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Potentiality of using Google Earth to Extract Material Stock Data from Technosphere for Material Flow Analysis

Muhammad Imran¹, Junbeum Kim^{2†}, S.M. Rahman³, Jaewook Ahn⁴, Yongwoo Hwang⁴
Bertrand Guillaume²

¹Civil Engineering Department, The University of Lahore, Lahore, Pakistan

²CREIDD Research Center on Environmental Studies & Sustainability, Interdisciplinary research on
Society-Technology-Environment Interactions, University of Technology of Troyes, 12 rue, Marie
Curie, 10300, Troyes, France

³ENSAM, Arte et Metier, IMC, Esplanade des Arts et Métiers - 33405 TALENCE Cedex , France

⁴Program in Circular Economy Environmental System Convergence, Department of Environmental
Technology and Safety Technology Convergence, Inha University, 253 Younghyun-Dong, Namgu,
Incheon, South Korea

†Corresponding Author: Junbeum Kim, junbeum.kim@utt.fr, Tel: +33.03.25.71.80.06,
Fax:+33.25.71.76.98, ORCID 0000-0003-0665-7989

ABSTRACT

Material flow analysis (MFA) is a powerful tool to track and estimate material flows and stocks and evaluate the efficiency of the materials used in the modern infrastructure. Several industries, such as raw materials, construction, energy, and transportation, have extensively employed the MFA method and approach. However, the use of MFA is mainly limited due to the lack of regional data, uncertainty in the available data, and lack of input data in some cases. Data limitation for MFA is addressed but with limited success, particularly for building infrastructure. This study has addressed this issue by employing Google Earth as a secondary method that can potentially extract data applicable to MFA. This data collection approach is applied to the French Railway Infrastructure by systematically selecting 95 railway tracks (20% of the total number of tracks) covering more than 9,000 km of track length (~31% of the total), and the results were verified with the SNCF (Societe Nationale des Chemins de fer Francais) statistical data based upon the developed parameters. This study contributes to overcoming data issues of MFA and accelerates the application of MFA on a broader scale.

Keywords: region, resource, material flow analysis, geographical information, railway, infrastructure

34 1. INTRODUCTION

35 Material flow analysis (MFA) is a tool effectively employed in the fields of resource
36 management, waste management, and environmental management studies for systematically
37 assessing a given material's flows and stocks within certain geographic and temporal system
38 boundaries. Mainly two approaches are used In MFA; top-down approach that uses annual
39 time-series statistical data for material production and the bottom-up approach that uses the
40 number of products and their material intensities to estimate the material stocks . Numerous
41 local, regional and global studies have been carried out for buildings and roads for
42 determining stocks present in the Technosphere .

43 Despite of being very effective tool, data that supports MFA is mostly available for developed
44 countries only as evident through evidence-based policy studies conducted in European Union
45 (EU) for environmental accounting (Vilaysouk et al. 2017). This is because data acquisition
46 is complicated and, thus, is expanded to include informal sources, including market research,
47 expert judgment, best scenarios, and other 'hands-on' knowledge (Rahman and Kim, 2019).
48 There exist some data issues with regard to MFA that are pertinent to data defecieny on
49 reginal level, uncertainty in the available data, problems in acquiring input data and lack of
50 data availability whatsoever, such as for developing or underdeveloped countries.

51 Bottom-up and top-down material flow approaches have been applied in numerous studies to
52 attain satisfactory results, however, this approach is practically limited to a national or global
53 scale due to data gaps on regional scale owing to to the lack of trade or consumption data on
54 the regional level. Thus, the estimation of stocks can also be a challenge for products with a
55 long lifetime, like buildings and infrastructure. A bottom-up approach can help but this
56 approach requires a lot of labor and highly depends on statistical data also. In addition, very
57 few case studies are available for cities and countries therefore, there is a need to reconstruct
58 MFA data for various spatial ranges, including a regional scale . It is because the regional data
59 that are somehow available are typically unstructured, cross-disciplinary, different in formats
60 and qualities, and come from heterogeneous sources. On the other hand, MFA data are
61 sometimes not based on empirically well-founded data sets but on the individual, isolated
62 values, which are not always provided in inconsistent formats (Schwab et al., 2017).

63 According to Tachibana (2008), the role of information in policymaking for local
64 governments has gained greater importance. However, the role of MFA has not propagated
65 that much to the local government scale due to the lack of local statistical data, and the MFA

66 methodologies for calculations of environmental indicators at the regional level have not yet
 67 been established. Another aspects of MFA is to ensure that uncertainties are kept to a
 68 minimum, but concerning results, it must be noted that uncertainties are inherent to MFA.
 69 Moreover, available statistical data sets do not sufficiently meet the specified data
 70 requirements in terms of completeness and level of differentiation (Schiller, 2017). Another
 71 limitation is that the data that support MFA studies are mostly available for developed
 72 countries. On the contrary, in developing countries, where public data statistics are not well
 73 organized or less frequently available, data related to in-use stock is very difficult to find .
 74 Developing countries like China, Russia, and India have an extensive stock of steel they lack
 75 in statistical data availability .

76 Similarly, some studies suggest that MFA can be coupled with other tools, such as, Satellite
 77 Imagery Programs, Geographic Information System (GIS) , Nighttime Light, and Remote
 78 Sensing for better estimation and understanding of stocks and flows to overcome data
 79 limitation issues arising due to availability of insufficient statistical data, uncertainties, and
 80 lack of available data for developing and under-developed countries. A list of a few studies
 81 has been summarized in Table 1 that employ such tools to address issues in MFA data.

82

83 Table 1. Research studies conducted using MFA along with secondary tools

Sr. No.	Studies	Purpose	Secondary Tool	Material/Domain
1	Novellino, A. et. al. (2021)	Using Satellite Data to Analyse Raw Material Consumption in Hanoi, Vietnam	Satellite Data	Urban stocks
2	Zhao, M. et. al. (2020)	Mapping urban dynamics (1992–2018) in Southeast Asia using consistent nighttime light data from DMSP and VIIRS	Nighttime light data	Mapping urban dynamics and stock
3	Bradshaw, J. (2020)	GIS-Based Material Stock Analysis (MSA) of Climate Vulnerabilities to the Tourism Industry in Antigua and Barbuda	GIS	Material Stock Analysis (MSA)

4	Bailang Yu et. al. (2018)	Spatial-Temporal Dynamics of Global Anthropogenic Resources Accumulation above Ground	Nighttime Light Images	Global anthropogenic stocks
5	Hanwei Liang et. al. (2017)	Estimation of in-use steel stock of buildings and civil engineering infrastructures	Nighttime Light Data	Steel stock, buildings
6	Fritz Kleemann et. al. (2016)	Analysis of Vienna's Material Stock in Buildings	GIS	Building stock
7	Hiroki Tanikawa et. al. (2015)	A Comprehensive Account of the Construction Material Stock of Japan	GIS	Construction material stock
8	Tomer Fishman et. al. (2015)	The socio-economic drivers of material stock accumulation in Japan's prefectures	GIS	Material stock
9	Hanwei Liang et. al. (2014)	Modeling In-Use Steel Stock in China's Buildings and Civil Engineering Infrastructure	Nighttime Lights	In-use steel stock, Buildings
10	Ryoma Hattoria et. al. (2014)	Estimation of in-use steel stock for civil engineering and building	Nighttime Light Images	In-Use steel stock, Buildings
11	Feng-Chi Hsu et. al. (2013)	Estimating in-use steel stocks in civil engineering and buildings	Nighttime Lights	In-use steel stock, Buildings
12	Feng-Chi Hsu, et. al. (2011)	Estimation of Steel Stock in Building and Civil Construction	Satellite Images	Steel stocks, buildings
13	Kazue Takahashi et. al. (2009).	Analysis of In-Use Stock of Copper	Satellite Nighttime Light Observation Data.	In-use copper stock

14	Hiroki Tanikawa et. al. (2009).	Spatial material stock analysis	GIS	Building stock
15	Zhang Q. & Seto K. (2011)	Mapping Urbanization dynamics at regional and global scale	Nighttime Light	Urbanization dynamics

84

85 Tanikawa and Hashimoto (2009) argued that national and regional level estimates of material
86 flows and stocks based upon available statistical data help assess material input, output, and
87 stock accumulation over a period but are unable to give their respective spatial distribution to
88 the policy-makers. They proposed a 4-dimensional Geographical Information System (4d-
89 GIS) bottom-up model by merging old available urban planning GIS maps of Japan with the
90 latest digitized maps that they prepared for parts of the two target cities that enabled them to
91 obtain additional information such as the number of floors, usage of buildings, road widths,
92 and ground or surface information. Fritz (2016) extended this approach to the city level by
93 applying a similar model to Vienna, Austria, using statistical and GIS data from various
94 municipal authorities to estimate material stock in building infrastructures. Their research
95 pointed out the lack of detailed localization of the material stocks while considering only
96 statistical data. The use of GIS takes care of this deficiency. Along similar lines, Gao (2021)
97 applied a dynamic model of material flow and stock to estimate material quantity from the
98 residential infrastructure of Shanghai from 1950-2100 .

99 Tanikawa et al. (2015) further proposed a bottom-up model to estimate the in-use construction
100 material stock in urban infrastructure for 47 prefectures of Japan using GIS. The scope of this
101 study includes buildings, roads, railways, underground water networks, airports, seaports, and
102 dams. Based on the structure type, different calculation methods and data sources were used.
103 For roads, country-wide GIS data and prefecture-level statistical data were used to obtain road
104 classification, road lengths, and widths, while for railways, only GIS data was considered.

105 Similarly, Nighttime Light (NTL) imagery data has recently become more relevant for
106 detecting, estimating, and monitoring socioeconomic factors in countries and subnational
107 regions where reliable official statistical data may be lacking (Bennett et al., 2017). Benefits
108 of NTL imagery include global coverage and high spatial resolution with pixels
109 corresponding to less than one square kilometer. Such high resolutions allow researchers to

110 collect desired global, national, and regional data. Moreover, NTL imagery offers consistent
111 quality all around the globe without any political manipulation .

112 Kazue et al. (2009) used nighttime light images as a helping tool to estimate in-use copper
113 stock in developing countries of Asia, which include India, South Korea, Malaysia,
114 Singapore, Taiwan, Thailand, Vietnam, and Sri Lanka. They argued that scarcity of available
115 data and difficulty estimating in-use stock material using bottom-up or top-down MFA
116 approaches require developing some novel method. They found the feasibility of their
117 method, but still, their study lacked any validity of their approach. Feng-Chi et al. (2011)
118 applied the same technique for in-use steel stock for building infrastructures. They argued
119 that, unlike copper, steel is not an excellent conductive material; hence, just estimating it and
120 correlating it to nighttime light will not yield good results.

121 Most of the studies mentioned above deal with building infrastructure systems' flow and stock
122 estimation. There is hardly any study that considers the technosphere as a whole or
123 specifically deals with the transportation infrastructure. Another common aspect is that all of
124 them, except a few, are an attempt to develop the data set, which could fill the gaps in already
125 existing data. This process is very cumbersome, and many assumptions had to be made to
126 simplify. Regarding the utility of the GIS data, according to Tanikawa et al. (2015), it helps
127 improve MFA methodology, but, like MFA, its availability is the primary concern. It is
128 beneficial for developed countries like Japan, where it is randomly available. Still, for other
129 nations where there is little to no GIS data, the problem of data deficiency
130 persists. Geographical Information System (GIS) and Nighttime (NTL) Satellite Imagery have
131 been applied as secondary tools along with MFA to solve data collection issues by various
132 researchers in their respective studies . They showed a significant level of success, displayed
133 the potential, and need for some external aids, which could help enhance data collection to
134 solve the data-related issues in MFA. However, still, there are many research gaps, that those
135 studies were unable to address.

136 NTL method is limited in its sector-specific application. For example, nighttime image, which
137 works on the principle of the light radiance received by satellite from a defined target area,
138 only considers the urban part of a geographic region. It does not consider the material stocks
139 present in the rural region due to the insignificant radiance received by satellite. . Similarly,
140 the NTL approach may take good care of the steel or copper stock of building infrastructure in
141 urban areas while failing to consider the steel stocks in the railway infrastructure located in

142 rural areas. This failing is because usually building infrastructures are equipped with lighting
143 facilities, which signifies the presence of copper.

144 In contrast, general transportation infrastructure and railway infrastructure are not always
145 equipped with lighting facilities, especially in far rural areas. In addition, these methods are
146 instrumental in determining economic growth, business activities, land occupancy, building
147 infrastructure, and electricity consumption. However, this approach is only feasible for
148 developed countries where the entire population and infrastructure system has energy and
149 electricity facilities. Such methods are not suitable for developing or underdeveloped
150 countries where energy or electricity is unavailable to the whole of population and
151 infrastructure. This approach is also limited to the areas and regions where urbanization is not
152 widespread . Another issue related to NTL is that instead of direct observation or input data
153 collection, these approaches heavily rely on empirical relationships or correlations, which
154 involve several uncertainties.

155 On the other hand, GIS-based methods are helpful in coping with the issues related to the
156 sector-specific application but do not help in estimating the precise volume of the structures.
157 These methods can take linear dimensions like lengths, widths, and surface areas but fail to
158 take vertical measurements e.g., height of the structure or floor height. This limitation
159 prevents such methods from volume estimation . GIS data at the national level can be
160 obtained directly from national statistical bureaus. However, at the regional and urban scale,
161 there is limited data accessibility because data are generally dispersed among several
162 organizations and firms and not found in one place. This deficiency makes it very tiring to
163 produce a consistent set of data. The other issue is data availability because many required
164 data are unavailable . Current practices of bottom-up and top-down approaches involved in
165 MFA incorporating GIS are underestimating material inflows and outflows because of
166 insufficient data availability . As far as building infrastructure is concerned, there is a
167 significant amount of GIS data and maps, but GIS data is available for very few economies
168 for transportation infrastructure. This problem is even more severe in the case of lesser
169 developed societies that lack geographical data collection.

170

171

172 GIS and NTL have solved a few issues and improved the data quality, but those methods still
173 cannot compensate for the lack of regional data. They can also not fetch reliable data for rural

174 parts of the infrastructure. The data collection problem is even more severe in lesser
175 developed economies. Moreover, data collection for transportation infrastructure (road
176 networks in general and railways in specific) is still a huge problem. Therefore, it is
177 fundamental to combine more comprehensive and readily accessible data collection methods
178 that may improve the application of MFA in developing countries and at a regional scale,
179 which may help assist in the extraction of missing data. In light of this discussion, we propose
180 using Google Earth to address limitations and uncertainties in data collection. It is feasible to
181 obtain in-use material stock data in developed as well as developing countries at city,
182 regional, national, or global levels. It can also capture all types of measurements, including
183 length, width, height, and area, enabling us to calculate volumes. This 3D view makes it
184 possible to see the current situation of the target area. It can also allow us to estimate
185 quantities of all types of infrastructures, including buildings, roadways, and railways.

186

187 **2. MATERIALS AND METHODS**

188 **2.1.Data Sources**

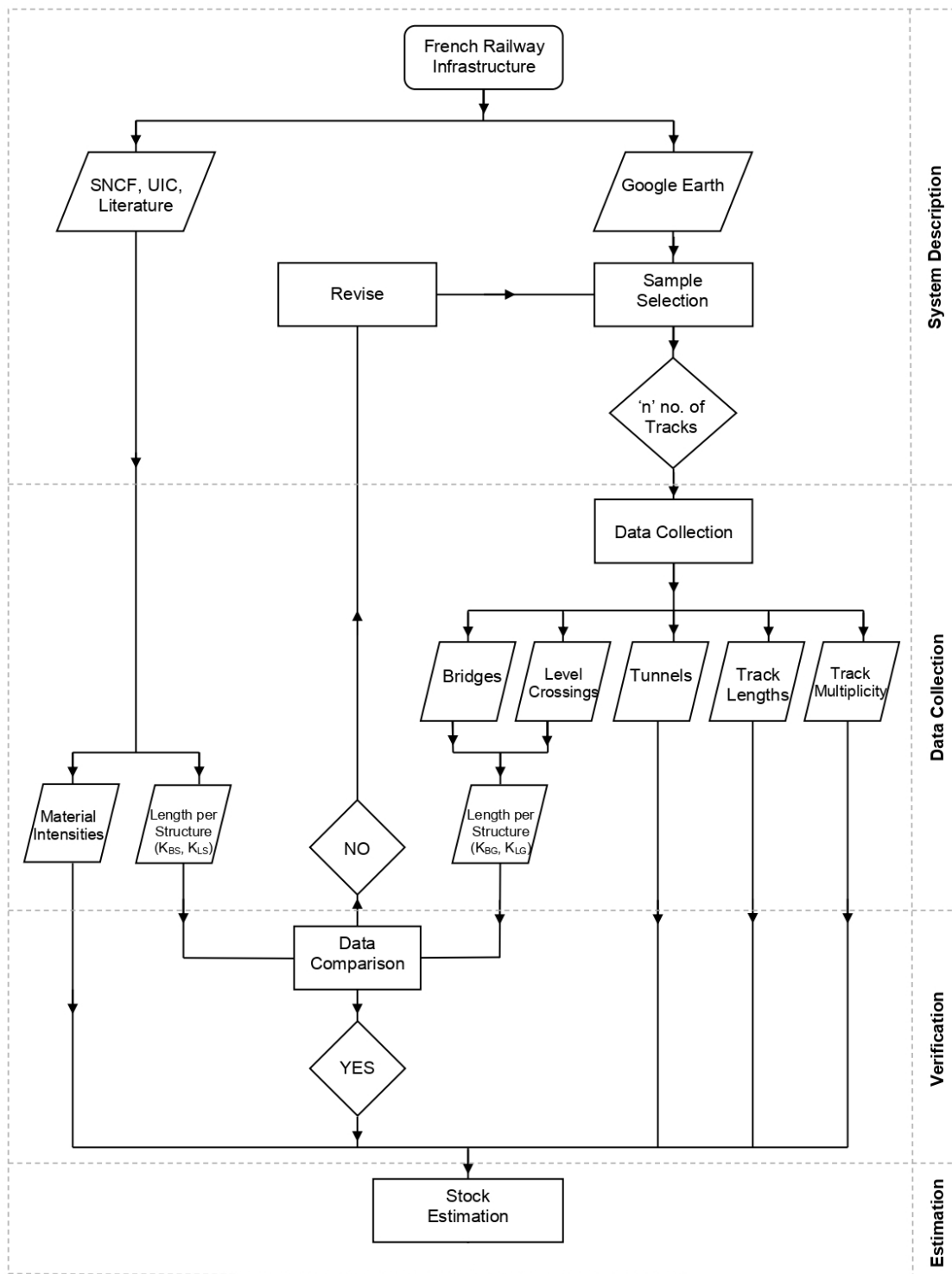
189 The method developed in this research uses two data sources; Google Earth as primary source
190 and multiple SNCF resources have been used to collect the secondary data on the over-all
191 railway network of France. [Further detail is given in SI.](#)

192

193 **2.2.Method Development**

194 The methodological framework for developing the method used in this research work is
195 described in Figure 1. The flowchart highlights four phases, i.e., System Description, Data
196 Collection, Validation, and Estimation.

197 **System Description:** This phase describes the general methodology and data sources adopted
198 for the proposed method's development. French railway infrastructure is the selected system
199 for the research work. Two types of data have been used as 'input' data; (a) Google Earth and,
200 (b) SNCF maps, inventories, UIC datasheets, and available literature. The sample selection
201 'process' includes a selection of 'n' number of tracks for which the data will be collected later
202 on. The criteria for sample selection, explained in [Section 3.4](#), are based upon the type of the
203 track, its geographical location in France, and the respective lengths of the tracks.



204

205

Figure 1. Flow Diagram of Development of Proposed Method

206

Data Collection: This phase presents the structural entities for which the data will be

207

collected. These entities include the length of the tracks along with their multiplicity, the

208

number of tunnels and their respective lengths, the number of bridges, and the number of level

209 crossings. The selected sample from the previous phase is then subjected to data collection in
 210 terms of the above entities using Google Earth. In parallel, material intensities were also taken
 211 from the available literature to be used for material estimation later in the research work.

212 **Verification:** This phase signifies verification of the approach which has been proposed in
 213 this research work. Due to the time stipulation of the research work and the cumbersomeness
 214 and difficulty in collecting manual data from Google Earth, data extraction using Google
 215 Earth for the French railway infrastructure was impossible. French railway system, just like
 216 any railway infrastructure, is brimming with civil engineering structures such as bridges,
 217 tunnels, and level crossings throughout the lengths of railway tracks. Out of all these
 218 structures, bridges and level crossings are the most frequently repeated structures that
 219 intersect or cross railway tracks. Based upon their frequent appearance along the paths of the
 220 railway tracks, four comparable parameters were developed, which were manually identified
 221 from Google Earth and, then compared with SNCF data for the same part of the French
 222 Railway Network for the sake of verification of the proposed method developed in this
 223 research work. These four parameters are;

- 224 a) Kilometer per bridge for Google Earth Data (K_{BG}),
- 225 b) Kilometer per level crossing for Google Earth Data (K_{LG}),
- 226 c) Kilometer per bridge for SNCF Data (K_{BS})
- 227 d) Kilometer per level crossing for SNCF Data (K_{LS})

228 In general, these parameters are simply the distances, after which each structure in
 229 consideration is repeated. These parameters were calculated using the following equations:

230

231
$$K_{BG} = \frac{\text{Total length of the tracks measured in Google Earth}}{\text{No. of bridges counted in Google Earth}} \dots \dots \dots (Eq. 1)$$

232
$$K_{LG} = \frac{\text{Total length of the tracks measured in Google Earth}}{\text{No. of level crossings counted in Google Earth}} \dots \dots \dots (Eq. 2)$$

233
$$K_{BS} = \frac{\text{Total length of the tracks in French Railway system as per SNCF}}{\text{No. of bridges in French Railway system as per SNCF system}} \dots \dots \dots (Eq. 3)$$

234
$$K_{LS} = \frac{\text{Total length of the tracks in French Railway system as per SNCF}}{\text{No. of level crossings in French Railway system as per SNCF}} \dots \dots \dots (Eq. 4)$$

235

236 **Table 2. K_{BS} & K_{LS} (km/Bridge & km/Crossing for SNCF Data using Eq. 3 & Eq. 4)**

Parameter	Value
K_{BS}	1.08
K_{LS}	1.67

237 Table 2 presents two unique values obtained from Eq. 3 and Eq. 4, which describe that, on
 238 average, there is a bridge after every 1.08 km while there is a level crossing for every 1.67 km
 239 of the French Railway System. The significance of these values is such that if similar
 240 parameters (K_{BG} and K_{LG}) are obtained using Google Earth for the data manually collected for
 241 one-third of the selected railway infrastructure and those values are found comparable to K_{BS}
 242 and K_{LS} (SNCF data), then, the newly developed approach of data collection is validated.

243 **Estimation:** This phase deals with the material stock estimation in the French railway
 244 infrastructure by considering several product data, i.e., track, bridge, tunnel, and level
 245 crossing data from Google Earth, and multiplying them with material intensities as taken from
 246 various sources.

247

248 **2.3.Data Collection Procedure Using Google Earth**

249 In Figure 3, the data collection procedure using Google Earth is shown. In the user interface
 250 of Google Earth, clicking the tab ‘Get Directions’, directs toward a new dialogue box pane
 251 which lets the user to enter two locations; A (origin) and B (destination), as shown in Figure
 252 2a. Inputting the selected track's origin and destination and clicking the railway route option
 253 (Figure 2b) pinpoints it on the Google Map by highlighting its route and extreme positions
 254 through markers (Figure 2c).

255 Once the selected rail track has been pinpointed on the Google Earth Graphic User Interface
 256 (GUI), zooming in the frame towards the origin of the track decreases the altitude of the
 257 satellite view and unveils the components of the railway infrastructure and the actual start
 258 point of the track (Figure 2d).

259 Once the screen and GUI are set on the starting point of the origin of the selected track,
 260 pressing forward or backward tab on the keyboard enables the user to advance or retreat along
 261 with the track respectively whereas the use of right and left movement tabs on the keyboards
 262 makes it possible to maneuvers the track direction. By following the track in the manner

263 described above, the user can move along the track and collect data by simply observing,
264 counting, and measuring the desired entities

265 With the help of the 'Zoom' option, it is possible to go to any altitude above the map to
266 observe various features on or around the selected track. It is also possible to go to virtual
267 street level using the 'Street View' option just above the zoom option on the right side of the
268 Google Earth screen as seen in Figure 3e. In Figure 3f, same bridge is shown through the
269 'Street View' option in which the user is virtually standing on the road bridge passing over
270 the selected line indicated by the blue line.

271 Track Multiplicity is one of the data collected in this research work using Google Earth. For
272 the scope of this work, this is defined as the number of tracks running through the route per
273 unit length. Track type (single, double, multiple) or purpose (proximity of a railway yard or
274 station) changes track multiplicity and can easily be observed and measured, as presented in
275 Figure 3g.

276 Another type of data that has been extracted through Google Earth is the measurement of the
277 lengths of different structures. When collecting data for the number of bridges, these were
278 divided into two categories; (a) Long bridges, which are longer than 50 m and (b) Short
279 bridges, which are shorter than 50 m. It was done to simplify the stock estimation where
280 material intensities will be used. Similarly, along with the number of tunnels in selected
281 tracks, their respective lengths have also been recorded. All this was done using the
282 measurement tool of Google Earth, as demonstrated in Figure 3h.

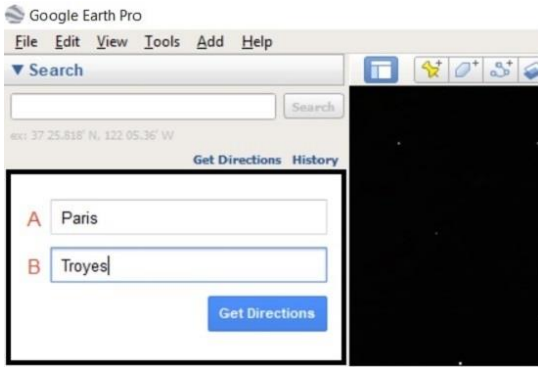


Figure 3a: Origin and Destination Dialogue Box

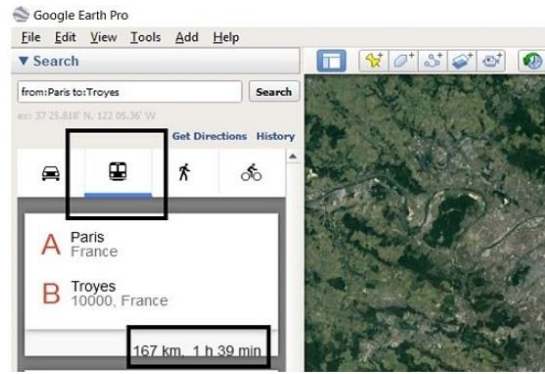


Figure 3b: Suggested Routes in Google Earth



Figure 3c: Selected Track on Google Earth

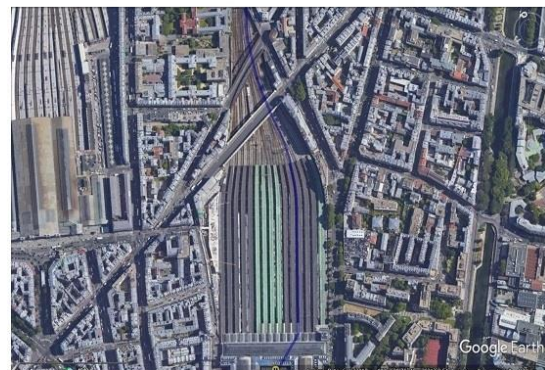


Figure 3d: Origin of Selected Track (Railway Station)

283



Figure 3e: A Bridge on Google Earth Map



Figure 3f: Same Bridge in Street View (in Google Earth)

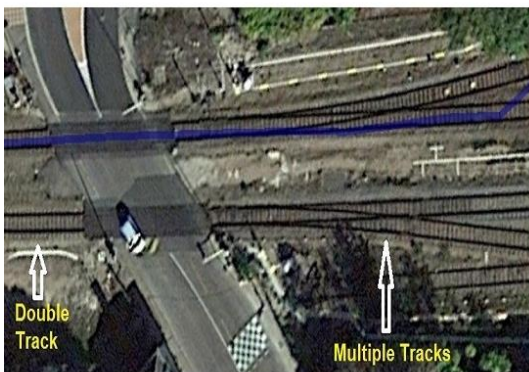


Figure 3g: Track Multiplicity



Figure 3h: Measurement Dialogue Box

284

285

Figure 2, Data collection procedure using Google Earth

286 **2.3.1. Estimation**

287 The above material intensities have been multiplied by the respective number of products to
288 estimate the related stock quantity in the system using Eq. 5.

289
$$MS_m = \sum L \cdot I_m \dots\dots\dots \text{(Eq. 5)}$$

290 *Where,*

291 MS_m = Material Stock quantity for material m

292 L = Length of the track

293 I_m = Material intensity of material m per Kilometer

294

295 **3. RESULTS & DISCUSSION**

296 **3.1.Data Representativeness**

297 One of the most critical aspects of data collection for the analysis is whether the collected data
298 is representative. Given the stipulated resources of this research work, it was not possible to
299 collect desired data for the complete French railway infrastructure. For the data to best
300 produce the generalized results, it was tried to make the data as representative as possible.

301 Based on working conditions (electric/non-electric), the number of lines
302 (Single/Double/Multiple), and operation (mixed line/freight line), there are various types of
303 railway lines in the French Railway System. Based on working, there are electrified and non-
304 electrified railway lines. Out of 95 selected tracks, 44 are electrified, while the remaining is
305 non-electrified. Almost half of the French railway lines' total length works on electricity. This
306 trend reflects in the sample of the selected railway tracks, as more than half of the selected
307 tracks (63%) are electrified.

308 Similarly, more than 55% of the French railway network consists of the Double Line railway
309 track. Of selected railway tracks for this research work, a comparable percentage of 64%
310 represents Double railway lines. As far as the operation is concerned, there are two types of
311 railway tracks in the French railway system; (1) *Mixed Lines*, that operate both passengers as
312 well as freight trains and (2) *Freight Line*, that operate freight trains only. Given the fact that
313 there are more mixed lines than the freight lines in the French railway network, 54 out of 95
314 selected railway tracks are mixed lines were 41 are freight lines.

315 **3.2.Data Analysis**

316 This section merely illustrates the data in terms of various parameters. Table 8 presents this
317 analysis in a systematic form. First, based on the working principle of the railway, a
318 comparison between selected electrified and non-electrified railway tracks has been given. In
319 terms of the number of tracks, 44 electrified tracks were selected while 51 were non-
320 electrified tracks but based upon the length of the tracks, a little above 63% of the selected
321 tracks were electrified. This amounts to 20% of the total track length of the French railway
322 infrastructure. The contribution of the non-electrical tracks is a little under 37%, which is
323 around one-tenth of the French railway system. Electrical tracks have 4,841 bridges with a
324 K_{BG} of 1.20, while non-electrical tracks have 2,313 bridges with K_{BG} of 1.46. Similarly, 1,821
325 level crossings were recorded for electrified lines as compared to 2046 level crossings for
326 non-electrified lines. The respective value of K_{LG} for them turned out to be 3.19 and 1.65,
327 respectively.

328 In terms of operation of the railway, 56 mixed lines while 39 freight lines were selected for
329 data collection. Mixed lines represent a mammoth percentage of 92% as compared to a slight
330 less than 8% of freight lines. Selected mixed lines represent around 29% of the total French
331 railway infrastructure. Mixed lines have 6755 bridges and 3343 level crossings with the K_{BG}
332 as 1.26 and K_{LG} as 2.55 respectively. Freight lines, the lesser part of the French railway
333 network, recorded only 399 bridges and 524 level crossings. The respective values of K_{BG} and
334 K_{LG} for level crossing came out to be 1.68 and 1.28.

335 Over-all value of *Kilometer per bridge for Google Earth*, K_{BG} turns out to be 1.28 that means
336 that throughout the selected railway tracks, after every 1.28 kilometers there is a bridge.
337 Similarly, Kilometer per level crossing for Google Earth, K_{LG} was calculated as 2.37. These
338 two values are vital and will come in handy when these two values will be compared with
339 their counterparts for SNCF statistical data, given in Table 3, i.e. K_{BS} and K_{LS} so that the
340 newly developed approach of data collection using Google Earth can be verified.

341

Table 3. Data Analysis of the Selected Railway Tracks

Parameter	Criteria	No. of Tracks	Length (km)	Percentage of Selected Sample by Length (%)	Percentage of French Railway Network by Length (%)	No. of Bridges	Kilometer per Bridge for Google Earth (K _{BG})	No. of Level Crossings	Kilometer per Level Crossing for Google Earth (K _{LG})
Working Principle	Electrified	44	5,811.1	63.28	20.04	4,841	1.20	1,821	3.19
	Non-Electrified	51	3,371.6	36.72	11.63	2,313	1.46	2,046	1.65
Operation	Mixed	56	8,511.9	92.69	29.35	6,755	1.26	3,343	2.55
	Freight	39	670.8	7.31	2.31	399	1.68	524	1.28
TOTAL		95	9,182.7	100.00	31.66	7,154	1.28	3,867	2.37

342

343

Table 4. Summary of Track (in km) based upon Track Multiplicity

Track Type	Electrical		Non-Electrical		Total
	Mixed	Freight	Mixed	Freight	
Single Line	373.8	41.8	1,319.6	457.7	2,192.9
Double Line	4,561.7	101	1,243.4	28.3	5,934.4
Multiple Line	717.3	15.5	296.1	26.5	1,055.4
Total	5,652.8	158.3	2,859.1	512.5	9,182.7

344 Table 4 summarizes the Google Earth track data based on *Track Multiplicity* and *Track Type*.
345 It can be observed that around 6,000 km of the selected railway tracks are double-line tracks
346 in which there are two rails running parallel. 2,192.9 km of the covered tracks fall into the
347 single-line track while a little over 1,000 km of the tracks are multiple lines in which more
348 than two rails run in parallel. These multiple tracks usually exist near metropolitan cities such
349 as Paris, Strasbourg, Lyon, Lille, etc.

350

351 **3.3.Method Verification**

352 One of the main objectives of this research work is to develop a new approach for data
353 collection using Google Earth to compensate for the deficiencies encountered during MFA
354 studies related to infrastructures. Using this newly developed method, nearly one-third of the
355 French Railway Network data was successfully collected using Google Earth. This approach
356 reasonably allows us to attempt a method verification, if not validation, based upon collected
357 data and comparing it with statistical data of SNCF.

358 The main idea behind the verification is based upon the frequency of occurrence of two
359 elements of the railway infrastructure, i.e., bridges and level crossings throughout the French
360 railway system. To make the comparison for verification purposes, four parameters, i.e., K_{BS} ,
361 K_{LS} , K_{BG} , and K_{LG} were developed, and the aim is to compare K_{BS} with K_{BG} and K_{LS} with K_{LG}
362 in order to attempt method verification. Values of K_{BS} and K_{LS} , related to the average distance
363 between bridges and level crossings for SNCF data, are calculated in Table 3 as 1.08 and
364 1.67, respectively. Related parameters (K_{BG} and K_{LG}) for track data collected from Google
365 Earth for various track types and their averages, as calculated using Eq. 1 and Eq. 2, have also
366 been presented in Table 5. In the following Table 5, these parameters have been compared,
367 and a brief analysis has been given.

368 As per Table 5, the value of K_{BS} , i.e., *Kilometer per Bridge for SNCF data* is 1.08. This means
369 that, on average, after every 1.08 km there is a bridge in French Railway System as calculated
370 using Eq. 3. On the other hand, for the railway data collected from Google Earth in this
371 research work, the corresponding value K_{BG} turns out to be 1.28. This value signifies that, for
372 the length of the railway for what the data has been collected using Google Earth, after every
373 1.28 kilometers, on average, there is a bridge. The percentage difference between these two
374 values is approximately 15%.

375 For the level crossings, *Kilometer per Level Crossing for SNCF data (K_{LS})* was calculated as
376 1.67 using Eq. 4. The corresponding value for Google Earth collected data, i.e., K_{LG} turns out
377 to be 2.37. The percentage difference between these two values comes out to be just less than
378 30%. Apparently, this difference seems huge as compared to that of bridge parameter.

379 There are several reasons which may explain this ambiguity. Apart from the overall values of
380 these parameters as presented in [Table 5](#), values for these parameters for various scenarios
381 have been summarized in [Table 6](#). Based on the type of tracks, tracks that work on electricity
382 have lower K_{BG} of 1.20 compared to those tracks that do not work on electricity which is
383 1.46. On the other hand, the value of K_{LG} for electrified tracks is 3.19 as compared to 1.65 for
384 non-electrified tracks. As per mentioned values and the observation of the railway tracks
385 while collecting data on Google Earth, there are rarely any level crossings on tracks, which
386 work on electricity. Such tracks usually cross over the road through railway bridges. Hence,
387 values of *Kilometer per Level Crossing (K_{LG})* are larger for tracks operating on electricity,
388 whereas values for K_{BG} are higher, affecting the overall values of K_{BG} and K_{LG} . Similar trends
389 have been observed for mixed lines compared to freight lines, as seen in [Table 6](#).

390 Additionally, it can also be seen that independent values of K_{LG} decrease and become closer
391 or lower than K_{LS} if calculated neglecting lengths of the tracks covered by High-speed
392 railways (TGV) and Mixed Double Track Electrical lines, which rarely have any level
393 crossing given their high-speed and priority during their run. It is evident that the values of
394 K_{BG} and K_{LG} will eventually become closer to K_{BS} and K_{LS} , respectively, if more length of data
395 is collected, which was not possible during the limited time and resources of this given
396 research work.

397 Hence, it can be concluded that for the part of the French Railway infrastructure covered in
398 this research, which is just one-third of the whole, these differences are within a reasonably
399 acceptable range for the sake of method verification and it suggests that this new method of
400 data collection has many potentials.

401

402

Table 5. A Comparison, K_{BG} vs K_{BS} and K_{LG} vs K_{LS}

Parameter	Kilometer Per Bridge for Google Earth Data (K_{BG})	Kilometer per Bridge for SNCF Data (K_{BS})	Percentage Difference $\frac{K_{BG} - K_{BS}}{K_{BG}} \times 100$	Kilometer per Level Crossing for Google Earth Data (K_{LG})	Kilometer per Level Crossing for SNCF Data (K_{LS})	Percentage Difference $\frac{K_{LG} - K_{LS}}{K_{LG}} \times 100$
Value	1.28	1.08	15.63	2.37	1.67	29.53

403

404

Table 6. A Comparison of K_{BG} and K_{LG} values in various scenarios with General K_{BS} and K_{LS} values

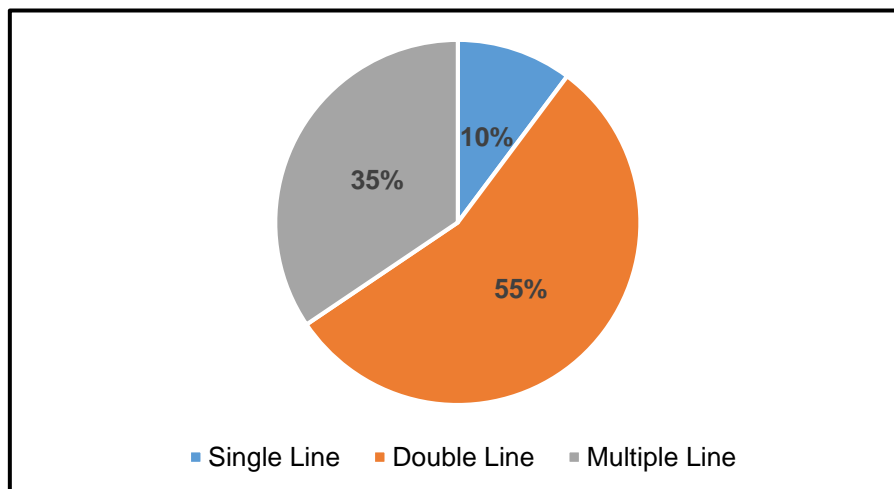
Parameter	Kilometer Per Bridge for Google Earth Data (K_{BG})	Percentage Difference $\frac{K_{BG} - 1.08}{K_{BG}} \times 100$	Kilometer per Level Crossing for Google Earth Data (K_{LG})	Percentage Difference $\frac{K_{LG} - 1.67}{K_{LG}} \times 100$
Electrified Lines	1.20	10	3.19	47.64
Non-Electrified Lines	1.46	26.02	1.65	-1.21
Mixed Lines	1.26	14.28	2.55	34.51
Freight Lines	1.68	35.71	1.28	-30.47
Excluding TGV	-	-	2.16	22.69
Excluding TGV and Double Electric	-	-	1.12	-49.11

405 **3.4. Material Stock Estimation**

406 A bottom-up MFA approach has been employed for the estimation purpose in which material
407 intensities of the railway materials have been used.

408 **3.4.1. Steel**

409 As a metallic component of the railway infrastructure, the amount of steel in the French
410 Railway Infrastructure covered using Google Earth has been calculated and given in Table 7.
411 As mentioned in Section 3.6.1, three rail standards have been considered, namely UIC50,
412 UIC54 and UIC60, which correspond to the rail's weight per meter i.e., 50 kg/m, 54 kg/m, and
413 60 kg/m. The table compares the amount of steel concerning the type of railway line based on
414 track multiplicity. Track multiplicity is the number of railway tracks (two parallel lines of
415 rails over which the train runs) on the railway right of way. This parameter is straightforward
416 for single and double lines. Still, for multiple lines, it has been calculated using a weighted
417 average of multiple tracks appearing over the length of the path of the railway line. The
418 double line is the most dominating part of the railway system. Multiple tracks exist for the
419 shortest length out of all types of lines but account for more steel quantity as compared to
420 single-line track. This comparison has been manifested in Figure 3 for a better graphical
421 explanation. The total amount of steel stock in the portion of the French Railway
422 Infrastructure for what data has been gathered through Google Earth has been summarized in
423 Table 8. A hefty amount of around 2,400 kilotons of steel is stocked in the covered part of
424 French Railway Infrastructure. This amount shows that the French railway network is a rich
425 depository of in-use steel.



426 Figure 3. Comparison of Steel Stock in Single, Double, and Multiple Tracks

427

Table 7. Amount of Steel for various track types (kiloton)

Type	Length of Track (km)	Track Multiplicity	Steel Quantity (Kiloton)		
			UIC50	UIC54	UIC60
Single Line	2,192.9	1	235	239	263
Double Line	5,934.4	2	1,270	1,294	1,424
Multiple Line	1,055.4	7	790	805	887

428

429

Table 8. Estimated Steel stock in Covered French Railway Infrastructure (kiloton)

Standard	Steel Quantity (kt)
UIC50	2,295
UIC54	2,338
UIC60	2,574
Average	2,402

430 Currently, the French Railway Network is struggling between two opposite infrastructural
431 issues as far as the railway is concerned. On the one hand, the government is all set to launch
432 new projects of High-Speed Railway lines to minimize travel time and infrastructural
433 upgrades for inter-city trains . On the other hand, more than 9,000 km length of small railway
434 lines throughout France are at the verge of obsolescence . Whatever the case may be, it means
435 a change in the material stock that needs to be assessed. As of 2022, SNCF is executing more
436 than 1,600 projects of railway track maintenance work, which encompasses 1,050 km of track
437 length throughout France . Although it is quite unclear what is the duration of these projects,
438 but according to available information, it is assumed that it is the annual upgradation of the
439 French Network i.e., every year, more than 1,000 km network is upgraded and the stock
440 material is replaced. An estimation of potential steel replacement from tracks indicates that
441 118 kt of steel has to be replaced each year.

442 Recently, as mentioned before, an issue of near-loss of more than 9000 km of railway tracks
443 situated in rural areas of France has come to the limelight. There are arguments that the
444 expansion of High-Speed Rails across France has come at the cost of these neglected *petites*
445 *lignes* (small lines). In the scenario that these lines are completely neglected, a huge in-use
446 steel material stock amounting to 1,000 kt will convert into hibernating stock. In the other
447 case, the maintenance or upgradation of these tracks might need additional steel resources that

448 might add up the existing in-use material stock. It should be noted that these projects, if
449 approved, are planned to be executed during the next ten years.

450

451 **4. CONCLUSION AND LIMITATIONS**

452 MFA is a competent and versatile tool for the systematic assessment of material flows and
453 stocks and provides a firm ground for stock estimation of various materials within different
454 systems and infrastructures for a diverse range of time boundaries. It has a great potential of
455 assisting in preparing an inventory of materials stocks for the ever-increasing
456 Anthroposphere. Its applicability and utility are afflicted by the data deficiencies resulting
457 from numerous reasons, such as lack of data at the regional level, the unreliability of data in
458 developing countries, uncertainties in available data and unavailability of the input data. By
459 eliminating these data issues, MFA can be more applicable in most studies.

460 Data issues encountered while conducting MFA can effectively be eliminated or reduced and
461 attempts have already been done to address them by using secondary tools and programs such
462 as Geographic Information System (GIS) or Nighttime Light Satellite Imagery. There is a lot
463 of potential in combining such tools with MFA for eliminating data deficiencies in MFA.

464 Google Earth is one such capable tool, which can be profitably combined with MFA for the
465 collection of data. It is a very advanced yet user-friendly and simple-to-use program that
466 allows the user to collect ground data with good precision. Especially for transportation
467 infrastructures, it offers a good opportunity to collect direct data which might not be available
468 in statistical records. Its features allow its user to track and collect real-time information
469 related to infrastructural products such as lengths of railway lines or road, bridges, tunnels and
470 other geological features which can then be converted into workable data. This data can
471 further be used to estimate the material stocks in the concerned system or infrastructure.

472 French Railway Infrastructure holds a vast quantity of Steel. Based upon data collected for
473 one-third of the French Railway Network by the length of the tracks, it has been found out
474 that this system carries, on average, 2402 kiloton of steel. Hence, it is very important to
475 maintain the inventory of the materials stock in the urban infrastructures.

476 This research work has been conducted with the best of efforts and by observing good and
477 honest practices pertaining to scientific studies. Despite all the efforts and available resources,

478 like other research works, there were a few limitations while doing this research. Those
479 limitations are specified below:

- 480 • Due to time and financial resources stipulations, it was impossible to cover the French
481 Railway Network for data collection through Google Earth. Hence, one-third of the
482 total French Railway Network has been covered by length, and the proposed method
483 was applied. Through the use of scientific justifications, assumptions and inference,
484 the proposed method has been attempted to be justified.
- 485 • Data collected through Google Earth may not be exactly identical to actual on-ground
486 data, given that it is an all-out human effort. Data extraction for such a large portion of
487 the complex system is very tedious and cumbersome. There were a very few portions
488 of the map which were efficiently available on Google Earth due to weather affected
489 imagery on the program (for example, clouds over a particular area), map distortion
490 due to pixel problems or in very rare cases, failure to locate parts of railway track on
491 the Google Earth corresponding to the actual one on SNCF map.
- 492 • There have been cases of simplification of data as well as calculations in the research
493 work. As far as the map itself is concerned, while calculating track multiplicity, the
494 weighted average has been considered in order to have one single and generalized
495 value so that calculation can be made easy. Similarly, exact material intensities for a
496 given rail line in French Railway System were most of the time were not available. In
497 order to counter that, available and most suited values from the literature have been
498 taken for stock estimation.

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503 **AUTHOR CONTRIBUTIONS**

504 **M.I. (Assistant Professor)** Conceptualization, Data curation, Writing- Original draft
505 preparation, **J. K. (Associate Professor)** Supervision, Writing- Reviewing and Editing, **S.M.**
506 **R. (Post-doc)** Writing- Reviewing and Editing, **J. A. (Ph.D student)** Reviewing and Editing,
507 **Y.H. (Professor)** Writing- Reviewing and Editing, **B. G. (Associate Professor)** Reviewing
508 and Editing

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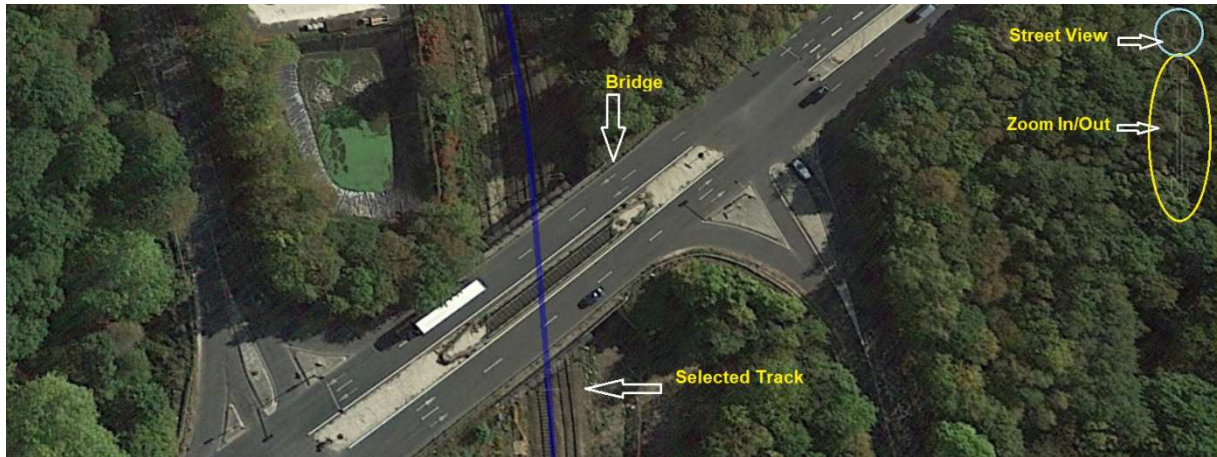
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Google Earth Screenshot of a Railway Bridge showing passing over a selected railway track

Graphical Abstract