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Artificial Neural Network for Transportation Infrastructure Systems

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Abstract. Artificial Neural Networks (ANNs) represents the overall interconnection of the systems together with numeric weighting that can be tuned based on experience, system Inputs, Processing and Outputs. Moreover, the real advantage of ANNs is the ability to solve complex system problems such as one which are found within the Transportation Infrastructure Systems. Artificial Neural Networks (ANNs) for Transportation Infrastructure System must incorporate system engineering techniques that will be sustainable for future years and maintained at acceptable levels. Accordingly, this paper will introduce the concept of Artificial Neural Networks (ANNs) and its core functions for the optimization of Transportation Infrastructure Systems in particular the maintenance processes.

1 Introduction

Generally, Artificial Neural Networks (ANNs) are nonlinear models that are non-parametric and are utilized to determine approximate functioning of a System for a real-life application. Commonly, the core action of Artificial Neural Networks (ANNs) tends to fall within the process and control categories [1].
Furthermore, the Artificial Neural Networks (ANNs) also represents the total interconnection of the systems together with numeric weights that can be tuned based on experience, making neural nets adaptive to inputs, and capable of learning [8], [9].

Although, ANN with Back Propagation (BP) learning algorithm is widely used in solving various classification and forecasting problems; streamlined ANNs are employed to treat super complicated problems in which too many variables need to be simplified in a model. ANN are also powerful data-driven, and flexible computational tool having the capability of capturing nonlinear and complex underlying characteristics of any physical process with a high degree of accuracy [8].

Furthermore, ANN are suitable for inverse modeling when the numerical relations between input and output variables are unknown, and cannot be established.

The main advantages of using Artificial Neural Networks (ANN) include ability to [9]:

- Operate large amount of data sets.
- Implicitly detect complex nonlinear relationships between dependent and independent variables.
- Detect all possible interactions between predictor variables.

Moreover, the real advantage of ANNs is the ability to solve complex system problems such as one which are found within the Transportation Infrastructure Systems (TIS). Transportation Infrastructure is seen as the interconnectivity between the physical and tangible assets that is required to support and develop a nation. It is therefore essential to administer the Transportation Infrastructure efficiently in order to provide continuous, sustainable and economic services to the population. A fundamental aspect of this effective administration is the design of Transportation Infrastructure Systems (TIS).

There are many competitive factors currently impacting the Transportation sector, which requires careful system considerations such as; the high capital cost of design and construction, changes to the legislations, and the impact of the increase in demand and usage of Transport Infrastructure [5]. Other areas which require careful system consideration include [4], [5]:

- Transport Infrastructure Planning and Development. Transport Infrastructure Planning and Development involves the various aspects of land use planning, building construction and land subdivision which are administered by governments at all levels. The aim is to achieve high quality and sustainable development outcomes in the urban and rural areas, and taking into account important issues such as preservation of the physical environment as a part of broader Transport Infrastructure Planning and Development assessment.
- Transport Infrastructure Economic Development. The main aim of major cities role as an increasingly dominant regional service centers are underpinned by a strong regional economy based in manufacturing, logistics, wholesale trades etc. Thus indicating the importance of regional areas, since their economy is usually dynamic and vibrant, making it well placed to cope with future economical structural changes resulting from the needs of an ever-changing demographic profile. As a part of a general economic development, regional economic development program for Transport Infrastructure needs

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to be created and encompass into any Transport Infrastructure Systems (TIS). The proposed TIS, in an economic sense (as well as overall methodology) is robust, sequential and more adaptive, and considers more parameters (such as Engineering requirements) than the other existing generic models.

- Transport Infrastructure Engineering Requirements [11]. These requirements provide fundamental tools of evaluation of Transport Infrastructure and their performances. These are four fundamental aspects (The Four Core Elements) which need to be built-in into the Transport Infrastructure Systems (TIS). The four Core Elements are:-

1) Infrastructure Asset Rehabilitation and Renewal. This element includes the assessment and renewal of all assets such as bridges, roads, and buildings. As a part of Infrastructure Asset rehabilitation and renewal this first core element initially includes *"Evaluating asset condition and performance"*. Once an extensive and detail asset condition and performance evaluation has been applied, the second phase *"developing an asset renewal strategy"* commences. This involves the identification of future asset renewal costs and addressing the prioritization and funding of the typical liabilities.
2) Structural Performance and Operation. This element includes, damage threshold for structures, performance of structures to extreme events such as act of GOD including earthquakes, and/or strategies for the development of the next generation of standards. This area includes the management and supervision of the Transportation Infrastructure Assets via theories and techniques such as structure performance analysis. The structure performance analysis methods are alternatives to avoid the computational complexity problem associated with other techniques such as discrete event simulation. In this process even if a finished conceptual and technical framework is not yet obtainable, significant advantages have been obtained not only from performance but also from correctness analysis stages.
3) Sustainable and Tangible Materials. This element includes the thorough investigation of utilized materials such as, Concrete, Timber, Iron, Steel and Asphalt. In addition, Sustainable and Tangible Materials approach could include developing new materials processes to enhance sustainability by decreasing pollution, emissions, energy consumption and improving eco-efficiency of materials processing, and modular construction and advanced materials.
4) Emerging Robust Technologies and Innovative Tools. This element includes the use of software such as RIVA (Real-time Asset Valuation Analysis) or Sensor applications in Infrastructure monitoring, and energy efficient structures. Moreover, this element includes the research, recommendation and implementation of the newly created and derived technologies (expertise, equipment and machinery) within the Transportation Infrastructure Assets. The Emerging Robust Technologies and Innovative Tools will be needed for Transportation Infrastructure Optimization in this new high technological era to meet the public's demand for high-quality and convenient transportation. The successful implementation of these practices will encourage and enable responsible authorities to utilize the new technologies appropriately to complete the works quickly with the minimum disruption to traffic, while incorporating quality that will ensure long-lasting, low-maintenance facilities.

All of these three areas need to be part of any system analysis and design process [11]. The Transportation Infrastructure Systems (TIS) provides this integration and a comprehensive system development strategy.

2 Transportation Infrastructure Systems (TIS)

System Engineering not only provides a structure break down but also stage by stage evaluation and modification [2] [10]. This is the most important stage of any system development, and therefore requires utilizing an appropriate Engineering methodology to further enhance the performance of TIS.

Fig. 1 represents the Engineering Mechanism for Transportation Infrastructure Systems (TIS), and its parameters and their relationship.

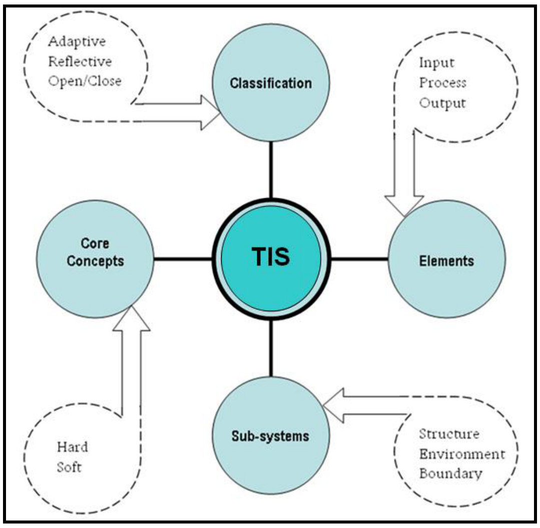

Figure 1. TIS parameters.

A primary objective, when designing the appropriate System parameters is not only to create a System and Sub-system mechanism but also (as demonstrated in figure 4), to establish classification and elements of the System. While the sub-systems typically deal with system environment and structure, system classification and elements provide the additional sub-categorization [6].

On the other hand, while the core concepts of System could be straight forward since it deals with Soft and Hard methodology, the elements is where the essential design questions will be considered. The process of System

Engineering Mechanism for TIS is unique and innovative and thus is the central methodology of this paper. To better design an operative TIS a comprehensive Transportation Infrastructure Management System (TIMS) need to be established.

3 Transportation Infrastructure Management System (TIMS)

As it can notice in Fig. 2, TIMS is a very dedicated process which deals with Varity of Transportation parameters. As a result, TIMS usually covers many subsystems, among which Pavement Management System (PMS) and Bridge Management System (BMS) are the most important.

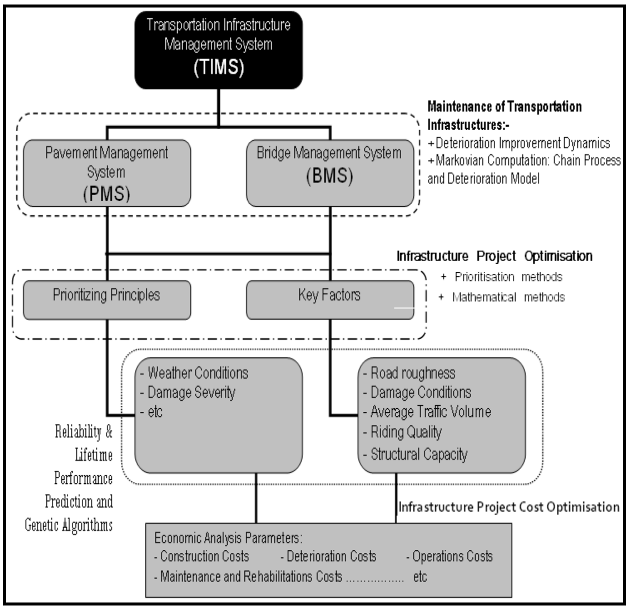

Figure 3. TIMS and its primary Sub-systems [3].

Achieving the ultimate goal of having an effective and successfully operative Transportation Infrastructure Management System (TIMS), dictates the collection of sizable data which relate to the condition of the various transportation infrastructures. This is imperative and necessary to be able to effectively carry out the TIS optimization process.

Furthermore, TIS performance models need to be constantly developed and maintained to assist with the development of priorities. In addition, in determining TIS performance enhancement, all of the TIMS and its subsystems need to be carefully analyzed and integrated. Also, and as part of a systematic approach to optimizing TIS, this paper promotes using a condition enhancement approach, which in turn augments the overall performance of the transportation infrastructure.

Characteristics of the different prioritization methods can be found in Gharehbaghi (2014). The mathematical optimization for TIMS, on the other hand, falls into two categories: static and dynamic. The latter is made possible via Dynamic Programming [5] and [6]. The static and dynamic categories usually use the maintenance strategy together with budgetary constraints as the decision variables. While the *static* category incorporates certain constant variables, the *dynamic* category is the most important and includes maintenance activities.

4 Damage detection and monitoring techniques

As Gharehbaghi (2015) correctly argued, the traditional damage detection strategies consist of visual inspection and localized non-destructive evaluation such as radio X-ray, Radiographic, Eddy current and Ultrasonic techniques. Moreover, the damages are normally modeled by structural parameter reduction (ie Young's modulus) other than establishing the damage (crack) scheme. On the other hand the monitoring techniques aim is to provide a proper structural diagnosis of the 'state' of the constituent materials, of the different parts, and of the full assembled and functioning structures. These two steps are perhaps the most appropriate of ANN application.

5 The use of ANN in damage detection and monitoring techniques

Generally, several damage detection schemes utilize neural networks to detect, localize, and quantify damage in structures. Zapico et al. (2001) utilized number of neural networks for damage assessment, namely the multilayer perceptron (MLP) network with back propagation and the radial basis function (RBF) network. They concluded that the MLP network might be used in connection with vibration-based inspection whereas the RBF network completely failed. Although there are other authors who have instigated various ANN models, none were closely aligned with TIS parameters, which are proposed in this paper.

6 Artificial Neural Network (ANN) for transportation infrastructure systems

The ANNs have significant advantages in particular for data mining prediction and Classification [7]. In addition, ANNs provides specific System tools such as Control devices which once utilized effectively, would be a significant benefits for specific domains such as Transportation Infrastructure. The proposed model (Fig. 3) is a robust prototype and it has additional benefits especially for the Process Control and System Performance predictions. These two (process control and system performance) are fundamental part of Transportation Infrastructure systems, thus any artificial Neural Network collaborations need to incorporates both TIS and TIMS.

ANNs for Transportation Infrastructure System must incorporate engineering techniques that will be sustainable for future years and be maintained at acceptable levels. As it can be noticed, the ANN for TIS is a *multi-layer* and involves traditional Inputs, Processing and Outputs stages. This procedure involves a general system engineering approach:-

$$\therefore\ IX_n \rightarrow \Sigma wq_n \rightarrow Ox_{nq}$$

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where:

- IX_1 …… IX_n = input: Transportation System Parameters = TIS
- W = Weights (TIMS)
- q = Function } • ***Process Control***
- OX_{1q}……. OX_{nq} = output: solution based on each of TIMS functions. ***System Performance***

Of these three system engineering stages, the most involving is the actual process control stage where it incorporates both weights (TIMS) together with the function segmentation. This process stage is a multi-layer segmentation where the system core exists.

The overall performance of this model needs to be constantly developed and maintained to assist with the total development of priorities. In addition, in determining system performance enhancement, all the three main system stages need to be carefully analyzed and integrated holistically.

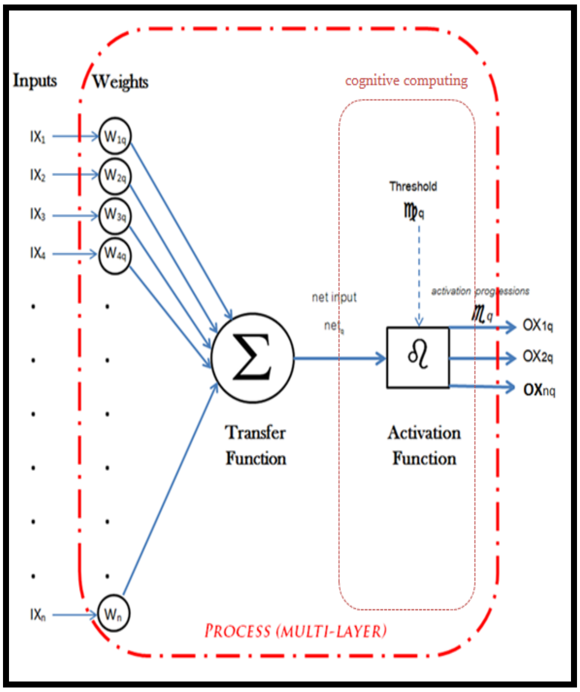

Figure 3. Artificial neural network function for transportation infrastructure systems.

7 Application of ANN for improved maintenance of transportation infrastructure

The inclusive application of ANN and improved maintenance of Transportation Infrastructures can be maximized in particular for the condition assessment of Transportation Infrastructures via the process control and system performance. This condition assessment should primary focus on the evaluation of the state of health, and then on concentrate on the regional or local damage assessment.

The utilization of ANN (multi-layer), involves: setting up the system parameters limits which categorizes the condition status; diagnosing the existing damage including the severity level; and finally measuring the consequence of damage on structural reliability scale. Conclusively, these steps consist with the mentioned damage detection and monitoring techniques.

Presently this model is in its development stage and hence need to combine working examples to further improve the ANN. These working case studies could consist of three main classifications of Transportation Infrastructures: Sea, Road, and Air Transportations Infrastructures. Furthermore, these case studies will be further refined into additional sub-classifications depending on their size, complexity and uniqueness. With the above processes, the proposed model could be refined specifically for an explicit group of Transportation Infrastructure assets.

8 Example of ANN for transportation infrastructure systems

ANN is ideal as a part of the Transportation Maintenance regime. Over time, traffic and environmental effects will damage traditional road surfaces, which require rehabilitation.

Although life expectation of Transportation maintenance projects varies from country to country, a typical expectation of several decades of service can be expected with major rehabilitation efforts performed depending on the planned schedules. Table 1, provides examples of ANN.

Table 1. ANN examples for periodic maintenance

Input (IX_n)	Process (Σwq_n)	Output (Ox_{nq})
Grading (IX_1)	Site preparation (Σwq_1)	Light and Heavy Grading (Ox_{1q})
Gravel Resurfacing (IX_2)	Site set up (Σwq_2)	Re-gravelling (Ox_{2q})
Bituminous Pavement (IX_3)	Repair of the pavement edges (Σwq_3)	Fog Seal (Ox_{3q})
Surface Treatment Resurfacing (IX_4)	Single surface dressing Resurfacing with 30mm asphalt concrete overlay (Σwq_4)	Slurry or Cape seal (Ox_{4q})

As it can be noticed, the examples of ANN are robust and specific especially for the Process Control and System Performance predictions. Accordingly, this table can be utilized (via various ANN software) to further develop and improve specific maintenance regimes, as shown in Fig. 4.

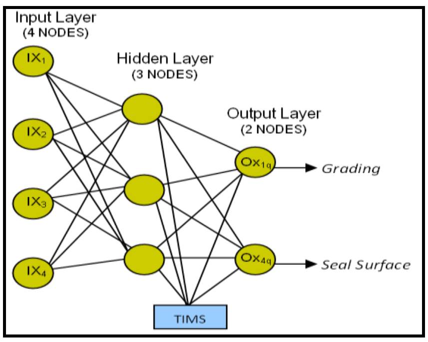

Figure 4. ANN example for periodic maintenance.

As it can be noticed the Fig. 4 consists of 9 interlinks. Although one issue with ANN is its ability to only converge to the local optimization, with the use of TIMS as a subsequent association this can be surpassed. In addition, the output layers can also be altered to represent the actual maintenance procedure more intimately.

9 Conclusion

Artificial Neural Networks (ANNs) represents the overall interconnection of the systems together with numeric weights that can be tuned based on experience, system Inputs, Processing and Outputs. This paper discussed the concept of a robust and sequential Artificial Neural Network (ANN) specifically for the Transportation Infrastructure Systems (TIS). In doing so this paper also argued the importance of ANN specifically as a part of damage detection and monitoring techniques régime.

As this paper demonstrated that ANN has many advantages if the problems cannot be solved by clear algorithm. In addition, ANN has the ability to be instructed to handle large dataset. There are various intelligent algorithms available and accordingly ANN is not a new concept. However the ANN overall ability to solve complex and interchangeable system problems (such as one which are found within the Transportation Infrastructure Systems) is its core advantage. Accordingly, this paper investigated and discussed the ANNs and its core functions for optimization of Transportation Infrastructure Systems.

Finally this paper presented an example of ANN for the Periodic Maintenance of Transportation Infrastructure. This example not only demonstrates the overall benefit of ANN but furthermore validates its process as the basis of the optimized Transportation Infrastructure Systems. Upon successful amalgamation, the proposed model could be specifically refined for definite group of Transportation Infrastructure assets. Lastly, the Fuzzy theories could also be utilized to further enhance the proposed model performance, thus further optimizing the results.

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