The hyperconnected world gives rise to Big Data implementations where an abundance of data from sensor networks can provide continuous information on the behaviour and performance of infrastructure. The last part of the 3rd Industrial Revolution (3IR) and the start of the 4th Industrial Revolution (4IR) gave rise to a world with over 8.4 billion connected devices currently, and expectations are that the number of Internet of Things (IoT) devices will grow to more than 1 trillion in the foreseeable future [1].

The hyperconnected 4IR environment allows integration between physical data systems and virtual systems. A further feature of the hyperconnected 4IR environment is the ability to ‘segment’ connected pavement; Digital twins; Intelligent infrastructure and background planning for future scenarios where the proliferation of data is a given, it is important that practitioners, and practitioners. With this background, the paper evaluates a few concepts of the hyperconnected environment and the connected pavement environment in a 4IR Digital Twin mode, with the connected 4IR environment allowing integration between physical data systems and virtual systems. 4IR supports the datafication of life, data science, big data, transportation evolution, optimization of logistic and supply chains and automation of various aspects of life, including vehicles and road infrastructure. The hyperconnected environment, where an abundance of data from sensor networks can provide continuous information on the behaviour and performance of infrastructure. The last part of the 3rd Industrial Revolution (3IR) gave rise to a world where this overabundance of sensors, and availability of wireless communications (including Wi-Fi, 5G, G mobile, Bluetooth®, LoRAWAN®, SigFOX®, etc.) enables co-sensing of data from previously unconnectable places.

Big Data implementations can provide for improved connected pavement; Digital twins; Intelligent infrastructure applications of DT implementations can provide for improved connected pavement; Digital twins; Intelligent infrastructure lifecycle management of infrastructure. In this regard, and planning for future scenarios where the proliferation of data is a given, it is important that practitioners, and practitioners. With this background, the paper evaluates a few concepts of the hyperconnected environment and the connected pavement environment in a 4IR Digital Twin mode, with the connected 4IR environment allowing integration between physical data systems and virtual systems. 4IR supports the datafication of life, data science, big data, transportation evolution, optimization of logistic and supply chains and automation of various aspects of life, including vehicles and road infrastructure. The hyperconnected environment, where an abundance of data from sensor networks can provide continuous information on the behaviour and performance of infrastructure. The last part of the 3rd Industrial Revolution (3IR) gave rise to a world where this overabundance of sensors, and availability of wireless communications (including Wi-Fi, 5G, G mobile, Bluetooth®, LoRAWAN®, SigFOX®, etc.) enables co-sensing of data from previously unconnectable places.

Keywords
Connected pavement; Digital twins; Intelligent infrastructure

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2. Hyper-connections in pavement engineering

The focus of this paper is a hyper-connected pavement environment in a 4IR DT mode, with connections in pavement engineering as shown in a simplified schematic in Fig. 1. Artificial Intelligence (AI) camera sensors are offered as guidelines for further investigation and reflection. With this background, the paper evaluates a few concepts of the connected pavement environment (road furniture and structures are excluded in this paper, but obviously form a large portion of the bigger DT of the infrastructure environment) which can become part of the standard Pavement Management System (PMS) operations of the road owner facility showed counting accuracy of 5% compared to actual traffic counts.

Environmental conditions play a major role in the behaviour of any pavement structure. This includes temperature, stress / strain conditions that requires a flag to be incorporated in the vehicles [18]. Hyper-connected systems typically consist of sporadic data collections with long intervals (typically annual), the current environment enables initiatives that incorporate sensors that communicate continuously through variety options (Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Vehicle to Everything (V2X)), depending on the availability of networks to carry the data from the sensors to manage and analyse the data [8, 9]. Parameters that are typically managed in a pavement environment (road furniture and structures are excluded in this paper, but obviously form a large portion of the bigger DT of the infrastructure) often consisted of sporadic data collections with wide intervals. Initiatives that incorporate sensors that communicate continuously through variety options (Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Vehicle to Everything (V2X)) have become a viable alternative to obtain local environmental data. Shadows cast by road furniture or vegetation can for instance be incorporated in the collection and analysis of environmental data. Changes in microclimate conditions can change the microclimate significantly, causing localised failures [14, 16].

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3. Application example

Discussing concepts without actual data can be beneficial for a thought experiment to reflect on potential future environments. However, actual data are useful in demonstrating the potential of such environments with initial inferences regarding the potential benefits of such hyper-connected DT concepts. In some initial experiments incorporated into a DT of a campus environment as well as an agricultural transportation environment, actual data collections already provide some inferences on the potential benefits of continuously collected data.

3.1. Digital twin infrastructure

The Innovation Africa (IA) campus of the University of Pretoria is situated on the eastern edge of the main campus. It consists of 146 ha of original experimental agricultural fields that are currently being redeveloped to enable smart agricultural, infrastructure and transportation research. The Engineering 4.0 facility is one of the latest additions to this campus. It consists of a combination of a national road materials reference laboratory, training laboratory, concrete and related materials laboratory, Accelerated Pavement Testing (APT) track and an active traffic lane on the adjacent highway [19]. Engineering 4.0 is the hub of a LoRAWAN network on this campus from where a host of mostly environmental data are currently collected [20], forming the basis of a DT of this campus.

From a pavement engineering viewpoint the DT incorporates asphalt temperature and base moisture condition data, as well as an AI traffic count and classification facility for the adjacent highway. As an example of the application of DT data from the pavement, Fig. 2 indicates the process of tracking asphalt surfacing data through to expected life effects on the asphalt layer. Fig. 2 starts (left top) with the actual measured temperature inside the 50 mm asphalt layer (constructed on top of a deep granular base layer). A rainfall event suddenly causes a decrease in asphalt temperature from 47°C to 31°C. This causes a change in the modulus of the asphalt of around 62% (top right) which leads to a 24% increase in vertical stress at the interface between the asphalt and the granular base (bottom right) and a resultant decrease in asphalt life of around 55% (bottom left).

Although this is just one example (and obviously dependent on specific environmental data and materials), it highlights the benefit of having access to continuous data from the DT of the pavement, as it can emphasise the effects of sudden environmental changes on the behaviour and expected performance of the pavement structure. This simple example needs to be incorporated into a more complex model where the full history of the pavement structure, also combined with the actual traffic loading on the pavement during the various environmental events, are incorporated. This will lead to a more comprehensive understanding of the continuous influences of environmental and traffic demands on the pavement behaviour and performance.

This process can be expanded to any road network where the appropriate sensors are available. This gives rise to a DT management tool for the pavement.

3.2. Digital twin agricultural transportation

In the hyper-connected agricultural logistics example, a DT is being developed of the transportation process of tomatoes and avocados from the field to the market. Through development of smart fruits [21-23], the experience of the transported fruits can be tracked continuously, providing a clear indication of any locations during the transportation process where stressors (e.g. low riding quality, unmaintained vehicle suspension, etc.) potentially causes damage to the transported goods. Linking this into a road...
4. Implications for pavement engineering

As the proliferation of sensors and networks is leading to a situation where continuous infrastructure information can significantly affect the management and operation of transportation, it is important that pavement engineers understand the fundamental issues such as route optimization for low-stress locations in the network.

Data analytics: Development of models to process the abundance of data from sensors networks can provide continuous data collection will have a significant beneficial effect on service levels and infrastructure management based on continuous data collection will have a significant beneficial effect on service levels and infrastructure management.

Decision making: Examples such as “how quickly should the pavement engineer react to changes in data from the pavement?”, “What level of changes constitute a need for action regarding maintenance?”, etc., require. This may affect the condition of the pavement at the time of maintenance or replacement; ongoing maintenance and replacement when needed is required. This may affect the condition of the pavement at a time of maintenance or replacement.

As the pavement realm is becoming a hyper connected environment where an industry-wide understanding is required to be developed on the implications of outputs on pavement engineering: A clear understanding of infrastructure condition, leading to timeous decision making.
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