PROCEEDINGS OF THE MATHEMATICS IN INDUSTRY STUDY GROUP

2015

Mathematics in Industry Study Group South Africa
MISGSA 2015

The manuscripts for the Proceedings of the MISGSA were written by the problem moderators in consultation with the other members of the study group for that problem and the industry representative.

The Editor of the Proceedings was

Prof D P Mason (University of the Witwatersrand, Johannesburg)

The Technical Reports were submitted to the Editor. Each Report was refereed by one referee. On the recommendation of the referees the Reports were accepted for the Proceedings subject to corrections and minor revisions. The Editor would like to thank the referees for their assistance by refereeing the Reports for the Proceedings.

Printed by the University of the Witwatersrand

ISBN 978-0-9870336-5-9

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PREFACE

The twelfth Mathematics in Industry Study Group (MISG) in South Africa was held in the African Institute for Mathematical Sciences, Muizenberg, Cape Town, from Monday 12 January to Friday 16 January 2015.

The total number of registered participants at the MISG was fifty-two. There were eight academic staff, thirty-four graduate students, five industry representatives and five invited guests. The invited guests were:

Chris Breward	Oxford Centre for Collaborative Applied Mathematics, University of Oxford
Graeme Hocking	Murdoch University, Western Australia, Australia
Neville Fowkes	University of Western Australia, Australia
Sarah Mitchell	University of Limerick, Ireland
Tim Myers	Centre de Recerca Matematica, Barcelona, Spain

The South African Universities and Institutes which were represented were:

African Institute for Mathematical Sciences
University of Cape Town
North-West University
University of KwaZulu-Natal
University of Venda
University of the Witwatersrand, Johannesburg

The MISG Workshop was opened by Professor Barry Green, Director of the African Institute for Mathematical Sciences (AIMS).

The MISG Workshop followed the established format for Study Group meetings held throughout the world. South African industry had been

approached to submit problems during 2014. Six problems were submitted. On Monday morning each Industry Representative made a twenty-five minute presentation in which the problem was described and outlined. The academics and graduate students then split into small study groups and worked on the problems of their choice. Some participants worked on one problem while others moved between problems and made contributions to several problems. Each problem was co-ordinated by a senior moderator and one or more student moderators. The role of the senior moderator was to co-ordinate the research on the problem during the week of the meeting and also to do preparatory work including literature searches before the meeting. The main function of the student moderators was to present short reports at the end of each working day on the progress made that day. The moderators were in contact with the Industry Representatives throughout the meeting. On Friday morning there was a full report back session to industry. Each senior moderator, with assistance from the student moderators, made a twenty-five minute presentation, summing up the progress made and the results that were obtained. Each Industry Representative then had five minutes to comment on the progress and the results which were reported. The MISG ended at lunch time on Friday.

The MISG was preceded by a Graduate Workshop from Wednesday 7 January to Saturday 10 January 2015. The objective of the graduate Workshop is to provide the graduate students with the necessary background to make a positive contribution to the MISG the following week. The students were given hands-on experience at working in small groups on problems of industrial origin, some of which were presented at previous MISG meetings, at interacting scientifically and at presenting oral reports on their findings. Four problems were presented to the graduate students. The problems and the presenters were:

Mine exploration	Jeff Sanders, Afican Institute for Mathematical Sciences and University of Stellenbosch

Optimal strategy for the conservation of the white Rhinoceros population in South Africa	Ashleigh Hutchinson University of the Witwatersrand
Support to rock excavations provided by liners	David Mason University of the Witwatersrand
Taxis in the BRT bus lanes	Neville Fowkes University of Western Australia

The graduate students worked in small study groups on the problem of their choice. Each group presented their results at a report back session on Saturday afternoon.

The sponsors of the Graduate Workshop and the MISG were:

- Hermann Ohlthaver Trust
- African Institute for Mathematical Sciences
- Centre of Excellence in Mathematical and Statistical Sciences

We thank the sponsors without whose support the Graduate Workshop and the MISG could not have taken place.

List of Delegates

Academic staff	
Ali, Montaz	University of the Witwatersrand
Breward, Chris	University of Oxford, England
Fareo, Gideon	University of the Witwatersrand
Fowkes, Neville	University of Western Australia, Australia
Hocking, Graeme	Murdoch University, Perth, Australia
Hutchinson, Ashleigh	University of the Witwatersrand
Jacobs, Byron	University of the Witwatersrand
Khalique, Masood	North-West University
Macdevette, Michelle	Centre for Research in Computational and Applied Mechanics, University of Cape Town
Mason, David	University of the Witwatersrand
Michell, Sarah	University of Limerick, Ireland
Myers, Tim	Centre de Recerca Matematica, Barcelona, Spain
Sears, Michael	University of the Witwatersrand
Postdoctoral Fellows	
Graduate Students	
Akugbe, Arasomwan	University of KwaZulu-Natal
Amar, Gilad	University of Cape Town
Akinyelu, Ayobamia	University of KwaZulu-Natal
Aphane, Dominic	University of the Witwatersrand

Bharath, Yachna	University of the Witwatersrand
Carrim, Abdul	University of the Witwatersrand
Carvalho, Cindy	University of the Witwatersrand
Gibson, Emma	University of the Witwatersrand
Choongo, Wilson	African Institute for Mathematical Sciences
Lourenco, Marcio	University of the Witwatersrand
Magagula, Vusi	University of KwaZulu-Natal
Magan, Avnish	University of the Witwatersrand
Makibelo, Vuvelwa	University of the Witwatersrand
Masakuna Jordan	African Institute for Mathematical Sciences
Mashigo, Thato	University of the Witwatersrand
Matshaba, Fulufhelo	University of Venda
Matuwane, Collen	University of the Witwatersrand
Mdingi, Sibabalwe	University of the Witwatersrand
Mhlanga, Washington	University of the Witwatersrand
Mncube, Busisiwe	University of the Witwatersrand
Mohammed, Mozzamil	African Institute for Mathematical Sciences
Molubi, Atlegang	University of the Witwatersrand
Mothapo, Mokhusu	University of the Witwatersrand
Motsepa, Tanki	North-West University
Mubai, Erick	University of the Witwatersrand
Mutandwa, Aron	University of the Witwatersrand
Nchabeleng, Mathibele	University of the Witwatersrand
Ndlovu, Nkosinathi	University of the Witwatersrand
Ndou, Ndivhuwo	University of Venda

Ngcobo, Zamafuze	University to the Witwatersrand
Nnakenyi, Assumpta	African Institute for Mathematical Sciences
Olusanya, Micheal	University of KwaZulu-Natal
Phora, Nelson	University of the Witwatersrand
Sejeso, Matthews	University of the Witwatersrand
Shingange, Matimba	University of the Witwatersrand
Staats, Kai	African Institute for Mathematical Sciences
Vukeya, Xichavo	University of the Witwatersrand
Wate, Maria-Helena	University of the Witwatersrand
Yemata, Reine	African Institute for Mathematical Sciences
Zoras, Despina	University of the Witwatersrand
Industry Representatives	
Fanucchi, Dario	Isazi consulting
Jack, Sam	Plant Conservation Research Unit, University of Cape Town
Loubser, Richard	Sugar Milling Research Institute, Durban
'T Sas-Rolfes, Michael	Conservation Economist (Independent)
Yilmah, Halil	School of Mining Engineering, University of the Witwatersrand

PROBLEMS

ENERGY EFFICIENCY INDEX FOR THE SOUTH AFRICAN SUGAR INDUSTRY

Industry: Sugar

Industry Representative:

Richard Loubser, Sugar Milling Research Institute, University of KwaZulu-Natal

Problem Statement

The sugar industry is moving from a pure sugar producer to a sugar cane processing industry. Although the main product will be sugar, several co-products will be produced. These products could include co-generated electricity and ethanol amongst others. The production of these co-products will require more efficient use of energy in the sugar manufacture process.

The aim of this project is to provide an index for comparing the energy efficiency of unit operations between factories. The index used to compare the operations needs to be independent of the detailed configuration within each of the factories.

The operations in the factory can be broadly divided into the following categories:

- Cane preparation – knifing and shredding
- Extraction – mill or diffuser
- Evaporation – four or five effects with various vapour bleed configurations.
- Pan boiling and centrifugation – using different bled vapours or exhaust steam
- Drying and conditioning
- Steam generation – boilers of various types and pressures

The index will be used to assist in identifying areas in the factory where operations are deteriorating and maintenance interventions are required. Comparison between factories will be used to justify capital expenditure to change configurations with the aim of improving energy efficiency closer to theoretical maximum.

THE USE OF SPRAY-ON LINERS FOR WALL STABILISATION IN MINES

Industry: Mining

Industry Representative:

Halil Yilmaz, School of Mining Engineering, University of the Witwatersrand, Johannesburg.

Problem Statement

Thin Spray-on Liners (TSLs) are applied in various mining environments for ground stabilization reasons. TSLs are expected to resist rock failure and in cases of failure they are expected to stabilize discrete rock blocks by resisting dilation. The TSL application could be on rocks with varying properties and structural compositions. The magnitude of closure or convergence on excavation boundaries tend to increase with depth. There have been a number of success or failure cases in the mining industry in terms to TSL applications.

TSLs have various mechanical properties, such as material tensile or shear strengths, tensile or shear-bond strengths, which can be tested in the laboratory. The magnitudes of these mechanical properties are variable. Normally, TSLs with high tensile strengths are stiffer and have higher bond strengths and vice versa. The end-users are facing a dilemma in the selection of the right TSL since there has been, so far, weak research effort in formulating the TSL performance or support requirements.

The view of end-users at the mines on the importance of TSL mechanical properties is opinion based. Some view tensile strength to be the most important property and the bonding to be an inferior one while some others consider the bonding to be an important property. Therefore, there is a need to move away from perceptions and quantify the significance of TSL mechanical properties. In this particular case the focus would be on the bonding property of TSL on rock substrate.

A few questions that could be addressed are the following:

- Is the bonding of TSL on a rock substrate a major contributing factor in ground stabilization?

- How do the tensile strength and/or bond strength become involved in ground stabilization? Do they act in isolation and in sequence or in combination. (Ground loading and reaction history)?
- What happens to support resistance after the bond failure?
- What is the contribution of TSL in preventing the crack formation? If cracks develop, how effective is the TSL to resist crack dilation?
- Would there be a match between TSL and rock properties for optimal support performance?

OPTIMAL STRATEGY FOR THE CONSERVATION OF THE RHINOCEROS POPULATION IN SOUTH AFRICA

Industry: Conservation/game ranching

Industry Representatives:

Michael 't Sas-Rolfes, Conservation Economist, Independent
Assistance from Tim Fitzgerald and Keith Lockwood

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Problem Statement

South Africa's white rhino population is under persistent threat from illegal killing (poaching) to supply the demand for rhino horn in East Asia. As a response to this threat, some rhino owners are taking defensive measures such as dehorning live animals and adopting intensive management practices (elevated stocking rates with supplementary feeding, sometimes outside the rhino's natural habitat or traditional range).

Conservationists and certain other interest groups (eco-tourists, trophy hunters) wish to ensure the continued survival of an extensively managed ('wild') white rhino population that is not subject to such interventions – i.e. rhinos are not dehorned, overstocked, artificially fed or otherwise genetically manipulated. However, to maintain rhinos in such extensive conditions is more costly (especially in terms of increasing security needs).

At this time trade in rhino horn is illegal, both within South Africa and to international markets. Some rhino owners argue that re-establishing a legal trade could provide an additional source of income to offset protection costs, thereby helping with rhino conservation. However, such a move would directly benefit the owners of intensive populations more than extensive ones.

A previous MISG workshop attempted to comparatively model the potential impact of two policy options: legal trade or no legal trade, examining the interactions of three parties: intensive managers, extensive managers and poachers. This was set up as an optimal control problem. The problem was only partially solved, and there has been some subsequent work by others. We now wish to build further on the work that has been done to establish a more sophisticated solution.

Ultimately we would like to be able to model the potential conservation impacts of several different scenarios, including one in which existing stockpiles of previously harvested horn are released onto the market. However, to achieve this, we need a robust model of the impact of poaching on rhino productivity rates.

Modelling goals

- Develop algorithms to computationally solve discrete, stochastic dynamic programs for surviving rhinoceros populations in South Africa
- Model the probability of poaching mortality of each individual in each time period. Calibrate time periods to months.
- Include ability to alter parameters affecting the survivability function of each individual.
- Age-and gender-specific state transition equations for each individual for horn growth, population and probability of poaching.
- Interaction between competing states/end states of white rhino: extant conservation population, poaching (killed), hunting demand for live animals (which are then killed), extant prophylactic dehorning population, demand for live animals in prophylactic dehorning population (which are not killed like hunting populations) and natural mortality.
- Include choice variable for anti-poaching measures appurtenant to each individual.
- Maximize computational efficiency.

THE EFFECT OF ALLOWING MINIBUS TAXIS TO USE BUS LANES ON BRT ROUTES

Industry: Transport

Industry Representative:

Dario Fanucchi, Isazi Consulting.

Problem Statement

The Bus Rapid Transport (BRT) system is a network of dedicated lanes, specialized traffic lights and mid-road bus stops that enables a rapid bus service in town centres. The BRT setup involves bus-lanes and bus-stops in the centre of a two-way road. The traffic lights for BRT buses are also on a different circuit to regular traffic.

In Johannesburg, the BRT project covers 325km of specialized lanes and intersections in the CBD, Hillbrow, Braamfontein, Soweto, Auckland Park and Parktown.

Since their introduction in Johannesburg in March 2010, the Rea-Vaya buses have become a popular form of transport, servicing over 80,000 regular commuters and operating from 5am to 9pm daily, with a fleet of over 300 buses. Nevertheless, most commuters in South Africa still use another form of transport - the Minibus taxi. It is estimated that 65% of commuters in South Africa use Minibus taxis to get to work and there are over 100,000 minibus taxis in Gauteng alone, varying from 8-seaters to 14-seaters.

The buses get from station to station more quickly	Bus lanes are often empty
Bus lanes are seldom or never congested	Regular traffic is often congested in places where the bus lane used to be available to other vehicles
The system is easily scaled to a much larger number of buses and passengers If needed	Buses block the bus lane at stations

Currently, minibus taxis are not permitted to drive on the BRT lanes. This may lead to inefficient transport in certain scenarios because the taxis cause traffic congestion on regular lanes and commuters are not able to get to work on time. The problem we propose is to investigate the effects of allowing minibus taxis onto the BRT lanes. There are three alternatives we wish to investigate:

1. Allow taxis in the bus lanes all the time
2. Allow taxis in the bus lanes at set times in the day
3. Do not allow taxis in the bus lanes

Ultimately the JRA is interested in moving the most people (not vehicles) in the shortest time on the roads, but some consideration must be given to maintaining the image of the BRT system as a fast and reliable system of transport.

SEMI-AUTOMATED PHOTOGRAPH MATCHING

Industry: Plant conservation

Industry Representative:

Sam Jack, Plant Conservation Unit, University of Cape Town

Problem Statement

In landscape ecology, repeat photography is a technique in which the researcher takes a photograph that matches, as closely as possible, an older photograph. The two photos can then be compared to assess, for example, changes in vegetation patterns or even the growth rates of trees in the photo.

Because changes can sometimes be small, matching the photographs as closely as possible is vital. For example, if the trees in a photograph grow by on average only 5cm per year, accurate measurement of changes in tree height over even a decade is challenging. Yet matching repeat photographs to historical images has, to date, been a time consuming and imperfect art, done manually. The process involves changing some photo-specific settings such as colour mode, dots per inch and image size such that both images have like characteristics. This always results in a loss of quality (both images being reduced to the poorer resolution) that often becomes a serious constraint in later analysis of more distant objects. Following the above steps and subsequent to the repeat image being overlain onto the repeat, much time is taken tilting and repositioning the repeat to match the original as closely as possible.

Automating this process through some form of error-minimization using several like-points in each image would greatly aid objectivity and processing speed. Two scenarios are suggested that would assist this process. First, simple tilting and repositioning that achieves as close a match as possible without any warping would facilitate analyses that require reading off actual measurements from measuring devices in one or more of the images. And secondly tilting and repositioning with warping to achieve as perfect a fit as possible. The ultimate goal of the project is to develop open source software that can do the above tasks and to embed this software in a citizen science website where people can download historical photographs, go and retake them and then match their repeats online.

As a further issue for study, a long-time limitation and criticism of the repeat photography technique is that true distance and area cannot accurately be quantified. This is because the photo is invariably taken from an oblique angle. Analysis of matched photo pairs is therefore usually a comparison of relative change (% increase/decrease) between each photo. A second goal of this project is to develop an approach that converts a 2D layer, with the aid of several GPSed points and a digital elevation model, into a layer that can be draped over a 3D landscape. Some assistance is provided in several publications that have attempted to do the same thing [1,2].

1. Corripio J. Snow surface albedo estimation using terrestrial photography. *International Journal of Remote Sensing* **25** (2004), 5705-5729.

2. Meire E, Frankel A, De Wulf A, Haile M, Deckers J and Nyssen J. Land use and cover dynamics in Africa since the nineteenth century: wrapped terrestrial photographs of North Ethiopia. *Regional Environmental Change* **13** (2013), 717-737.

AUTOMATED QUALITY CONTROL OF TEMPERED GLASS

Industry: Glass

Industry Representative:

Dario Fanucchi, Isazi Consulting.

Problem Statement

Thermally toughened glass (tempered glass) is used in a variety of applications where safety glass is required, from high-rise buildings to bullet-proof windows. It is therefore obvious that the quality of such glass be guaranteed by rigorous standards. Many quality-control procedures exist to ensure this. We are interested here in a family of tests known as *fracture-tests*, where the tempered glass is shattered with a pneumatic punch and the resulting fracture pattern is analysed. Typically the test will involve counting the number of fractured cells within different regions of the glass, or identifying the largest few cells and determining if their size is within some band.

There is currently no software that automates the process of counting and localizing the fracture cells in an image of shattered glass. Such a tool would simplify the process of performing quality control tests as well as reduce errors in such tests. Furthermore, it would enable further research and investigation into the exact relationship between the fracture pattern and the stress and strength properties of the glass, thus leading to better tests.

Existing literature (papers by Gulati, Redner, Joehlin, etc) has both theoretically and empirically confirmed a correlation between surface stress and the fracture-cell-count and/or area of the largest cells in tempered glass. These are both derived properties of the distribution of cell-size, which could be measured directly if a counting tool were available. The cell shapes could also be directly measured.

The problem we propose to the MIGS has two main components:

- To design an image processing tool that can localize and count cells in a fracture pattern.

- To better understand the mechanics of how such fracture patterns form, partially in order to aid the tool in the point above, but also to develop new insights that may lead to new quality control procedures.

There are some key challenges in completing this task correctly. Firstly, we cannot assume a standardized environment in which the photograph of the fractured glass will be taken. Secondly, the formation of fractures is such that the cells formed are often not completely closed. This poses a challenge for traditional cell-segmentation image processing algorithms like the watershed algorithm.

A successful solution would need to resolve these challenges.

EXECUTIVE SUMMARIES

AN ENERGY EFFICIENCY INDEX FOR THE SOUTH AFRICAN SUGAR INDUSTRY

Sugar Industry

Industry Representative:
Richard Loubser, Sugar Milling Research Institute, Durban, South Africa

Moderators:
Graeme Hocking, Murdoch University, Perth, Australia

Sarah Mitchell, University of Limerick, Limerick, Ireland

Student Moderator:
Emma Gibson, University of Witwatersrand, Johannesburg, South Africa

1 Introduction

The South African Sugar Research Institute brought the problem to determine a method by which the efficiency of different refineries in South Africa could be compared. The method should be relatively simple to implement and be based on output related to resource use. The main complication is the fact that the refineries no longer produce only sugar, but may produce a range of different products.

At a time when only sugar was produced, the simple measure of efficiency was to divide the energy input by the amount of cane input, i.e. steam/cane. The smaller the number, the more efficient the factory. The question is how to determine an equivalent simple measure when the output is no longer a single item. In addition, the group decided to consider methods by which the efficiency of different components of the process could be monitored, so that if the refinery was determined to be less efficient than its sisters some method was available to find out exactly where the inefficiency might be.

2 Mapping the process

The group decided to begin by creating a map of the process in the refineries so that a clear picture could be obtained of the flow of energy, water, cane, sugar

and by-products. Figure 1 shows a simplified map of the flow of water, cane, juice and steam through a refinery during a typical cycle. A similar, more detailed map was worked out to enable the group to understand the various processes that are occurring as the procedure takes place. Once the process was understood we were able to consider different measures of efficiency throughout the plant. To ensure that the comparison was valid, we did some basic analysis of the properties of the cane across the country to ensure that all were dealing with similar input products.

Following the flow, we can see the sugar juice is removed from the cane via a *Diffuser* in the "Extraction" phase. Some of the juice is then diverted to make other products while most continues into the condensers where the water is boiled off to leave a concentrated sugar solution. Cane waste from the diffuser is burned (in the "Boiler-turbine" section) to create steam and generate power that is used in condensers to refine the juice and elsewhere to drive the mechanical processes in the plant. The vapour from the condensers then feeds back into the extraction to provide water for the flushing process in the diffuser. The process is self-contained in that it is rare that external energy (via burning coal) is required to power the plant.

3 Bulk model

3.1 Index for sugar-only

The energy required to drive most of the refining process comes almost exclusively from the boiler and almost all of this energy passes from the boiler to the condenser. Energy requirements to drive the processes for other by-products is extracted at this point. The energy input from the boiler must compensate for all energy losses via water "dumped", losses through surfaces, friction energy used to drive the diffuser, crusher, pumps and other mechanical devices. The "traditional" efficiency figure can be computed as

$$EI = \frac{\text{Steam Energy} = S_T}{\text{Cane input} = C_I}$$

This quantity provides an accurate representation of the energy required for the amount of cane used. This can still be calculated even though new by-products are being produced, but does not provide any finer scale resolution of where the energy is used. If sugar is still the main product then it is certainly an approximate ranking, but as other products become more significant it is less so. However, it is still true that a measure of efficiency will be the amount of production for the amount of energy input. The question is then how to quantify the output in some meaningful way. It may be that the best strategy is to continue with this calculation but include one or two other simple numbers to provide a better picture.

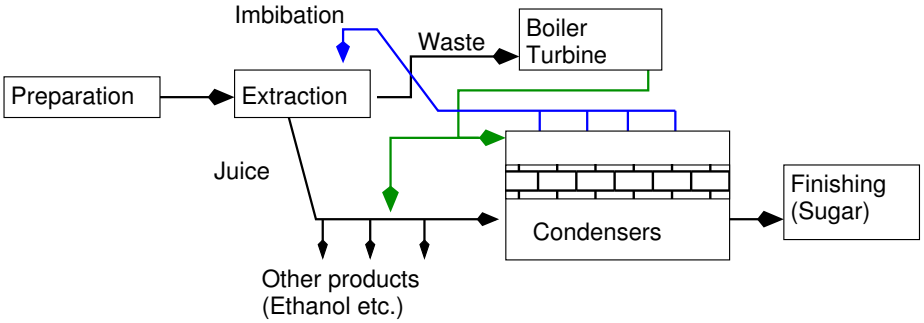

Figure 1: *Map of the passage of water, juice and steam through the system during a refinery cycle. Blue indicates vapour, green steam and black the juice and cane waste products. This is a greatly simplified flow chart.*

3.2 Bulk model - new index

The processes for the new products divert energy and so not all of the steam from the boiler is used to make sugar. This diversion needs to be considered in the context of the production of other outputs.The energy input from the boiler must STILL compensate for all energy losses. One approach is to compute an "energy equivalent" (or even "sugar equivalent") for each by-product.

Suppose there are several goods produced (e.g. sugar, ethanol etc.) then input energy is diverted to each of those processes. Instead of using energy/input to measure efficiency it may be more appropriate to use energy/output, so that an estimate of efficiency is

$$EI_{NEW} = \frac{\text{Steam Energy}(= S_T)}{\text{Sugar energy equivalent output}(= E_S)}$$

The sugar equivalent may be as simple as the amount of sugar tied up in each product, or it may be a calculation of energy. In this way the old index of steam/cane can be replicated quite closely. The efficiency of each product within the plant can be estimated as the amount of steam required for that part of the process divided by the output derived. The quality of the incoming cane can also be factored into the calculation. It may not be immediately obvious what these things mean but in time the users will develop an understanding. Given sufficient data, it may be possible to compute historical values for comparison.

4 Detailed energy flow

In a parallel computation, the group developed a detailed model of energy input and output from each part of the process and kept an account of energy, cane, water,

sugar and other components that arose. Efficiencies or inefficiencies show up in this accounting. This algorithm can be used to identify any shortcoming if the bulk parameters identify a problem. Thus for example the energy and steam input to each condenser was accounted for and any missing parts were added up at the end. In this way each component of the process could be tested for its efficiency. This aspect of the project will be described in detail in the final report.

5 Concluding remarks

The problem was to develop an efficiency index for comparison of different plants and processes. The group identified two components to the project. Firstly a method was suggested for the bulk energy efficiency to provide a rapid comparison between plants, and secondly a much more detailed, fine-scale algorithm was created so that if inefficiencies were identified by the bulk process then follow-up would provide pointers to the particular location of the inefficiencies. Another aspect that attracted some discussion (but was not considered further) was to consider the financial efficiency of each plant. Although the group was asked not to consider this it is clear that any consideration of efficiency of a plant needs to take into account the financial outcomes. However, this does not provide a measure of true energy efficiency because of the price variability of different inputs (cane, coal, salaries, shipping) and outputs (sale price of the different products). It is clear that a combination of these two factors is the correct approach to manage the plants.

THE USE OF SPRAY-ON LINERS FOR WALL STABILIZATION IN MINES

Industry Representative:
Halil Yilmaz, School of Mining Engineering, University of the Witwatersrand, Johannesburg

Moderator:
David Mason, University of the Witwatersrand, Johannesburg

Student Moderators:
Reine Yemata and Assumpta Nnakanyi, African Institute for Mathematical Sciences

Executive Summary

Thin spray-on liners (TSL) are intended to resist rock failure and if failure occurs, to stabilize rock blocks. They have been found to be effective in supporting walls of mining excavations due to the penetration of liner material into cracks and joints. Thin spray-on liners are also used to simply stabilize rock surfaces by preventing rock fall. In this application liner penetration of cracks and joints is desirable but not necessary. The tensile and shearing strength and adhesive properties of the liner to the rock determine its contribution. The study group was asked to investigate the effectiveness of non-penetrating TSLs in rock support and examine the relative importance of the tensile and shear stresses in the liner. It was also asked to investigate if bonding of the liner to the rock is a major factor in rock stabilisation and what happens to the support after bond failure.

The effect of a TSL on a global lined tunnel subjected to a perturbation due to a seismic event or mining excavation was considered. Imperfect banding was described by a weak bonding factor. An expansion in powers of ε, the ratio of the liner thickness to the radius of the tunnel, was considered. It was found that the effect of the perturbation on the liner tensile stress is large and occurs at zero order in ε through a factor depending on the ratio of the reduced Young's moduli of the liner and rock mass. This zero order term does not depend on the weak bonding factor. The shear stress at the interface is small, of order ε, and to this order is independent of the weak bonding factor. The analysis showed that the liner tensile stress is more important than the shear stress in supporting rocks and that debonding does not significantly affect stress.

Local rock support at the tunnel wall was also examined, It was found that support of the movement of loose rock is better achieved by a TSL with small Young's modulus but high rupture tensile strength. Adhesive detachment from the tunnel wall is likely to occur before the stress in the liner is sufficient to cause rupture because the bonding strength is less than the shear and tensile strength of the liner

OPTIMAL STRATEGY FOR THE CONSERVATION OF THE RHINOCEROS POPULATION IN SOUTH AFRICA

Conservation and Game Ranching

Industry Representative:
Michael 't Sas-Rolfes, Independent Conservation Economist

Moderator:
Michael Sears, University of the Witwatersrand, Johannesburg

Student Moderator:
Ashleigh Hutchinson, University of the Witwatersrand, Johannesburg

Executive Summary

The aim of this project is to model the white rhino population in South Africa and how it is influenced by poaching. The study is motivated by the need to conserve the rhino population by decreasing poaching to a manageable level. We attempt to identify the factors that influence the poaching levels, and to incorporate poaching control strategies into the model. In particular we analyse the impact of the legalisation of the selling of rhino horn to the Asian market. Stockpiles that are managed correctly can be used to outsource rhino horns to the buyers and satisfy the demand or even to flood the market. The price of a legal rhino horn must be chosen carefully to ensure that the demand for rhino horn does not increase suddenly. Stockpiles can be replenished by the optimal humane harvesting of rhino horns on private farms. Our understanding of the Asian consumer market is limited. However, we do attempt to relate poaching and anti-poaching costs to price and demand.

Models

We divide the rhino population into two classes: wild rhinos in national parks and the like, and rhinos on farms. Without interference these populations would grow logistically, but the populations are impacted by poaching, trophy hunting, transfer between groups and natural mortality. Reasonable estimates were made for these factors. It was necessary to link poaching and anti-poaching strategies to the costs in order to obtain a 'poaching effect' term in these equations. The equations are presented below:

$$\overbrace{\frac{dR_1}{dt}}^{\text{Rate of change of wild rhinos}} = \overbrace{\alpha_1 R_1 \left(1 - \frac{R_1}{k_1}\right)}^{\text{Logistic growth term}} - \overbrace{\chi_1 R_1}^{\text{Poaching effect term}} - \overbrace{\eta_1 R_1}^{\text{Rhino translocation}} - \overbrace{\eta_2 R_1}^{\text{Trophy hunting}} - \overbrace{\rho_1 R_1}^{\text{Natural wild rhino death}}, \tag{1}$$

$$\overbrace{\frac{dR_2}{dt}}^{\text{Rate of change of farm rhinos}} = \overbrace{\alpha_2 R_2 \left(1 - \frac{R_2}{k_2}\right)}^{\text{Logistic growth term}} - \overbrace{\chi_2 R_2}^{\text{Poaching effect term}} + \overbrace{\eta_1 R_1}^{\text{Rhino translocation}} - \overbrace{\rho_2 R_2}^{\text{Natural farm rhino death}}. \tag{2}$$

The parameters α_i, k_i and ρ_i for $i = 1,\ 2$ denote the logistic growth rates, carrying capacities and the natural death rates respectively. The rate at which wild rhinos are removed from their population and placed into a private farm i.e translocated is given by η_1. The death rate for rhinos that are selected for trophy hunting is denoted by η_2. The parameters χ_1 and χ_2 represent the ratio of the cost of poaching effort to anti-poaching effort in each population group.

We then developed equations for the way in which the stockpiles of rhino horn would change over time, giving relations for legal wild rhino horn stockpile, legal farmed rhino horn stockpile and the poached stockpile. In order to link price and demand, we modelled a three player game to determine the price in terms of the quantities supplied from the different sources. Assuming each player attempts to maximize cash flow, we obtain optimal values for the quantities and these can then be used in the population models.

A separate horn growth model was also developed to address the question of optimal harvesting of rhino horn for farmed rhinos (without harming the rhinos). Preliminary work was also done on a two sex population model, and an age structured population model, which would clearly be the more realistic options.

Results

A variety of simulations were run using the first model described above. The outcomes of these runs led to the following preliminary conclusions:

- Without a new intervention strategy, the wild rhino population will decline under poaching pressure;

- With legalization of rhino horn sales, the wild rhino population increases and a sustainable industry for farmed rhinos could develop;
- The model is insensitive to most of the parameters that can only be crudely estimated.

Further work

- Improvements to the model can be provided by building in the age structure of the population and by using sex based models;
- Analysis of horn growth and harvest timing can assist with optimal strategies for rhino farming management;
- The pricing model needs further refinement and investigation;
- The functions χ_1 and χ_2 are important in the results of the model. Further investigation of these will be important.

THE EFFECT OF ALLOWING MINIBUS TAXIS TO USE BUS LANES ON BRT ROUTS

Transport Industry

Industry Representative:
Dario Fanucchi, Isazi Consulting

Moderator:
Neville Fowkes, University of Western Australia

Executive Summary

The Rea Vaya (BRT) is Africa's first rapid transit system and has been designed to ensure fast, reliable and affordable public transport across Johannesburg. The system supplements the Metrobus system by providing good (4 or 6 lane) roads along major routes, with (2) dedicated lanes for buses. The dedicated bus lanes are normally not congested whereas the normal lanes are usually congested especially during peak hours, and the authorities are investigating the effect of allowing minibus taxis to use the bus lanes.

One would expect the shared bus lane arrangement to increase the net flow of all traffic and at MISG 2014 this was found to be the case for traffic densities greater than a critical value which was identified in terms of the road traffic parameters and the relative proportion of cars and cabs, buses, and minibus taxis. Of course the effect of the shared bus lane arrangement is to increase the flow in the bus lane and thus potentially effect the bus timetable reliability; estimates were obtained again in terms of traffic flow parameters and vehicle numbers in 2014.

Flow (dynamics) instabilities can cause major disruptions to traffic flow and are more likely to arise under lane change circumstances, especially under dense traffic flow conditions. In MISG 2015 we examined the dynamic effect of lane change on the traffic flow with special emphasis on the bus lane. Lane change design can make a big difference to the flow behaviour and the models examined were constructed to expose the effect. It is no surprise that such effects are greatly magnified under high congestion conditions especially if the relative proportion of minibus taxis is large. These issues are under investigation and will be presented in the final report.

Problems of traffic flow can be dealt with in several ways. One is to make a large capital investment and build more roads, another is to change the traffic flow in

other ways such as is being considered in this project. A third possibility is to reduce the number of vehicles on the road using some form of incentive model to change people's behaviour so that they no longer use their own car or so that they transfer to some more efficient means of transport.

The group proposed a framework to consider an incentive scheme to do such a thing. It is clear that in the problem under consideration the reasons for the use of taxis over buses is partly cultural, partly convenience and partly financial. The goal is to encourage people into moving from taxis to buses to improve the flow of traffic. We considered transportation by bus and taxi, but also that the buses are unimpeded in travel. People travelling in cars are assumed to continue this behaviour, but it would not be difficult to include them in the model. Instead of moving taxis to the bus lane, the goal is to move a significant number of people onto the buses, thereby reducing the number of taxis on the road.

Possible incentives might be travel time and cost. Thus, we set up a simple model that tried to allow for changes in behaviour of travelers as travel times and price signals change. If there are more people on the buses and less in taxis then this will manifest itself as a decrease in average travel time. Taking a greatly simplified approach we were able to estimate some effects of a price signal. The effectiveness of this depends on many factors and the current costs. For example if the buses are already full then this procedure will have no affect (except by putting on more buses). It is important to have access to further data to consider whether this approach might be effective. A much more sophisticated, data-linked model would be required if this simple "proof-of-concept" showed promise.

SEMI-AUTOMATED PHOTOGRAPH MATCHING

Industry Representative:

Sam Jack, Plant Conservation Unit, Department of Biological Science, University of Cape Town

Moderators:

Ian Durbach, African Institute for Mathematical Sciences and Department of Statistical Sciences, University of Cape Town

Byron Jacobs, School of Computational and Applied Mathematics, University of the Witwatersrand, Johannesburg

Description

In landscape ecology, two photographs taken from similar but not identical positions are matched" based on unchanging features occurring in each photograph, for example rocks. Matched photos can be used to address several biological questions of interest, for example, changes in vegetation patterns or growth rates of trees. Typically this matching is performed manually and is a painstaking and time-consuming process. The objective of this project was to develop a method for automating the matching process as far as possible.

Executive Summary

The group began by considering the extent to which the matching process could be automated. Landscape photos comprise living material (e.g. trees) that change over time and are thus poor candidate features for matching, and inert material (e.g. rocks) that are more favourable. Discerning these features in a general way is a difficult problem. The final approach developed by the group is thus semi-automated: a user must select pairs of like points in each photo, each pair corresponding to the co-ordinates, in the native photograph, of a feature common to both photographs.

After the selection of a set of such co-ordinate pairs, points in one photograph can be mapped onto the corresponding points using an affine transformation defined by five parameters implementing three geometric operations: translation (adding a fixed amount to each point in the horizontal and vertical direction), scaling (multiplying each point by a fixed amount in the horizontal and vertical direction), and rotation (through some angle). Parameter values are selected so as to minimize the least-square error between observed and transformed points.

Based on a set of test images the algorithm appeared to match most photograph pairs reasonably well based on three or four selected pairs, although not as well as expert manual matches that simultaneously evaluate the entire image. Adding more co-ordinate pairs was found to lead to increased instability in the transformed values.

The approach was implemented in Mathematica with a user-friendly interface in which users can upload and view unmatched photographs, and select co-ordinate pairs. Transformation parameters and subsequent matched photographs are iteratively updated as more pairs are added. An opacity slider allows the user to shift smoothly between the original and matched repeat photograph. The final step in this process will be to embed this tool into a citizen science website hosted by the Plant Conservation Unit where people can download and repeat historical photographs, and then match their repeats online. Finally, the group attempted to address the problem of automatic inert feature extraction. Running a local feature extraction algorithm (Speeded Up Robust Features, SURF) on the raw images led to the identification of many living features and hence was deemed unsuited to the current problem. Pre-processing the image by binarizing it into foreground and background using a filling transform forced the keypoints identified by SURF to lie on the horizon of the image, which often but not always contains suitable matching features like rocks. This provides an occasional solution to the feature detection problem for well-behaved photographs, in which a horizon exists and contains most of the features on which one would like to match. Much further work could no doubt be carried out on this particular topic.

AUTOMATED QUALITY CONTROL OF TEMPERED GLASS

Glass Industry

Industry Representative:
Dario Fanucchi, Isazi Consulting

Moderator:
Byron Jacobs, University of the Witwatersrand, Johannesburg

Student Moderator:
Mathews Sejeso

Executive Summary

The problem that was presented to the Study Group concerned the counting of the number of glass cells in a shattered pane of glass. The glass industry requires knowledge of the average size of a glass cell in a shattered pane of safety glass. With this information safety specifications of the glass can be tested and met. Typically this process is done by a human who hand counts the number of cells within a small area. The assumption is made that the average cell count is uniform across the entire pane which determines the average glass cell density. This process is obviously prone to error and an automated approach was sought.

A preprocessing step was taken to create a binary image of the shattered glass pane. This step is based on a nonlinear partial differential equation model which produces a binary result. The processed image can then be treated by standard image processing techniques. The group explored standard filtering, image segmentation, morphological approaches and a state-of-the art superpixel approach.

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