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AI On The Management Of Existing Bridges
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ABSTRACT

The present paper presents a brief discussion on the current practice regarding bridge management. The main goal of this discussion is the attempt of finding some trends in the research and development of existing bridge management systems (BMS). To achieve this, it is firstly important to analyse the entire process of bridge management, understand which parts of the process are being properly addressed by current BMS and which parts are not account for nowadays. The next step consists in providing some guidance on how to improve BMS considering the parts not being well covered. Likewise, some orientation is required to deal with the parts not yet being accounted for in existing BMS. To this end, insights and tools already used in other fields of knowledge can be considered, adapted and adopted in future BMS. In this regard, artificial intelligence algorithms appear as a sound candidate.

Keywords: BMS, Asset Management, AI, BrIM.

1 INTRODUCTION

Mobility is nowadays taken for granted all over the world. Contrarily to what happened a few centuries ago, today's human life is highly dependent on the capacity of moving people and goods between places increasingly more distant one from another. In the particular case of terrestrial mobility, transportation systems composed by roadways and railways play a crucial role in assuring the desired mobility.

From the various assets that compose the referred transportation systems, bridges are one of the most important due to their relevance for the entire system. In fact, while the amount of bridges in each network is normally very limited, when compared with the extension of other longitudinal elements (e.g. pavement/rail track), they can behave as bottlenecks of the network in case of functionality loss, thus assuming a considerable importance.

This importance is highly recognized, and since beginning of 1970's several proposals have been presented worldwide on how to manage bridge stocks – the so called Bridge Management Systems (BMS). Following sections presents an overview of current BMS.

Bridges, due to their inevitable exposure to natural environment, deteriorate with time. This deterioration can be slower or faster, depending on many factors such as quality of design and/or construction. Also, adequacy of design to real loads (e.g. traffic load tends to increase beyond what was considered in design). Finally, natural and man-made hazards are also a source of concern regarding bridges performance throughout their lifetime. In particular, regarding natural hazards it has been seen lately that they are happening more frequently and with higher impacts due to climate-change effect [1].

On the other hand, many bridges are approaching the end of their design lifetime. This increases the criticality level of bridges regarding the mobility of people and goods that they need to ensure.

2 BRIDGE MANAGEMENT SYSTEMS

Bridge management systems (BMS) were originally proposed as simple inventory databases [2]. Since then, other modules have been added and, nowadays, the current BMS are constituted by at least three major modules, namely, Inventory Module, Performance Model and Maintenance Optimization Module [3]. In the following, each of these is further presented.

The content of following sections resulted from the review on more than 40 BMS [4]. This is still an ongoing work, thus the observations written in what follows are the first preliminary observations that can be extracted from that review.

2.1 Inventory Module

The basilar module of BMS is, as already mentioned, the inventory one. Despite the evolution suffered by BMS, the data related with the bridge stock being managed is still required to be stored and used [5]. The major difference from the original inventory modules to the current ones, lies in the bigger amount of data stored but, most importantly, in the type of data stored. In fact, as new modules became included in BMS, the type of data required to feed them was also required to get its own space in the inventory database. Hence, this inventory module gained a wider amplitude and nowadays includes also data not directly related with the bridges.

2.2 Performance Module

Soon bridge managers understood that, while having a systematic data collection of the bridge stock was very important, the real advantage would come from the use of the stored data. That was the trigger for the appearance of what can be designated a performance module. This module is dedicated to the hard task of predicting bridges' performance in time. To that purpose, deterioration models, associated with the most relevant deterioration mechanisms found in bridges, begun being applied in the context of bridge management.

Five main types of deterioration models can be found in the literature [6], namely:

• Physical models: this type of models considers the mechanical behavior of the bridge components, as well as the deterioration mechanism undergoing and influencing the performance evolution. Some examples of physical models include carbonation-induced corrosion, chloride-induced corrosion, alkali-aggregate reaction and freeze/thaw attack, among other;

• Deterministic models: like physical models, deterministic models are based on a set of analytical expressions. However, deterministic category includes models that are deduced essentially in a mathematical fashion. This category includes multiple linear regression, polynomial regressions and ordinal logistic regressions, and similar regression-based models;

• Stochastic models: in this category can be found all those models that include uncertainty, regardless to its source, in the prediction process. Majority of bridge management systems available worldwide use predictive models of this category. Particularly, Markov models (including pure, semi and hidden versions) are the most widely used;

• Artificial intelligence (AI) models: this category has been increasingly used in the last years, benefiting from the widespread of AI algorithms and tools. These models aim at exploring the large amounts of data available from multiple monitoring sources existing nowadays, which is not possible using previous models. Models based in artificial neural networks, fuzzy logic and case-based reasoning, are just few examples of what can be found recently in the literature.

• Graph theory-based models: besides the four categories mentioned before, there can be also found some other prediction models. These, even though used with promising results in many cases, do not fall within a single category thus are grouped in this last and generic category. Bayesian networks and Petri nets are two examples of such kind of prediction models.

2.3 Maintenance Optimization Module

Performance module was a big step forward in the existing BMS. However, considering the final goal of BMS, which should be supporting the bridge managers to take decisions regarding their stock maintenance, this was not enough. Hence, next big module implemented, that most advanced BMS worldwide include, was the maintenance optimization module.

This module aims at providing a schedule of maintenance interventions for a provided time horizon. It is supported on the performance predictions produced by performance module. Those are now combined with new information related with the maintenance interventions. This information includes, at least, a description of each possible maintenance intervention, the frequency in which it can/should be applied, the effect it produces in the current performance, as well as the associated costs. This is one example of the new type of data, not directly associated with the bridge itself, that nowadays inventory module store.

Up to this point, the present module behaves just as a maintenance module. The term optimization only appears when this process of maintenance schedule is provided with some kind of optimization. And this is one major difference between existing BMS, i.e. the type of optimization strategy implemented. To this purpose, optimization can be single-objective or multiple-objective, depending on the number of optimization goals considered. The most common adopted goals refer to overall performance (either cumulative, average or worst, among other possibilities), the overall maintenance costs and/or other specific goals such as performance/cost for specific critical bridges in the stock. On the other hand, it is usual to set some boundary conditions in this optimization process, either in terms of performance or costs limitations.

3 AI ON THE MANAGEMENT OF BRIDGES

Following the overview on bridge management systems, presented in previous section, in the next paragraphs some of the most relevant uses of artificial intelligence (AI) are highlighted. For a matter of clarity, these AI uses are introduced in the same order that BMS modules were discussed before: inventory, performance and maintenance optimization modules.

3.1 Inventory Module

Inventory module in many BMS still consists on simple tables where bridge data is stored. This is not adequate as the stocks increase. Thus, first improvement mandatory for those BMS that do not already have that implemented, is to move to better database technologies. Relational databases are the most widely used technology to this purpose. However, as the databases increase, both in terms of number of bridges but most importantly, in terms of the amount of data being collected per bridge, new technologies should be considered in the next years. This aspect is further discussed.

On the other hand, even the data already existing in the inventory module, is not being fully used. In fact, majority of BMS seldom explore other data besides bridge condition state rate. However, it would be very relevant to take advantage of all other data available in the inventory module. This would allow identifying behavioural tendencies, which would then be important in the definition of bridges' clusters, thus improving the results obtained by performance module [7,8].

3.2 Performance Module

As referred in section 2.2, one of the types of performance models already being used consists on artificial intelligence algorithms. Several examples can be found in the literature of the use of such models.

Ariza et al. [9] is one of several examples that could been shown. In particular, in that work a comparison was made between AI performance prediction models and the most commonly used stochastic models. It was clearly shown the superior behaviour of AI models when compared to stochastic ones. However, it was also highlighted that more data is employed in AI models. In that work, from the 116 data types available in the bridges' database, only 8 were used in the final model.

This aspect, further emphasizes the importance of developing new models that further explore the available databases. It is a waste of time and resources to collect large sets of data if, at the end of the day, only small parts of it are used.

3.3 Maintenance Optimization Module

At a first glance, from all the three modules in classical BMS, this would be the module in which AI algorithms might seem to fit better. This is somehow right. In fact, majority of optimization algorithms implemented in optimization modules belong to the family of AI algorithms.

One example of maintenance optimization module was presented by Denysiuk et al. [10]. To this purpose, a multi-objective optimization algorithm was implemented. This algorithm aimed at defining the best maintenance actions' schedule, which simultaneously minimized the deterioration of the bridge and the total costs of the maintenance actions during the analysis period.

4 FUTURE BRIDGE MANAGEMENT SYSTEMS

The future of bridge management systems is highly associated with the future of the sector to which it belongs. Nowadays, a transition to digitalization is taking place in the Architecture, Engineering and Construction (AEC) sector. The most visible aspect of this transition is related with the Building Information Modelling (BIM) working philosophy, even though this digitalization transition goes far behind it, and concepts such as virtual reality or augmented reality are no longer just buzz words in the sector [11].

In the context of the present work, what is relevant to emphasize is that next generation of BMS are already being developed considering their capability to be used in a BIM context [12]. To this purpose, the most direct impact in the classical BMS presented in previous sections, is associated with inventory module. In fact, the data associated to each bridge available in the inventory will now be replaced by bridge digital models, usually designated BrIM (Bridge Information Models). Hence, all the functionalities that are nowadays included in existing BMS, will need to be adapted to this new context. On the other hand, new functionalities are expected to be added in the next generation of BMS, taking advantage of the digital environment in which the entire bridge management process will take place.

Analysing what can be this digital BMS and some of the features it might have, several aspects are easily found, in which AI tools will essential.

Firstly, the problem of creating the BrIM itself. While this can be done by hand from scratch, using any of the several BIM software available, that is not feasible for large stocks of bridges. The process being attempted, consists on the use of laser scanners to obtain the cloud of points which represent the external surfaces of the bridge components. Then, this cloud of points is imported to the BIM software and structural elements are created using the cloud of points as reference. The idea is to inscribe the structural elements inside the cloud of points, so that the external surface of the elements lies over the cloud of points. This process is time-consuming and new algorithms are required to allow element detection, directly from the cloud points. In this regard, artificial intelligence algorithms would be certainly valuable in the near future, even though work in this topic is already undergoing [13].

Secondly, assuming BrIM models are already in place, one can look at the use of data contained in those models. At this stage, two main issues might arise, one related with the number of parameters (or the number of data types involved) and another one related with the amount of data (total amount of memory required to store data) involved.

One solution to the first aspect might be related with the use of different database technologies. Recently NoSQL was proposed as alternative to traditionally used relational databases [14]. Likewise, one solution to second aspect might be found in the adoption of big data technologies [15]. In both situations, it is not difficult to foresee the appearance of other alternatives based on the use of AI in the near future. In fact, there are very good AI algorithms that can be applied in these contexts.

Thirdly, now that BrIM and tools to use the data stored are in place, one might think on how to update the existing models as new data becomes available. This might be the case of updating the BrIM with data obtained in new inspections or data obtained from some intervention made on the bridge. To address this issues, several research works are undergoing presently worldwide. In particular, works related with updating BrIM with damage detected in bridges' inspection are already being conducted [16,17].

5 CONCLUSION

The common practice in bridges management is nowadays assisted by the use of Bridge Management Systems (BMS). An overview on the evolution of such systems was presented, and the most relevant features were detailed in the present work. It was then highlighted some successful application of Artificial Intelligence (AI) algorithms in the context of existing BMS.

Considering the future developments associated with BMS, it is now clear that Bridge Information Modelling (BrIM) is the direction in which all BMS should evolve in the next years. BrIM should be a reality in the near future, thus a more efficient management of bridges is expected to occur. Also in this regard, AI tools are expected to play an important role. Several examples of aspects that will benefit from the use of AI were left herein.

A fully integrated approach, supported by AI tools, should be the next step in bridge management systems' evolution after BrIM become standard. In that longer future, when the technology allows us to, a complete Digital Twin model of the whole network will be possible. While today it might seem an ambitious goal, it is almost an inevitable one and all signs point in that direction [18].

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