A GIS Based Walkway Management System

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Abstract

The Walkway Management System (WMS) uses geographic information system (GIS) software to calculate an estimate for the level of maintenance required for walkway segments. It then assists the user in prioritising the maintenance on segments of the walkway that require repair. The development of the WMS is a cooperative effort between a team of researchers at Lincoln University and Department of Conservation (DoC) staff. DoC staff provided guidance and data, and the Lincoln University research team has implemented the system in ArcInfo software. This paper provides an analysis of the walkway maintenance problem and an overview of a GIS application developed for use as an applied tool for resource management.

1 Background

Outdoor recreation is a major pastime of New Zealanders and visiting international tourists. In recent years, there has been a dramatic increase in demand for wilderness[1] experiences. This demand has put tremendous pressure on the country's walking tracks (Kearsley & Gray, 1993). With the changes in patterns of visitor numbers, use and expectations, it is vital that managers plan for the future to provide appropriate services and facilities, without endangering the resources that the visitors have come to experience (Marshall, 1994).

An estimated 2.4 million visits were made to DoC offices in 1994/95. Current international visitor numbers are over one million each year, and the Tourism Board expects numbers to increase to two million by the year 2000 and three million by the year 2004. About half of these people visit areas managed by DoC (DoC, 1996a).

In April 1987, administrative changes led to the creation of the Department of Conservation. DoC assumed management of New Zealand's national parks, forest parks and other protected areas, including the numerous walkways from the Department of Lands and Survey and New Zealand Forest Service.

In September 1994, DoC published a Visitor Strategy Discussion Document (DoC, 1994). It states the Department's objectives as being:

> "(a) to protect New Zealand's natural and historic heritage
>
> (b) to provide opportunities for people to appreciate, use and enjoy the lands and waters it manages - but with care and respect
>
> (c) to act as a voice for conservation in the community and in government."

1 We use wilderness as a relative term depending on the user's perspective. A user may consider the wilderness to be a short walk on a wooded trail near an urban area, while others may consider the wilderness to be a back country trail.

This document was written as the first step in the process of addressing the issues of management and planning for the resources under DoC's care in relation to the changes taking place in visitor flow and needs.

In October 1996, the Greenprint documents outlined DoC's policies to the incoming government (DoC, 1996a and b). The Visitor Strategy in this document set five goals:

"(a) Protection
(b) Fostering visits
(c) Managing tourism concessions on protected lands
(d) Informing and educating visitors
(e) Visitor safety."

When the documents were written, DoC was responsible for the management of about 27 per cent of the country's land area, with about 8600 kilometres of walking tracks, 1200 kilometres of roads, 960 huts, 250 campsites, 40 visitor centres and thousands of roadside, waterside and road-end facilities. Visitor structures managed by DoC include boardwalks, boat ramps, jetties, pedestrian and vehicle bridges, retaining walls, safety fences, guard rails, and viewing platforms. There are between 15-20,000 structures at 4500 sites.

The Department recognises the value of GIS in the management of these land, facilities and walkways. McEwen (1990) discussed the ways GIS could be used to assist DoC with its land and facility management problems.

DoC classifies walkways into four categories; path, walking track, tramping track and route. The level of visitor use for each walkway segment is an important consideration in determining the upkeep of the walkway. The greater the walkway's use, the more investment usually goes into its upkeep. Another consideration is the walkway category. Due to user needs and perception, a path requires more maintenance than a route. A path is used predominantly by families, less experienced walkers and the disabled. These users require a higher standard of walkway and facilities, and as there are more of these users there is a need for more facilities to be provided. Whereas, a route is generally used by well equipped and experienced trampers who are interested in the rough and rugged wilderness, and do not require carefully maintained walkways and facilities.

Walkway maintenance is one of the major problems that DoC has. McQueen (1991) has outlined some of the environmental impacts of visitor use on walkways. In addition, Simmons and Cressford (1989), Stewart (1985), and Young (1985) have researched the effects of the environment on walkways. Some general conclusions drawn from this research are discussed below. These conclusions are supported internationally (Department of Parks Wildlife and Heritage[2], 1994), and by the casual observation of locals and frequent walkers (Grzelewski, 1995).

One of the major areas of concern for DoC is the environmental impact of the increased visitor use on walkways. Frequency of visitor use is often one of the major causes of walkway deterioration. The higher the number of users, the greater the impact of trampling (although on gravel surfaces high user numbers compacts the substrate, lessening the need for maintenance). Other problems, such as walkway widening, occur where the walkway is congested and walkers overtake each other or where the walkway shows signs of deterioration, in which case the users will walk on the more stable edges of the walkway. Unplanned walkway formation occurs when users go off the designated walkway creating a new walkway through formerly untracked areas. This can lead to locally severe environmental impacts, as well as lowering the recreational and wilderness value of the area.

Other factors such as slope, aspect, soil type, rainfall, walkway surface and vegetation influence the rate of walkway deterioration. Walkways on steeper slopes tend to have water flowing off the slope over the walkway causing erosion. Walkways on flat surfaces may have drainage problems. High intensity rainfall has a more detrimental impact on walkways than low intensity rainfall. Organic soils are more susceptible to damage than gravel soils. The north, west, and northwest aspects receive more impact from

2 The Tasmanian Parks & Wildlife Service has developed a management strategy document. The Lincoln research team has been in contact with the Tasmanian Parks & Wildlife Service and we will be sharing ideas and results with them.

wind during the year than the other directions. All these factors and others need to be considered in the management of walkways.

The Mount Thomas and the Oxford Forests in North Canterbury were selected for use in the WMS prototype development. The Mount Thomas Forest, located 60 kilometres northwest of Christchurch, covers an area of 10,800 hectares. It has six walkways of varying length, a picnic/ camping area, permanent fire places, toilets and running water. The Oxford Forest, located approximately 56 kilometres from Christchurch, covers an area of 11,350 hectares. It has four walking tracks and four tramping routes of varying length (DoC, 1991). These two sites were chosen for their proximity to Christchurch, the number of walkways and facilities associated with the area, the available data, and the availability of local knowledge to assist in the development of the prototype.

2 *System Development*

2.1 Problem Definition

DoC is in the unenviable position of having to balance the need to protect the environment and resources for which it is responsible with the desires of the recreational visitors who wish to use those very resources. In making management and planning decisions, DoC must keep these two apparently opposing needs in mind.

Due to the limited funding that DoC receives and the large number of facilities, services and lands it has to manage and maintain, there is a need for DoC to efficiently allocate its limited financial resources. Currently, DoC uses a

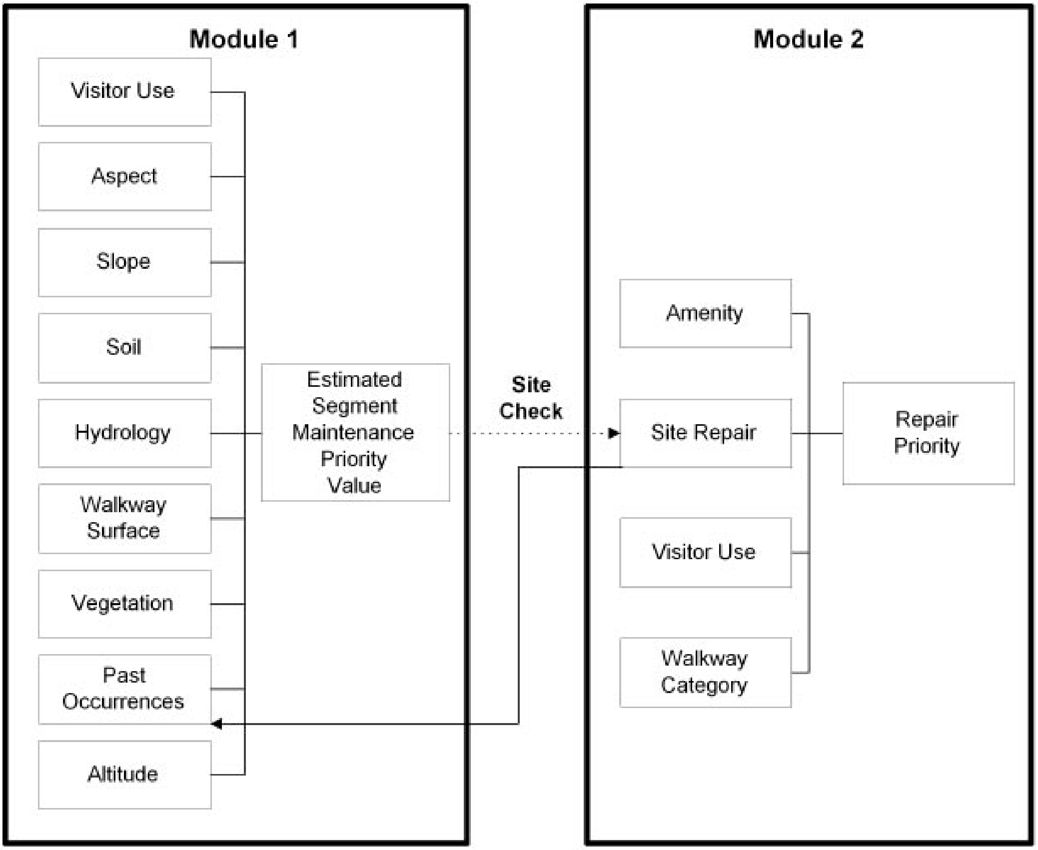

Figure1 - WMS Prototype Maintenance Model Structure Diagram

combination of manual and automated techniques to evaluate the need for walkway maintenance and repair. No one system has the information required to make a standard and efficient evaluation of walkway maintenance priorities.

2.2 Problem Solution

The WMS prototype was implemented primarily in ArcInfo GIS software. GIS provided the functionality to analyse the spatially coexistent factors that impact upon walkways. In the early stages of the conceptual design, the research team recognised that modeling the physical factors could only provide a range of probabilities for maintenance on walkway segments. There needed to be a knowledgeable observer to then evaluate these segments for actual maintenance needs. The actual maintenance requirement could then be input into the system and a prioritised maintenance ranking would be generated based on walkway characteristics and use. Figure 1 illustrates the conceptual solution consisting of two principal modules.

Module One calculates an Estimated Segment Maintenance Priority Value for each walkway segment based on its level of visitor use, aspect, slope, soil type, hydrology, vegetation, track surface, altitude, and past maintenance characteristics. The higher this value, the greater the likelihood that this segment will require maintenance. This result gives the user a set of rank order track segment locations where maintenance problems would most likely exist. These results provide an indication of the resources needed to inspect the walkway network for required maintenance and potential maintenance needs.

Module Two maintains information on the required maintenance or repair. Needed repairs are input into the Site Repair component of the Repair Priority module (Module Two). This is done from a pick list of different categories of maintenance required. The amenity value (Archaeological Sites, Species Index, Areas of Natural Significance, Geological Preservation Sites), site repair value, walkway category and level of visitor use values are combined and sorted to provide the user with a segment repair priority listing. Armed with this information, the user can then determine a walkway maintenance schedule.

3 Prototype Implementation

Most of the digital geographic data required for the prototype was held by the DoC Canterbury Conservancy Christchurch office in Terrasoft GIS format. Data such as contours, walking tracks, streams and soil and vegetation polygons were converted to ARC/INFO format by DoC staff. The Lincoln University research team then manipulated the base data layers to include only the information relevant to walkway maintenance. These layers are the maintenance factors in the WMS prototype.

The item's (database fields) Factor Class, Factor Value and Factor Weighting were added for each maintenance factor and populated with data. These values were discussed with DoC experts and adjusted based on their input.

ArcView was used for display and query purposes. This software was chosen because of its relative simplicity and availability at DoC conservancies. The ability of DoC users to query attribute information and produce maps of the walkway network was considered to be important.

Both modules required graphical display of results. Walkway segments were colour coded to indicate priority. Maps can be simply produced to show the location and rank of all track segments or to highlight only those which have been designated within the highest priority range.

3.1 Module One

Slope and aspect polygons were derived from 20 metre interval contour data. A 50 metre resolution lattice was created from a TIN of the study area which provided appropriately generalised slope and aspect information. Walkway visitor numbers were obtained from DoC field records and linked to the walkways by walkway site number. Walkway surface attributes were manually attached to walkway segments. A hydrology coverage was created by buffering streams to a distance of five metres.

Maintenance factors were combined using line-in-polygon overlay to produce a segmented walkway coverage. Walkway segments varied in length from tens of centimetres to tens of metres depending on the variation in visitor use, aspect, slope, soils, hydrology, walkway surface, vegetation, and altitude.

A model that sums the maintenance factors was developed using the following equation (factor values and factor weighting variables are defined in Table 1).

Estimated Segment Maintenance Priority Value = **[**(Fvu *Wvua) + (Fa *Wa) + (Fsl *Wsl) + (Fs *Ws) + (Fh *Wh) + (Fws *Wws) + (Fv *Wv) + (Fal *Wal) + (Fpo *Wpo)**]**

The result is a numerical maintenance priority value for every walkway segment. These priority values are sorted and grouped into classes for display.

3.2 Module Two

Module Two operates on the same segmented walkway coverage as Module One (only necessary attributes were retained). Actual repair event data are added by selecting the location graphically and inputting a site repair value and a description of the repair required using an input form.

Input of repair events is obtained through the use of a pick list of different categories, such as trees over the walkway, landslide, and walkway wash-out. Each of these categories has a different value based on the degree of walkway blockage that they cause. Amenity values are given to each walkway segment leading to a specific amenity.

In addition to actual repair events, statutory site inspection requirements are incorporated. These are assigned site repair values such that they would rank the highest. Those walkway segments that have site inspection requirements assigned to them are displayed in a separate category.

A model was developed that sums this repair data with walkway usage, walkway category and amenity value to calculate a repair priority value using the following equation (factor values and factor weighting variables are defined in Table 2).

Site Repair Priority Value = **[**(Fam *Wam) + (Fvu *Wvub) + (Fwc *Wwc) + (Fsr *Wsr)**]**

The results of this equation are displayed on a colour coded map to show the ranking of the walkway segments by repair priority.

4 *DoC Feedback and Field Test*

The results from an initial test run were used by the research team to review the system with DoC staff at Mount Thomas. The structure of the system, the factors that should be used in each module, the factor values, and weight values were all reviewed. Whilst the initial results were deemed to be reasonably accurate, a number of factor values and weightings were revised, along with the factors and their categories. A similar meeting was held with DoC management staff at the Canterbury Conservancy office in Christchurch where additional suggestions were made. Both field and management staff could see the potential value of the system for their respective long term planning and day to day implementation of maintenance. Interest was expressed, without formal commitment, to see full implementation of the system.

The results of the WMS prototype were field tested on the Mount Thomas Forest tracks. Researchers found that maintenance priority values should have been higher where introduced vegetation species occurred and in areas of southwest aspect. Introduced plant pest species result in consistent problems of encroachment on the walkway. The snow on the southwest aspect of the hills, which had not been taken into account has caused considerable damage to trees along walkways in years past.

The changes from the discussions and field test were noted and incorporated into the system. The results generated by the revised WMS prototype were more realistic and useful.

5 *Assumptions and Limitations*

Visitor numbers are taken by DoC as one way traffic. This has major implications for the amount of deterioration on a walkway due to visitor use. For instance, if the walkway is a single return route, the visitor would be counted once, even though the trail would have been traverse twice by

Table 1 - Evaluation Tables used in the Prototype Maintenance Model: Module One

Maintenance Factor	Factor Class	Factor Value	Factor Weighting	Description
Visitor Use (Fvu *Wvu)	0 - 499	1	10	* little impact
	500 - 999	2		* walkway deterioration
	1000 - 1999	3		* moderate walkway Deterioration
	2000 - 2999	4		
	3000 - 4999	5		* almost total soil removal
	5000 - 9999	6		
	10000 - 19999	7		* severe walkway Deterioration
	>=20000	8		
Aspect (Fa *Wa)	North	2	5	* Number represents the level of impact from rain, wind and Snow
	North - East	1		
	East	1		
	South - East	0		
	South	1		
	South - West	2		
	West	3		
	North - West	3		
Slope (degrees) (Fsl *Wsl)	S <= 1	5	3	* flat to gentle
	1 > S <= 2	5		
	2 > S <= 3	5		
	3 > S <= 5	5		
	5 > S <= 10	1		* gentle to moderate
	10 > S <= 20	2		* moderately steep
	20 > S <= 35	3		* steep
	35 > S <= 55	4		* very steep
	55 > S <= 90	5		* precipitous
Soil (Fs *Ws)	Gravel soils	1	2	* low impact
	Associated Yellow-brown shallow & stony soils	1		
	Yellow-grey earths	2		* moderate impact
	Yellow-grey to Yellow-brown earths intergrade	2		
	Lowland Yellow-brown earths	2		
	Upland & high country Yellow-brown earths	3		* high impact
	Recent soils	3		
	Organic	4		* severe impact
Hydrology (Fh *Wh)	> 5 metres	1	1	Potential for washing out and erosion from stream overflow and flooding
	< 5 metres	2		
Walkway Surface (Fws *Wws)	Rock	0	3	* little impact
	Top Course	1		* compacts down
	Natural	3		* top soil and vegetation easily Impacted
Vegetation (Fv *Wv)	Alpine Tussockland	1	2	* high durability to trampling
	Grassland	2		
	Beech Forest	3		* maintenance required
	Broadleaf Forest	4		
	Introduced - all types	5		* high maintenance required
Past Occurrences (Fpo *Wpo)	0	0	20	Number of past occurrences increases the potential of Occurrences
	1-2	1		
	3 - 4	2		
	> 4	3		
Altitude (Fal *Wal)	>= 750 metres	0	7	The higher the altitude the less maintenance required
	< 750 metres	1		

Table 2 - Evaluation Tables used in the Prototype Maintenance Model: Module Two

Repair Factor	Factor Class	Factor Value	Factor Weighting	Description
Amenity (Fam * Wam)	Only way to 2 or more sites	4	2	All sites of significancesuch as archaeological sites, areas of natural significance, geological preservation sites and species index
	Only way to 1	3		
	Shared way to 2	2		
	Shared way to 1	1		
	None	0		
Visitor Use (Fvu4 * Wvu4)	0 - 499	1	4	The more users the greater the priority for maintenance
	500 - 999	2		
	1000 - 1999	3		
	2000 - 2999	4		
	3000 - 4999	5		
	5000 - 9999	6		
	10000 - 19999	7		
	>=20000	8		
Walkway Category (Fwc * Wwc)	Route	1	1	Expectations and level of experience differs from Path users to Route users therefore needs for quality of walkway and facilities differ
	Tramping Track	2		
	Walking Track	3		
	Path	4		
Site Repair (Fsr * Wsr)	Fallen tree: Minor	2	5	Tree has fallen on walkway. Walkway still useable.
	: Major	10		Tree has fallen on walkway. Walkway impassable.
	Landslip : Minor	2		Small slip. Walkway still useable with little or no danger.
	: Major	10		Major slip. Walkway closed due to danger to users.
	Washed out: bridge	10		Walkway impassable.
	: walkway	10		Walkway impassable.
	Damaged: stairs	1		Stair broken or damaged. Walkway still useable.
	: bridge	2		Bridge broken or damaged. Walkway still useable.
	: boardwalk	1		Boardwalk broken or damaged. Walkway still useable.
	: platform	3		Platform broken or damaged. Walkway still useable.
	Tree roots	2		Tree roots damaging walkway. Walkway still useable.
	Flooding	4		Walkway or structure flooded. Walkway still useable.
	Site inspection	200		Mandatory site inspection.

the person walking up and back. This highlights the need for more precise visitor monitoring to fully gauge the actual number of people walking on each segment.

Some of the data in the current tables have been developed from studies of other areas, localised information sources and input from local DoC staff. More research needs to be done to confirm the relationship between the physical factors and track maintenance, so that the results obtained for the Estimated Segment Maintenance Priority Value more closely reflect reality. User feedback will also be necessary from actual operational experience to adjust the factor values and factor weights to ensure the greatest model accuracy.

Generalisations were made for some of the physical factors that may not be valid for an expanded area of analysis. For instance, due to the relatively small size of the current study area, it is assumed precipitation is constant. The impact of precipitation is taken into consideration by using the walkway surface and category, slope, soil, hydrology, and vegetation factor values. Precipitation variation will need to be used if the WMS is applied to a wider area.

Data input for actual repair events is associated with walkway segments, rather than point locations. This may result in accuracy problems for longer segments.

6 Implications and Further Development

DoC staff can use the prototype to more efficiently apportion their resources for maintenance and repair activities on walkways. The system can be used for both long-range planning or short-range evaluation of priorities.

The WMS prototype uses the Mount Thomas and Oxford Forests as a test case. After the system is refined, there is potential to expand it to cover more areas managed by DoC (e.g. conservancy or nationwide).

The system could provide an estimate of the cost for repairs and maintenance based on a standard set of costs for different categories of work. This would then enable DoC staff to quickly determine not only priority, but total cost. A report on specific maintenance that is needed could also be sent from the WMS to project planning software for efficient scheduling of these tasks.

If new or altered walkway construction is planned, an extension of the WMS software could be used to determine estimated maintenance requirements based on the physical features of the land and the estimated visitor use. DoC could use this data to manage the tradeoffs between maintenance costs and provision of access to walkways.

For the long term, WMS could be incorporated into a broad based GIS Walkway Management System (WMS) that could include an interactive visitor interface. This visitor interface could provide information on walkway category, level of use, current walkway conditions, distances and average walking times for the walkway, equipment required, recommended experience level, points of interest along the walkway segments, and map printouts.

7 Conclusion

The Walkway Management System prototype is a first attempt to model the complex physical and human factors that result in maintenance needs on the different categories of walkways. GIS has already been used to record maintenance needs for transportation infrastructure, but this research extends GIS capabilities beyond a record's management function to provide an analytical and management tool that can be used for short term and long term decisions for walkway management, maintenance and viability.

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