Improving Productivity of Road Surfacing operations with the help of Lean and Discrete Event Simulation techniques; a UK case study.

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Abstract

Road surfacing is an important module in Highways Development and Maintenance sector. The resurfacing and rehabilitation of road pavements has become a costly requirement due to large number of private and commercial vehicles using the roads that cause pavements to disintegrate rapidly. The roadworks incur not only direct work costs, but also indirect costs from factors such as congestion, motor accidents, traffic disturbance and pollution. Maintenance activities on the roads usually cause delays and queuing. There is obviously a need for quick and cost effective maintenance that minimizes the occurrences and duration of these disruptions. This research investigates the role of Discrete Event Simulation (DES) to enhance the productivity of the delivery of road surfacing operations through achieving higher production rates and minimum road closure times.

Keywords

Paving, Process Improvement, Productivity, Resurfacing, Discrete Event Simulation

1. Introduction

Road surfacing is a critical component in Highways Development and Maintenance all over the world. In England, Office of National Statistics (2013) claimed that in the first quarter of 2015, the output of road works, as part of infrastructure works, reached up to £1,115 million. New infrastructure and congestion relief projects can be delayed and are usually delayed due to various reasons, mainly financial problems. However, maintenance (resurfacing, rehabilitation etc.) projects cannot be deferred as they directly affect the road network. As soon as a road is built, it starts deteriorating due to many causes like weather, traffic and quality of materials (Department for Transport, 2013). It is a common phenomenon worldwide and its timely mitigation is necessary. Even in a developed country like USA, 32% of roads are in poor or mediocre condition and motorists are paying $67 billion a year in repairs and operating costs (ASCE, 2013). Without appropriate rehabilitation, these structures will eventually collapse causing even bigger challenge for traffic (Christory et al., 2008). Road surfacing process is carried out every night throughout the year in almost every country around the globe. There can be differences in terms of timing, contract types and techniques used, however, the machinery and task is similar everywhere and what really need to change is the working style itself. Furthermore, there is an urgent need for improving the productivity of road works projects within the construction industry to deliver ongoing and future projects with the maximum efficiency and minimum waste

Highways context is very unique when compared to other industries like manufacturing or processing because of its fragmented nature which requires more in depth approach (Dutta et al., 1993; National Research Council 1994). This business consists of various engineering companies, contractors, suppliers, and equipment manufacturers and equipment providers (BIS, 2013). Since different stakeholders are involved in the construction and maintenance of highways at different tier levels, numerous improvement schemes are frequently overlooked due to deficiency of consensus between stakeholders. This was also acknowledged by the Office of the Parliamentary Counsel, (2013) that having more stakeholders in any project makes it complex and the improvement schemes are often ignored. However, if there is an improvement scheme with firm evidence e.g. a computer based simulation model, which manages to take all stakeholders on board, there is less room for rejection.

This paper looks in to current practices of pavement in United Kingdom and then strive to improve the productivity of overall process by 1) using discrete event simulation to find the most efficient methods by performing various what-if scenarios and 2) by improving traditional mapping techniques e.g. value stream mapping with the help of simulation techniques. This paper is further divided in to sections including relationship between lean and DES, case study work, simulation model design, discussion and conclusions.

2. Value Stream Mapping (VSM), a Lean tool and Discrete Event Simulation (DES)

The implementation of simulation techniques in highways context is limited and only a handful of studies have been done to advance the process e.g. by (Maji & Jha, 2009; M Marzouk et al., 2011; Jones 2011). Existing optimisation approaches rely heavily on manual process methods like Process Activity Mapping, Quality Filter Mapping, Decision Point Analysis and Value Stream Mapping. VSM was derived from Toyota production and Lean manufacturing philosophies (Womack et al., 1990). It is defined as a repetitive method to map and analyse value streams to evaluate and connect production process aspects like information and material flows plus other non-value adding actions (Rother and Shook 2003; Lasa et al., 2008).

It is used in improvements schemes like increasing throughput and for reduction of lead time and work in progress (Álvarez et al., 2009). VSM, however, cannot provide hard facts for decision making and simply points toward a direction. It cannot help to forecast analytically the effects on upcoming performance of a system, hence the need of Simulation arises to experiment and evaluate the future behaviour of a scheme (Jarkko et al., 2013). VSM is used frequently in Highways sector, especially Highways England at various levels and processes, which makes it important to optimise it by eliminating its deficiencies to achieve the purpose of this research. Discrete Event Simulation (DES) along with Value Stream Mapping (VSM) has been recognised as a technique that can improve the overall process as well as some specific key areas. The deficiencies in VSM can be reduced by combining it with DES and it has been experimented well in different industries. Literature indicates that manufacturing (Marvel and Standridge, 2009), process (Abdulmalek and Rajgopal, 2007), construction (Jarkko et al., 2013) and healthcare sectors (Xie and Qingjin Peng, 2012) have improved their processes and benefitted from simulation, value stream mapping and the integration of both. Simulation has been trialled in Highways process by (Marzouk et al., 2011), however, it only focussed on a very particular activity (effect of maintenance activities on traffic).

Literature review indicates the use of different approaches to describe productivity. Despite the use of different techniques, the fundamental concepts remain the same. Rebholz, Al-Kaisy, & Nassar (2004) defined productivity in road construction industry as the quantity of laid asphalt in tonnes per hour or per day was adopted. For purposes of this research, this definition was adopted.

3. Case Study work

This section presents a detailed case study of a road surfacing process improvement project at the project level, involving usage of lean tools alongside Discrete Event Simulation to explore opportunities of optimising existing road surfacing process. All types of road work processes, whether new constructions or maintenance work, are classified into two major types i.e. surfacing and resurfacing. Every road surface has its diverse characteristics, which vary according to its geography, location, surrounding terrain, speed related parameters, intended use, and type of pavement. To optimise the current resurfacing operations in

UK, Highways England trialled a lean experiment to identify the wastage in the process and improve it using lean methods. The motivation was to deliver efficiency by maximised output and use of resources, improved utilisation of road space and benefit the travellers through less road closures. There were inefficiencies noticed in the process and due to incompetent working style of subcontractors, huge amount of resources were wasted and traffic was disrupted on daily basis.

After studying the process in detail for a few days, it was noticed that key constraints that must be addressed before start of pavement process were setting up of Traffic Management (typically 15 minutes), material call-off and planer mobilisation (typically 30 minutes), and planning a head start (typically 45 minutes), leading to a total non-value adding the pre-paving time of 1 Hr 30 minutes. Key post-pavement process constraints include rolling (typically 30 minutes), cooling and curing (typically 75 minutes) and Traffic Management removal (typically 30 minutes). This means a total of 2 hours and 15 min post is paving shift period. A safety margin of around 1 Hr 30 Mins is left for safety related activities. Installation and removal of Traffic Management has an average duration between 30 minutes to 45 minutes and depend on a wide range of variables including use of different designs and types of TM, delays and operator/process related variables.

In this particular case, to improve the process and minimise the wastage between motorway closure and planing operation, several opportunities were recognized. The work plan was divided into three major steps. Initially, by allowing an early contact between local traffic control centres, the process was expedited and waiting time for clearance process was shortened. It was noticed that material was called off after the operation starts every night and while the material travels from quarry to work site, workforce was sitting idle. Secondly, traffic management was set out to close two lanes earlier and bring plant and material ahead of full closure (safety constraints were addressed). This assured that plant and material are accessible ahead of full road closure. In order to boost the productivity of pavement process, calling material earlier would allow paver to begin operations early. There is a time lag of 14 minutes involved between planer and paver processes to commence, to allow time for cleaning and preparation. (Moore 2015) The third step was to ensure that work continues close to 6 am – the allocated work window rather than 4:30 am (traditional time). Given the fact that paver utilisation in an average shift is just 33%, doubling pavement productivity by addressing constraints (E.g. earlier mobilisation of paver, full utilisation of work window) has the potential to double paver productivity and thus, the output produced. According to Moore 2015, the possibility of extending work windows particularly over weekends or public holidays, when lesser than average traffic volumes are accepted, provided an opportunity to increase working window, which had a direct positive correlation with productivity. It involved increasing work window to 10 hours and 36 minutes.

Table: 1 Showing Various Improvements in baseline process using lean. (Adapted from Moore 2015)

Activities	Baseline Process	Improved Process
Shift Duration	10 hours	10 hours (staggered)
Working Window (Theoretical)	8 hours (22:00 – 06:00)	13 hours (20:00 to 9:00 am)
Working Window (Actual)	6 Hr 31 Mins (22:08-04:39)	10 hours 36 minutes (21:03 – 7:39)
Tonnage Laid	298 T	1024 Ton
Paving Duration	2 Hr 11 Min	6 hour 50 minutes (22:15 – 5:05am)
Average hourly tonnage laid	137 T (@45 mm thin surfacing)	149 T (@45mm thin surfacing)
Pavement length laid (in meters)	938 m	2700 metres
Paver Productivity	33 % (2Hr 11 Min / 6Hr 31 Min)	64 % (6hr 50 min / 10 hours 36 mins)

4. Simulation Model Design

The definition of the simulation scope is crucial for defining the analysis boundaries. Clearly defined scope of simulation system and boundaries could result in more useful simulation. The scope of simulation development in this study is limited to all activities involved from road surfacing activity start (i.e. from the time of road closure for surfacing purpose) till the road is open again. After defining the boundaries, it is important to identify key assumptions of how the system being studied, act together with its defined external environment (Beaverstock, Greenwood, & Nordgren, 2014). Preparation and logistic activities were included in the model, taken as fixed timings as measured on site, and are not part of the analysis. The simulated operation activities included planing, sweeping and pitch spraying, paving, rolling, white-lining, and testing. Any sub-activities within each one of these activities is not considered. All required material in the process is assumed to be always available and delivered on time. Downtime of equipment is not included in the simulation. Also, the Simulation is based on paving 45mm thick surface course.

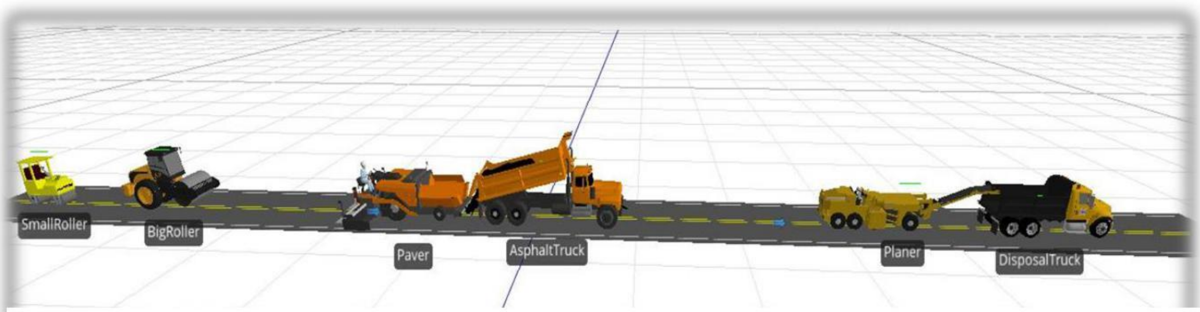

Figure 1 showing the 3d model of asphalt machinery in operation. (Software used Simio)

In modelling the random elements within the road surfacing process, it is important to replace time certain components with a probability distribution. Three randomly distributed components are used: asphalt inter-arrival delivery, asphalt truck position time, and paving times. To determine the probability distributions that are used to model the resurfacing process, historical data collected over 115-night shifts over a six months period was used. To select the suitable Probability Distribution, the historical data collected from 115-night shifts was analysed and tested against Anderson-Darling normality, using a statistical distribution software application (i.e. *Minitab 17)*. Since the paving process constitutes a major operation, other subsidiary processes e.g. planing were assumed to match the production rate of the paver. However, detailed analysis of data indicate the average time for planing is 2.17 tonne/minute, and for paving it is 2.19 tonne/minute (Figure 2).

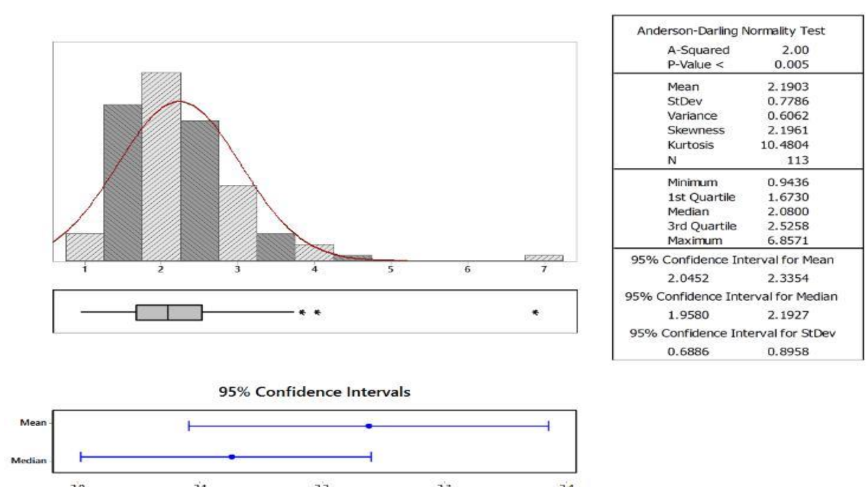

Figure 2 Summary for Paving Rates (Tonnes/min)

The following calculations were done to have unified units to be used in *FlexSim:* Assuming process flow-item equals one (1) tonne of asphalt. For Paving, the average paving rate is 2.19 tonne/min i.e. 131.4 tonne/hr, which means that (1) tonne requires 27.40 sec to be paved.

4.1. Simulation outputs and Validation

With a small difference in values, the simulation outputs came as a confirmation of the need to improve the current state as the percentages of paver utilisation is considered to be low compared to the permissible working window of the shift. The paver is working only for thirty-eight percent (38%) of the time starting from road closure until the road is open again (Table 2). These outputs and percentages provide a credible evidence of the waste existence in the process of road surfacing. It can be concluded that the major waste in the process is in the form of “waiting” for the paver to start processing.

Table: 2 showing Discrete Event Simulation Output of the based on as-is process

As-is Process Simulation		
Output per hour	**Total Output**	**Paver utilization in working time**
136.5 Ton	298 Ton	38.06%

Figure 3 below illustrates simulation model of the improved state. Key improvements involved an order of material before the start of on-site activities. Because of increased of shift size and early commencement of pavement operations, overall paver utilization has reached up to 67%.

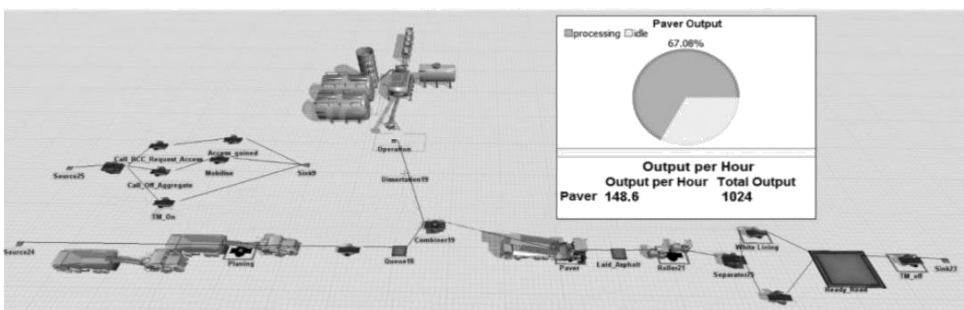

Figure 3 Future-State after Eliminating the "waiting" Waste from the Process

To validate a simulation model, there are two required categories of data. Firstly, there is need to collect robust and detailed data from the job site. Secondly, for validation purpose, empirical data on production rates and machine utilisation rates are required, to allow for a comparison with the model output. The output created by a DES simulation model consists of results mimicking the physical project for the model to be validated. Both categories of data came from various sources including, company's sheets, reports, site observations. Also, some scenarios were simulated to validate the model and they produced the following results:

Table: 3 showing Various what-if Simulated scenerios and their effect on output

Paver Total Output (Tons)	**Paver Average Output (Tons/hour)**	**Paver Utilization (%)**
Scenario 1: Using Two pavers and closing two lanes together		
	276.9	65.3% for each paver

1892		
Scenario 2: Providing a 30 min break from 2:00-2:30 am		
865	126.6	59.7
Scenario 3: Closing two lanes at once and using 2 Pavers		
1892	276.9	65.3 % for each paver
Scenario 4: Closing the Road for 55 hours (like California)		
15,954	358.4	71

5. Discussion & Conclusions

Although, there is an uptake of simulation concepts and tools within the construction industry; there are very few examples and limited use of it within road transportation context. There is alos a need for integrated approach that allow for a comparison between the performances of lean practices to the existing systems (Detty & Yingling, 2000). An Integrated Value Stream Map and Discrete Event Simulation Framework based on the review of literature presented a systematic description of how future VSM can be validated before implementation. McDonald, Aken, and Rentes (2002) explained how the integration might be able to predict the outcomes of dynamic situations that VSM is not capable of addressing alone. Once the current state is mapped, the workflow splits into two paths where DES and VSM are conducted in parallel. The flow diagram of the integrated framework is shown in Figure 4 below.

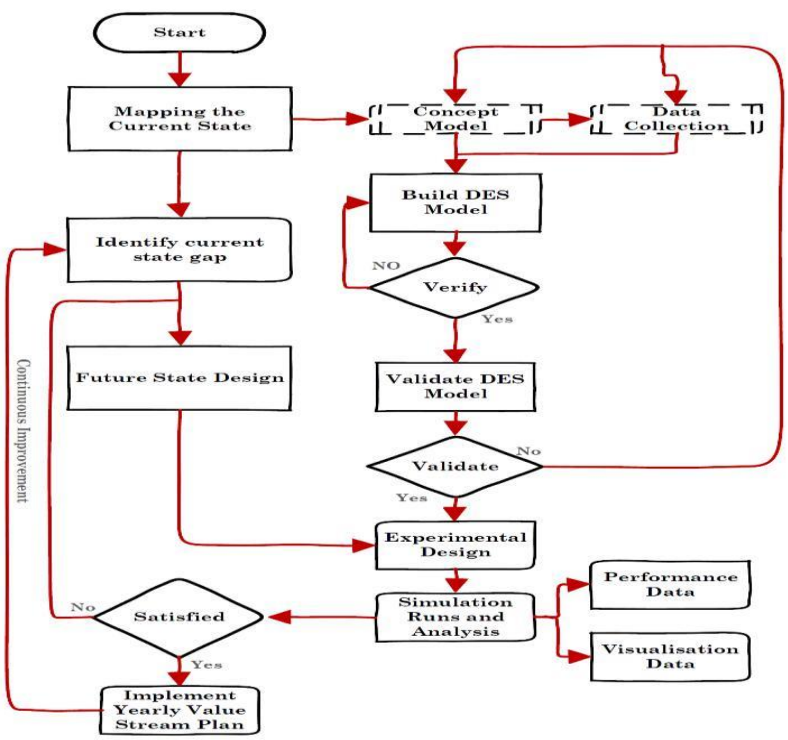

Figure 4 DES-VSM Integration Framework (McDonald, Van Aken, & Rentes, 2002)

This research dealt with the complicity of adopting Lean concepts and process simulation technology in changing the construction industry. It presented a systematic approach for the application of lean construction concepts and tools into computer simulation models. Moreover, research demonstrates how road surfacing productivity can be enhanced by applying lean concepts and tools. These improvements are tangible; noticing the waste (waiting) was eliminated or reduced as well as non-value added activities. The hourly production rate, resource (paver) utilisation, and project duration were improved dramatically, as a result of implementing Lean concepts and tools.

In terms of the simulation, the numbers and rates shown in models output confirm the validity of the built models which open opportunities of producing a template model that includes deeper and more detailed factors that could affect the entire process, such as distance between job site and asphalt plant; failure of machines; delays caused by work accidents, severe weather conditions; delivered Material is failing under initial inspection and more site observation and detailed collection of data are required in order to build a further realistic model.

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