Risk-based Infrastructure Management System (RIMS)

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1 Introduction

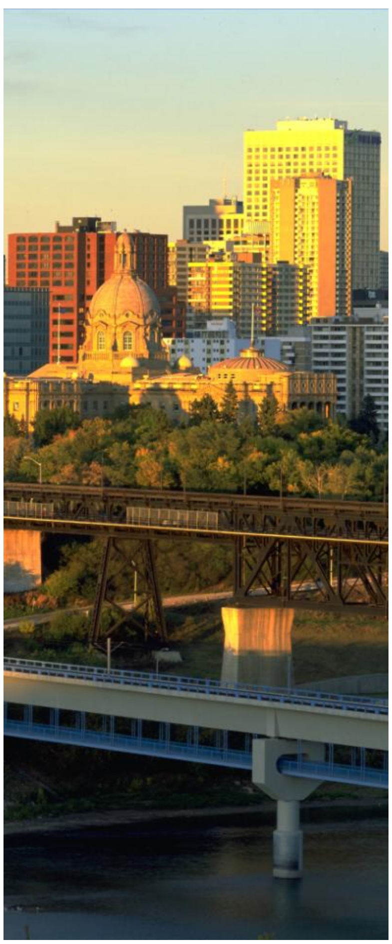

Figure 1. City of Edmonton

The City of Edmonton's (Figure 1) Office of Infrastructure manages the City's Infrastructure Strategy, and as such, is responsible for over 11,730 lane-km of roads (including bridges, arterials, collectors, and residential and industrial roads) and nearly 5,600 km of sewers (including manholes, catchbasins, pump stations, storm ponds, and lakes).[1] In addition to monitoring and maintaining the large number of Edmonton's infrastructure assets, the Office is further challenged by having to do so on a limited budget determined by the available funding. An additional challenge to infrastructure management is the requirement that these assets function at a level that will not endanger members of the public or undermine human health. In order to identify and address these risks and complications, the City of Edmonton partnered with SMA Consulting, who developed an award-winning risk-based infrastructure management system (RIMS) to generate efficient asset management strategies. RIMS informs decision-makers of the options available for asset management at different cost and performance levels, which helps optimize investments while reducing negative environmental impacts. This system has been awarded top honours through the Canadian Society for Civil Engineering and the Consulting Engineers of Alberta.

A report assessing Canada's infrastructure needs, published in 2012, found that the cost of improving Canada's aging infrastructure assets to an acceptable range is approximately \$171.8 billion; that is, approximately \$13,813 per Canadian household. The total present value of Canada's infrastructure has been estimated to be in the range of \$3 to \$5 trillion. This situation of aging infrastructure and insufficient budget will only lead to an increase in required spending in the future.

[1]http://www.edmonton.ca/city_government/news/2012/national-report-card-shows-need-for-long-term-funding-plan.aspx

Infrastructure investment and budget allocation vary in complexity from simple ranking and project prioritization exercises to project level optimization. Methods for assessing infrastructure needs typically consider only one asset at a time, which might prevent managers from determining a more holistic optimum solution.

SMA Consulting's RIMS software presents a new approach for the optimization of budget allocation using genetic algorithms. When used in civil engineering applications, these algorithms employ evolutionary sequences to optimize solutions that involve large numbers of possible combinations.

Management strategies typically target performance or budget. RIMS offers decision-makers a comprehensive picture of the targeted solutions available for asset management at different cost and performance levels, allowing managers to pick the most suitable strategy. The system also takes into account risks related to public safety, service level, and the environment.

2 Innovation

Infrastructure management is complex because of the number and variety of factors that must be balanced: initial cost, condition, public safety, timing and prioritization of repairs, and repair costs. SMA Consulting, in partnership with the City of Edmonton, has developed an innovative, award-winning risk-based infrastructure management system (RIMS) to generate efficient asset management strategies, which can either minimize cost or maximize performance.

SMA Consulting's RIMS software presents a new approach for the optimization of budget allocation using genetic algorithms. When used in civil engineering applications, these algorithms employ evolutionary sequences to optimize solutions that involve large numbers of possible combinations.

2.1 How RIMS Works

RIMS informs decision-makers of the options available for asset management at different cost and performance levels, thereby allowing managers to optimize their investments. The system also takes into account the risks of failure in several dimensions: public safety, service level, environmental, and so forth.

The Importance of Infrastructure Management: Fiscal Responsibilities

Federal, provincial, and municipal politicians and their staff are accountable to taxpayers, particularly in terms of responsible spending. The City of Edmonton currently owns over $33 billion worth of infrastructure assets[2], and recently approved a $2.8-billion capital budget to cover infrastructure renewal and new development over the next three years.[3] Meanwhile, the province of Alberta's capital maintenance and renewal expenditures for public infrastructure in 2011–12 totaled $9.9 million.[4] Lorna Rosen, CFO for the City of Edmonton, describes the challenges of working within this limited budget: "Our infrastructure will continue to age and deteriorate, [but] growth pressures will also continue."[5]

The value of these public infrastructure services must also factor into the fiscal responsibilities of politicians and decision-makers. The value of services refers not to the expenditures of physically creating and maintaining infrastructure assets, but rather to the well-being they provide to the community by allowing citizens to travel to and from work, to access safe water, and so on.

The Pembina Institute determined the net public stock of public infrastructure in Alberta to be $250 billion (1998$), with the value of the services from public infrastructure estimated at $17.5 billion (1998$), or 7% of the capital stock value.[6]

[2] http://www.edmonton.ca/city_government/initiatives_innovation/infrastructure-strategy.aspx
[3] http://www.edmonton.ca/city_government/news/2012/national-report-card-shows-need-for-long-term-funding-plan.aspx
[4] http://www.infrastructure.alberta.ca/Content/Publications/production/annualreport.pdf
[5] http://www.edmonton.ca/city_government/news/2012/national-report-card-shows-need-for-long-term-funding-plan.aspx
[6] http://pubs.pembina.org/reports/11.Public%20Infrastructure.pdf

The specific steps are as follows:

2.1.1 Enter inventory and degradation curves.

RIMS users enter the full inventory of their infrastructure assets, including information about conditions, repair types and costs, replacement costs, and typical lifespans and deterioration curves. Deterioration curves show how long an asset will stay at a certain condition given a certain assumed maintenance level: 25 years in Condition A, 15 years in Condition B, and so on until deterioration to Condition F. At any point, rehabilitation or renewal may be performed, which moves an asset back up the deterioration curve. An overall Level of Service, typically defined as a percent of assets in a certain condition, is also defined.

2.1.2 RIMS creates asset profiles.

All possible investment strategies for each asset or class of assets over a certain period (typically 30 years) are then generated. This step uses the information provided in Step 1 about the potential rebuilding and rehabilitation actions and unit costs, as well as the deterioration curves and current condition of the assets. There are usually tens of thousands of potential investment strategies.

2.1.3 Enter budget scenarios.

Decision-makers can define the budget scenarios that they are interested in investigating. There are four basic budget scenarios that RIMS generally considers:

a. Doing nothing: This assumes that managers do not invest any money into infrastructure renewal.
b. Maintaining an acceptable performance level: This does not assume an investment value, but instead seeks to determine the investment value based on an acceptable level of asset performance.
c. Striving for optimal performance: Again, this does not assume an investment value, but instead seeks to determine the investment value based on the optimal level of asset performance.
d. Determining the best return on investment for the available budget: This scenario assumes an investment level based on the available budget, and seeks to determine the resulting level of asset performance.

2.1.4 RIMS models asset condition over lifespan.

For the budget scenarios listed above, RIMS finds the optimum selection of assets and rehabilitation strategies to satisfy the given budget and market capacity that will produce the best physical condition.

Infrastructure Performance

Infrastructure performance is typically assessed via inspection using a condition index (CI) of some sort to assign categories. A CI may be a simple rating scheme, or may be defined by a complex evaluation that encompasses multiple indices, such as Alberta's Pavement Quality Index (PQI). The maintenance of infrastructure involves well-timed and -executed activities employed to extend infrastructure lifespan; rehabilitation involves application of appropriate measures including reconstruction to extend infrastructure asset lifespans when their condition becomes unacceptable. Rehabilitation strategies have different effects on the condition index; for example, replacement of an asset can take the CI from the lowest grade (e.g., F) to the highest (e.g., A). The concept of modelling rehabilitation in this research is based on rehabilitation impact on the asset CI. If five conditions are assumed (A, B, C, D, and F) then ten rehabilitation actions are possible (F→D, F→C, F→B, F→A; D→C, D→B, D→A; C→B, C→A; B→A), each with an attendant cost and benefit.

Infrastructure rehabilitation and budget allocation strategies will vary depending on objectives, as well as other factors, e.g., the current asset condition or type of asset under consideration. RIMS focuses on two different types of budget allocation strategies: first, minimizing the budget required for a certain performance level, and second, maximizing the performance of a limited budget.

2.1.5 RIMS generates reports for decision-makers.

With the infrastructure assets, their lifespans, and the budget scenarios entered into the program, RIMS is able to generate a budget allocation report for decision-makers (Figure 2).

This report allows administrators to look at all of their infrastructure assets at once, and see when and where to direct funds in order to have the entire system of assets functioning at as high a level as possible for the best investment. This is very beneficial in presentations to senior management and facilitates finding the best balance between growth and renewal, developing funding strategies that allocate renewal dollars fairly amongst infrastructure areas (Figure 3). Furthermore, this report helps inform staff how long-term budgets and policies affect their overall asset portfolios over time.

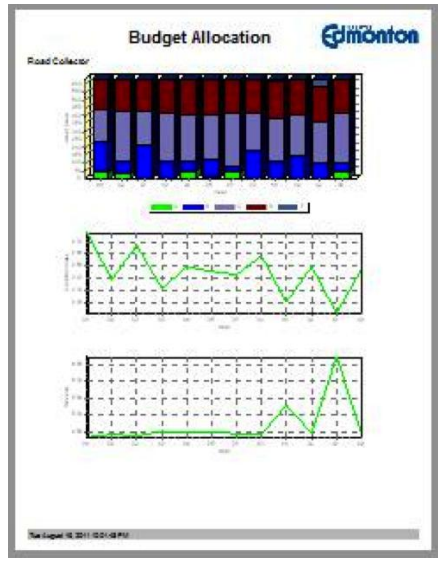

Figure 2. Budget allocation report

Figure 3. RIMS helps managers decide between repair and replacement for aging infrastructure assets

2.2 How RIMS Advances Infrastructure Management Techniques

All infrastructure assets deteriorate over time, and the challenge for managers is to keep as many assets functioning at as high a level as possible while minimizing spending on maintenance and repairs. The innovative RIMS software package allows decision-makers to manage their infrastructure assets as a complete system, rather than as individual, unrelated structures. Decisions made are defensible, with ample supporting information. RIMS’ developers, SMA Consulting and the City of Edmonton, have advanced the technology of infrastructure management and demonstrated technical excellence by incorporating complex genetic algorithms (Figure 4) into the software.

Genetic Algorithms

SMA's RIMS software uses genetic algorithms to develop these optimized strategies. Merging computer science and evolutionary theory, genetic algorithms have been used in many areas of research over the past fifty years. They attempt to mimic the processes of mutation, reproduction, and natural selection using software and text-string "chromosomes." The "chromosomes" represent potential solutions to a problem, which are evaluated against a goal. In each generation, the top chromosomes are allowed to advance, until the system converges on the best solution. Genetic algorithms can rapidly find answers to multifaceted questions. RIMS uses them to find solutions that meet the multiple needs of infrastructure managers.

The selection mechanism allows "chromosomes" of higher fitness values to reproduce more often than less efficient chromosomes. The initial population is typically randomly initialized, and the evolution process continues until a time limit is reached, a certain number of populations evolve, some error level is reached, or the variance of the fitness functions reaches a certain level. A genetic algorithm provides the flexibility necessary to explore both objectives with a similar modeling framework.

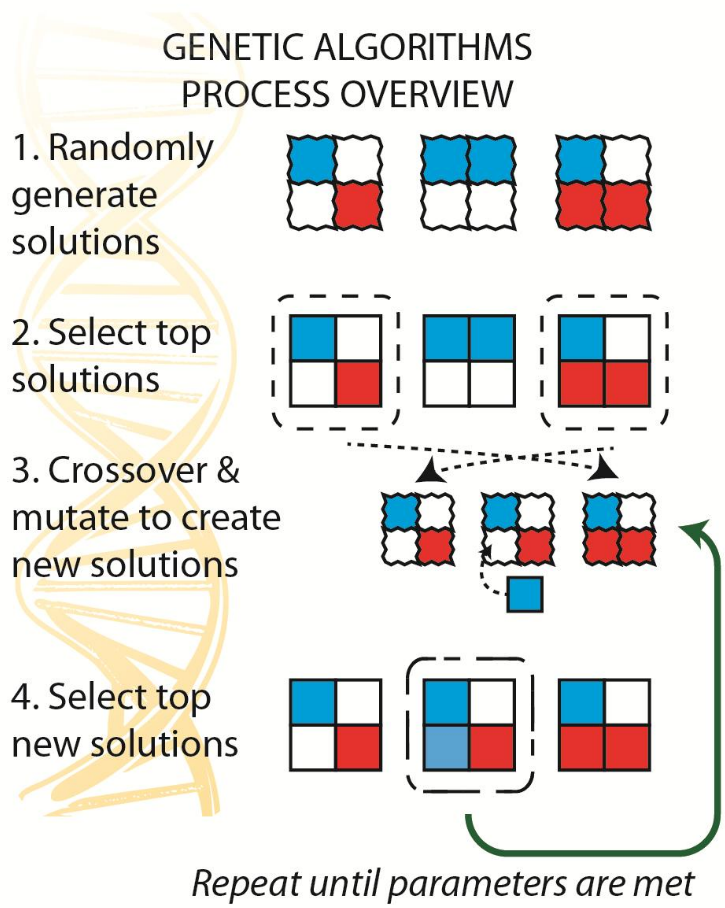

Figure 4. Genetic algorithms process overview

2.3 The Neighbourhood Renewal Program

A City of Edmonton Sustainable Infrastructure Success Story

Faced with deteriorating roads, sidewalks, and street lights; sporadic funding; and increasing maintenance and renewal costs, the City of Edmonton and SMA Consulting built the Neighbourhood Renewal Model to develop a business case for sustainable, predictable funding for maintenance and renewal of over 300 neighbourhoods (including industrial areas) in Edmonton. The information RIMS provides supports objective and systematic decision-making, and clearly communicates program goals and expected benefits to the public and to decision-makers. The City of Edmonton successfully used RIMS methodologies to develop its Neighbourhood Renewal Program, which targets the renewal and rebuilding of Edmonton's roads, sidewalks, and streetlights. The results of the study showcased the benefit of investment in infrastructure and led to the approval of tax levies and strategic borrowing to fund a combination of renewal, repair, and maintenance. The program will reach target service levels within 30 years.

In 2008, City Council established the Neighbourhood Renewal Program (NRP). This program initially allocated provincial funding, but soon took on a leadership role in the country by establishing a dedicated municipal tax levy. The City committed to an annual growth in this dedicated tax levy, in order to allow the program to become a sustainable funding source while eliminating its dependence on uncertain funding programs from other orders of government. The tax levy component of the program addresses residential and industrial neighbourhood roadways, sidewalks (including cost-sharing with residents), street lighting, and traffic safety measures.

The Neighbourhood Renewal Program complements two other City programs dedicated to the deliberate, coordinated, and sustainable investment in neighbourhood infrastructure. A complementary program, the Drainage Renewal Program, is funded by a dedicated drainage utility funding source, and addresses underground storm and sanitary system upgrades. This program is focused on the renewal and replacement of sanitary and storm sewers. The second coordinated program is the Great Neighbourhoods Capital Program, which is focused on improving the livability of Edmonton neighbourhoods to renew the physical infrastructure of neighbourhoods and create vibrant, sustainable neighbourhoods. Together, these programs are building great neighbourhoods.

Social and Economic Benefits

By sustainably maintaining all of its infrastructure assets for the best price possible, the City of Edmonton ensures that it is making efficient use of public funds, thereby conserving taxpayers' dollars for use in other important City-provided programs and services. Furthermore, the vigilant upkeep of roads, water treatment systems, utilities, and other infrastructure assets ensures the safety of the public in their daily activities. The value of these public infrastructure services refers not to the expenditures of physically creating and maintaining infrastructure assets, but rather to the well-being they provide to a community by allowing citizens to travel to and from work, to access safe water, and so on.

RIMS also offers economic benefits. It is used to determine the most effective use of City funds for infrastructure maintenance, and reduces the amount of payable work time spent by City employees by calculating the best spending scenarios for repairing the City's aging infrastructure.

The application of RIMS in the Neighbourhood Renewal Program has also presented opportunities for the City to implement new technologies and processes that have provided cost efficiencies and promoted sustainability. 6-year long-term contracts for the reconstruction of neighbourhoods have been implemented, and these maximize the certainty of locations and reduce the exposure to inflation. The application of new technology for materials has ensured cost effectiveness, while recycling both pavement and aggregates has minimized the cost of materials as well as the costs of the disposal of waste material.

For the Neighbourhood Renewal Program, the type of renewal work varies depending on the state of infrastructure:

- **Collector Road Renewal**: priority given to bus routes
- **Preventive Maintenance**: reseal roads to extend their lifespans
- **Overlay**: repave roads and treat sidewalk panels to eliminate trip hazards
- **Reconstruction:** repave roads; replace streetlights and sidewalks

By effectively combining preventive maintenance, overlay, and reconstruction, the City's goal is to improve all Edmonton neighbourhoods within 30 years. The City used the RIMS software to help determine investment targets that would be required to meet this 30-year goal. The RIMS model demonstrated the following:

- By performing reconstruction, overlay, and preventative maintenance work at the same time, the Neighbourhood Renewal Program benefits neighbourhoods faster and at a lower cost than a reconstruction-only program.
- The neighbourhood renewal program tax levy could achieve this goal by providing predictable, reliable, and stable funding of 1.5 to 2.0 percent per year until the program can be completely funded by the levy alone, which should be achieved by adding 1.5 percent annually over the next 10 to 15 years.

The Importance of Infrastructure Management: Public Safety Implications

Taxpaying citizens engage with numerous forms of public infrastructure every day, and in many cases, the level of performance of these structures affects the health and safety of those individuals. A national study of 123 Canadian municipalities, released in 2012, found that Canadian roads averaged a "fair" condition; wastewater systems, a "good" condition; and storm water systems, a "very good" condition. Edmonton's results mirrored those national averages.[7] However, the study made some alarming findings with regard to human health and safety; for instance, more than 50% of municipal roads are in very bad condition, and approximately 25% of roads are operating over capacity. Furthermore, just 12.6% of water plants, reservoirs, and pumping stations achieved a "very good" rating; only 4.2% of pipes were determined to be "very good"[8]; and 25% of wastewater treatment plants were found to be in need of upgrades or replacements. While roads and water systems represent only a portion of all forms of infrastructure, their ubiquity results in immediate and significant potential implications for human health.

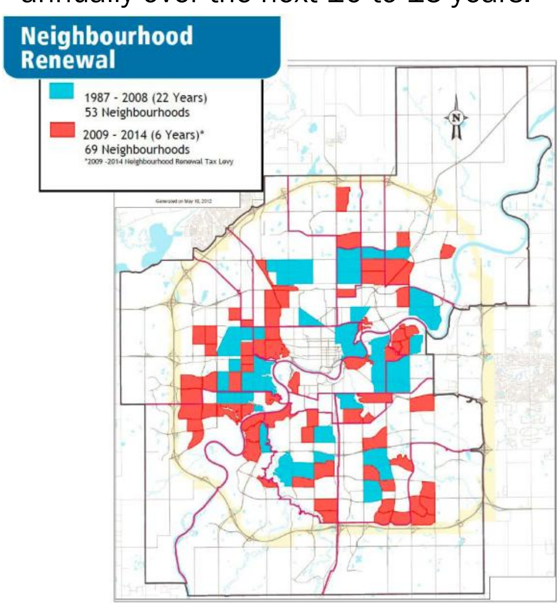

Figure 5. City of Edmonton neighbourhood renewal

Edmonton is the only Canadian city to dedicate an annual property tax levy toward the renewal and reconstruction of neighbourhood streets and sidewalks. Prior to the approval of the Neighbourhood Renewal Property Tax levy, the City carried out renewal in 53 neighbourhoods over the 22-year period from 1987 to 2008 (approximately 2 ½ per year). With the new funding mechanism and the current approved budget, the City will renew 69 neighbourhoods in the 6-year period between 2009 and 2014 (approximately 11 ½ per year). A summary of the neighbourhood renewal from 1987 to 2008 and 2009 to 2014 is shown in Figure 5.

[7] http://www.edmonton.ca/city_government/news/2012/national-report-card-shows-need-for-long-term-funding-plan.aspx
[8] http://www.canadainfrastructure.ca/downloads/Canadian_Infrastructure_Report_Card_Highlights_EN.pdf

3 Complexity

The sheer scope of the problem of maintaining and updating infrastructure assets presents difficulties. All infrastructure assets deteriorate over time, but do so at different rates. Some of these assets can be repaired and maintained, while others require replacement. The challenge for managers is to keep as many assets functioning at as high a level as possible while minimizing spending on maintenance and repairs.

To address this complex combination of problems, typical approaches in the past have involved depending on one person's experiential knowledge without having a backup plan for continuity or knowledge transfer; referring to spreadsheet models that frequently break down; or applying general rules of thumb. While these applications approach a solution to the problem, they do not address its root or systematically incorporate the complicated system of interdependencies and weighted requirements.

The innovative RIMS software package allows decision-makers to manage their infrastructure assets as a complete system, rather than as individual, unrelated structures. Decisions made are defensible, with ample supporting information. RIMS' developers, SMA Consulting and the City of Edmonton, have advanced the technology of infrastructure management and demonstrated technical excellence by incorporating complex genetic algorithms into the software.

National Recognition

In 2012, the Canadian Society for Civil Engineering (CSCE) presented the City of Edmonton with the Award for Governmental Leadership in Sustainable Infrastructure, for the Risk-based Infrastructure Management System (RIMS) developed by SMA Consulting. In January 2013, the Consulting Engineers of Alberta (CEA) recognized SMA Consulting's work on the RIMS project with the Award of Excellence in the "Small Firm – Big Impact" category, and with the Award of Merit in the "Studies, Software, and Special Services" category. In doing so, the CSCE and the CEA recognized the innovation, leadership, and technical excellence the RIMS development team demonstrated in advancing the state-of-the-art in sustainable infrastructure management.

4 Environmental Impact

Figure 6. Edmonton river valley

By proactively identifying and addressing infrastructure updates that should be done before an asset's performance falls below an acceptable level, managers can avoid expensive emergency remedial treatment down the road. This is not only a financial benefit, but also an environmental one: safe and properly-functioning infrastructure saves water and other resources.

The range of potential impacts that deteriorating infrastructure can have on the environment is wide and far-reaching. Aging bridges and other metal structures rust over time, releasing components into the air and water (Figure 6). Deteriorating pipes may result in water or sewage leaking into the ground, thereby contaminating groundwater. Furthermore, roads that are in poor condition can have a network effect on the efficiency and environmental well-being of an entire community.

The proper maintenance of infrastructure conserves materials by minimizing the need for asset replacement.

The conversion to LED streetlights as part of the Neighbourhood Renewal Program implementation and the application of best practice design has helped minimize energy consumption and greenhouse gas generation.

5 Meeting Client's Needs

Figure 7. Neighbourhood renewal

In addition to monitoring and maintaining the large number of Edmonton's infrastructure assets, the Office of Infrastructure Management is further challenged by having to do so on a limited budget determined by the available funding. The Office sought an asset management system that could be used to minimize repair costs or maximize the performance of its infrastructure assets. RIMS informs decision-makers of the options available for asset management at different cost and performance levels, which helps optimize investments and conserve taxpayers' dollars while ensuring public safety.

Figure 8. Utility work for neighbourhood renewal

The City of Edmonton has used RIMS methodologies to develop its Neighbourhood Renewal Program, which targets the renewal and rebuilding of Edmonton's roads, sidewalks, and streetlights, one neighbourhood at a time (Figures 7, 8, and 9).

Figure 9. Sidewalk renewal

6 Results and Future Directions

Figure 10. City of Edmonton infrastructure

The City of Edmonton's use of the award-winning RIMS methodology has resulted in several exciting initiatives. First, a presentation of the RIMS output to City Council led to the approval of a 1% tax increase, which allows the City budget to cover more infrastructure maintenance costs each year. Second, the findings from the RIMS output led the City to create a comprehensive management strategy (Figure 10). Third, RIMS and the Neighbourhood Renewal Program have served as the catalyst for strategic social change in Edmonton, prompting the creation of the Great Neighbourhood Initiative, which focuses on social and environmental sustainability. Finally, the success of RIMS in infrastructure management has encouraged its developers to begin expanding the program to model optimal spending strategies for maintaining buildings.

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