

SHORT NON-REFEREED PAPER

THE USE OF NETWORK ANALYSIS TECHNIQUES TO IDENTIFY OPPORTUNITIES FOR SYSTEM PERFORMANCE IMPROVEMENT IN THE KOMATI TRANSPORT SYSTEM

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Abstract

Identifying opportunities for system performance improvement is often a difficult task when analysing a Complex Adaptive System (CAS) such as the sugarcane supply network of a mill area. With regards to the sugar industry, transport is the thread that connects all the primary agents. Hence, it is where most system problems in the supply chain are bound to transpire. Analysing the transport segment is often important in unlocking opportunities to improve overall system efficiency. In this study, network analysis techniques in the form of correlation graphs were used to study Komati mill delivery data. The application of the graphs revealed interactions within the system which would otherwise have been overlooked or ignored. If implemented correctly, the application of correlation graphs may become a valuable tool to drive system improvements, and thus justifies further research.

Keywords: Complex Adaptive Systems, system performance, network analysis, correlation graphs, Poisson distribution

Introduction

Due to non-linearity, emergent phenomena and large numbers of heterogeneous agents, Complex Adaptive Systems (CAS) are generally difficult to understand, describe, predict or control (Morel and Ramanujam, 1999). This makes it challenging to readily identify opportunities for improving overall system performance. It can be argued that a sugarcane supply network can be viewed as a CAS. There are valuable network analysis techniques that may provide an insight into understanding the CAS. These techniques allow researchers to capture the diverse behaviour and important interactions within groups of heterogeneous agents, such as sugarcane trucks.

In this short paper, correlation graphs (Costa, 2011) were used to study delivery data from the Komati mill. The data included truck arrival times, queuing times, payloads, mill turn-around times and a derived mill crush rate. Analysing the transport segment may be an important key to unlocking opportunities to improve overall supply network system efficiency. The transport segment interconnects the growers and the miller, and larger system problems in the sugarcane supply chain are more likely to transpire here.

Methodology

Komati mill delivery data for the 2010/11 season were used. The data include approximately 80 000 deliveries to the mill over a 245 day milling season. Fourteen daily variables were identified as being potentially important for unpacking underlying patterns in the data. These variables are described in Table 1.

Table 1. Komati mill daily variables.

ABBREVIATION	DESCRIPTION
<i>DOWs</i>	The particular day of the week (Monday, Tuesday.....)
<i>DDev</i>	Number of daily truck deliveries to the mill
<i>AvAR</i>	The average truck arrival rate
<i>SDAR</i>	Standard deviation in hourly crush rate over one day
<i>AvCr</i>	Average daily crush rate
<i>SDCr</i>	Standard deviation of daily crush rate
<i>TUQ</i>	Amount of tonnes in queue
<i>AvQT</i>	Average truck queuing time
<i>P_w</i>	System utilisation
<i>P₀</i>	Probability that queuing area is empty and a truck will not have to queue
<i>PL10</i>	Probability that a truck will wait in queue for less than 10 minutes
<i>PG60</i>	Probability that a truck will wait in queue for more than 60 minutes
<i>P180</i>	Probability that a truck will wait in queue for more than 180 minutes

P_w and P_0 were calculated using techniques from queuing theory. These were based on the assumption that the Komati system followed the M/M/1 queuing model. The M/M/1 model assumes that the inter-arrival times (gaps between two consecutive arrivals) are exponentially distributed. This implies that the number of arrivals occurring within a given interval of time (t) follow a Poisson distribution and are independent of each other. The service times are also assumed to be independent and identically distributed. It has been shown that arrival processes can be considered to be Poisson processes if the system's arrival intervals follow an exponential probability distribution (Taha, 2011). The Komati data fit this criterion. Therefore system utilisation, P_w , and the probability that there are no trucks in the queue, P_0 , were calculated as follows:

$$P_w = \frac{\lambda}{\mu} \dots\dots\dots (1)$$

$$P_0 = 1 - \frac{\lambda}{\mu} \dots\dots\dots (2)$$

where

λ is the daily average truck arrival rate

μ is the daily average service rate, that is the rate at which trucks leave the mill

P_w is the system utilisation

P_0 is the probability that there are no trucks in the queue.

Correlation graphs

All variables were normalised and a 245×245 Pearson correlation matrix between individual days over all the variables was calculated. A strong positive correlation between two days

implies that variables behaved in the same way and that the logistics on those two days were probably similar (Bezuidenhout, 2012). The correlation matrix was then projected as a correlation graph with 245 vertexes and 29 890 edges. Each vertex represents a day in the season and each edge represents the correlation coefficient between two respective days. The large number of edges produces statistical redundancy and the maximum spanning tree (MST) approach was subsequently used to select the most critical correlation coefficients within the data structure. The MST approach is based on Integer Programming and removes all the redundancy without disconnecting any vertex from the network, while simultaneously retaining the strongest overall correlation structure (Bezuidenhout, 2012).

The well documented Kamada-Kawai energising algorithm was then used to determine an equilibrium position for each vertex in the network (Kamada and Kawai, 1989). The PAJEK networking software was used to apply the algorithm to the correlation graph.

Results

Figure 1 displays the connectivity of the different days in the season (numbered according to the day of the year). Based on a betweenness index, the graph has been subdivided into four sub-groups. On closer inspection each sub-group appears to represent particular conditions, viz. (a) days when rainfall was experienced, (b) days when the mill was crushing well, (c) weekends and (d) days when mill maintenance and interruptions occurred.

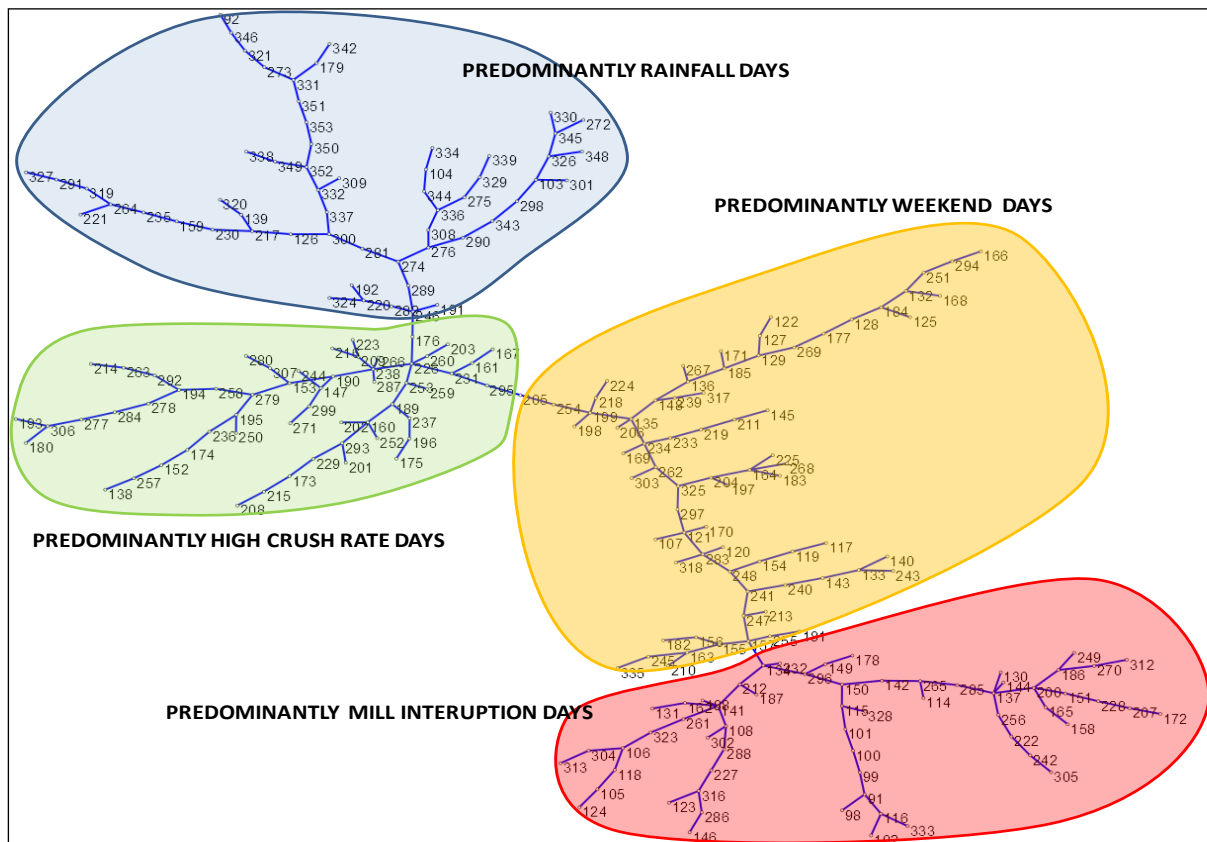


Figure 1. The four main sub-groups with regards to daily performance of the Komati system.

Discussion and Conclusion

The study revealed that the Komati mill area system is made up of four distinct operational modes. From a logistics perspective, there may be scope to change the overall rules that manage the system during different modes. The application of correlation graphs was able to reveal interactions within the system, which would otherwise have been overlooked or ignored. Correlation graphing is a valuable and robust approach to unpack and identify system efficiencies, and justifies further research.

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