Evaluation of Welded and Jointed Noise Rail Propagation in North Carolina Right-of-Way Railroad Environments

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16. Abstract

Over the last decade, the incident of pedestrian trespass strikes has increased in the United States (US) resulting in injury, loss of life, as well as costly disruptions in sensitive transportation and logistics systems. Though pedestrian trespass strike events are well documented, little work to date has investigated the relationship between sound propagation and the effects of rail type (*welded and jointed*) and the surrounding environment on sound propagation as it relates to rail trespass strikes. ***Therefore, additional work is needed to identify and evaluate the feasibility of current rail noise models for use with jointed rails in the various North Carolina rail environments.***

The *purpose* of this Technical Assistance Request (TAR) is to explore whether existing Computational Models are capable of replicating jointed rail noise in various environments. The following *questions* are be answered:

1. What are the similarities and differences between the existing computational models that are currently used for modeling rail noise propagation, respectively, in terms of their ability to model different types of rail environments (i.e., both welded and jointed rail segments)?
2. What are the advantages and limitations associated with the identified existing computational models in terms of their ability to model different types of rail type (*welded and jointed*) environments?

The outcomes from this work support improved understanding regarding the noise levels that are perceived by pedestrians on the rail right-of-way for different rail types (*welded and jointed*) in a range of rail environments.

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I. Project Abstract

Over the last decade, the incident of pedestrian trespass strikes has increased in the United States (US) resulting in injury, loss of life, as well as costly disruptions in sensitive transportation and logistics systems. Though pedestrian trespass strike events are well documented, little work to date has investigated the relationship between sound propagation and the effects of rail type (*welded and jointed*) and the surrounding environment on sound propagation as it relates to rail trespass strikes. ***Therefore, additional work is needed to identify and evaluate the feasibility of current rail noise models for use with jointed rails in the various North Carolina rail environments.***

The ***purpose*** of this Technical Assistance Request (TAR) is to explore whether existing Computational Models are capable of replicating jointed rail noise in various environments. The following ***questions*** are be answered:

1. What are the similarities and differences between the existing computational models that are currently used for modeling rail noise propagation, respectively, in terms of their ability to model different types of rail environments (i.e., both welded and jointed rail segments)?
2. What are the advantages and limitations associated with the identified existing computational models in terms of their ability to model different types of rail type (*welded and jointed*) environments?

The outcomes from this work support improved understanding regarding the noise levels that are perceived by pedestrians on the rail right-of-way for different rail types (*welded and jointed*) in a range of rail environments.

Related Recruitment and Education Outreach:
We recruited a student through the UNC Charlotte OUR Summer Research Scholar Program (https://our.charlotte.edu/programs/our-summer-research-scholar-program), which provided funding support via the associated UNC Charlotte OUR program for the participating student to perform directed tasks. This engagement helps stimulate student interest in science, technology, engineering, and mathematics (STEM) and provides education regarding this NCDOT topic area.

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III. Acronyms, Abbreviations, and Definitions

Table 2-1, shown below, provides a list of common acronyms and abbreviations used in this document.

Table III-1: Acronyms and Abbreviations

Abbreviation / Symbol	Definition
3D	Three-dimensional
CAT	Corrugation Analysis Trolley
CFD	Computational Fluid Dynamics
dB	Decibel
dB(A)	A-weighted Decibel
DAS	Delay-and-Sum
DGM	Digital Ground Model
EEMD	Ensemble Empirical Mode Decomposition
FE	Finite Element
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GNN	Graph Neural Network
GUI	Graphical User Interface
IRJ	Insulated Rail Joint
NC	North Carolina
NCDOT	North Carolina Department of Transportation
OSM	OpenStreetMap
SPL	Sound Pressure Level
SWL	Sound Power Level
TA	Technical Assistance
UNC Charlotte	University of North Carolina at Charlotte
U.S.	United States
WBT	Wave based technique

1. Project Objective and Purpose

This section provides an objective statement for the report and summarizes the overall purpose of the project. This document provides a technical

The *objectives* and *methods* for this work are discussed below:

1. Conduct a *literature review* on existing rail noise source models and identify their *advantages* and *limitations*.
2. Conduct a *simulation case study* with the identified rail noise model using existing standard computational software to predict the noises produced by trains on welded and jointed rails. The anticipated welded/jointed rail location will focus on an applicable representative railway in North Carolina (NC). The model results for the simulation test case will be compared to highlight the welded and jointed rail differences regarding noise propagation.

2. Research Methods

Timeframe for Execution of Proposed Project:

Table 2-1: Task Descriptions

Task #	Task Descriptions
1	Perform literature review regarding existing rail noise computational models
2	Identify existing computational model advantages and limitations
3	Model the rail noise via the computational model for both welded and jointed rails
4	Final Report

Table 2-2: Timeline

Task / Month	Year 1		
	Month 1	Month 2	Month 3
1			
2			
3			
4			

Task 1: Perform literature review regarding existing rail noise computational models

- Complete a literature review of the types of train noises propagated and factors that would influence the decomposition of noises emitted.
- *Milestone*: The literature review will provide an assessment of existing knowledge on existing train noise propagation and decomposition models and their limitations.

Task 2: Identify existing computational model advantages and limitations

- Development of a methodology for modeling noise propagation and decomposition subject to the localized environmental and other factors.
- *Milestone*: The broader impact of this task will be developing a state-of-the-art computational/numerical noise modeling approach for NCDOT to use when railway noise is difficult to measure and analyze through field investigation (e.g., when railway noise under dispute occurs infrequently and is difficult to capture through field studies, when receptor locations are not accessible, and for situations where background ambient noise levels are interfering with the measurement of the rail-way noise). The following subtasks will aid in achieving this task:
    - Subtask 2.1. Identify existing noise propagation models.
    - Subtask 2.2. Review and evaluate through modeling noise propagation via a state-of-the-art three-dimensional (3D) noise modeling program called SoundPLAN, which is a powerful and efficient software application that is completely integrated for analyzing noise generation transmission through walls and the noise propagation into the environment. It is a reliable tool for engineers working in such environments and it allows the development of numerical and graphical presentations.

Task 3: Model the rail noise via the computational model for both welded and jointed rails

- Develop a computational/numerical simulation model (i.e., SoundPLAN) for a representative test case that can demonstrate how propagated train noises are perceived by individuals on the rail right-of-way via the methods and factors determined in Task 2.
- *Milestone*: The proposed work will incorporate a developed state-of-the-art SoundPLAN model for the representative test case study.

3. Introduction and Literature Review

Railways were first implemented in the United States in the early 1800's. For the average low speed train, the dominant source of noise comes from the wheel-rail interaction [1]. As trains became more popular throughout the world and cities began to develop, a concern for noise pollution and health risk for the population surrounding railways began to rise. The main health risks of noise pollution include cardiovascular disease, lack of sleep, and increased stress [2]. Since then, the goal for the railway system was to increase efficiency, speed, and reduce noise. Fig. 1 provides an example mapping of rail noise via SoundPLAN, adapted from [46].

Pedestrian trespassing along railroad rights-of-way is the leading cause of rail-related deaths in the United States (U.S.). This statement was made by Ronald L. Batory, the Administrator of the Federal Railroad Administration (FRA), at the 2018 American Public Transportation Association Rail Conference and summarizes the largest issue in railroad safety to date. Nationally, more than 400 trespass fatalities and nearly as many injuries occur each year in the United States [21]. Over the last decade, the incidence of pedestrian strikes by train has increased in the United States resulting in injury, loss of life, as well as costly disruptions in sensitive transportation and logistics systems. In the period of 2009–2016, 95 percent of railroad deaths were caused by trespassing and grade crossing collisions. The figure for trespassing casualties from 2013 to 2016 is 16 percent higher than 2009 to 2012 [22], [23], [24]. This issue is recognized as a major concern of safety within the U.S., which is supported by the U.S. House Committee on Appropriations Fiscal Year 2018 Transportation Budget Report [25].

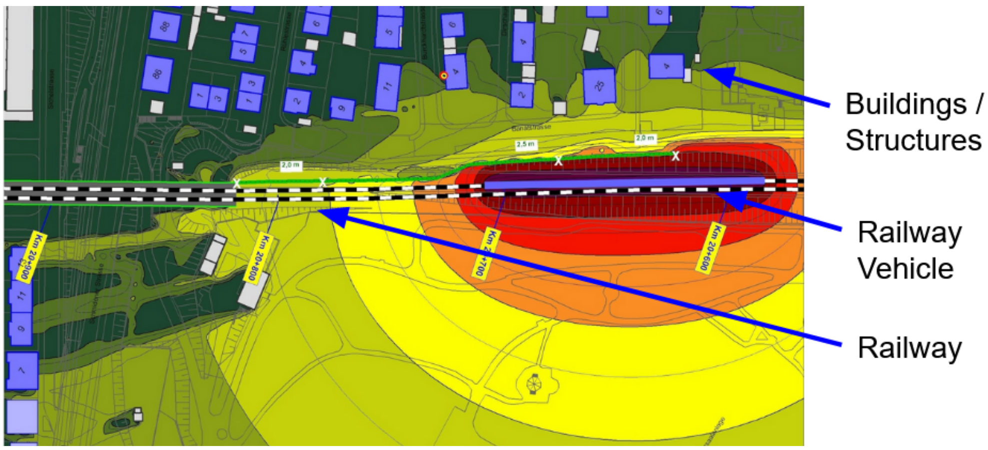

Figure 3-1: Example rail noise mapping via SoundPLAN, adapted from [46]

Suburban sprawl and population growth are likely to lead to even more pedestrian incidents in the coming decade. A small minority of people enter the railroad to cause intentional harm to themselves. The vast majority do not. Because railroad tracks often cut neighborhoods and cities in half, those killed and injured most often are pedestrians that walk across or along the railroad tracks to get to their destination. Children who live in neighborhoods bisected by or adjacent to tracks are another class group of people drawn to railroad rights-of-way. According to FRA statistics, 1,099 pedestrian rail trespass casualties (fatalities + injuries) occurred in 2020 nationwide. In 2020, North Carolina was number 12 out of 50 states [26]. From January to May 2021, 14 deaths have occurred in North Carolina.

For these reasons, railway noise has been the subject of scientific research for many years. Fig. 3-2 provides an overview regarding the wheel and rail contributions to the wheel/rail noise generation, adapted from [47] (WRI 2021). While there are many publications about wheel/rail noise generation with sophisticated models [27], [28], [39], [40], only a few are about railway noise propagation [36]. Similarly, there is little work regarding how train propagated noise is perceived by the human ear. Though trespass strike events are well documented, little research to date has investigated the relationship between sound propagation and its effect on rail trespass strikes.

Railroad Pedestrian Trespassing is a major issue in North Carolina. In 2019, Norfolk Southern launched a two-day safety operation in Gastonia North Carolina following a deadly rise in the number of pedestrians being struck and killed by trains [29]. Norfolk Southern Manager of Special Investigations Hugh McCormack stated, “four people died in the last fifteen months while illegally walking along a four-mile stretch of track in the city of Gastonia, North Carolina.” McCormack also stated, “the number is relatively high compared to the rest of its nearly 20,000 miles of tracks and it's raising concern for us of coming into the community and getting education out to the community about the dangers of being on railroad tracks." In June 2021 on the CSX railroad bridge off US 64 in Apex North Carolina, an 18-year-old woman lost her life when an Amtrak train struck her on the right-of-way. Her 17-year-old companion narrowly escaped death, literally by inches. On the day of August 25, 2021, in Lexington North Carolina, a man was hit and killed by an Amtrak train. This was the second such accident in the same county in a two day span, the Davidson County Sheriff's Office said in a news report [30].

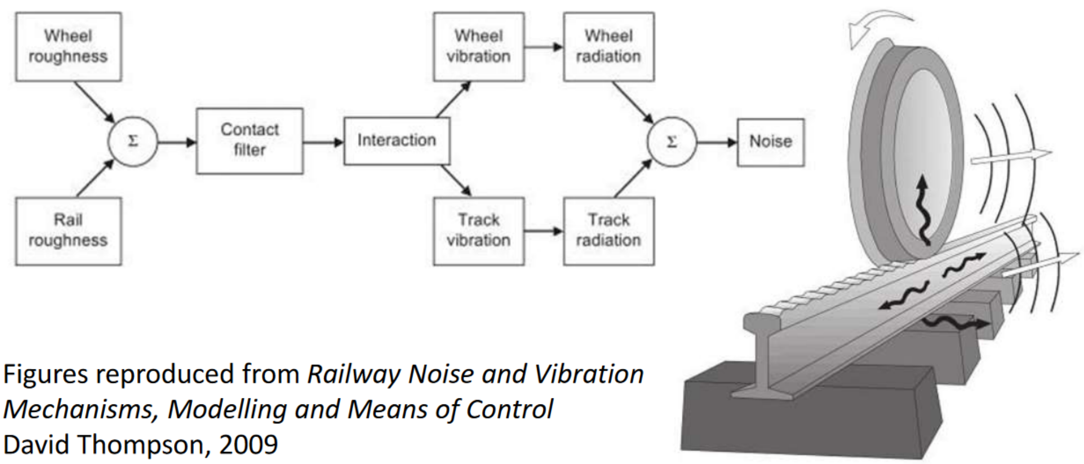

Figure 3-2: Wheel and Rail Noise Generation, adapted from [47] (WRI 2021)

The number of pedestrian trespass incidents are increasing in the Charlotte region. These types of accidents and casualties also occur with the Charlotte CATS Lynx light rail system. In 2018, a Lynx light rail train hit three people, killing one of them [31]. These accidents happened at South Boulevard north near Clanton Road, the Woodlawn Station, and the J.W. Clay Station in Charlotte, North Carolina. In 2019, a homeless man was hit by a light rail train near Old Pineville Road south of Woodlawn Road in Charlotte. Two men were mourning the loss of their brother, who had been struck by a light-rail train, when they were also struck and killed by a Lynx train in North Carolina on August 7, 2021 [32]. In February 2023, an Amtrak train in Charlotte fatally hit a person trespassing on the track [33]. In August 2023, a person was hit in Lexington by an Amtrak train that was heading from Charlotte to New York [35].

In December 2020, NCDOT released its assessment report on a funded research project focused on assessing network trespass severity and predictive modeling statewide. Key findings from this 4-plus years of North Carolina trespass research reveal astonishing counts and profiles of North Carolina’s railroad trespassers. The eleven trespass sites utilized static thermal cameras at known ‘hot spot’ railroad trespass sites that have a history of fatal railroad trespass events. 15,570 individual trespassers were identified during 721 observation days of which 652 days recorded trespasser activity. Scaled trespasser count data from these sites equal more than 12,200 annual trespassers at the Elon site and more than 11,600 annual trespassers in Mebane with 15,300 annual trespassers in Greensboro. The 2019 population of Mebane was 14,952. These trespassing are counts from one trespass site where many communities have dozens to even hundreds of known railroad trespassing locations. Additional research findings revealed 1% of the trespassing events occurred with a train present in camera view, 35% traveled in pairs and involved family groups with children, strollers, bicycles, and walking dogs. These findings support the need for increased public education regarding railroad trespassing risks, especially in communities with greater population densities and less access to vehicles for personal transportation. This also highlights the need for considering appropriate mitigation approaches to reduce trespassing events in higher risk areas.

Large amounts of research have been done to implement mitigation approaches (e.g., noise barriers) to reduce the level of noise pollution reaching the population (e.g., traditional noise barriers, non-traditional noise barriers, specialized joint types for bridges, vegetative screening and wheel skirts) [3], [4], [34], [37], as seen in Fig. 3-3. An alternative way to reduce train noise is to identify the main contributors and implement noise reduction designs and techniques. The original method to identify noise sources was to use a technique called beamforming. Typically, this method is used on stationary objects, but can be applied to moving objects resulting in lower spatial resolution [5]. Recent research has developed an improved version of beamforming using microphone arrays. Novel techniques use sparse beamforming arrays, regularization methods, and graph neural networks [6], [7], [8].

Figure 3-3: Railway Noise Abatement Measures adapted from [48] (SNCF RÉSEAU)

Railway noise can also be affected by a number of factors [38], including track conditions and joints. A typical railhead surface defect called corrugation can cause unwanted vibrations and increased noise [9]. One of the leading factors of corrugations is a rail joint. As the rail joint deteriorates the corrugations become worse, leading to increased vibrations and noise [10]. To mitigate rail vibrations, better fastening mechanisms can be used to constrain the rail. Changing the fastening stiffness and damping can control the rail frequencies and amplitude [11]. Many early models attempted to simplify vibrations sources and under calculated its effect. Vibrational noise is not limited to the wheel and rail but includes the ballast and sleeper [12]. A proposed validated model was able to provide a 3D model of an insulated rail joint and successfully predict joint impact vibrations up to 10kHz [13]. Another study was able to identify the contributions of the wheel, rail and sleeper at a rail joint impact [14].

For railway crossings it is imperative to implement safety precautions. These include signs, lights, audible warnings and wishbone gates to alert pedestrians of oncoming trains. There are many ways to activate the warnings from GPS systems to rail vibration detection. One approach attempts to identify train types based on sound pressure levels. The system could detect trains with a seven second delay [15]. Sound waves from a moving source have an unfavorable property called the doppler effect. The doppler effect is the phenomenon when the distance between an observer and a source changes, there is a change in frequency at the observer [16]. There are many modeling software and standards for determining the propagation of noise. The problem resides in a lack of agreement on the standard to use. Some countries suggest models that are inaccurate due to assumptions that have been deemed incorrect [17]. Even recent models for calculating noise propagation still need work to provide a comprehensive and agreeable model [18], [19], [20].

Table 3-1: Summary of related studies for Rail Noise

Ref.	Paper Title / Topic Area	Problems / Issues	Research Objectives	Main Contributions	Main Findings / Conclusions
[4]	Breaking Barriers: Alternative Approaches to Avoiding and Reducing Highway Traffic Noise Impacts (2022)	Cost effective alternatives to traditional noise barriers	Identify non-traditional noise barriers, Evaluate strategies for inclusion, Improve implementation of noise-reducing strategies	Practitioners handbook (4 step process)	Proposes when to apply alternative noise reduction strategies Offers 14 primary strategies with sub-strategies
[2]	Railway rolling noise prediction under European conditions	Development of railway models to predict noise propagation and to provide insight into how noise is generated	Create a rail noise model that can include relevant factors (e.g., noise growth, corrugations, environment and friction modifiers)	RRNPS - Railway Rolling Noise Prediction Software	The RRNPS and original validated TWINS model agree well with each other. Negligible differences at 1000 Hz due to different creep coefficient models.

Ref.	Paper Title / Topic Area	Problems / Issues	Research Objectives	Main Contributions	Main Findings / Conclusions
[7]	Separation of rail and wheel contributions to pass-by noise with sparse regularization methods	Need for a method to determine the difference in wheel and rail noise in pass-by noise that can be validated	Investigate the performance with synthetic data and experimental data to validate per reference predictions with the TWINS software for train pass-by noise measurements (40, 80 and 160 km/h.	Enable the joint separation of the two components without requiring static tests prior to the pass-by using a collection of microphones near the track.	Separated spectra of the rail and the wheel are in good agreement with the reference data predicted by the TWINS software.
[8]	Evaluating railway noise sources using distributed microphone array and graph neural networks	Need for a more economical and flexible strategy while achieving equally satisfactory results in comparison to the beamforming device	Effectively evaluate the predominant noise sources for a railway acoustic system. Infer the SWL in one-third octave frequency bands. Increase the overall spatial resolution of the acoustic system	Provide new tools for rail noise interpretation to gain understanding of noise sources. The (graph neural network) GNN allows for the replacement of the costly, cumbersome and high maintenance beamforming strategy.	The GNN naturally encodes the distance between the microphone and each bogie. The GNN also allows for a flexible microphone arrangement. After the model training, the GNN model can be used as a replacement to the costly beamforming system.
[10]	Measurement methods and analysis tools for rail irregularities: a case study for urban tram track	Current data processing for thresholds of acceptability do not accurately describe the actual conditions of the rail.	Provide a method of analysis for data processing of rail profilometric data	A method for determining the acoustic roughness spectrum measured with the Corrugation Analysis Trolley (CAT) and is in line with the UNI EN Standard	The tram rail acoustic roughness spectrum calculation is always over the standard limit. The new limits should be established for tram rails which operate in conditions that are more critical than railway rails.
[17]	Problems of Railway Noise - A Case Study	Current interim methods (SRM II/RMR) suggested for countries without a current model are not accurate	Compare existing models to the suggested interim model and evaluate any discrepancies	Description of limitations and discrepancies between existing models for the Polish area and surrounding countries	The suggested model for countries without a national standard is inaccurate due to the assumption that the rail roughness is too low and this parameter cannot be adjusted
[11]	Vibration modes and wave propagation of the rail under fastening constraint	Very little documentation on the effects of rail fastening restraints on longitudinal rail vibrations have been reported	Provide a systematic method to investigate 3D rail vibration under the control of fastening constraint via a 3D FE model, experimental investigation, numerical simulations and validation	Improve understanding of 3D rail vibrations under fastening constraint and gain insight into rail vibration control by fastening dynamic parameters	Changing the fastening stiffness and damping can control rail frequencies, amplitude and influence wave propagation velocities and attenuation along the rail

Ref.	Paper Title / Topic Area	Problems / Issues	Research Objectives	Main Contributions	Main Findings / Conclusions
[13]	Numerical and experimental study of wheel-rail impact vibration and noise generated at an insulated rail joint	Previous analytical models failed to address issues of the complex wheel-IRJ impact contact solutions and high-frequency impact dynamics over 5 kHz	Establish a 3D FE interaction model, Validate the model, Compare the current model to previous models.	Provides a validated 3D transient explicit FE wheel-IRJ interaction model that is able to take into account complex wheel-rail dynamic interaction with non-linear material properties and arbitrary contact geometries	The proposed method mentions improved calculation of impact forces, vibration and noise directly in the high frequency range. The proposed FE method is capable of reproducing impact vibration and noise excited by an IRJ up to 10kHz.
[14]	Experimental and Theoretical Studies on Impact Noise Generation due to Rail Joints	Develop a better understanding of impact noise generation mechanism experimentally and theoretically	Determine the contributions of the wheel rail and sleeper to the total impact noise along with model validation	Creation of a model that is validated to predict the contribution of noise from each component	Two facing rails at a joint do not always move together above 1000 Hz. Weighted levels at three rail joints show an increase around 9 dB for doubling of train speed. The sleeper has the largest contribution below 630 Hz where the wheel is predominately above 2 kHz.
[6]	Localizing Noise Sources on a Rail Vehicle during Pass-By	Improving the deconvolution technique for delay-and-sum (DAS) beamforming maps	Use a commercially available system to improve the deconvolution of DAS and increase the resolution of the noise maps	Identified a potential aerodynamic phenomenon at the front of an IR4 train. Created a system that increased the resolution of pantographs	The resolution of pantographs using deconvolution was increased. Deconvolution was efficient at pinpointing the position of aerodynamic sources
[9]	Noise-source identification of a high-speed train by noise source level analysis	Identify main noise sources in high-speed trains	Examine the effects of real sound pressure by applying the method using a new array configuration	Creation of real sound power maps identifying real noise pressures at specific positions	The main noise sources were identified as the inter-coach spacing, wheels and pantograph. The pan head of the pantograph is the main noise source at 1000 Hz.
[12]	Influence study of rail geometry and track properties on railway rolling noise	Mitigation of rolling noise	Determine the influence of the track properties on the sound radiation using periodic structure theory, finite element techniques, and statistical techniques	Creation of a vibroacoustic model to calculate the sound power radiated by the wheel, rail, and sleeper	The most influential parameters of railway sound radiation in descending order are: rail pad stiffness, rail pad dampening, rail foot width, ballast stiffness, and ballast dampening

Ref.	Paper Title / Topic Area	Problems / Issues	Research Objectives	Main Contributions	Main Findings / Conclusions
[18]	Detecting approach of emergency vehicles using siren sound processing	Detection of emergency vehicle sirens in self-driving cars	Evaluate the detection and identify multiple types of emergency vehicle sound sources in the presence of background noise	Developed and evaluated a system for detecting and identifying types of emergency vehicle sirens	The system was able to detect and identify types of emergency vehicle sirens. The system was able to detect sirens when there was a change in frequency, in noisy environments (when the siren sound was smaller than the engine sound). The detection distance deteriorated due to engine sound.
[15]	Railway Line Occupancy Control Based on Distance Determination Sound Method	Train detection and classification methods	Analyze and evaluate the use of acoustic waves as an information carrier on approaching rail vehicles	The pilot studies show the possibility of using an acoustic wave as an information carrier on an approaching train (e.g., warning time associated with lowering the gate)	A sound pressure level (SPL) measurement does not have to be done directly at the head of the rail. Changes in position of the sound level meter slightly change the observed characteristics. Sound propagation is associated with the appearance of the train front concerns relatively short distances of several dozen meters (100-150 m) and 160 m for freight trains.
[19]	GIS-based modeling of tornado siren sound propagation: Refining spatial extent and coverage estimations	Current models of tornado sirens do not consider the complexities of noise propagation	Incorporate a sound propagation model to more realistically evaluate siren coverage	Comprehensive GIS-based approach to evaluate tornado siren coverage via sound propagation modeling techniques	Compared with traditional approaches, this method produces spatially continuous surfaces that allow users to identify problem areas using specific quantities (e.g., dB levels)
[3]	A Prediction Model of Urban Rail Transit Noise	Lack of effective model to predict rail transit noise in China	Establish a model for rail transit prediction in China	Determined a noise prediction model of urban rail transit that conforms to the national conditions of China	Per the established model, this work analyzes the methods, noise reduction, and cost. During line construction, damping rails and sound absorption boards can be installed (noise reduction rate >10%). By adjusting speed and frequency, the noise is adjusted. Acoustic barriers can be installed on existing

Ref.	Paper Title / Topic Area	Problems / Issues	Research Objectives	Main Contributions	Main Findings / Conclusions
					lines (noise reduction rate of up to 20%).
[1]	A Study on Dynamic Response Character of HighSpeed Railway Joint	Determine more accurate parameters to determine rail corrugations	Determination of parameters and formation mechanism of rail corrugation near the joint	An adaptive synchrosqueezed short-time Fourier transform method based on Ensemble Empirical Mode Decomposition (EEMD)	The response energy around the weld joint increases with a running speed increase. The main frequency is < 500Hz. Rail corrugation is easy to form behind the rail joints. Serious rail surface damage can occur if not repaired in time.
[16]	College Physics, PHYS 1101/1102 Custom Edition for University of North Carolina ISBN: 978-1-337-68545-0	N/A	N/A	N/A	General physics regarding longitudinal sound waves and the Doppler effect.
[20]	Analysis of sound propagation for outdoor emergency speakers networks	The area in Arequipa, Chili, needs a model to determine the effect and placement of emergency speakers	Communication system design using terrestrial digital TV and broadcast radio in order to send a warning signal to the population in case of a natural disaster	Document that provides all the technical information required to implement a network of emergency speakers in Arequipa city in the Chili river	Development of a model in Matlab to determine the sound propagation of a speaker network that has been validated with other commercial softwares
[5]	Research on the Control of Wheel-rail Noise by Wheel Sound-proof Skirt for High-speed Train	The wheel is a dominant source of wheel-rail noise. Therefore, shielding the noise at the wheel will reduce the overall sound propagated.	Determine the noise reduction effect of a skirt based on acoustic theory and statistical energy method. Using transmission loss as the evaluation index, calculate and analyze the influence of different shapes and material parameters.	Established the model of sound-proof skirt, including the calculated transmission loss based on acoustic theory. Discussion of the structural and material parameters that affect the noise reduction effect of skirts.	Increasing the thickness of the end face of the skirt is beneficial to effectively separate noise. Multi-layer composite materials can be used to improve the noise-reducing performance of skirts. Adjusting the thickness and shape of the skirt can also improve the transmission loss.

4. Methodology: Noise Propagation Analysis

This section provides an overview of the rail noise modeling methodology to support noise propagation analysis. There are a number of existing noise propagation models (e.g., STAMSON v5.03 / STEAM model, U.S. DoT - Federal Transit Authority model, and ISO 9613-2 model), each with advantages, as well as limitations. As highlighted in the literature review (Introduction and Literature Review section), there has been much work in the area of acoustic / sound modeling (e.g., noise propagation modeling). While it is possible to develop a physics-based noise propagation model for a particular application using a general programming application (e.g., MATLAB or Python), there are a number of commercially available software applications that specialize in acoustic analysis. Therefore, it is recommended that such applications be used to develop models with sufficient fidelity to accurately evaluate rail noise propagation. The table below provides a summary of commercial applications for modeling acoustic behavior (e.g., noise propagation).

Table 4-1: Acoustic Analysis Software Applications

Software Name	Description (Features: Advantages / Limitations)
ALTAIR Acoustics (AVL EXCITE Acoustics) https://www.altair.com/avl-excite-acoustics	Altair is part of a simulation software platform that can model a large variety of physical problems across a range of engineering fields (e.g., aerodynamic and thermodynamic behavior of fluids). It is similar to COMSOL and ANSYS. AVL EXCITE Acoustics is a tool for the calculation of sound radiation in free field from vibrating structures such as engines and power units using the wave based technique (WBT). It includes interfaces to common finite element (FE) tools for the import of the vibrating structure geometry. Key Features and Functionality Include: ● Fully automated model setup to support fast modeling for obtaining results to support design decisions ● Capability for simulation speedup (fast results) ● High computational performance (efficient processing) ● Highly efficient sound radiation calculation ● Wave based technique (WBT) that express the dynamic acoustic pressure as a linear combination of wave functions ● Automated WBT model generation
ANSYS (Acoustics Analysis) https://www.ansys.com/products/acoustics-analysis	ANSYS is a very well known and established product in engineering simulations across a large array of applications and industries (e.g., aerospace, automotive, manufacturing, medical devices and semiconductors). The Acoustics Analysis module permits users to model and analyze the acoustic performance to optimize designs.

Table 4-1: Acoustic Analysis Software Applications

Software Name	Description (Features: Advantages / Limitations)
	Key Features and Functionality Include: ● Listen to and analyze sound quality ● Optimize engine sound for E-motor ● Listen to Mechanical and Fluids simulations ● Evaluate sound perception ● Active Sound design for automotive applications ● Component and system level simulations Applications include: ● E-motor NVH and Active sound design for EV ● Electric Motors ● Gas Turbines ● Rotating Machinery ● Vehicle Powertrain ● Vehicle Electrical System
COMSOL Multiphysics (Acoustics Module) https://www.comsol.com/acoustics-module	COMSOL Multiphysics is a versatile multiphysics software package. This module can be used to analyze the Acoustics and Vibrations behavior of products and designs. This software includes multiphysics couplings that enable the user to evaluate the performance of a product or design in an environment that is as close as possible to the real world (i.e., acoustics can be coupled with other physical effects). Applications Include: ● Pressure Acoustics, Electroacoustics: Speakers and Microphones, Microacoustics, Elastic Waves and Ultrasound in Solids, Ultrasound in Fluids, Aeroacoustics, Geometrical Acoustics, Acoustic Streaming. Key Features and Functionality Include: ● Built-In User Interfaces ● Finite Element and Boundary Element Methods ● Pressure Acoustics Interfaces ● Boundary Conditions and Sources for Pressure Acoustics ● High-Frequency Pressure Acoustics ● Acoustic–Structure Interaction Interfaces ● Elastic Waves Interfaces ● Thermoviscous Acoustics Interfaces ● Aeroacoustics Interfaces ● Ultrasound and Convected Wave Equation Interfaces

Table 4-1: Acoustic Analysis Software Applications

Software Name	Description (Features: Advantages / Limitations)
	● Open Domains and Radiation ● Ray Acoustics and Acoustic Diffusion Interfaces ● Flow-Induced Noise ● Acoustic Losses and Porous Materials
Odeon Room Acoustics Software https://odeon.dk/	This is an application that permits users to simulate the acoustics of a room, such as predicting how sound will travel and echo in a room. Then, users can adjust the acoustic properties of a room to help improve its sound quality. As a limitation, this software is task specific, since it is specialized in only simulating room acoustics. Key Features and Functionality Include: ● Import 3D Geometries ● Fast and Accurate Simulations ● Measure Real Rooms ● Output Results: Acoustics in Graphs and Numbers, Visualize the acoustics, Acoustics in Color Maps, Frequency response ● Acoustic Surface Properties ● Many Types of Sound Sources ● Reflector Coverage ● Compare Measurements and Simulations
OpenFOAM Aeroacoustics https://www.openfoam.com/	This is a free, open-source software package (CFD software) that was developed by OpenCFD Ltd (since 2004). However, the user interface may be somewhat limited in comparison to other software applications for similar analysis. This application can be used to solve fluid simulation problems, such as acoustics in air. Key Features, Functionality, and Applications Include: ● Complex fluid flows involving chemical reactions ● Turbulence and heat transfer ● Acoustics ● Solid mechanics ● Electromagnetics
SIMULIA (Dassault Systèmes)	This is a versatile tool that can be used for a wide range of applications. It provides a user interface that can be customized per the individual user needs. Wave6 provides an analysis method for efficiently and

Table 4-1: Acoustic Analysis Software Applications

Software Name	**Description (Features: Advantages / Limitations)**
https://www.3ds.com/products-services/simulia/ (Wave6: Vibro-acoustic Simulation Software) https://www.3ds.com/products-services/simulia/products/wave6/	accurately simulating noise and vibration across the entire audible frequency range. Key Features and Functionality Include: ● Aero-acoustics of exterior flow noise from a rigid structure ● Vibro-acoustics via airborne and structure-borne transmission paths ● Aero-vibro-acoustics of interior wind noise due to fluctuating surface pressures ● Simulation of acoustic wave propagation in bounded or unbounded acoustic spaces at low frequencies via acoustic boundary elements
SoundPLAN https://www.soundplan.eu/en/ Navcon Engineering Network https://navcon.com/www/content/soundplan-sound-propagation-modeling-software-0 SoundPLAN Rail Module https://navcon.com/www/content/soundplan-rail-module	This is an acoustic ray tracing program for noise propagation prediction that can be used as an acoustical planning and modeling tool with a wide range of applications (e.g., Urban Planning, Environmental Assessment, Noise Analysis, Noise Control Optimization, Field Noise Mapping, OSHA / MSHA, Road Rail Noise Modeling). Key Features and Functionality Include: ● Traceable propagation models ● Versatile definition of the sources input ● Numerous control and QA features ● Documentation feature to annotate the the models ● Graphic tools for the visualization and presentation ● Noise control optimization features ● Rail Noise Modeling Features: ○ Numerous rail standards in SoundPLAN (Over 16+), such as the FRA (High Speed Ground Transportation Manual from Sept. 2012) and the FTA (Transit Noise and Vibration Impact Assessment 2006). ○ Emission and propagation calculations ○ Standard vehicles in geo-database: train vehicle library, train library to assemble the desired train vehicle and units, length, maximum speed ○ Predicted noise levels: single receiver computation, noise contour maps, or cross section maps ○ Rail track segmentation ○ Terrain model (spacial, GIS-based, data input)

Table 4-1: Acoustic Analysis Software Applications

Software Name	**Description (Features: Advantages / Limitations)**
Siemens Acoustic Simulation	This application permits users (e.g., architects, engineers, and environmental consultants) to simulate the acoustic behavior of rooms, buildings, and structures (offering both interior and exterior acoustic simulation) to identify potential noise pollution issues. It is similar to COMSOL and ANSYS in being a versatile simulation tool. Key Features and Functionality Include: ● Design analysis to support compliance with noise regulations ● Unified and scalable modeling environment ● Efficient solvers ● Easy-to-interpret visualization capabilities

Based on the computational applications considered, for general-purpose simulation needs, COMSOL and ANSYS can be used for a variety of engineering problems to analyze behavior. In this work, we are focusing on analyzing the propagation of rail noise, specifically looking at the contribution of rail types (i.e., welded rails and jointed rails). Therefore, SoundPLAN was selected for this work, since it provides a versatile platform to analyze sound and includes built-in tools to model and analyze rail noise.

A rail noise model (e.g., 3D acoustic data model) needs to incorporate several types of data (e.g., noise source data, spatial data, and demographic data) in an integrated model framework to provide meaningful information, as highlighted in Fig. 4-1.

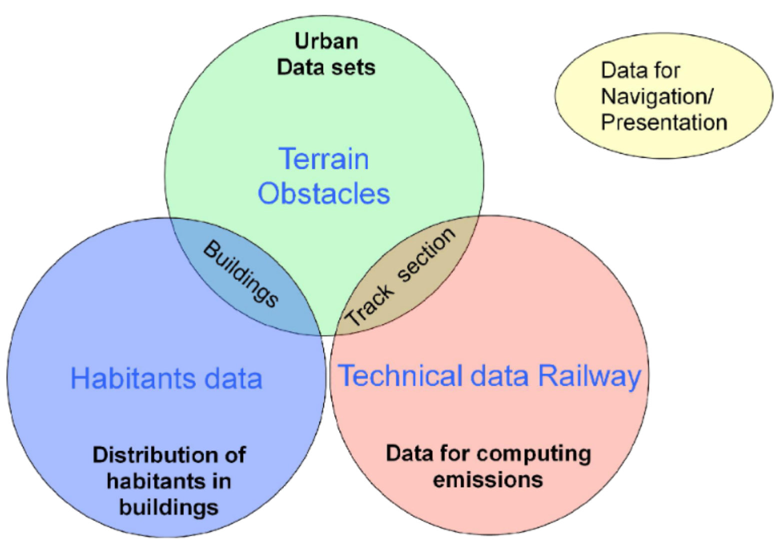

Figure 4-1: Data Integration for Rail Noise Model (adapted per [44])

When comparing current models that could potentially provide the simulations needed per the available data, SoundPLAN (https://www.soundplan.eu/en/) [42] is a viable option that was selected for this work. SoundPLAN, first introduced in the United States in 1992 [42], is a well established and recognized software application throughout the world for modeling noise propagation. As discussed in [42], [44], [45], SoundPLAN is an acoustic ray tracing program (created by SoundPLAN GmbH, which is a German acoustical consulting firm) that is used for noise propagation prediction. The software is an acoustical planning and modeling tool with a wide range of applications, including noise analysis. A brief description of SoundPLAN and associated methodology for modeling rail noise is provided in this section. Additional information for SoundPLAN is provided in the Appendix section of this document.

SoundPLAN is a three-dimensional (3D) graphics oriented program. The software application is capable of performing rail noise simulations and producing various analysis outputs to support decision making (e.g., color noise contour plots and tabulations of the input data and results). Graphical displays can be used to visualize the performance benefit(s) of noise mitigation strategies (e.g., compare noise level reduction) and compare design alternatives. SoundPLAN is offered as a graphical user interface (GUI)-based modeling and analysis tool that allows the user to visualize the effects of noise propagation throughout the analysis location, such as railroad lines, and optimize designs.

SoundPLAN includes the following features [42]:

- Traceable propagation models
- Versatile definition of the noise source input (e.g., frequency spectrum, direction, and time).
- User definition of input geometry and source data.
- User annotation of the inputs, data processing, or the results (e.g., specific input object, calculation, detailed result tables, etc.)
- Graphical-based tools for the visualization and presentation of the data (input and output) and analysis results.
- Features for noise control optimization.

The SoundPLAN Road/Rail Noise model includes numerous road/rail standards, including the Federal Highway Model (U.S.), FRA (High Speed Ground Transportation Manual), and the FTA (Transit Noise and Vibration Impact Assessment) [42]. As discussed in [42], [44], [45], the “road and rail” module consists of two main parts: (a) the emission calculation and (b) the propagation calculation. The first part, the emission calculation, is performed inside the Geo-Database, which performs the emission level calculator based on the relevant data inputs (e.g., vehicle data, vehicle speed, road surfaces/track conditions). The second part, the propagation calculation, is performed inside the Calculation Core, where calculations can be performed for single receivers or various types of noise maps, with the analysis results presented in the documentation, spreadsheet, and in the graphical results, as appropriate.

To create a Rail Noise model, several key input definitions and data input are required [45]:

- Input of the project geometry,
- Assembly of the trains, and
- Traffic information for each track section.

Furthermore, to facilitate consistent and accurate modeling, SoundPLAN includes a library of vehicles and trains for the FTA and FRA models, where the vehicle library includes the data from the FTA and FRA standards. In the SoundPLAN train library, predefined trains can be selected or new train configurations can be defined, as necessary. The emission levels and source heights can be adjusted, as needed for the event scenario in the simulation.

5. Simulation Case Study: Test Case, Results, and Discussion

The goals of this project are to (a) identify existing computational model advantages and limitations and (b) model the rail noise via the computational model for both welded and jointed rails. As this topic is not well researched, the ideal computational model does not exist yet. The only options are to develop a new and comprehensive model or use current modeling software that could provide insight. Using current modeling software is the most reasonable option for time savings. When comparing current models that could potentially provide the simulations needed per the available data, SoundPLAN 9.0 (https://www.soundplan.eu/en/) [42] is a viable option that was selected for this work. SoundPLANnoise 9.0 is a professional noise software used in a wide variety of applications such as road and rail noise, commercial and leisure noise, aircraft noise, and 'Hallin' (i.e., sound propagation indoors).

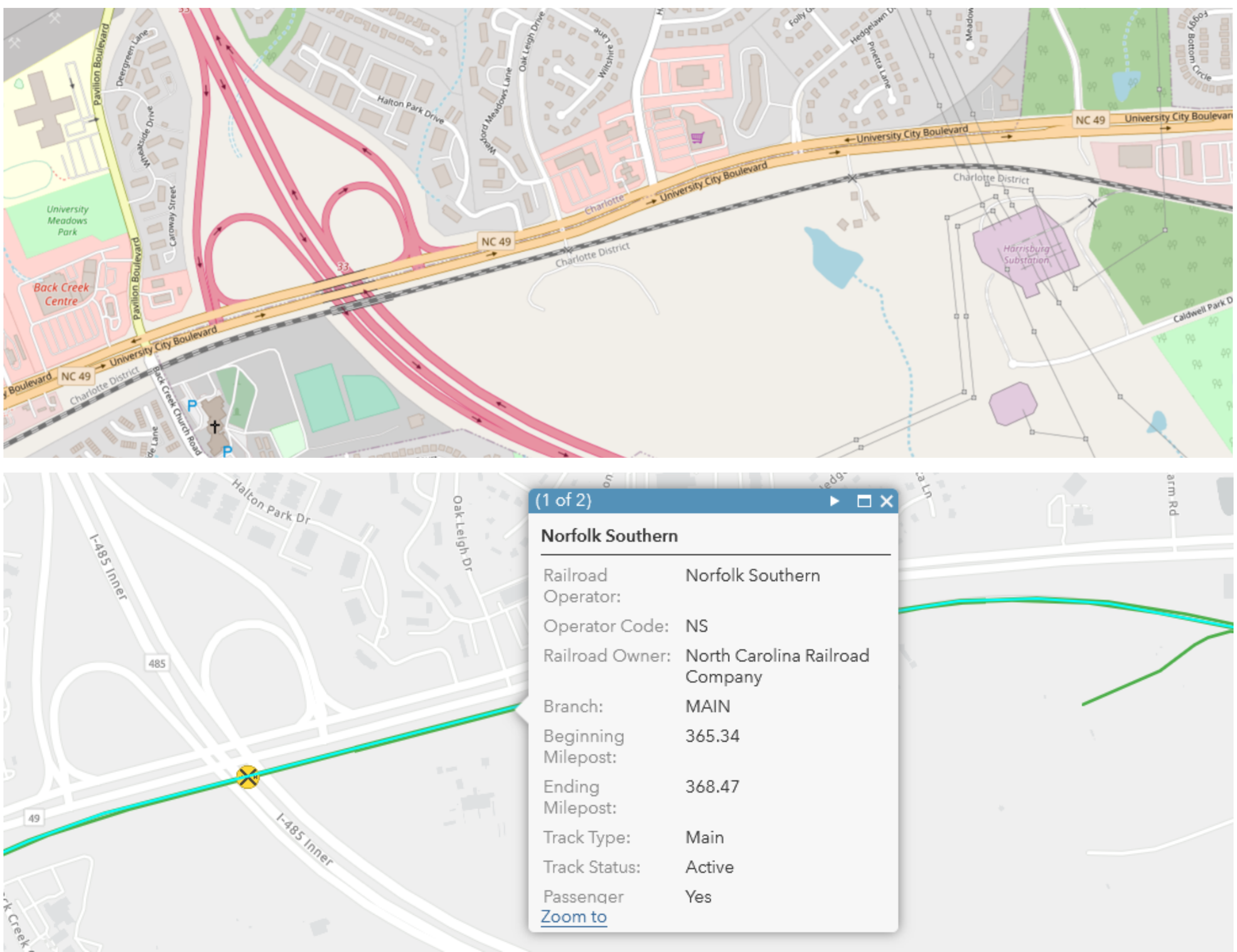

Figure 5-1: Railroad Location - (top) University City Bitmap and (bottom) NCDOT Rail System [41]

North Carolina has a number of good candidate locations. Due to the availability of modeling information (e.g., digital ground model) and proximity, a rail location in the Charlotte region was selected for this study, as this site is useful to model for comparing the noise propagation with different rail types and is close by for visual inspection (as needed).

The selected rail location is a 0.25-mile length segment of the Norfolk Southern rail that is near NC-49 and I-485, as shown in Fig. 5-1. This location is directly adjacent to a shopping center and is an ideal location for an individual to walk to the train tracks to reduce their commute compared to walking on the sidewalks. The location can be seen below in Fig. 5-1. The length of track chosen is to reduce the computational time of the model, while providing sufficient length to simulate having multiple joints in the track.

To produce a model in the Geo-Database interface of SoundPLAN, the first object needed in the simulation is the digital ground model (DGM). This object can be created from LiDAR (Light Detection and Ranging) data collected from North Carolina's Spatial Data Download [43] (https://sdd.nc.gov/). Once the data is collected, the *.las file can be imported and filtered in SoundPLAN. The purpose of filtering the lidar data is to reduce the computational time and power needed due to each point needing to be calculated. Once the DGM is filtered, all the points are scaled along the x, y, and z axis by 0.3048 (i.e., 1 ft = 0.3048 m). This scaling is due to the LiDAR scan being measured in feet and SoundPLAN evaluates the model in meters. After the digital ground model is created, the railroad tracks need to be imported from Google/OpenStreetMap (OSM). This automatically imports any data for the railroad tracks into the model. Next, all objects imported from Google/OSM need to be set to the DGM. The 3D model shows how the objects have no height and setting them to the DGM will place them on the same plane as the elevation data. As an example, the DGM and OSM objects for this test case are shown in Fig. 5-2 (DGM).

Figure 5-2: DGM

Once the DGM and OSM objects are aligned, the calculation parameters need to be set. The first object to be inserted is the calculation area. This is chosen by drawing a box within the bounds of the DGM. The next object type to be inserted is the receiver. The density of the receiver placement for this simulation is focused on the track and decreases away from the track. The receiver placement for this text case is shown in Fig. 5-3 (Receiver Placement).

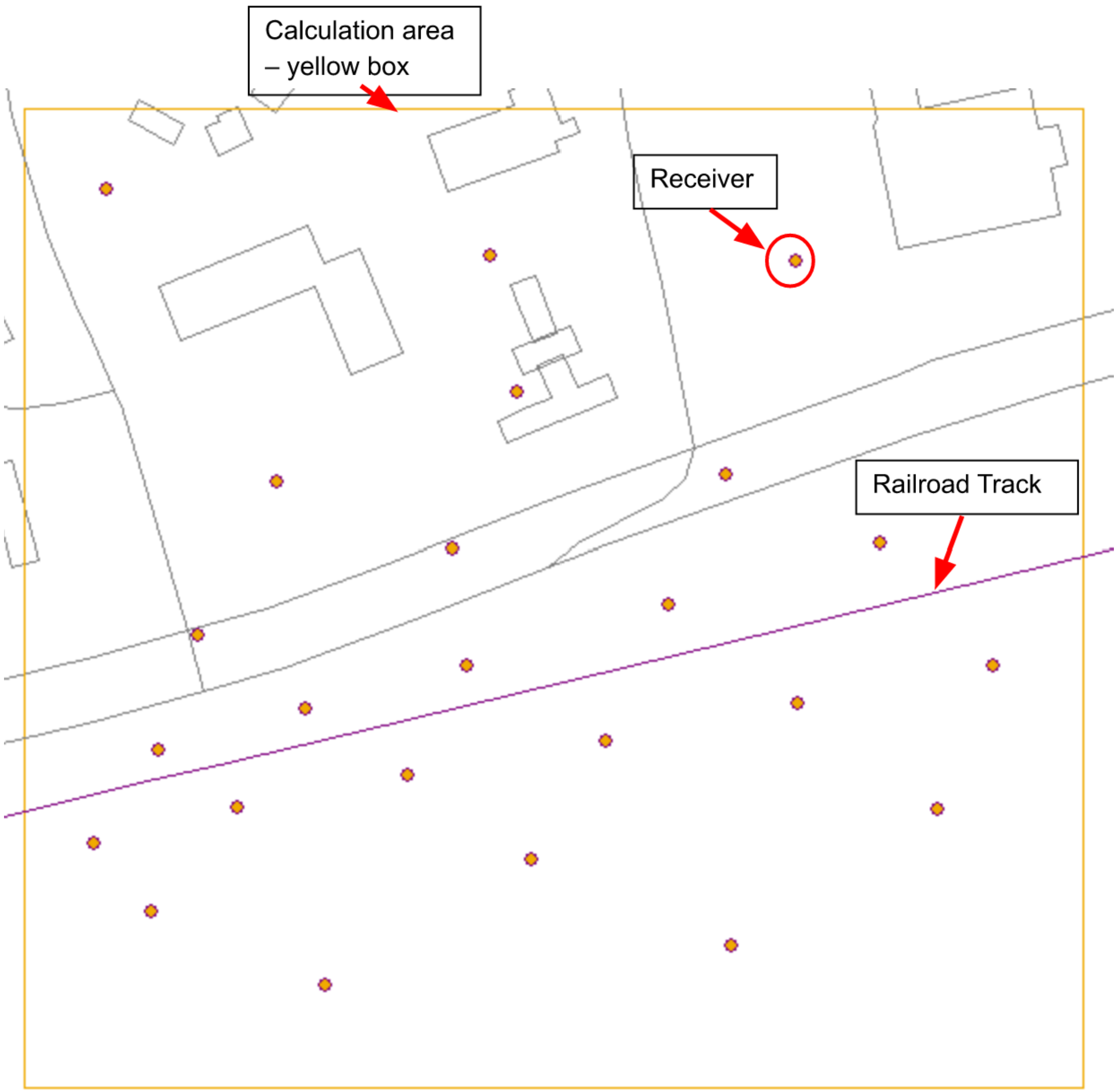

Figure 5-3: Receiver Placement

To assess the difference between jointed rails and welded rails, the software needs to know which emission standard to calculate the data from in the model. For example, the CNOSSOS-EU 2021 railway emission standard allows for multiple configurations of joint conditions. This model uses a welded rail joint, 1 joint per 100m and 2 joints per 100m with a normally maintained railhead roughness, as seen in Fig. 5-4 (Rail Joints) for this test case. The chosen joint types allow for a cumulative analysis of the potential joint types used.

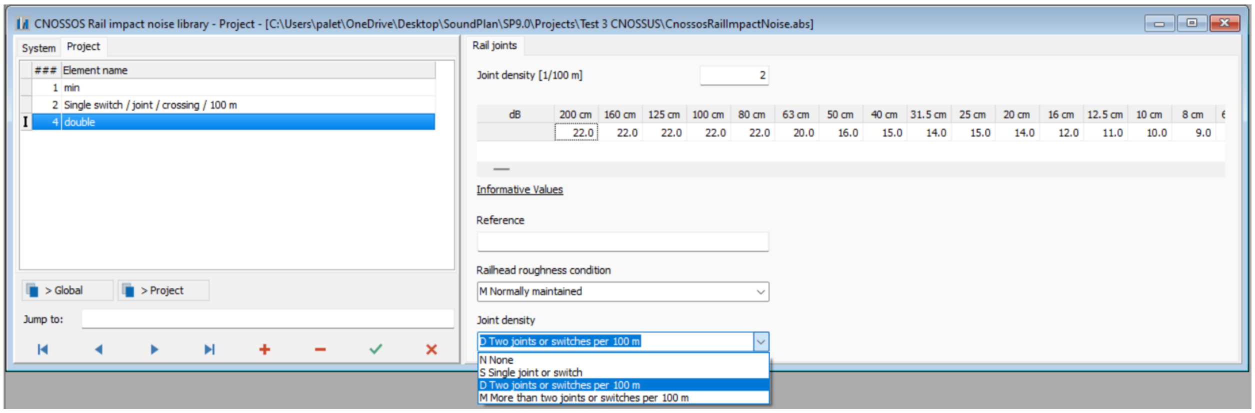

Figure 5-4: Rail Joints

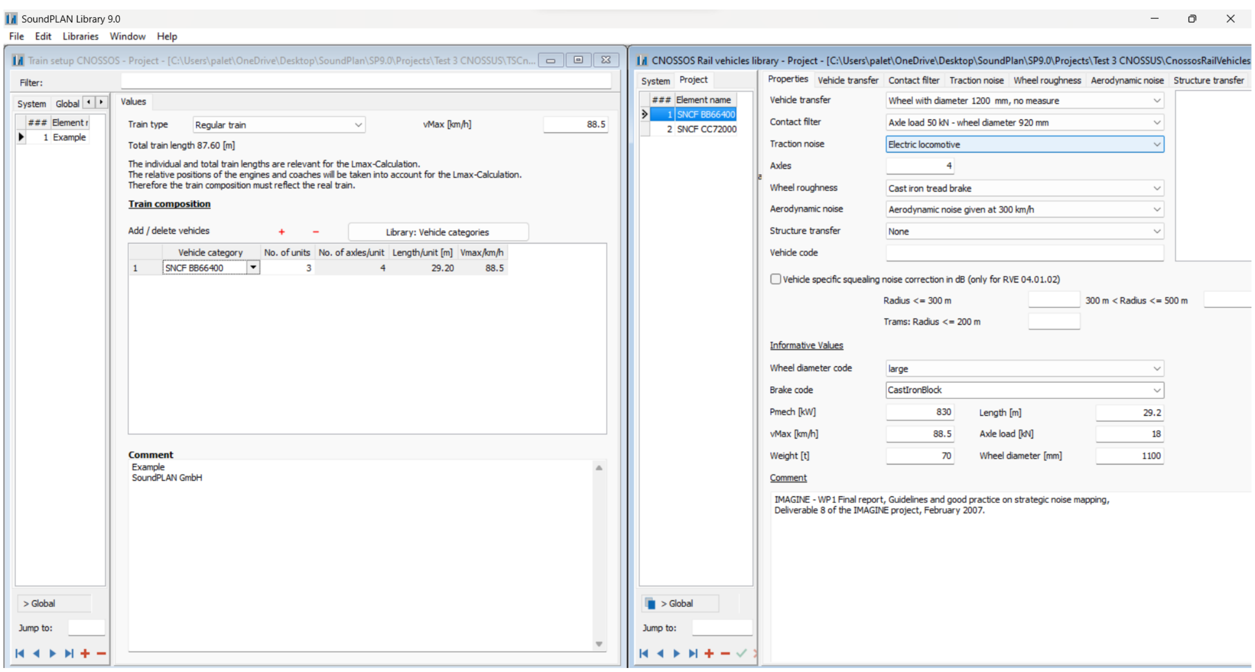

Figure 5-5: Train Setup

For this test case, the train is modeled as a light rail passenger train. This is due to the light rail train passing directly through the city where the largest population is thus, producing a higher chance for a train-pedestrian collision. The train setup starts with the SNCF-BB66400. In the vehicle categories section, this train is set up with a traction noise parameter set as an electric locomotive and a length [m] of 29.2 m. Under the train setup this train is defined with the following parameters, as seen in Fig. 5-5 (Train Setup):

- vMax [km/h] = 88.5 (maximum velocity)
- No. of units = 3.

The computational analysis of the simulation can be made using the Calculation Kernel. A new run is created with the outdoor noise via a single points calculation type. The data selected for the outdoor calculation is the simulation scenario (event situation) made in the Geo-Database and the DGM, as shown in Fig. 5-6 (Simulation Calculation). After the calculation is created, the simulation can be run.

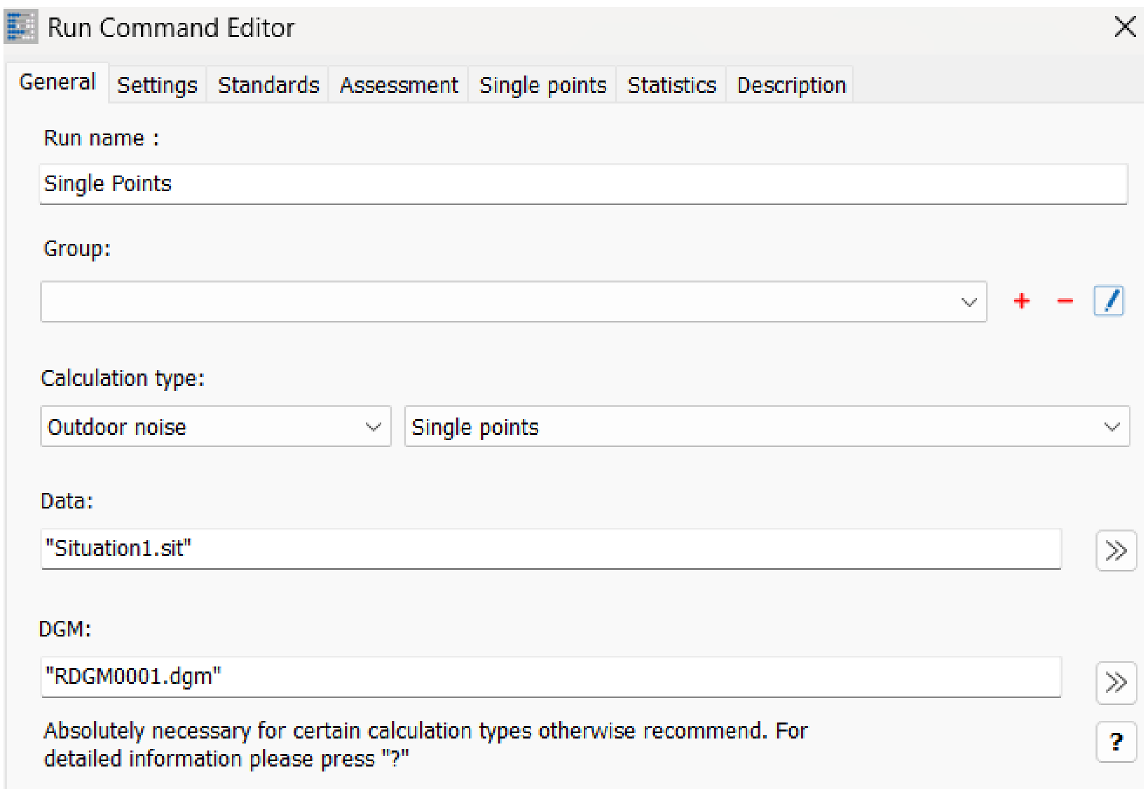

Figure 5-6: Simulation Calculation

The case study results are provided in Fig. 5-7 and Table 5-1, which provide the noise magnitudes at each receiver, respectively. The A-weighted decibel, dB(A), expresses the relative loudness of a sound as perceived by the human ear (i.e., a measure of how loud sounds appear to the human ear). For this test case, the computational analysis produced the following average (noise) magnitudes in dB(A) for each of the rail joint configurations, as seen in Fig. 5-8 (Average dB(A) for rail joint type): welded rail = 34.3 dB(A); 1 joint per 100m = 35.8 dB(A); 2 joints per 100m = 36.8 dB(A). The percent increase in dB(A) is shown in Fig. 5-9 (Average Noise Magnitude Increase forRail Joint Type versus Welded Rail). Comparing welded rail to 1 joint per 100m, there was an average increase of 4.38%. Comparing welded rail to 2 joints per 100m, there was an average increase of 7.64%.

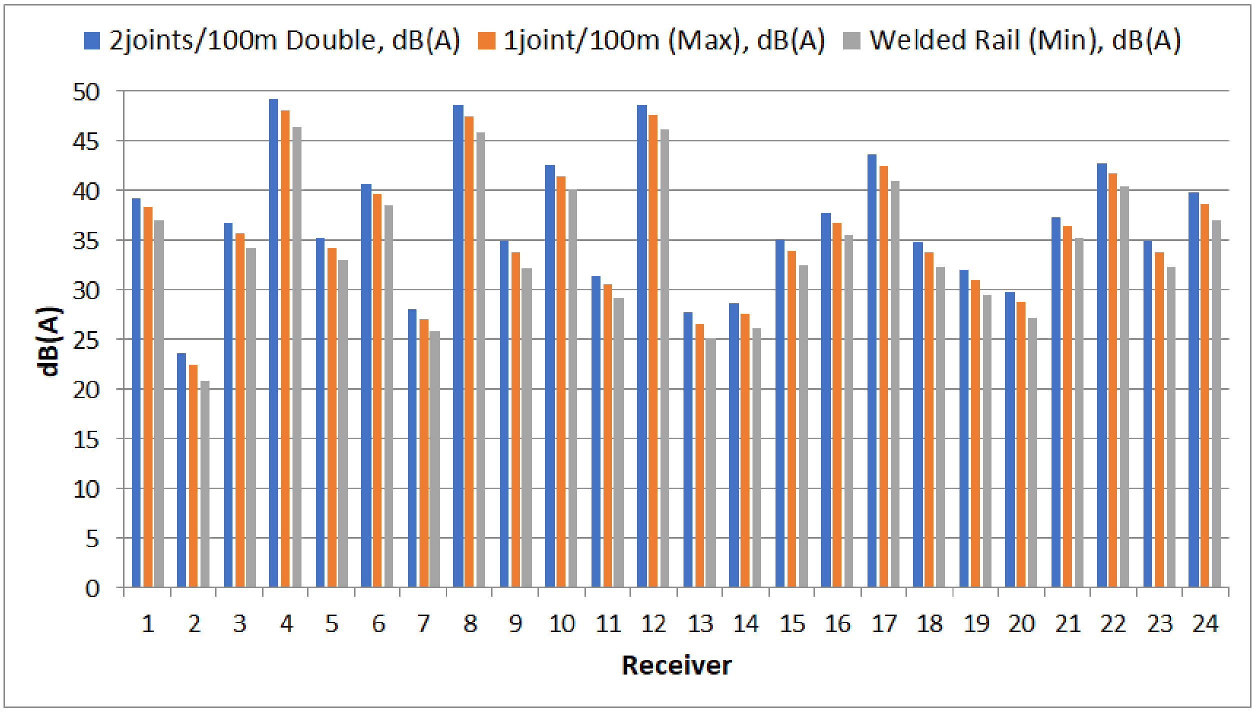

Figure 5-7: Noise Magnitude for each Rail Type per Receiver

Table 5-1: Rail Noise Case Study Results

Receiver	2 joints / 100m (Double) dB(A)	1 joint / 100m (Max) dB(A)	Welded Rail (Min) dB(A)	delta (Min-Max) dB(A)	delta (Double-Min) dB(A)	% increase Min vs Max	% increase Min. vs Double
1	39.2	38.3	37.1	1.20	2.10	3.23%	5.66%
2	23.7	22.5	20.8	1.70	2.90	8.17%	13.94%
3	36.8	35.7	34.2	1.50	2.60	4.39%	7.60%
4	49.2	48.1	46.5	1.60	2.70	3.44%	5.81%
5	35.3	34.3	33	1.30	2.30	3.94%	6.97%
6	40.7	39.7	38.5	1.20	2.20	3.12%	5.71%
7	28.1	27.1	25.8	1.30	2.30	5.04%	8.91%
8	48.6	47.5	45.9	1.60	2.70	3.49%	5.88%
9	35	33.8	32.2	1.60	2.80	4.97%	8.70%

Receiver	2 joints / 100m (Double) dB(A)	1 joint / 100m (Max) dB(A)	Welded Rail (Min) dB(A)	delta (Min-Max) dB(A)	delta (Double-Min) dB(A)	% increase Min vs Max	% increase Min. vs Double
10	42.6	41.5	40.1	1.40	2.50	3.49%	6.23%
11	31.4	30.5	29.3	1.20	2.10	4.10%	7.17%
12	48.7	47.6	46.1	1.50	2.60	3.25%	5.64%
13	27.8	26.6	25.1	1.50	2.70	5.98%	10.76%
14	28.7	27.7	26.2	1.50	2.50	5.73%	9.54%
15	35.1	34	32.5	1.50	2.60	4.62%	8.00%
16	37.7	36.7	35.6	1.10	2.10	3.09%	5.90%
17	43.6	42.5	41	1.50	2.60	3.66%	6.34%
18	34.9	33.8	32.3	1.50	2.60	4.64%	8.05%
19	32.1	31	29.5	1.50	2.60	5.08%	8.81%
20	29.9	28.8	27.2	1.60	2.70	5.88%	9.93%
21	37.4	36.4	35.2	1.20	2.20	3.41%	6.25%
22	42.8	41.8	40.4	1.40	2.40	3.47%	5.94%
23	35	33.8	32.3	1.50	2.70	4.64%	8.36%
24	39.8	38.7	37.1	1.60	2.70	4.31%	7.28%
Average	**36.8**	**35.8**	**34.3**	**1.44**	**2.51**	**4.38%**	**7.64%**

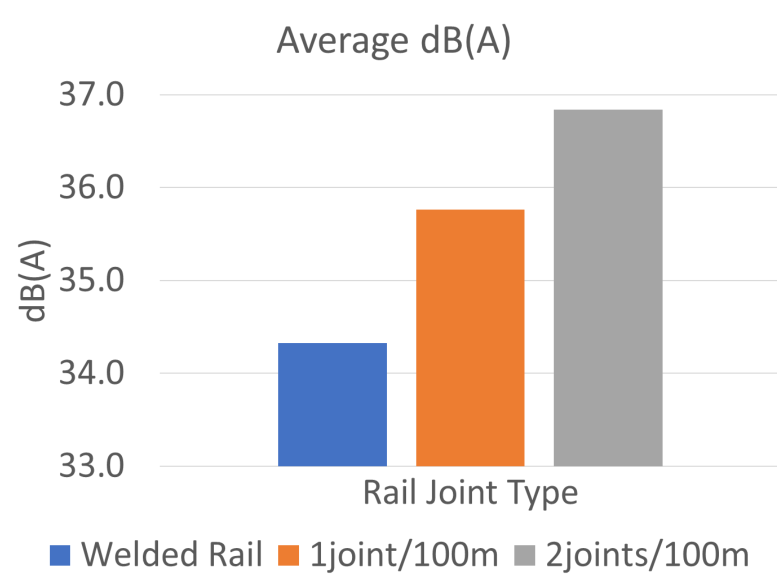

Figure 5-8: Average dB(A) for rail joint type

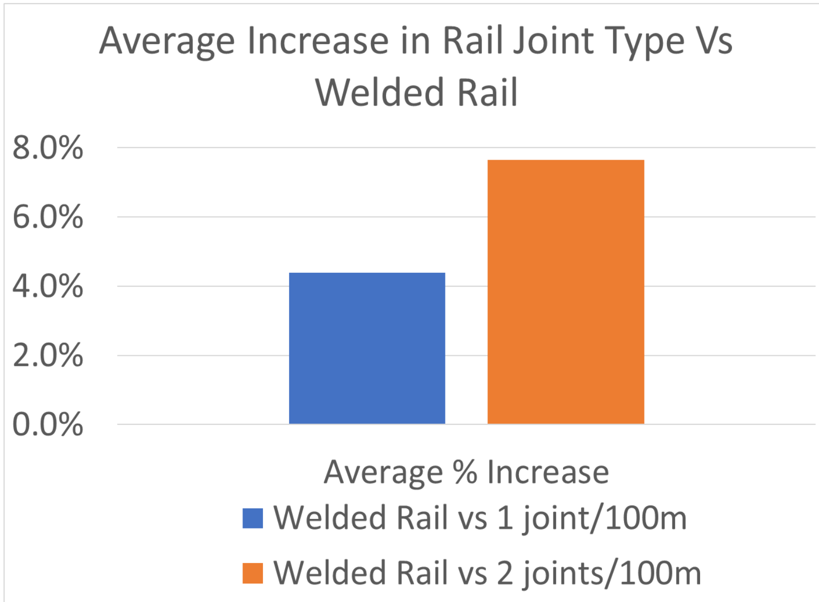

Figure 5-9: Average Noise Magnitude Increase for Rail Joint Type versus Welded Rail

The outcome of this project is a computational model that provides insight into the increased noise level of jointed rails over welded rails and the associated effect on noise propagation. The current model can be further enhanced by incorporating additional details to reflect process characteristics with higher fidelity. While the results are not an exactly replicated model of the real-world environment, the model does reasonably demonstrate that a single change in the rail joint type provides a corresponding increase in noise level and furthermore its propagation.

6. Conclusion

To support effective planning, design, management, and public education of rail systems (e.g., risks of trespassing on the rail right-of-way), it is important to quantify the rail noise propagation (e.g., apparent noise at a certain track location ahead of a train, given a particular rail location, rail vehicle specification, track type, environmental condition, etc.). As detailed in this report, this project focused on investigating the rail noise propagation differences between welded and jointed rail types in North Carolina to provide an improved understanding regarding the noise contribution from different rail types. This work included a literature review of existing rail noise source models and identified their advantages and limitations (e.g., the literature review discussion includes a summary of the problems explored, their objectives, main contributions, and findings / conclusions.). In addition, we conducted a representative simulation case study with the identified rail noise model using a professional computational software (SoundPLAN) to predict the noise propagation produced by trains on welded and jointed rails, which is consistent with the findings in the related literature. The simulation results showcase the relative increase in noise with jointed rails as compared to welded rails. Depending on the rail configuration, there was an average increase of 4.38% to 7.64% with the joined rails as compared with the welded rails.

As a next step to enhance overall understanding and support a more generalized approach, future work could more deeply explore the difference in noise propagation between welded rails and jointed rails.

1. To verify the findings in the current work, future work could include conducting additional simulation test cases using the computational analysis software (SoundPLAN) for a range of NC rail location environments and statistically analyzing the results.
2. For validation, future work could include conducting experimental (field) test studies to record noises produced by trains on welded and jointed rail and modeling the same scenario (e.g., environmental conditions, rail type, rail vehicle, ect.) using the computational analysis software (SoundPLAN). The field test results will serve to validate and verify the computational model via statistical comparison of the experimental test results and the simulation results.

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Appendix

SoundPLAN videos regarding rail noise:

- SoundPLAN Rail Noise Modeling (FTA / FRA)
  https://www.youtube.com/watch?v=rjfJl5S4voQ

- SoundPLAN Rail Pass-BY 3D train noise animation
  https://www.youtube.com/watch?v=yYCrrcJe8tc

- SoundPLAN Graphics create an Animated Noise Map
  https://www.youtube.com/watch?v=56GQaIlg-tY

- Rail noise animation
  https://www.youtube.com/watch?v=b1TUA3KzsYY

CNOSSOS Test Simulation Setup for SOUNDPLAN noise 9.0

1. Navigate to https://sdd.nc.gov/ to select simulation location.
    a. Download and save .las file.
2. Open SOUNDPLAN noise 9.0 and create a new project.
    a. Select Coordinate system – US-SPCS 1983 (3200) North Carolina Lambert coord.
    b. Select Reference system – NAD (83NSRS 2011) (US), geocentric GRS80.
3. Open Library.
    a. From the drop-down menu follow Libraries > Train Setup > CNOSSOS-EU > Rail Joints
        i. Under system select min, max, and single joint/110m and copy to project.
        ii. For all elements, change rail head roughness condition to normally maintained smooth.
        iii. For max element, change joint density drop down to D Two joints or switches per 100m. Also change joint density [1/100m] to 2.
    b. From the drop-down menu, Libraries > Train Setup > CNOSSOS-EU > Vehicle Categories.
        i. Under system select SNCF BB66400 and copy to project.
        ii. Change Traction noise to electric locomotive
        iii. Change length[m] to 29.2
        iv. Change vMax [km/h] to 88.5
    c. From the drop-down menu, Libraries > Train Setup > CNOSSOS-EU > Train Setup.
        i. Change Train type to Regular train
        ii. Change vMax [km/h] to 88.5
        iii. Change No. of units to 3
4. In SOUNDPLAN Manager select Standards in the lower right-hand corner.
    a. Under Railway noise select CNOSSOS-EU: 2021.
    b. Under Railway noise emission select CNOSSOS-EU: 2021.
5. Open Geo-Database
    a. Select a new situation.
    b. Under the Fundamentals tab in the ribbon select the import drop down menu.
        i. Select elevation points.
        ii. Using the file browser, select the .las file downloaded from sdd.nc.gov
            1. Run execute command.
        iii. After the execute command is complete, under filter options.
            1. change Grid distance [m] to 12.
            2. Change Max. point distance [m] to 200
            3. Change Maximum height difference to original points [m] to 1.5.
            4. Run execute command.
        iv. After execute command is complete select OK on Elevation Filter prompt on the bottom
    c. The DGM should be loaded on the screen and labeled as Geo-File1 in the Geo-manager.
    d. Right click on the map area and select all points.
        i. Navigate to the Start tab on the ribbon and select the edit drop-down.
        ii. Select coordinate operation.

        iii. For x, input into Operation: *.3048
        iv. For y, input into Operation: *.3048
        v. For z, input into Operation: *.3048
        vi. Select the check mark after all operations are complete.
        vii. *NOTE. This operation is to scale the DGM because the .las file is in feet and SOUNDPLAN interprets files formatted in meters.
    e. Navigate to the Fundamentals tab on the ribbon and select the Oen Google Maps / OSM
        i. Under image data, select save image viewport as…
            1. Save file.
        ii. Under Import select Download & import OSM data…
            1. Select railways.
    f. Navigate to the Fundamentals tab on the ribbon and select the Calculate DMG.
        i. In the Run Command Editor rename the run name.
        ii. In the Data: selection remove "OSM_Railway.geo" leaving only "Geo-File1.geo"
        iii. Select Start
        iv. After completion select OK
    g. Select and trim railway until one rail is inside the DMG.
    h. Select Railway under Object manager and select Current object type in the View filter portion of the ribbon.
        i. Right click and select all.
        ii. Under the Fundamentals ribbon select set objects to DGM.
        iii. Select the green check mark.
    i. On the ribbon select the dropdown under objects
        i. Select Calculation area.
            1. Draw a box inside of the DGM including the railway.
        ii. Select receiver.
            1. The density of receiver placement is focused on the track and decreases away from the track.
    j. Select Rail on map.
        i. Under geometry select segment 1.
        ii. Under Properties select Emission "CNOSSUS-EU: 2021" > Emission.
            1. Under train type select the custom SNCF BB66400
            2. Change N(d) to 1
            3. Change N(e) to 1
            4. Change N(n) to 1
            5. Change V [km/h] to 88.5
        iii. Under Properties select Emission "CNOSSUS-EU: 2021" > Correction.
            1. Beside Rail joints is where the only change will be made between simulations. Only one simulation can be run at a time. Start with min.
    k. Save Situation
6. Open Calculation Kernel from SOUNDPLAN Manager
    a. Create a new run with the following properties.

        i. Calculation type: Outdoor noise, Single points
        ii. Data: From the situation created in step 5.
        iii. DGM: From DGM created in step 5f.
        iv. Select Green Check
    b. Select calculation dropdown and choose to start all runs checked for calculation.
7. After completing the simulation open Result Tables from the SOUNDPLAN manager
    a. In the open file prompt select Single Point Sound Results beside filter
    b. Select open.
8. Results are shown in the Single Receiver tab.
9. Rerun calculation after changing the Rail Joint type Under Properties select Emission "CNOSSUS-EU: 2021" > Correction in Geo-Database