Use of Traffic Data in Bridge Assessment

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ABSTRACT: The paper presents an overview of the newly constituted IABSE Task Group 1.10 which is focused on the utilization of traffic data in research, design and assessment of bridges. TG1.10 is investigating how road vehicle loads can be presented in a standardized format so that the used traffic data is transparent, fast to use, reusable and error free, thus accelerating research and reducing the uncertainty in the assessment process. As a result of TG1.10 recommendations for best practices and tools for research, design, and assessment of bridges will be developed. The experience already available will be taken into account. The scope is not limited to any structure or construction material.

Of the loads to be modelled on a highway bridge, by far the most variable are those termed, *Traffic Loads*. This variability results not only from the stochastic variables describing the individual vehicles themselves, i.e. weight, axle spacing, speed, impact etc. but also from the probability of multiple presence longitudinally within an individual lane or transversely in multiple lanes.

Recognising the importance of the comprehensive and accurate use of traffic data for bridge assessment, IABSE, the International Association of Bridge and Structural Engineers, constituted a new TG1.10 to focus on the utilisation of traffic data in research, design and assessment of bridges. The task group began its work in January 2023 and will run for almost 4 years until October 2026.

The bridge community is committed into creating safe and sustainable structures for future generations. During the drafting work of bridge design standards many compromises are needed to achieve a consensus, and the resulting design verifications developed can be seen as the best commonly agreed practice and a way to achieve safe structures. However, there is inherent conservatism in developed generations of standards.

Decision makers and road administrations, often due to lack of expertise, are very careful in adopting new methods developed by the scientific community, and often the route from research to practice is tediously long.

This paper outlines the work of TG1.10 in focusing on how actual traffic load conditions monitored on site can be integrated into assessment of capacity of bridge structures. Often different experts are dealing with these very different sub-fields of the structural engineering; hence the community is in dire need of tools bringing relevant knowledge together, allowing a holistic view of the problem in hand.

New assessment tools should be developed to get relevant and trustworthy background information to support calibration of current and future design standards, and also to form a basis for realistic site-specific load determination for existing bridges. A transparent, open, and commonly agreed basis for conducting the loading and capacity evaluation would accelerate the research and give more continuity by allowing the passing of current best knowledge to the next research generations of bridge engineering as well as to practitioners.

1. IABSE TG1.10 – UTILISATION OF TRAFFIC DATA IN RESEARCH, DESIGN AND ASSESSMENT OF BRIDGES

The stated objective of TG1.10 is to provide a platform to exchange knowledge and provoke understanding of the benefits of using road traffic data in research, design, and assessment of bridges.

The task group is chaired by Prof. Alan O'Connor of Trinity College Dublin. Mr. Heikki Lilja of the Finnish Transport Infrastructure Agency (FTIA) is the vice-chair of the TG.

Prof. O'Connor is Professor and Chair of Structural Engineering at Trinity College Dublin, Ireland. He is a Chartered Engineer with both Engineers Ireland and the Institution of Structural Engineers (London) and is a Fellow of TCD. He is an internationally recognised expert in traffic load modelling on bridges. He was involved in the development of the original Eurocode normal load model for design of bridges. He has 20 years' experience in the areas of probability-based safety assessment of structures, in risk and resilience assessment, in probabilistic load modelling, engineering for extremes, design code development, and structural reliability analysis. He is a national member of CEN/TC 250/SC10, CEN/TC 250/WG2 and CEN/TC 250/WG6. He was a member of the project team which developed the Eurocode for Assessment of Existing Structures (prEN1990-2) and led the project team tasked with incorporating robustness into the material related Eurocode parts. He is currently engaged in the revision of the Danish Roads guideline for reliability-based classification of the load carrying capacity of existing bridges and in producing a chapter for the JCSS PMC on traffic load modelling. He is an active member of IABSE as Co-Chair of TG6.1 – Effects of Climate Change on Infrastructures and member of TG1.3 – Calibration of Partial Safety Factors for the Assessment of Existing Bridges.

Heikki Lilja has 25 years of hands-on experience in the design of bridges from a wide variety of roles (design, proof-checking, steering, standard/design guide drafting, client, national authority) and know-how on transferring research results into everyday practice for safe and sustainable design.

Possessing a deep knowledge of the CEN standardization, especially on the interconnections between different Eurocode parts, he has been involved in the drafting of 2nd generation Eurocodes; most notably Eurocode parts prEN1991-2 Traffic Loads (as a member of the Project Team) and prEN1990 Annex A.2 Design Basis for Bridges (as a Convenor for CEN/TC250/SC10/WG2 Bridges).

In addition to standardization Heikki has developed the industry forward with various design guides and practices prepared for Finnish Transport Infrastructure Agency, including special and one-off structures that sometimes may fall between different codes, thus lacking ready-made verification rules.

The TG is truly international with participants from 16 countries, which emphasizes the international importance and relevance of the work being performed.

The TG has defined an ambitious work programme with defined objectives listed as:

- agree on standardized format of traffic data (road/rail)
- recommendations for data collection (WIM/WILD)
- recommendations for traffic simulation for short, medium, and long-span bridges
- monitoring and modelling special transports/permit vehicles
- Best practice for dynamic amplification selection
- developing "Units of measures" for different influence line lengths to compare traffic compositions to each other
- Traffic forecasting to future
- Simulations for platooning effects
- Extrapolation of characteristic loads for certain return period for design/assessment (ULS/extreme values)
- Extrapolation of frequent/quasi-permanent traffic loads for certain return period for design/assessment (SLS)
- Calibrating design fatigue load models
- Individual structure-specific tools for practice

- Links between traffic data and structural health monitoring
- Best practices for data and tool storing and sharing to accelerate research
- Recommendations for decision makers

Further information on the TG can be found at https://iabse.org/TG1.10 and readers are encouraged to remain in touch with the work performed and to consider joining in delivering on the ambitious work programme.

2. USE OF TRAFFIC DATA IN BRIDGE ASSESSMENTS – CHALLENGES AND PERSPECTIVES

Having presented the TG the paper will now consider some challenges faced by bridge owners/managers in the use of traffic data and will offer some perspectives from the authors in this regard.

How to Tackle the Huge Variation in Traffic Data

Figure 1 provides an indication of the variation in traffic data in a temporal and spatial context. The data was recorded on motorways in France and Ireland respectively. It is apparent form the figure that the French traffic is far heavier than the Irish traffic.

Significant disparities in traffic compositions can arise due to varying regional regulations. For instance, in Northern Europe, it is customary to permit vehicles weighing well over 60 tons, while in some other parts of Europe, regulations typically restrict vehicles to a maximum weight of 40-44 tons. These regulatory differences can substantially impact the types and weights of vehicles traversing the region's bridges.

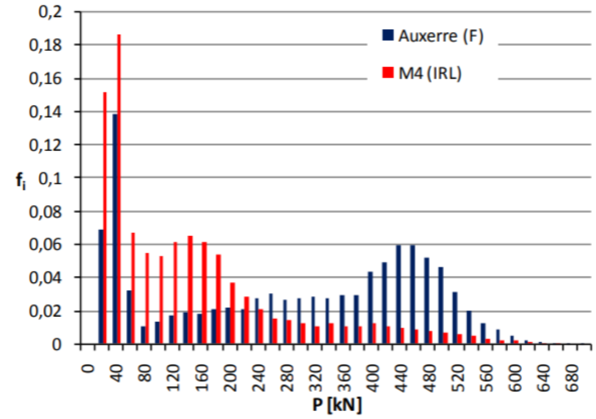

Figure 10.1 Frequency histograms of the total lorry loads in Auxerre and in M4 motorway (adapted from Jacob et al., 2002)

Figure 1: Frequency Histograms of Total Vehicle Loads in Auxerre, France and on the M4 in Ireland

Calibration of Fatigue Load Models

Figures 2 - 5 provide an indication of the variety of bridge types. Design standards often simplify fatigue design load models to ensure their safety for all traffic compositions. However, this approach can lead to substantial overdesign. During the development of these design load models, a multitude of conservative assumptions are generally made, and the analysis usually considers only a limited number of structures, often focusing on simple beam models.

Moreover, these design load models can sometimes be calibrated for the lighter traffic, and thus, may not accurately capture the effects of the heavier traffic found in some regions.

There are several exceptional structures where the applicability of these standard fatigue load models may be questionable, necessitating more precise tools for accurate evaluation. These special cases underscore the need for comprehensive and adaptable solutions in bridge design and assessment.

Figure 2: Standard Bridges

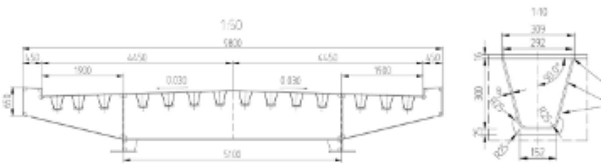

Figure 3: Orthotropic Steel Decks

Figure 4: Cable Supported Bridges

Figure 5: Culverts

Extrapolation to Characteristic Extremes

The occurrence of any load or load effect on a bridge may be discretised and described by a stationary time series (X_1), for i=1,..,n, where the ith lorry has a gross weight X_i (Flint and Jacob, 1996). Y_N and Y_T denote the random maximum load and load effect occurring after N events or during the reference time period T, respectively. The return period of any value x, R_x is the mean time interval between two exceedences of the value x by the stationary time series X_i, i=1,..n, or the mean time elapsed before the first exceedence of x. Thus it may be shown that if y_α is the (1-α) fractile of Y_N, for N and $T \to +\infty$, the return period is given in equation [1] as (Jacob, 1991):

$$R = R_{y\alpha} \cong \frac{-T}{Ln(1-\alpha)} \cong \frac{T}{\alpha} \qquad \text{if} \quad 0 < \alpha << 1 \tag{1}$$

The relationship is independent of the value of y_α and of the common density of all of the random variables X_i. The characteristic values for extrapolation of the traffic effects, are determined such that the probability of exceeding the load effect during the specified design life of e.g. T = 100 years can be calculated with a 0.9 fractile probability that y_α is exceeded during T. Thus e.g. from equation (1), a return period of R = 1000 years is required for prediction of the characteristic extremes.

The characteristic value is sensitive to the method of prediction, as described below. The list of methods is not intended to be exhaustive but rather instructive.

Rices Extrapolation

Extrapolations of the extreme load effects may be performed, under the assumption that the load effect behaves as a stationary Gaussian process, X(t). The hypothesis of stationarity is necessary as the extrapolation may not take account of any future changes in traffic patterns which might reasonably be only expected to result from human decision and road and transport management strategies. The assumption of normality is used to derive the theoretical upcrossing distribution which is asymptotically normal for large values, i.e. above a given threshold, (Leadbetter, 1983). The level crossing distribution, given by the Rice's formula is not itself normal but has a normal tail which governs the extrapolation. It is written as:

$$p(x) = \frac{1}{2\pi}\frac{\sigma_{\dot{x}}}{\sigma_x}\exp\left(-\frac{\left(x-\bar{x}\right)^2}{2\sigma_x^2}\right) = k.\exp\left(-\frac{(x-m)^2}{2\sigma^2}\right) \quad (2)$$

The parameters k, m and σ are calculated and the censoring level from which the adjustment is made by a statistical test (Cremona, 1995). Then the extrapolation gives the value of the effect 'a' having a specified probability of exceedance during the period T.

Gumbel Extreme Value Distribution

The extreme values of the load effects may be modelled using a Gumbel type extreme value distribution. A Weibull (i.e., Gumbel type III) distribution results when the maximum values are sampled from a parent frequency distribution having a finite upper bound. An alternate distribution is the Gumbel I distribution. In this case, the maximum values are sampled from a parent distribution with no upper bound (Gumbel, 1958).

The principle of tail equivalence (Castillo 1991, Maes 1995) is employed in determining an appropriate extreme value distribution. The extreme value and parent distributions, G(x) and F(x) respectively, are considered tail equivalent if:

$$\lim_{x\to\infty}\frac{1-G(x)}{1-F(x)} = 1 \quad (3)$$

Where the extreme value distribution $G(x)$ is modelled by either the Gumbel or Weibull distribution, given by equations 4 & 5.

$$G(x) = \exp\left[-\exp\left(\frac{-(x-\lambda)}{\delta}\right)\right] \quad -\infty < x < \infty \quad \delta > \quad (4)$$

$$G(x) = \exp\left[-\left(\frac{\lambda - x}{\delta}\right)^{\beta}\right] \quad -\infty < x \le \lambda \quad (5)$$

The parameters of the Gumbel law G(x) are estimated by the maximum likelihood approach (Castillo, 1991).

The suitability of either distribution is assessed by plotting the extreme data on probability paper, where linearity indicates the appropriateness of the mathematical model.

Comparison of Method of Prediction of Characteristic Extremes

Figure 6 illustrates, in ascending order, the predicted extremes of simply supported moment for span lengths 5, 10, 20, 50, 100 & 200 m (O'Connor & O'Brien, 2005). It should be noted that the extremes predicted by Rice extrapolation were performed from simulations using real WIM data. Whilst those calculated using the Gumbel I & Weibull extreme value distributions were from Monte Carlo (MC) simulations. The relative errors, with respect to the Rices extrapolations, are listed in table 1. It is apparent, that the characteristic extremes predicted by all methods are in reasonable agreement, when the differences already noted between direct simulation and MC, listed in table 1 under the heading SSM, are taken into account.

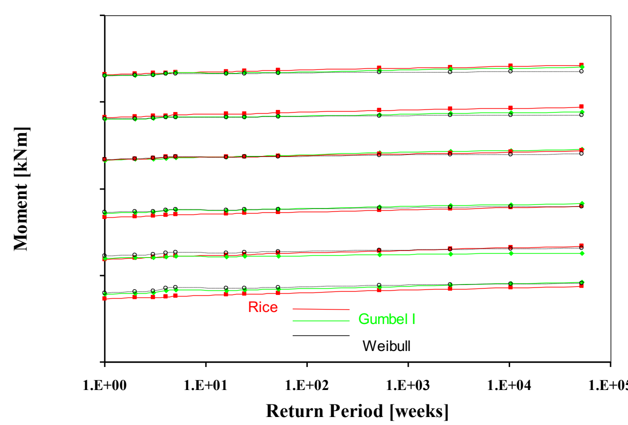

Figure 6 – Comparison of Characteristic Extreme Prediction Methods (O'Connor & O'Brien, 2005)

Table 1: Extrapolation Results.

Return Period Span [m]	1 Year	20 Years	100 Years
5	**-11.1** (-14.6)	**-11.0** (-12.6)	**-11.1** (-10.7)
10	**10.1** (-1.1)	**12.4** (1.1)	**14.1** (2.9)
20	**-9.1** (-5.9)	**-9.1** (-3.7)	**-9.1** (-1.7)
50	**3.5** (6.9)	**4.1** (9.1)	**4.5** (10.9)
100	**10.1** (13.7)	**10.8** (15.9)	**11.3** (17.7)
200	**4.4** (10.4)	**4.2** (12.2)	**4.0** (13.7)

Bold : % Difference between Rices & Gumbel
() : % Difference between Rices & Weibull

Special Transports

Figure 7 provides an indication of the type of heavy transports traversing the bridge stock. The key question here is what damage these transports do to the bridge stock? For example, older bridges frequently fail under special transport loads at intermediate supports (negative moment) before in their spans (positive moment). This is largely due to the fact that heavy special transportations are often quite lengthy, resulting in significantly large negative moments on the intermediate supports of a bridge. It has been observed that previous design load models frequently fail to account for this phenomenon, as they are typically short and primarily represent normal vehicles.

Additionally, certain transitions in design methods can often cause assessed bridges to fail. For example, this may be due to the absence of requirements for shear reinforcements in older design codes.

An understanding of the relationship between action effects from special transports and those from regular traffic flow can provide critical insights for decision-makers. By studying these differences, engineers can improve their bridge assessment methods and preventive measures to better accommodate heavy and special transportations.

Figure 7: Heavy Transports

Regulatory Changes

Figure 8 provides an indication of the impact of regulator changes on the traffic composition. The key question here is what is the effect for the bridge stock and as such regulatory amendments should be undertaken with utmost caution. What might appear as minor changes can actually result in significant impacts due to the inherent nature of fatigue and durability phenomena in bridge engineering. These subtle yet crucial factors may greatly influence the structural integrity and lifespan of a bridge.

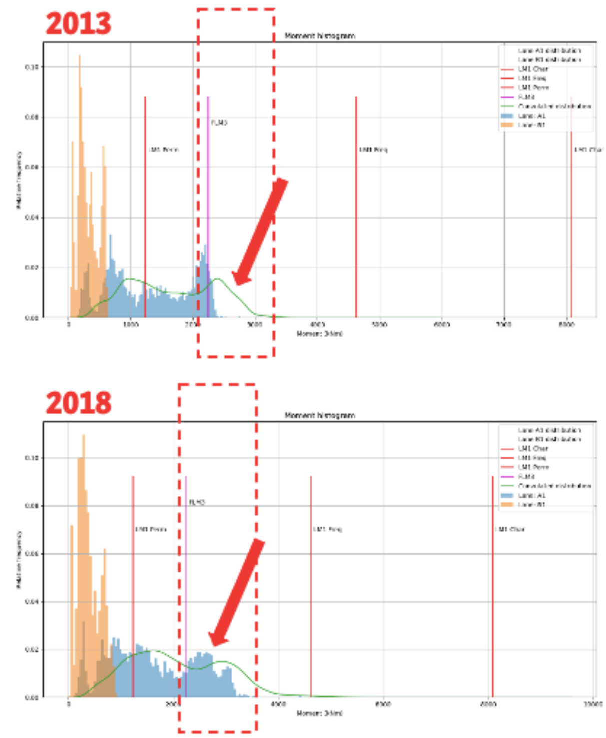

Figure 8: Impact of Regulatory Changes

Optimum Decision Making for Ageing Bridges

Figure 9 provides a typical indication of the temporal condition of a network of bridges. The key question here is what optimal decision making process to manage the stock?

Maintenance of bridge infrastructure constructed in the last century presents a complex challenge. Design codes and load models have undergone numerous revisions over time, with the reliability of bridges hinging on these changes. Further complicating matters, characteristics such as span length and transverse load-bearing properties significantly impact a bridge's reliability.

Comprehensive knowledge of actual traffic loads could substantially inform decision-making. However, acquiring this depth of understanding is a formidable task. It requires extensive data processing to identify all influencing factors, making it a complex but invaluable endeavor in the quest for enhanced bridge reliability.

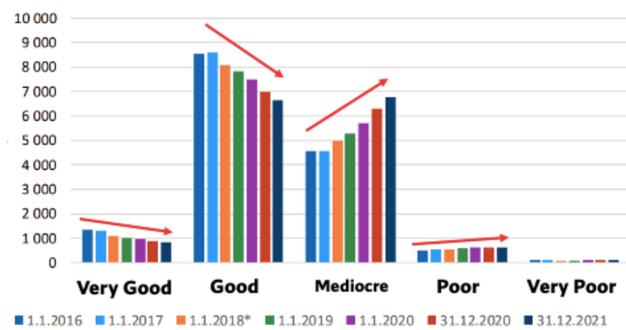

Figure 9: Ageing Bridge Stock

3. CONCLUSIONS

The purpose of this paper is to present some of the challenges faced by TG1.10 of IABSE in providing guidance on the use of traffic data for the assessment of bridges. The paper has provided a description of the aim of the TG as well as detail of the proposed deliverables. Challenges and perspectives are provided on the use of traffic data to provide context for the work. Readers are encouraged to stay in contact with the TG over the coming years via the website address provided. Interested parties are also encouraged to contact the TG Chair and Vice Chair with contributions and possible participation in the TG.

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