Optimized #20 Turnout](image)

**FIGURE B: Leading Axle Wheel/Rail Forces in an Optimized #20 Turnout**

(Turnout Geometry optimization with dynamic simulation of track & vehicle by Author “J. Rainer Oswald”)
FIELD TEST –II ANALYSIS

(Source: BWG Butzbacher Weichenbau GesmbH BWG (a company of VAE) concept of Turnout Geometry optimization.)

Kinematic Gauge Optimization (KGO) is a method of optimizing the transition geometry in the switch area developed by BWG (Butzbacher Weichenbau GesmbH), a company of the VAE Group. The following illustration is done for a high speed turnout for 190 mph on the straight line and 140 mph in the diverging line. The only thing that changes is the transition geometry in the switch area with the first turnout having no KGO transition and the second is with KGO.

FIGURE- C: Leading Axle Wheel/Rail Forces in a High Speed Turnout without KGO.
(Turnout Geometry optimization with dynamic simulation of track & vehicle by Author “J. Rainer Oswald”)

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By comparing the FIGURE “C” and FIGURE “D”, it is found that only changing the transition geometry in the switch area it is possible to reduce the maximum forces in this area by approximately 40%. Due to this, the life of turnout can be increased.

By using the above mentioned concept of optimization process, VAE in association with NORTAK and BWG has developed optimized high speed turnouts with KGO method for various countries in world. The author has come to the conclusion that above concept of track geometry optimization is feasible for various railroad companies in the world.
DETAILS OF A REHABILITATED MNRR (Metro-North Railroad) HIGH SPEED TURNOUT
(Source: Railway age article-1990; M-N: 60-mph turnouts - Metro-North Commuter Railroad; by Douglas John Bowen)

The following is the information about MTA, MNRR in High Speed Turnout design operating at 60 MPH and a higher Cant Deficiency (Eu) through a No 20 crossover. The Previous turnout and its interlocking arrangements at Scarsdale on the Harlem Line were in poor condition along with its associated infrastructures which allowed speed up to 45 mph on diverging portion of the track.

PRE-REHABILITATION CONDITION OF EXISTING TURNOUT

1. Existing AREMA#20 turnout with its associated infrastructure (e.g. Interlocking arrangement, lead length, switch entry angle, track structure, etc.) Were not sufficient to cope with higher diverging speed up to 60 mph.
2. Existence of AREMA #20 conventional turnout with a speed restriction of 45 mph on diverging portion of the track.
3. The traffic on the said turnout consists of light MNRR railcars and negligible freight traffic. MNRR car axle loads are lighter, M-1 and M-3 car weighs 22,500 and 26,000 pounds per axle respectively. This creates favorable conditions for proposed rehabilitation for diverging speeds of 60mph.

FEATURES OF THE REHABILITATED TURNOUT

1. Tangential geometry, the diverging turnout curve designed on the concept of kinematic gauge optimization. The new interlocking measures 877 feet long, 65 feet longer than its predecessor.
2. Stock rails provided with a pandrol clip on the rail and special clamps on gauge side to eliminate the need for braces, to provide easy removal and replacement of worn running rail or guard rail.
3. The details of the interlocking, including the steel and azobe wood ties, were manufactured and numbered by BWG. [(Butzbacher Weichenbau Gesmbh), a company of the VAE group]
4. The rehabilitated turnout assembly consists of special frog construction.
5. The diverging track is designed for higher Cant deficiency (more than 3”), which contributes for higher diversion speed up to 65mph.
6. This rehabilitated turnout consists of double-track interlocking on both sides of Scarsdale, station.
7. The approximate cost of turnout switches and total track structure associated with turnout was $380,000 and $850,000 respectively. (Nelson and others at Metro-north Railroad estimate, 1990).
REDESIGN METHODS TO ACHIEVE HIGHER DIVERGING SPEED IN THE SAME INTERLOCKING FOOTPRINT OF EXISTING TURNOUTS

The following steps can be taken in suitable combination of as mentioned below for increasing diverging Speed in the same interlocking footprint of the Existing turnout.

1. Reduction of Switch Entry angle. Flatter entry angle thereby reducing the angle of attack and reduced lateral forces resulting in increased passenger comfort. By reducing the switch angle, entry gets smoothened and flange force gets reduced. The small switch angle is obtained by providing curved switches.

2. Provision of Transition curve in Diverging portion of track- Switch Rail, Lead Rail, Closure Rails etc.
   a. At Toe of Switch
   b. At Heel of Switch
   c. At Toe of Frog
   d. At Heel of Frog

   Or at intermediate locations between Point of Switch and Point of Frog to reduce the unbalance forces acting on railroad vehicle negotiating the turnout.

3. Turnout diverging track structure should be designed for higher Cant Deficiency. Cant Deficiency can contribute to increase the diverging Speed over Turnout: This is mentioned in detail in “Research Methodology Section” of this paper. For a given Turnout geometry and Speed, there is an Equilibrium Cant. If the super elevation provided is excess than the equilibrium super elevation, then Excess cant exists. On the other Hand, if provided super elevation is less than equilibrium super elevation, then Cant Deficiency exists.

4. Use of Kinematic Gauge Optimization OR Thick Web Switches Technique: Kinematic Gauge Optimization (KGO) is a method of optimizing the transition geometry in the switch area allows undisturbed passage of wheel on the rail in a consistent sinusoidal wave pattern so as to minimize wheel flange contact with gauge face of switch through out the movement. In order to provide lateral rigidity to switch rails, and prevent its vibration under traffic, thick web switches are used. [Developed by- BWG (Butzbacher Weichenbau Ges. m.b.H, a company of the VAE Group.)] The optimized turnout geometry for the diverging route curve consists of a back to back spirals having following parameters (initial radius, beginning radius of second spiral , final radius as well as the distance between the two spirals, location of
minimum radius (i.e. vertex location in the body of the turnout). (J. Rainer Oswald, VAE Aktiengesellschaft of Zeltweg, Austria)

5. Provision of Special type of Heel and Switch Plates with braces (Inside/Outside) to withhold higher lateral forces. This will assist Turnout diverging track components to take additional load for longer life. This will assist in effective holding of stock rail

6. Stock rails provided with a pandrol clip on the rail and special clamps on gauge side to provide easy removal and replacement of worn running rail or guard rail. This technique was used by MTA-Metro-North Railroad in rehabilitation of AREMA No. 20 turnouts at Scarsdale on the Harlem line.

7. Proper Rolling stock characteristics can be used to increase diverging speed over turnouts. Rolling stock suspension system can be properly designed to absorb the lateral forces which will allow higher diverging speed with safety. It will also add comfort to the passengers of railroad cars. It is fact that rolling stock with poor suspension system for absorbing shocks is more prone to derailments while negotiating diverging portion on turnout.

8. Provision of Special type of Frog with features like
   - Reduction in Gap “V” at Crossing
   - Crossing material should be head hardened
   - Curved Crossing: Normally the lead curve curvature ends at the toe of the frog and Crossing has straight legs. If Lead curve is not provided with the transition curve, there is unbalanced lateral force at the toe of the crossing. Few railroad companies are coming with the idea of using Curved crossings which helps in reducing the unbalanced forces at the crossing if it is planned with other lead curve curvature requirements.

9. Provision of Check/Guard rails Level Higher than Stock Rail or Inner Curve Rail: this will relieve additional pressure on stock rail in for railroad movement in diverging track.
10. Provision of suitable Flange way: Depending upon the turnout number, flange way can be varied for smooth movement of Railroad on the track. If turnout is sharp, it is recommended to provide wider flangeway. Use of spring operated switch setting device can be used to ensure proper flangeway clearance.

11. Use of Heat Treated Switch Tips: It will help Switch tip to take higher lateral force and function properly.

12. Provision of Guarded Turnout which allows Higher Diverging speed with Given Lead Length: Guarded or unguarded Turnout: Depending upon degree of curvature of Turnout, we need guarded as well as unguarded.

13. Turnout materials should have high fatigue strength to withstand impact loading. Also, Use of higher UTS steel for turnout would further harden to reduced wear.

14. Use of specially designed synthetic rail pads between rail and ties would reduce vibration of switch assembly for higher diverging speed.

15. Other miscellaneous methods like Provision of thermal restraints to arrest differential thermal expansion of stock and tongue rail, etc. .
LIMITATIONS

The author’s whole intention is not to make basic change in infrastructure, which is the scope of my paper while allowing higher diverging speed. The main points of limitations can be listed as

1. As the paper title “Turnout design, Higher Diverging speed in same interlocking footprint” suggest that the research is limited to by not changing the basic infrastructure.

2. This condition is more critical for Railroad passing through critical infrastructures e.g. Bridges, Tunnels, Urban area where changing the infrastructure is a costly proposition.

3. This paper is more applicable for Low cost Redesign of existing Turnout system rather than design of brand new High speed railroad system.

4. Execution of commercial field tests was not within the scope of this paper, but the recommendations were made, based on the author’s proposed hypothesis and the detailed study conducted by the author on the existing techniques.

5. Some of the advanced new turnout design techniques on mass scale cannot be employed for low-cost modifications of existing turnout on mass scale for higher diverging speed as this will increase the overall cost of the project beyond the financial limits of the most of the railroad organizations. (e.g. Use of Tangential geometry (Switch Entry Angle virtually Zero), Change in frog angle, Increase in total lead distance, Change of interlocking footprint etc.)
ROADMAP AHEAD

1. The author is proposing further investigation of Rolling stock characteristics to increase diverging speed over turnouts. Rolling stock suspension system can be properly designed to absorb the lateral forces which will allow higher diverging speed with safety.

2. The increasing pace of change in the rail road industry and the current economic down turn forces rail road organizations around the World to go for more cost effective as well as value added technology without changing the existing infrastructure.

3. This paper proposes for additional future works for Modification of various types of Turnout for higher diverging speed in the same interlocking footprint, used by various railroad organizations. The technique identified by the author could be tested at Field level for commercial implementation.

4. Future challenges are to extend the study even to commercial level by using different methodologies. As such the Turnout design methods & techniques (for higher diverging speed in the same footprint) discussed here should be regarded as “work-in-progress” rather than a conventional theory. Many rail road companies around the world are trying to find ways to improve the effectiveness of existing turnout with low cost modification, without changing the basic infrastructure of track.

5. A broad level of research could be initiated down the road to promote the techniques to real life with adequate funding, for which the author is also committed to.

6. This paper proposes for additional future works for Modification of various types of Turnout for higher diverging speed in the same footprint, used by various railroad organizations. Considerations can be made for partial Relaxation of the constraints in Optimization Techniques without changing the basic track structure in future research.

CONCLUSION
1. The paper concludes with a discussion of accomplishments of switch design for higher diverging speed in the same footprint in the current rail road industry and also highlights opportunities of future work without changing the basic track infrastructure.

2. When a railroad vehicle negotiates a diverging portion of turnout, the lateral force is generated due to centrifugal action and varies due to unbalanced forces throughout the length of the turnout. The author proposes to use concept of same amount of work done in moving of a railroad vehicle from point of switch (P.S.) to point of frog (P.F.) through various diverging routes. Here the author has concentrated on lateral force variation by optimal geometric design of diverging portion of the track.

3. The various special techniques that are developed in design of low cost modification of existing turnout would help railroad organizations across the world to function effectively in a cost-effective manner.

4. The recommendations for higher diverging speed in the same footprint are applicable to most of the existing turnouts throughout the world. These techniques show the potential to permit higher speed operation through turnout diverging routes and enhance ride quality at current speed limits.

5. The recommendations were made by the author purely based on the detailed research done on the existing techniques along with the extensive field experience the author has in the railroad industry and his interaction with other experts within the same industry.

6. The turnout design methodology proposed by the author is his personal opinion and is based on his railway engineering knowledge with proper references of developments in railroad world.

**LISTING OF ALL FIGURE CAPTIONS**

Figure F1: Sketches of various types of Special Trackworks

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Figure F2: General Turnout Configuration affecting Diverging Speed / Visualization of Lateral Unbalance Forces

Figure F3: Illustration of Concept of Optimal Lateral Force for Turnout Design

Figure A: Leading Axle Wheel/Rail Forces in a Standard #20 Turnouts
(Turnout Geometry Optimization with Dynamic Simulation of Track and Vehicle by Author “J. Rainer Oswald” Figure 4)

Figure B: Leading Axle Wheel/Rail Forces In an Optimized #20 Turnouts
(Turnout Geometry Optimization with Dynamic Simulation of Track & Vehicle by Author “J. Rainer Oswald” Figure 5)

Figure C: Leading Axle Wheel/Rail Forces in a High Speed Turnout without KGO
(Turnout Geometry Optimization with Dynamic Simulation of Track & Vehicle by Author “J. Rainer Oswald” Figure 6)

Figure D: Leading Axle Wheel/Rail Forces in a High Speed Turnout with KGO
(Turnout Geometry Optimization with Dynamic Simulation of Track & Vehicle by Author “J. Rainer Oswald” Figure 8)

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33. VAE Aketiengesellschaft of Zeltweg, Austria concept of Turnout Geometry optimization.

34. BWG Butzbacher Weichenbau GesmbH Concept of Turnout Geometry Optimization.

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39. Amtrak- FRA Plan T-4- Typical Universal crossover for non transit use without the special crossing in the middle.

ACKNOWLEDGEMENTS

My special thanks go to:

1. Indian Railway, MTA agencies (MTA-MNRR, MTA-LIRR, etc.) and various Consulting firms Officials where the author worked since the last two decades.


3. NYU-Poly Civil Engineering Department; Prof Bud Griffis, Prof Iskander, Prof Andrew

TURNOUT DESIGN
(HIGHER DIVERGING SPEED IN THE SAME FOOTPRINT)

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TURNOUT FEATURES

- TURNOUTS ARE ESSENTIALLY THE WEAKER PART OF TRACKWORK.
- THEY ARE MOST SENSITIVE TO IMPROPER DESIGN, CONSTRUCTION AND MAINTENANCE.
- FREQUENT MAINTENANCE REQUIREMENT OF TURNOUT
- TURNOUT DIVERGING ROUTE - SUBJECT TO UNBALANCED LATERAL FORCES
- TURNOUT INHERENT GEOMETRY CONTRIBUTES TO REDUCED SPEED OVER DIVERGING ROUTE.
- REDUCED LINE CAPACITY
TYPES OF SPECIAL TRACKWORKS

(Source: "Turnout what you need to know," Rich Kolm 2008)

- CONVENTIONAL [MAINLINE & DIVERGING TRACKS ARE STRAIGHT & CURVED RESPECTIVELY].
- CURVED [MAINLINE (HIGHER RADIUS) & DIVERGING TRACKS (LOWER RADIUS) CURVED IN SAME SIDE].
- WYE [MAINLINE (HIGHER RADIUS) & DIVERGING TRACKS (LOWER RADIUS) CURVED IN OPPOSITE SIDE], SPECIAL CASE WYE TURNOUT IS EQUILATERAL.
- SINGLE AND DOUBLE CROSSTRADE.
- SINGLE AND DOUBLE SLIPS.
- CROSSTRADE- CRESCENT UNIVERSAL No. 20 INTERLOCKING (NON TRANSIT) (Reference: AMTRAK- FRA Plan T-4)
SKETCHES OF VARIOUS TYPES OF SPECIAL TRACKWORKS; (FIGURE-F1)  
(Reference: AMTRAK- FRA Plan T4)

Standard Turnout

WYE Turnout (Special Case - Equilateral)

Crossover - Crescent Universal No. 20 Interlocking (Non Transit)
NECESSITY FOR TURNOUT DESIGN-HIGHER DIVERGING SPEED IN SAME FOOTPRINT & LOW COST MODIFICATION OF EXISTING TURNOUTS

- Railroads around the world consist of huge number of turnouts, but only a small percentage of existing turnouts are entirely rehabilitated. Majority of turnouts are rehabilitated with second hand materials or component wise replacement. For example freight railroads in North America have approx. 280,000 turnouts of which only about 25% are ever replaced entirely (Bonaventura, C.S., Holfeld, D.R., Zarembski, A.M., Palese, J.P., 2005).

- Trackwork systems consisting of various types of turnouts with higher diverging speed can increase higher line capacity & better dynamics /mobility of the railroad system.

- The procurement of new high speed turnout with change in existing infrastructure is a costly proposition and it needs huge upfront funding which many railroad companies cannot afford.

Keeping the above facts in view, the author proposes the necessity for turnout design-higher diverging speed in same footprint with low cost modification of existing turnouts.
GENERAL TURNOUT CONFIGURATION AFFECTING DIVERGING SPEED

- TTS (TOE OF SWITCH): KINK IN ALIGNMENT
- TTS (TOE OF SWITCH): CHANGE IN CURVATURE
- HEEL OF SWITCH: CHANGE IN CURVATURE
- TOE OF FROG: CHANGE IN CURVATURE
- GAP AT THE "V" OF CROSSING
- HEEL OF FROG: CHANGE IN CURVATURE
- DIVERGING TRACK WITHOUT CANT
GENERAL TURNOUT CONFIGURATION AFFECTING DIVERGING SPEED/VISUALIZATION OF LATERAL UNBALANCE FORCES (FIGURE-F2)

NOTE: R, R1, R2, R3, R4, R5, R6 are radius of turnout at various locations as mentioned in the sketch.

GENERAL TURNOUT CONFIGURATION: UNBALANCED FORCE VISUALIZATION
PROPOSED HYPOTHESIS FOR TURNOUT DESIGN - CONCEPT OF OPTIMAL LATERAL FORCE

ASSUMPTIONS:
1. FROG ANGLE, LEAD DISTANCE [DISTANCE BETWEEN POINT OF SWITCH (P.S.) & POINT OF FROG (P.F.)] REMAINS SAME FOR VARIOUS DIVERGING ROUTES.
2. ENERGY LOST IN HEAT, SOUND, ETC. IS NEGLIGIBLE/CONSTANT THROUGH DIFFERENT DIVERGING ROUTES.
3. LONGITUDINAL FORCE IS CONSTANT THROUGHOUT THE TURNOUT MOVE OF RAILROAD VEHICLE.

PROPOSED HYPOTHESIS:
THE AUTHOR PROPOSES TO USE THE CONCEPT OF SAME AMOUNT OF WORK DONE IN MOVING OF A RAILROAD VEHICLE FROM P.S. TO P.F. FOR VARIOUS DIVERGING ROUTES.

PROPOSED SOLUTION:
TO REDESIGN THE DIVERGING TRACK ALIGNMENT BETWEEN P.S. AND P.F. SO THAT AVERAGE LATERAL FORCE REMAINS WITHIN THE OPTIMUM LEVEL.
MATHEMATICAL FORMULATION OF PROPOSED HYPOTHESIS: (CONCEPT OF OPTIMAL LATERAL FORCE)

MATHEMATICALLY,

\[ \sum[(\text{FORCE EXERTED BY RAILROAD VEHICLE TO THE RAIL}) \times (\text{DIFFERENTIAL DISTANCE ALONG THE PATH OF VARIOUS DIVERGING ROUTE})] \]

= \[ [(\text{AVERAGE LATERAL FORCE}) \times (\text{LATERAL DISPLACEMENT BETWEEN P.S. AND P.F.})] + \]

\[ [(\text{AVERAGE LONGITUDINAL FORCE}) \times (\text{LONGITUDINAL DISPLACEMENT BETWEEN P.S. AND P.F.})] \]

APPLYING THE ASSUMPTIONS MENTIONED ABOVE,

HENCE ; \[ \sum(\text{INSTANTENEOUS LATERAL FORCE} \times \text{DIFFERENTIAL LATERAL DISPLACEMENT BETWEEN P.S. AND P.F.}) \] IS SAME FOR ALL DIVERGING ROUTES
EFFECT OF CANT DEFICIENCY ON DESIGN OF TURNOUT (1 of 2)
(Source: AREMA-Section 3.3.1b: Elevations & Speeds for Curves 1962)

TURNOUT DIVERGING TRACK STRUCTURE SHOULD BE DESIGNED FOR HIGHER CANT DEFICIENCY. FOR A GIVEN TURNOUT GEOMETRY AND SPEED, THERE IS AN EQUILIBRIUM CANT.

IF THE SUPER ELEVATION PROVIDED IS EXCESS THAN THE EQUILIBRIUM SUPER ELEVATION, THEN EXCESS CANT EXISTS. ON THE OTHER HAND, IF PROVIDED SUPER ELEVATION IS LESS THAN EQUILIBRIUM SUPER ELEVATION, THEN CANT DEFICIENCY EXISTS.

CANT DEFICIENCY ($E_{u}$) = [{0.0007 ($V^2$) ($D$)} – $E$]

WHERE

$E$ = EQUILIBRIUM ELEVATION (INCHES) OF THE OUTER RAIL
$D$ = DEGREE OF CURVATURE OF THE CLOSURE CURVE OR THE SWITCH CURVE, WHICHEVER IS SHARPER;
$V$ = SPEED IN MILES PER HOUR
$R$ = RADIUS OF CURVE (FEET)
1. PROVIDE SUITABLE SUPERERELEVATION TO REDUCE THE VALUE OF CANT DEFICIENCY.

2. INCREASE THE TURNOUT SYSTEM STRENGTH/STABILITY/SECTION MODULUS.
   a. HIGHER UNIT STRENGTH OF RAIL.
   b. TURNOUT RIGIDITY FASTENERS.
   c. STRONGER PLATES CONNECTING RAILS & TIES,
   d. TIES WITH HIGHER LATERAL STRENGTH
   e. TIES ARE PROPERLY SECURED TO THE TRACK BASE DEPENDING UPON VARIOUS TYPES OF CONSTRUCTION.

IN THE FOLLOWING SECTIONS, A REHABILITATION PROJECT OF A METRO-NORTH RAILROAD AT SCARSDALE, NY IS MENTIONED (SLIDES 26-28), IN WHICH THE HIGHER CANT DEFICIENCY (MORE THAN 3") ON DIVERSING PORTION OF TRACK ASSIST IN ACHIEVING HIGHER SPEED.
OBJECTIVE FUNCTION OF THIS RESEARCH

TURNOUT DESIGN - HIGHER DIVERGING SPEED IN THE SAME FOOTPRINT WITH LOW COST MODIFICATION OF EXISTING TURNOUTS

SATISFYING THE GIVEN CONSTRAINTS AND ENABLE ATTAINMENT OF DESIRABLE RESULTS, AS MENTIONED IN SUBSEQUENT SLIDES
CONSTRAINTS

THE AUTHOR’S RECOMMENDATION OF FOR LOW COST MODIFICATION OF EXISTING TURNOUTS FOR HIGHER DIVERGING SPEED, WHICH CAN BE ACHIEVED BY:

- KEEPING THE SAME INTERLOCKING FOOTPRINT.
- KEEPING THE FROG ANGLE TO FIXED.
- KEEPING THE LOCATION OF POINT OF SWITCH (P.S.) & POINT OF FROG (P.F.) AS FIXED.

NOTE: IT IS TO BE NOTED THAT THE SOME OF THE ABOVE CONSTRAINTS CAN BE RELAXED DEPENDING UPON SPECIAL REQUIREMENT.
JUSTIFICATION FOR PROPOSED CONSTRAINTS

- TWO EXTREME CASES OF TURNOUT REHABILITATION
  A. REPLACEMENT IN-KIND
  B. NEW HIGH SPEED TURNOUT DESIGN WITH ADVANCED FEATURES WITH CHANGE IN TRACK INFRASTRUCTURE.

- CHANGING TURNOUT LEAD LENGTH AND/OR FROG ANGLE AND/OR INTERLOCKING FOOTPRINT MAY REQUIRE CHANGE IN BASIC TRACK INFRASTRUCTURE, WHICH IS A VERY COSTLY PROPOSITION IN THIS POOR ECONOMY.

- IT IS TO BE NOTED THAT THE SOME OF THE ABOVE CONSTRAINTS CAN BE RELAXED DEPENDING UPON SPECIAL REQUIREMENT.
DESIRABLE RESULTS OF MODIFICATION OF EXISTING TURNOUTS FOR HIGHER DIVERGING SPEED (1 of 2)

- TURNOUTS /CROSSOVERS WITH HIGHER DIVERGING SPEED CAN PROVIDE HIGHER LINE CAPACITY & BETTER DYNAMICS /MOBILITY OF THE RAILROAD SYSTEM.

- REDUCED LATERAL WHEEL FORCES AND ACCELERATION

- BETTER RIDE QUALITY & COMFORT

- REDUCED [LATERAL FORCE) / VERTICAL FORCE). [L/V]

- PREDICTED RAIL WEAR RATES

- MINIMIZE LIFE CYCLE COST - LOWEST LIFE CYCLE COST WITH MINIMUM TRAFFIC INTERRUPTION FOR REPAIRING AND RECONDITIONING.
SAFETY: THE MODIFICATIONS MADE IN THE TRACK SHOULD COMPLY WITH SAFETY REQUIREMENTS.

MAINTAINABILITY: PLANNED MAINTENANCE WITHOUT EMERGENCIES, TRACK GEOMETRY MAINTAINABILITY COMPARABLE WITH NORMAL TRACK.

MINIMIZE WHEEL DRAG AND FLANGE WEAR.

WARNING BEFORE FAILURE.

LONGER SERVICE LIFE.
## DETAILS OF AREMA#20 CONVENTIONAL TURNOUT

(Source: Plan No 910-41; Plan No 20-71 AREMA Portfolio of Track Work Plans-2010 Edition)

<table>
<thead>
<tr>
<th>FROG NO.</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>FROG ANGLE</td>
<td>2° -51’-51”</td>
</tr>
<tr>
<td>GAUGE OF TO</td>
<td>4.7083’</td>
</tr>
<tr>
<td>FLANGEWAY</td>
<td>1.75”</td>
</tr>
<tr>
<td>THEORETICAL LEAD</td>
<td>151’-11.5”</td>
</tr>
<tr>
<td>CL RADIUS OF TURNOUT ARC</td>
<td>3289.29’</td>
</tr>
<tr>
<td>SWITCH ANGLE</td>
<td>0°-58’-30”</td>
</tr>
<tr>
<td>CL ANGLE OF SWITCH POINT</td>
<td>0° -25’-19”</td>
</tr>
<tr>
<td>CL ANGLE OF TURNOUT</td>
<td>1°-35’-15”</td>
</tr>
<tr>
<td>LENGTH OF SWITCH POINTS(STRAIGHT)</td>
<td>30.0’</td>
</tr>
</tbody>
</table>
FIELD TEST-I; COMPARISON OF AREMA #20 CONVENTIONAL & OPTIMIZED GEOMETRY

(SOURCE: VAE AKTIENGESELLSCHAFT OF ZELTWEG, AUSTRIA CONCEPT OF TURNOUT GEOMETRY OPTIMIZATION)

- FIGURES A & B (SHOWN IN NEXT TWO SLIDES) ILLUSTRATE AREMA #20 TURNOUT (CONVENTIONAL AND REBUILT RESPECTIVELY) RESPONSE I.E. THE VARIATION OF LATERAL FORCES (POUNDS) ALONG THE DISTANCE FROM TURNOUT START (FEET).


- BY COMPARISON OF FIGURES A & B, IT IS EVIDENT THAT REDUCTION OF LATERAL FORCES IN OPTIMIZED AREMA TURNOUT GEOMETRY.
FIGURE A: LEADING AXLE WHEEL/RAIL FORCES IN A STANDARD #20 TURNOUT
(SOURCE: TURNOUT GEOMETRY OPTIMIZATION WITH DYNAMIC SIMULATION OF TRACK AND VEHICLE BY AUTHOR "J. RAENER OSWALD")
FIGURE B: LEADING AXLE WHEEL/RAIL FORCES IN AN OPTIMIZED #20 TURNOUT

(SOURCE: TURNOUT GEOMETRY OPTIMIZATION WITH DYNAMICS SIMULATION OF TRACK & VEHICLE BY AUTHOR "J. RAINER OSWALD")
FIELD TEST II - CONCEPT OF KINEMATIC GAUGE OPTIMIZATION (KGO)
(Source: BUTZBACHER WEICHENBAU GESMBH (A COMPANY OF VAE) BWG CONCEPT OF "KGO" FOR CONCEPT OF TURNOUT GEOMETRY OPTIMIZATION)

- KINEMATIC GAUGE OPTIMIZATION (KGO) IS A METHOD OF OPTIMIZING THE TRANSITION GEOMETRY IN THE SWITCH AREA [BWG (BUTZBACHER WEICHENBAU GESMBH), A COMPANY OF THE VAE GROUP].

- (KGO) IS A METHOD ALLOWS UNDISTURBED PASSAGE OF WHEEL ON THE RAIL IN A CONSISTENT SINUSOIDAL WAVE PATTERN SO AS TO MINIMIZE WHEEL FLANGE CONTACT WITH GAUGE FACE OF SWITCH THROUGHOUT THE MOVEMENT.

- THIS ACTION PROVIDE LATERAL RIGIDITY TO SWITCH RAILS, AND PREVENT ITS VIBRATION UNDER TRAFFIC.

- THICK WEB SWITCHES ARE USED.

REFER FIGURE "C" & FIGURE "D" (SHOWN IN NEXT TWO SLIDES). IT IS OBSERVED THAT, ONLY BY CHANGING THE TRANSITION GEOMETRY IN THE SWITCH AREA, IT IS POSSIBLE TO REDUCE THE MAXIMUM FORCES IN THIS AREA BY APPROX. 40%. THIS CONTRIBUTES TO INCREASE IN USEFUL LIFE & THE REDUCTION OF LIFE CYCLE COST OF TURNOUT.
FIGURE- C: LEADING AXLE WHEEL/RAIL FORCES IN A HIGH SPEED
TURNOUT WITHOUT KGO
(SOURCE: TURNOUT GEOMETRY OPTIMIZATION WITH DYNAMIC SIMULATION OF TRACK & VEHICLE BY AUTHOR "J. RAINEOSWALD")
FIGURE D: LEADING AXLE WHEEL/RAIL FORCES IN A HIGH SPEED TURNOUT WITH KGO

(SOURCE: TURNOUT GEOMETRY OPTIMIZATION WITH DYNAMICSIMULATION OF TRACK & VEHICLE BY AUTHOR *J. RAINER OSWALD* )
PRE-REHABILITATION CONDITION OF EXISTING TURNOUT

- EXISTING AREMA #20 TURNOUT WITH ITS ASSOCIATED INFRASTRUCTURE (e.g., INTERLOCKING ARRANGEMENT, LEAD LENGTH, SWITCH ENTRY ANGLE, TRACK STRUCTURE, etc.) WERE NOT SUFFICIENT TO COPE WITH HIGHER DIVERGING SPEED UPTO 60 MPH.

- EXISTENCE OF AREMA #20 CONVENTIONAL TURNOUT WITH A SPEED RESTRICTION OF 45 MPH ON DIVERGING PORTION OF THE TRACK.

- THE TRAFFIC ON THE SAID TURNOUT CONSISTS OF LIGHT MNRR RAILCARS AND NEGLIGIBLE FREIGHT TRAFFIC. MNRR CAR AXLE LOADS ARE LIGHTER, M-1 AND M-3 CAR WEIGHS 22,500 AND 26,000 POUNDS PER AXLE RESPECTIVELY. THIS CREATES FAVORABLE CONDITIONS FOR PROPOSED HIGHER DIVERGING SPEEDS OF 60 MPH.
FEATURES OF THE REHABILITATED TURNOUT

- TANGENTIAL GEOMETRY, THE DIVERGING TURNOUT CURVE DESIGNED ON THE CONCEPT OF KINEMATIC GAUGE OPTIMIZATION. THE NEW INTERLOCKING MEASURES 877 FEET LONG, 65 FEET LONGER THAN ITS PREDECESSOR.

- STOCK RAILS PROVIDED WITH A PANDROL CLIP ON THE RAIL AND SPECIAL CLAMPS ON GAUGE SIDE TO ELIMINATE THE NEED FOR BRACES, TO PROVIDE EASY REMOVAL AND REPLACEMENT OF WORN RUNNING RAIL OR GUARD RAIL.

- THE DETAILS OF THE INTERLOCKING, INCLUDING THE STEEL AND AZOBE WOOD TIES, WERE MANUFACTURED AND NUMBERED BY BWG. [(BUTZBACHER WEICHENBAU GESMBH), A COMPANY OF THE VAE GROUP]
FEATURES OF THE REHABILITATED TURNOUT

- THE REHABILITATED TURNOUT ASSEMBLY CONSISTS SPECIAL FROG CONSTRUCTION.
- THE DIVERSING TRACK IS DESIGNED FOR HIGHER CANT DEFICIENCY (MORE THAN 3”), WHICH CONTRIBUTES FOR HIGHER DIVERSION SPEED UPTO 65mph.
- THE REHABILITATED TURNOUT CONSISTS OF DOUBLE-TRACK INTERLOCKING ON BOTH SIDES OF SCARSDALE, N.Y., STATION ON THE HARLEM LINE.
- THE APPROXIMATE COST OF TURNOUT SWITCHES AND TOTAL TRACK STRUCTURE ASSOCIATED WITH TURNOUT WAS $380,000 & $850,000 RESPECTIVELY. (NELSON AND OTHERS AT METRO-NORTH ESTIMATE, 1990)
1. REDUCTION OF SWITCH ENTRY ANGLE: SIGNIFICANT REDUCTION IN UNBALANCED LATERAL FORCE.

2. PROVISION OF SUITABLE TRANSITION CURVE IN DIVERGING PORTION OF TRACK (SWITCH RAIL, LEAD RAIL, CLOSURE RAILS, ETC.)
   A. AT TOE OF SWITCH
   B. AT HEEL OF SWITCH
   C. AT TOE OF FROG
   D. AT HEEL OF FROG
   E. AT INTERMEDIATE LOCATIONS BETWEEN POINT OF SWITCH (P.S.) & POINT OF FROG (P.F.) TO REDUCE THE UNBALANCE FORCES ACTING ON RAILROAD VEHICLE WHILE NEGOTIATING THE TURNOUT.
3. TURNOUT DIVERGING TRACK STRUCTURE SHOULD BE DESIGNED FOR HIGHER CANT DEFICIENCY.


\(a. \text{BUTZBACHER WEICHENBAU GESMBH (A COMPANY OF VAE) BWG CONCEPT OF “KGO” FOR CONCEPT OF TURNOUT GEOMETRY OPTIMIZATION} \)
5. EFFECTIVE HOLDING OF STOCK RAIL. PROVISION OF SPECIAL TYPE OF HEEL AND SWITCH PLATES WITH BRACES (INSIDE /OUTSIDE)- TO SUPPORT HIGHER LATERAL FORCES.

6. EFFECTIVE HOLDING OF STOCK RAIL. STOCK RAILS PROVIDED WITH A PANDROL CLIP ON THE RAIL AND SPECIAL CLAMPS ON GAUGE SIDE TO PROVIDE EASY REMOVAL AND REPLACEMENT OF WORN RUNNING RAIL OR GUARD RAIL. THIS TECHNIQUE IS USED BY MTA-METRO-NORTH RAILROAD IN REHABILITATION OF AREA NO. 20 TURNOUTS AT SCARSDALE ON THE HARLEM LINE.

7. PROPER ROLLING STOCK CHARACTERISTICS CAN BE USED TO INCREASE DIVERGING SPEED OVER TURNOUTS. ROLLING STOCK SUSPENSION SYSTEM CAN BE PROPERLY DESIGNED TO ABSORB THE LATERAL FORCES WHICH WILL ALLOW HIGHER DIVERGING SPEED WITH SAFETY.
REDESIGN METHODS TO ACHIEVE HIGHER DIVERGING SPEED IN THE SAME FOOTPRINT OF EXISTING TURNOUT (4 of 5)

8. PROVISION OF SPECIAL TYPE OF FROG WITH FEATURES
   A. REDUCTION IN GAP V AT CROSSING
   B. PROVISION OF CURVED CROSSING LEG
   C. PROVISION OF HEAD HARDENED MATERIAL

9. PROVISION OF WIDER FLANGEWAY GAP FOR SHARPER TURNOUTS AND VICE VERSA. USE OF SPRING OPERATED SWITCH SETTING DEVICE CAN BE USED TO ENSURE PROPER FLANGEWAY CLEARANCE.

10. USE OF HEAT TREATED SWITCH POINTS & STOCK RAILS TO PROTECT HIGH-WEAR AREAS.

11. PROVISION OF GUARDED TURNOUT WHICH ALLOWS HIGHER DIVERGING SPEED WITH GIVEN LEAD LENGTH.
12. TURNOUT MATERIALS SHOULD HAVE HIGH FATIGUE STRENGTH TO WITHSTAND IMPACT LOADING. USE OF HIGHER UTS STEEL FOR TURNOUT WOULD FURTHER HARDENED TO REDUCED WEAR.

13. USE OF SPECIALLY DESIGNED SYNTHETIC RAIL PADS BETWEEN RAIL AND TIES WOULD REDUCE VIBRATION OF SWITCH ASSEMBLY FOR HIGHER DIVERGING SPEED.

14. PROVISION OF CHECK/GUARD RAILS LEVEL HIGHER THAN STOCK RAIL OR INNER CURVE RAIL.

15. OTHER MISCELLANEOUS TECHNIQUES. E.G. PROVISION OF THERMAL RESTRAINTS TO ARREST DIFFERENTIAL THERMAL EXPANSION OF STOCK AND TONGUE RAILS, ETC.
LIMITATIONS

- THE PAPER TITLE “TURNOUT DESIGN, HIGHER DIVERGING SPEEDS IN SAME FOOTPRINT” SUGGESTS THAT THE RESEARCH IS LIMITED TO, BY NOT CHANGING THE BASIC INFRASTRUCTURE.

- THIS CONDITION IS MORE CRITICAL FOR RAILROAD PASSING THROUGH CRITICAL INFRASTRUCTURES (EXAMPLE: BRIDGES, TUNNELS, URBAN AREA) WHERE CHANGING THE INFRASTRUCTURE IS A COSTLY PROPOSITION. ALSO, IT IS MORE APPLICABLE FOR LOW COST REDESIGN OF EXISTING TURNOUT SYSTEM RATHER THAN DESIGN OF BRAND NEW HIGH SPEED RAILROAD SYSTEM.

- EXECUTION OF COMMERCIAL FIELD TESTS WERE NOT WITHIN THE SCOPE OF THIS PAPER, BUT THE RECOMMENDATIONS WERE MADE, BASED ON THE AUTHOR’S PROPOSED HYPOTHESIS AND THE

- SOME OF THE ADVANCED NEW TURNOUT DESIGN TECHNIQUES ON MASS SCALE CANNOT BE EMPLOYED FOR LOW-COST MODIFICATIONS OF EXISTING TURNOUT ON MASS SCALE FOR HIGHER DIVERGING SPEED AS THIS WILL INCREASE THE OVERALL COST OF THE PROJECT BEYOND THE FINANCIAL LIMITS OF THE MOST OF THE RAILROAD ORGANIZATIONS. (E.G. USE OF TANGENTIAL GEOMETRY (SWITCH ENTRY ANGLE VIRTUALLY ZERO), CHANGE IN FROG ANGLE, INCREASE IN TOTAL LEAD DISTANCE, CHANGE OF INTERLOCKING FOOTPRINT ETC.)
ROADMAP AHEAD

- The author is proposing for further investigation of rolling stock characteristics to increase diverging speed over turnout. Rolling stock suspension system can be properly designed to absorb the lateral forces which will allow higher diverging speed with safety.

- The increasing pace of changes in the railroad industry and the current economic down turn, forces railroad organizations around the world to go for more cost effective as well as value-added technology, without changing the existing infrastructure.

- The technique identified by the author could be tested at commercial field level for commercial implementation. A broad level of research could be initiated down the road to promote the techniques to real life with adequate funding, to which the author is also committed to.

- Relaxation of the constraints in optimization techniques without changing the basic track structure in future research.

- This paper proposes for additional future works for modification of various types of turnouts for higher diverging speed in the same footprint, used by various railroad organizations.
CONCLUSION (1 of 2)

- This paper concludes with a discussion of accomplishments of switch design for higher diverging speed in the same footprint in the current railroad industry. This also highlights the opportunities for future work without changing the basic track infrastructure.

- The author proposes to use concept of same amount of work done in moving of a railroad vehicle from point of switch (P.S.) to point of frog (P.F.) through various diverging routes. Here the author has concentrated on lateral force variation by optimal geometric design of diverging portion of the track.

- The various special techniques that are developed in design of low cost modification of existing turnout would help railroad organizations across the world to function effectively in a cost-effective manner.
THE RECOMMENDATIONS FOR HIGHER DIVERGING SPEED IN THE SAME FOOTPRINT ARE APPLICABLE TO MOST OF THE EXISTING TURNOUTS THROUGHOUT THE WORLD. THESE TECHNIQUES SHOW THE POTENTIAL TO PERMIT HIGHER SPEED OPERATION THROUGH TURNOUT DIVERGING ROUTES AND ENHANCE RIDE QUALITY AT CURRENT SPEED LIMITS.

THE RECOMMENDATIONS WERE MADE BY THE AUTHOR PURELY BASED ON THE DETAILED RESEARCH DONE ON THE EXISTING TECHNIQUES ALONG WITH THE EXTENSIVE FIELD EXPERIENCE THE AUTHOR HAS IN THE RAILROAD INDUSTRY AND HIS INTERACTION WITH OTHER EXPERTS WITHIN THE SAME INDUSTRY.

THE TURNOUT DESIGN METHODOLOGY PROPOSED BY THE AUTHOR IS HIS PERSONAL OPINION AND IS BASED ON HIS RAILWAY ENGINEERING KNOWLEDGE WITH PROPER REFERENCES OF DEVELOPMENTS IN RAILROAD WORLD.
ACKNOWLEDGEMENTS

MY SPECIAL THANKS GO TO:

- INDIAN RAILWAY, MTA AGENCIES (MTA-MNRR, MTA-LIRR, MTA-AMTRAK) AND VARIOUS CONSULTING FIRM’S OFFICIALS WHERE THE AUTHOR WORKED FOR THE LAST TWO DECADES.

- MY SENIORS AND COWORKERS AT MTA-NYCT A. CABRERA, G. GOBBATO, B. PARASRAM, W. CUOMO

- NYU-POLY CIVIL ENGINEERING DEPARTMENT: PROF. BUD GRIFFIS, PROF. MASOUD, PROF. ISKANDER, PROF. ANDREW

- MY WIFE INDIRA AND DAUGHTERS PURNIMA & PRAYAGA.

NOTE: APPROPRIATE REFERENCES RELATED TO THIS PRESENTATION IS PROVIDED IN THE ORIGINAL VERSION OF MY CONFERENCE PAPER WHICH IS ALSO PUBLISHED BY AREMA SEPARATELY.
Questions

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THANK YOU!!!