# New opportunities for bridge management using independent datasets

Connor O'Higgins
*Research Fellow, The School of Natural and Built Environment, Queen's University Belfast, Belfast, United Kingdom*

Myra Lydon
*RAEng Research Fellow, The School of Natural and Built Environment, Queen's University Belfast, Belfast, United Kingdom*

Kristopher Campbell
*Department For Infrastructure, Belfast, United Kingdom*

Nicola-Ann Stevens
*Research Fellow, The School of Natural and Built Environment, Queen's University Belfast, Belfast, United Kingdom*

ABSTRACT: Bridge managers have increasingly utilised databases to aid in the efficient allocation of resources. For the most part, these databases have been compiled from existing bridge management tools such as bridge inspection records and historical bridge information. However, this trend of utilising databases is not limited to bridge management, with organisations such as the Rivers Agency, Health Services and Census agency data also utilising their own databases. The linking of such datasets can pose a challenge; bridges are generally given a unique identifier that can be used to match any information collected to that particular bridge. However, if the data sets are independent of each other, they must rely on other common factors such as location. This paper investigates methods for combining various types of datasets and the opportunities that may arise when these databases are linked. Specifically, what new factors, which are not included in the original data, can be obtained when utilising various sources? Using multiple datasets, such as bridge, traffic and river data, bridge properties can be estimated to influence bridge management decisions. These properties include an estimation of detour length if the bridge were to close and the river catchment area of the bridge. These properties could then be used to find the most critical bridges in the network or to help determine if a bridge is susceptible to scour from river flow. This work gives some examples of how independent datasets can be linked and the new information that can result from this. The focus of this work has been on bridge and river data, but other datasets such as public transport or health resources could also be used in the bridge management process.

## 1. INTRODUCTION

SHM, especially in the field of structural/civil engineering, is a rapidly developing area. One of the most promising areas of SHM is big data. Entezami et al. (2020) stated that due to the advances in sensor technology, focus has been shifted from the SHM systems themselves to the analysis of the data they produce. While this is true that more advanced sensors and data acquisition systems have led to the production of much more data that can be used for analysis, there is much historical data that could be just as beneficial.

The Department for Infrastructure (DfI) is a Northern Ireland (NI) government department that encompasses a range of strategic functions, including acting as the local roads authority. DfI owns and maintains over 6,900 bridges varying in construction type, age, span and function. As part of the maintenance of these bridges, DfI holds historical records of each bridge's construction and inspection record. A review of the masonry arch bridges has been undertaken by Campbell et al. (2020).

This paper will look at the opportunities for bridge management that can arise when the DfI records are combined with other independent datasets. This research will review the dataset used and then discuss some of the methods that can be used to combine the datasets. After the datasets have been combined, a small case study will be undertaken to illustrate what information can be gained by using a combination of independent datasets.

## 2. DATASETS

This section outlines and reviews the datasets that will be used throughout this paper.

### *2.1. General Bridge records*

DfI stores the general bridge records that contain data about the construction, location, general arrangement or use of the bridge. The dataset available for this study contains data for approximately 7000 bridges. The general bridge records contain the following data:

- Construction of bridge (steel/masonry)
- Length and width
- Number of spans
- Location (longitude/latitude)
- The function of the bridge (over road/river)
- Road type supported by structure (Local Road/Motorway)
- Type of traffic on structure
- Skew angle
- Bed to soffit height

### *2.2. Historic bridge inspection records*

This dataset contains the records for the visual inspection undertaken since the early 1970's this data was originally in paper format but has since been converted to a digital format.

This data mainly contains data from inspections undertaken using the BD63/17 (Volume 3 Highway Structures: Inspection and maintenance document with the Design Manual for Roads and Bridges) standard. Each inspection record generally consists of a list of defects and a condition rating for the main elements of the bridge.

### *2.3. River data and geological data*

The river dataset was acquired from the river agency via a publicly available repository (Open Data Northern Ireland. n.d.).

There are many datasets available regarding rivers including flood maps, this dataset contains the following data:

- A unique id number for each of the 17,000 river segments
- Location data for every river segment
- Strahler stream order
- If the river is part of a large river system (catchment area > 5000 km2)
- If the river is part of a main river system (catchment area > 500 km2)

Figure 1 shows all of the river segments colour coded according to their Strahler stream order. The Strahler stream order will be explained and used in Section 4.4 to estimate waterway properties.

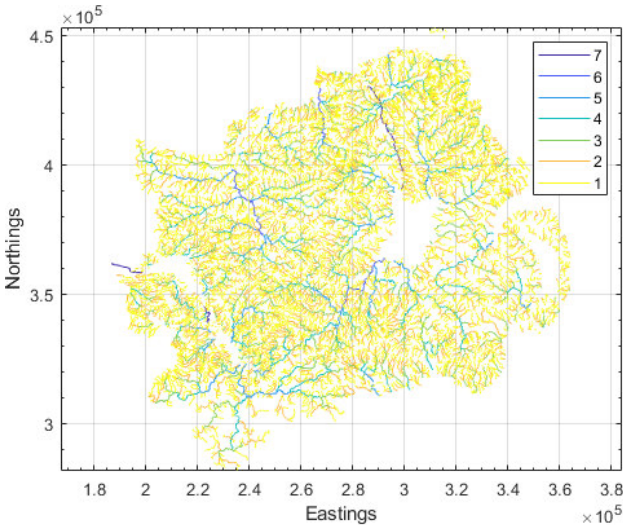


*Figure 1: River segments location and Strahler stream order*

The catchment areas and boundary locations for each of the 450 catchment areas in NI were also well-defined. The catchment areas can be seen in Figure 2.

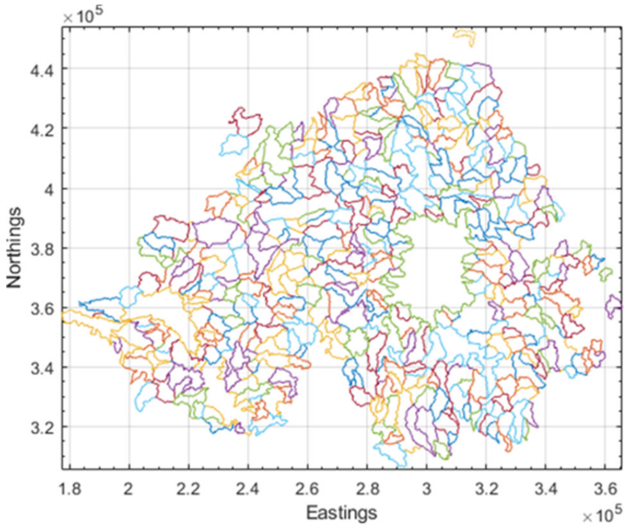


*Figure 2: River catchment areas*

As part of a different dataset, we also have access to 130 hydrometric stations. These stations record the water level with a frequency ranging from hourly to daily. While the most recent of this data is available publicly, the river agency has a record on file for over a decade.

The geological data that was available consisted of the topography of the area and the bedrock type and location and outcropping locations.

### *2.4. Traffic data*

The traffic data come in the form of a survey, the last of which was undertaken in 2013. This survey was undertaken over 24 hours at 350 locations and includes the number of vehicles on an hourly basis and the percentage of the vehicle that are HGVs.

## 3. JOINING DATASETS

The datasets described above were all obtained from different sources. To make use of the information contained within each set for bridge management, they needed to be linked. The process of linking these datasets is not a trivial task. This section describes some of the options for linking separate datasets and the processes used in this study.

### *3.1. Spatial*

The most straightforward method to join the datasets is to use the spatial data within each dataset as a common marker. Difficulties with this method arise from the different accuracies of location data between the dataset and the different formats of the location data. In the datasets used in this study, the location data was stored in either longitude/latitude format or Irish grid format. It was decided to convert the Irish grid position data into the longitude/latitude format as this is a more standard form. The conversion introduced a small error into the data, but this was less than the tolerances of the original data and so could be worked with. The dataset could be joined when all the location data was in the longitude/latitude format. This was undertaken using the following steps:

- Each of the river catchment boundaries were defined using the river dataset (Figure 2)
- Using the boundary data, each of the river segments (Figure 1) were matched with an individual catchment area
- Each induvial bridge was then matched with the closest river segment (if the bridge was indicated as being over water)

After this process was complete, every bridge was matched with an individual river segment and river catchment area. An example of an individual catchment area with all the river segments and bridges can be seen in Figure 3.

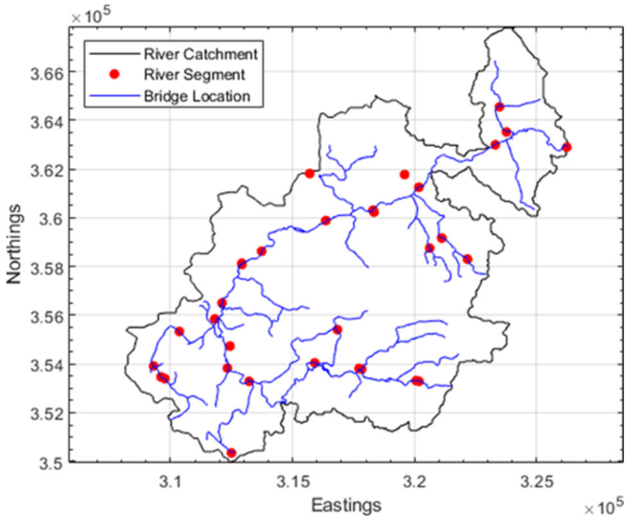


*Figure 3: Individual river catchment area showing river segments and bridge locations*

### *3.2. Temporal*

While the datasets as a whole could be joined using the spatial data, a temporal element had to be considered. These elements come from the historical bridge inspection records and the 130 hydrometric stations that record data that changes over time. During every inspection, a date and bridge id number were recorded. Using these pieces of information, a chronological list of defects can be linked to every bridge in the now consolidated database. The hydrometric data is relatively sparse, and so the database was only updated to indicate if a hydrometric station is on the same or adjacent river segment as a bridge and the id number of the station. Any data collected by the station was then linked to the bridge through the station id number.

## 4. EXTRACTING USEFUL INFORMATION FROM COMBINED DATASETS

This section will describe a case study to show how the combined dataset can estimate new parameters that can be utilised for bridge management. The case study will utilise work undertaken by Stein et al., (1999). This work uses information contained within the National Bridge Inventory (NBI) to prioritise scour vulnerable bridges using risk. The method proposed in this paper uses only information that was collected and stored in the NBI. Some of the required data, such as the number of spans, span length and construction material, were available in the combined dataset. However, some factors such as detour length if the bridge was closed were not available for any of the bridges. Factors such as average daily traffic and average daily truck traffic were available for specific sites but not for every bridge which was required for the risk assessment method. For this case study, all unknown required factors were estimated using information contained within the combined database.

### *4.1. Bypass, detour length*

The method used to estimate the detour length for each bridge began by plotting the main roads (any that could accommodate heavy goods vehicles) for the whole road network. Then for each bridge, the density of roads within a 5 km radius was found. Figure 4 shows the road network and two 5 km radius for two bridges. Here it can be seen that the road network indicated with the green points is less dense than the road network indicated with the red points.

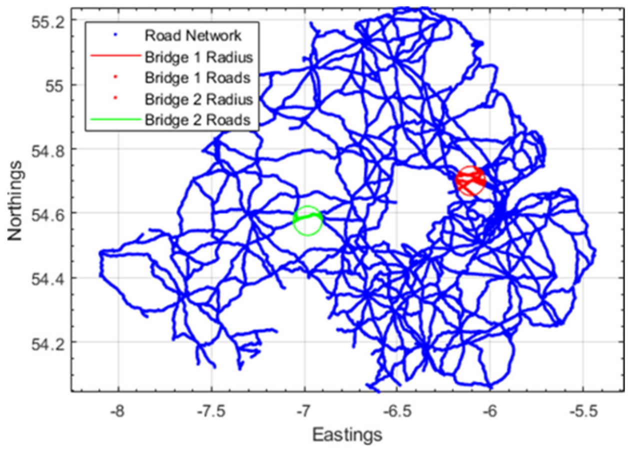


*Figure 4: Road network and the 'road density factor' for 2 bridges*

This density of roads factor was used because if there is a dense network of roads surrounding a bridge, there would be more opportunities for shorter diversion lengths. This hypothesis was then tested by selecting 50 bridges and finding the detour length manually by using mapping software. When the road density factor was used in a regression analysis to fit the detour length to the road density factor, it was found that there was an RMSE factor of 1.932, indicating a strong correlation. As the road density factor was correlated with the detour length, the function found from the regression analysis was used to estimate detour length using 'Road density'.

The determined function could then be used to estimate the detour length for all ~7,000 of the bridges in the database. Figure 5 shows the regression analysis results with the blue markers indicating the manually found detour lengths and the red line indicating the function to link road density and detour length.

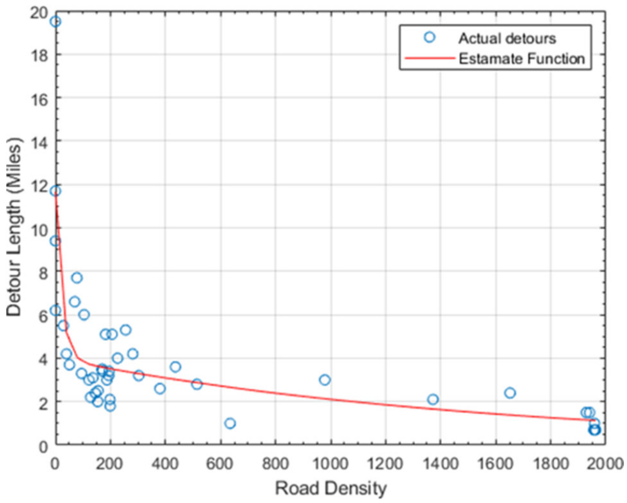


*Figure 5: Results from the regression analysis to fit road density to detour length*

*4.2. Average daily traffic & truck traffic*

Using the traffic count information in the database, an estimate could be obtained for every bridge in the dataset. The traffic count data collects traffic data at approximately 350 locations over a 24 hour period. This traffic count data was split into 5 road types; Motorway, A Class, B Class, C Class, Unclassified. An average value was obtained for both the daily traffic and the truck traffic. These average values were then assigned to each of the bridges in the database depending on the type of road that the bridge was carrying.

*4.3. Substructure condition*

While the substructure condition is not explicitly recorded in the combined database, the inspection records do contain information on defects that have been observed on the substructure of the bridge. Using these records a substructure condition rating from 1 to 5 could be defined as required for the risk assessment. The rating was based on the number of defects observed on the substructure and the extent of the defects.

*4.4. Waterway adequacy*

This feature appraises the waterway opening with respect to the passage of flow through the bridge. To get an estimate of the waterway adequacy, the river data was used. For each of the bridges in the database, the Strahler stream order was used to give an indication of the water level in the river. The Strahler stream order is a positive whole number used in geomorphology and hydrology to indicate the level of branching in a river system. The higher the number, the closer that segment of the river is to the river mouth and, therefore, more likely to carry a more significant amount of water. Figure 6 shows a diagram of how the Strahler stream order is assigned to each of the river segments based on the relative location of the segment in the whole river system.

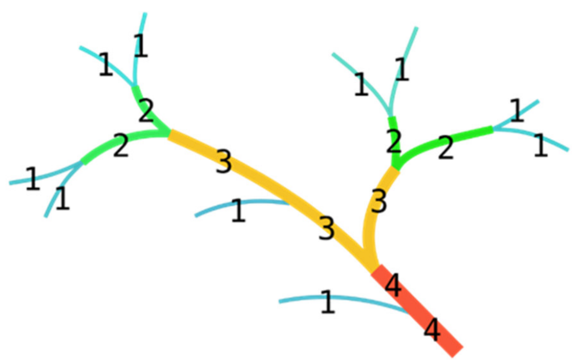


*Figure 6: Diagram showing how Strahler stream order is assigned*

Using the Strahler stream order an estimate of the waterway adequacy could be determined for each of the bridges and used in the risk assessment.

### *4.5. Scour risk assessment*

Using the method proposed in Stein et al., (1999) and the estimated parameters discussed previously. The scour risk assessment was undertaken on all the bridges in the database. This resulted in a prioritised list of bridges from most to least at-risk/would have the highest impact if the bridge had to be closed due to scour. While this risk assessment was successful, the risk assessment seemed to be weighed heavily in the economic impact of failure, which is of use to bridge managers but alterations would need to be made to the method proposed by Stein et al., (1999) for the full benefit to the bridge maintained by DfI.

## 5. FUTURE WORK

The case study described in Section 4 gives an example of the benefit of using the combined dataset. However, there is other information contained in the dataset that was not utilised. In future work, information such as the bedrock data will be used to potentially gain insight into the probable foundation type/depth of the bridges. The land height data could be used to better understand the amount of water in each of the catchment areas and may potentially correlate to the risk of flooding in the local area around each of the bridges.

## 6. CONCLUSIONS

This works shows the benefit of using historical bridge records as a tool for bridge management and how other independent datasets can be utilised to gain more information that can benefit the bridge management process. The case study described in this study illustrated how other factors could be estimated, such as the bypass detour length of a bridge and estimation of the water levels of the rivers crossed by each bridge. The method used in the case study was able to produce a prioritised list of at-risk structures to scour; however, as stated in the main body of the work, the method focused more on the economic factors than the scour factor. Due to this the method would need to be altered to better reflect the bridge network in Northern Ireland, however, the main purpose of the case study was to show how other factors that were not originally in the database could be estimated and used for bridge management purposes.

In the future work section of this paper, other examples of how the combined dataset could be used in bridge management are given. This work has mainly focused on bridge deterioration and, more specifically, scour of bridges; however, the principle of big data can be used in most fields of SHM.

## 7. ACKNOWLEDGMENTS

The authors would like to thank the Department for Infrastructure (DfI) for access to the complete bridge management records, technical and financial support, and for allowing the analysis and findings to be used in this paper. The financial support of the Royal Academy of Engineering under the research fellowship program is also gratefully acknowledged. The authors also gratefully acknowledge the support of the UK Engineering and Physical Sciences Research Council (EPSRC) through the ROSEHIPS project (Grant EP/W005816/1).

## 8. REFERENCES

Campbell, K., M. Lydon, N.-A. Stevens, T. Neeson, and S. Taylor. 2020. “A review of the data held on 3,437 masonry arch bridges in Northern Ireland.” *CERI 2020 : Civil Engineering Research Ireland*. Cork, Ireland.

Entezami, A., H. Sarmadi, B. Behkamal, and S. Mariani. 2020. “Big Data Analytics and Structural Health Monitoring: A Statistical Pattern Recognition-Based Approach.” *Sensors*, 20 (8): 2328. https://doi.org/10.3390/s20082328.

Open Data Northern Ireland. n.d. "OpenDataNI." Accessed July 4, 2022. https://www.opendatani.gov.uk/.

Stein, S. M., G. K. Young, R. E. Trent, and D. R. Pearson. 1999. "Prioritizing Scour Vulnerable Bridges Using Risk." *Journal of Infrastructure Systems*, 5 (3): 95–101. https://doi.org/10.1061/(ASCE)1076-0342(1999)5:3(95).