Saskatchewan Bridge Management from a Spatial Perspective

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Abstract

The Saskatchewan Association of Rural Municipalities (SARM) in conjunction with Saskatchewan Highways and Transportation (SHT) retained Associated Engineering (AE) in September of 2006 to complete a strategic asset management plan for the management of over 3900 rural municipal bridges and bridge sized culverts valued at over 700 million dollars. The key objective of the strategic plan was to establish a methodology to manage the prioritization of repair and rehabilitation plans in view of the sustainability and existing and proposed network service levels.

The terms of reference for this project required that an objective priority rating system be derived for structures on a system wide basis. AE chose to employ a value, priority, risk and value approach to determine the relative importance of the structure from a service level aspect in addition to the evaluation of structural integrity and inspection levels. This approach allowed for the structures to be evaluated outside of their respective structural adequacy envelopes and allowed for a determination of the value of each structure in terms of serviceability or adequacy in relation to service level.

AE employed an advanced spatial or Geographical Information System,(GIS), based rating engine to examine structure stressors including but not limited to : structural adequacy, inspection frequency, traffic loading, financial value, road class, primary / grain haul uses and functional redundancy in view of existing and proposed service levels.

The results of the study were communicated to the stakeholders SARM, SHT and individual rural municipalities, (RM), through a conventional paper report and via a custom WEB GIS and relational database application which was updated throughout all phases of the project as results became available. The digital based deliverable allowed stakeholders to maintain both the project structure inventory and decision making regime beyond the life of the project.

This paper / presentation demonstrates an innovative approach to sustainable bridge asset management and the use of an alternative project delivery mechanism to provide a sustainable data record and decision making regime.

The results of this project assisted in the securing of a substantial increase in funding for both bridge inspection and renewal.

Saskatchewan Bridge Management from a Spatial Perspective

Saskatchewan Association of Rural Municipalities, (SARM), in conjunction with Saskatchewan Highways and Transportation, (SHT), retained Associated Engineering (**AE**) in August of 2006 to provide a strategic plan for the management of approximately 1800 culverts and 2100 bridge structures. This analysis involved the juxtaposition of individual structure functional needs with available funding while determining and maintaining a fixed or uniform service level based on various stressors or metrics.

Fundamental to this study was the establishment of both a sustainable funding regime for the structure network along with a prioritization, value and risk assessment in order to determine the critical classes of structures in need of pre emptive or immediate repair or rehabilitation. The study is consistent with the ***National Guide to Sustainable Municipal Infrastructure, (Infraguide)*** [(1)], key considerations for the sustainability of municipal infrastructure. These are generally defined as:

What do we own?
Where is it?*
What is it worth?
What condition is it in?
What needs to be done?
How much does it or will it cost?

** Supplemental condition state added by* **AE** *Staff for the purposes of this study*

The scope and budget of the project precluded an in depth evaluation of the above on a structure specific basis however the thorough examination of all available information sources yielded significant insight into current service levels, overall culvert and bridge asset condition, future needs in relation to condition assessment and existing and future financial needs.

Methodology and Background Data

Saskatchewan Highways and Transportation staff supplied all of the required information for the purposes of the study. The information submissions occurred over a period of six months as decisions relating to priority ranking, value and risk mitigation were developed through the review of relevant information and in discussions with the two stakeholders.

Each supplied information set was reviewed for its currency, consistency and applicability to the stated goals of the project. The supplied bridge specific information generally consisted of the following.

1. Bridge / Structure Inventory
2. Location / Spatial References
3. GIS data sets describing structure surrounding environment

    - Saskatchewan Highways and Rural Municipal Road Network.
    - Provincial Hydrology – Creeks, Rivers etc..
    - Populations by Area and R.M.
    - Truck and Blended Average Annual Daily Traffic, (A.A.D.T.) values.
    - Road Classes.

(GIS data cont)

- Posted Grain Haul Routes.
- R.M. and Populated Area Boundaries.
- Additional Data for Bridge and Culvert Locations.
- Section, Township and Range Delineators.
- Modeled Grain Haul Routes
- Primary Haul Corridors

In order to perform much of the analysis relative to primary haul corridors, traffic volumes and other spatially based stressors, locations were required for each of the structures in the network. The supplied location based information fell into three general categories:

1. Definitive northing, easting and elevation, (x,y,z).
2. References to legal description, road section, township, range and meridian.
3. RM name and or number.

The lack of definitive location information, (x,y,z) for 35% and 96% of the bridge and culvert inventories respectively did impact a portion of the location based analysis performed however SHT and **AE** staff deemed it suitable for a planning level study of this type.

AE staff successfully geo referenced the vast majority of these structures within a GIS environment using all available location based information contained in the source information, in conjunction with the GIS based information submission received from SHT Geomatics Division.

The hierarchy of the methods employed successfully to locate the ambiguous locations and their relative accuracies are as follows:

1. GPS coordinates, (X,Y,Z) - < .01 km
2. Road / Control Section - +/ .10 km
3. Section, Township and Range - +/- .40 km

The lack of a definitive location for some of the structures being analyzed may have impacted the analyses being performed in that stressor data such as AADT, TAADT and grain haul route information may not have been transferred to the structure given the ambiguity of its position. The project committee agreed that this potential inaccuracy, in view of the level of study being conducted, was acceptable.

Structure Priority Assessment

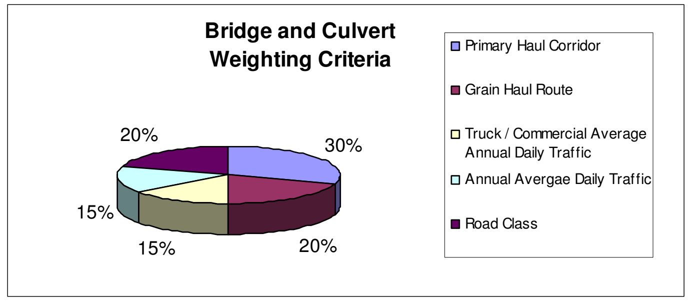
The terms of reference for this project required that an objective rating system be derived for structures on a system wide basis to allow for both the assessment of risk and the assignment of a priority for the purposes of a proactive inspection, maintenance and replacement program. A secondary consideration at the outset of the study was the examination of the feasibility of the elimination of structures on Class 7 roads based on their respective demands.

In order to assess the individual importance, from a service delivery point of view of the structures in inventory a structure condition or rating array based on the available supplied information was constructed. The intent of this array was to describe the usage of each structure in the context of its condition age and structural adequacy.

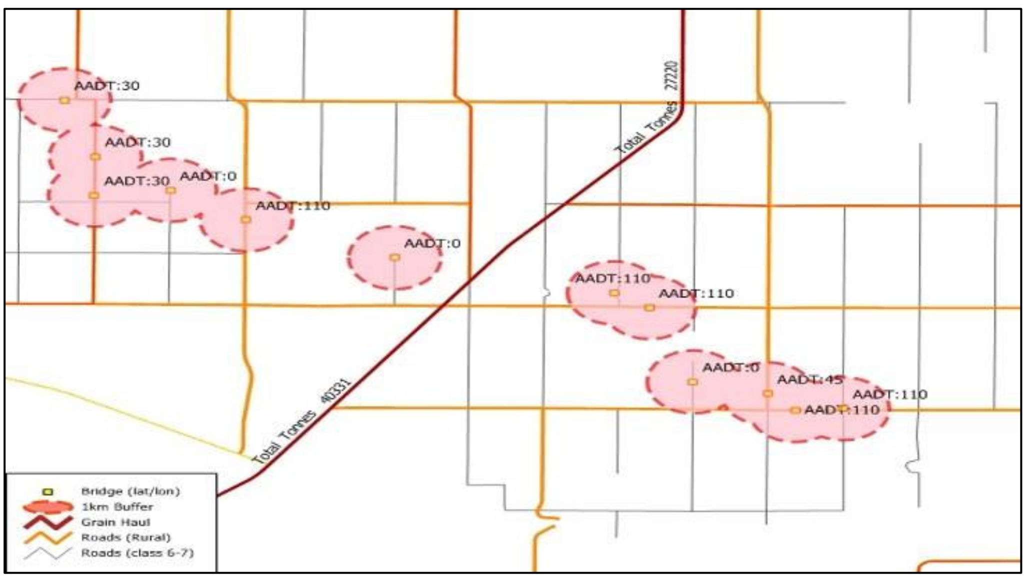
The final weighted rating array is shown in the following Table and Figure.

Bridge and Culvert Risk and Priority

Metric	Weighting
Primary Haul Corridor	30
Grain Haul Route	20
Truck / Commercial Average Annual Daily Traffic	15
Annual Average Daily Traffic	15
Road Class	20
	100



The above metrics were applied to the inventory en masse on a spatial or proximity basis using the individual structure's position relative to the closest road segment and the metrics associated with it. An illustration of this process is shown in the following figure.



Proximity distances and tolerances were adjusted through several iterations to ensure that the appropriate metrics were being applied to all 3,500 structures in inventory.

Condition metrics were then assigned to each structure within the project database. Individual scores for each structure were calculated in the project database as follows:

1. Primary haul corridor – structure was given 0 or 30 points based on its location relative to a primary haul corridor.

2. Grain haul route – structure was given 0 or 20 points based on its location relative to a defined grain haul routes.

3. TADDT / AADT – structure was given 0 through 15 points, on a sliding scale, relative to the observed traffic load. This sliding scale was established through the assignment of a value of 15 relative to the maximum value encountered. All subsequent point assignments were assigned on an even division of the maximum value by 15.

4. Road Class – structure was given 0 through 20 points on a sliding scale relative to the road Class 1 through 7.

The resulting data set classified each structure relative to its importance from a service delivery point of view. It is important to note that the rankings were assigned on an individual structure basis.

Pilot Bridge Inspection / Condition Assessment

The volume of the inventory of the structures being examined at a planning level for the purposes of this study and project budget prevented the inspection and rating of all structures on an individual basis. To that end AE selected a grouping of 6 structures within the inventory that were considered to be indicative of the overall structure population. Structures within this group exhibited differing structural elements, age and geographical location and were considered to be reflective of the overall structure demographic.

When comparing the information in the bridge inventory database with the six bridge sites visited, some concerns were evident. The locations of the bridges appeared to be accurate; however, the repair and/or replacement history was not reliable for at least two of the six sites visited. Three of the structures had not been inspected for over 30 years. In general all of the structures examined required some form of maintenance repairs in order to extend the service lives of the structures and to defer considerably more expensive future capital replacements.

The apparent lack of accurate information contained in the inventory and inspection records did not allow for the comparative analysis of the structure inventory at a network level. AE staff recommended a summary level inspection of all structures to allow for the identification of potential immediate risks and for the update of the inventory and inspection record. This inspection program would establish a baseline condition level for the entire inventory thereby allowing SHT staff to direct their existing resources to bridges identified as being significant from a risk or value perspective.

Structure Valuation Assessment

In the formation of any asset strategic plan the determination of both the current and depreciated asset values figure prominently in the establishment of funding priorities and regimes. The bridge and culvert inventory was valued based on the inventory information and derived statistical average costing practices.

Bridge Inventory Valuation

Inventory records were examined for available attributes to support the costing of the bridge network. A replacement cost of $2500 per square metre of deck surface was used for valuation of each structure with an additional disposal cost for timber bridges of $25,000 applied where necessary.

All timber bridges less than 10 metres in length were assumed to be replaced with twin barrel 2000mm diameter culverts 25 metres in length assuming $2300 per metre for materials and labour and $25,000 for disposal for a total cost of $140,000 per structure. This replacement rationale was considered to valid in view of Department of Fisheries and Oceans requirements in reference to the fish habitat

Depreciated costs were established based on a linear deprecation method linked to the original construction date of the structure and the current replacement cost. Future replacement cost was established using a 3% inflation rate compounded annually to the predicted bridge replacement year.

Bridge life is assumed to be approximately 75 years based on available document research and review. Supporting documents for this review are available. Please note that the bridge life expectancy does not take into account substantial rehabilitation and replacement that can and does promote extended lifespan beyond 75 years or for that matter indefinitely.

SHT staff requested that a 60 year bridge life be used based on their considerable past experience.

<u>Culvert Inventory Valuation</u>

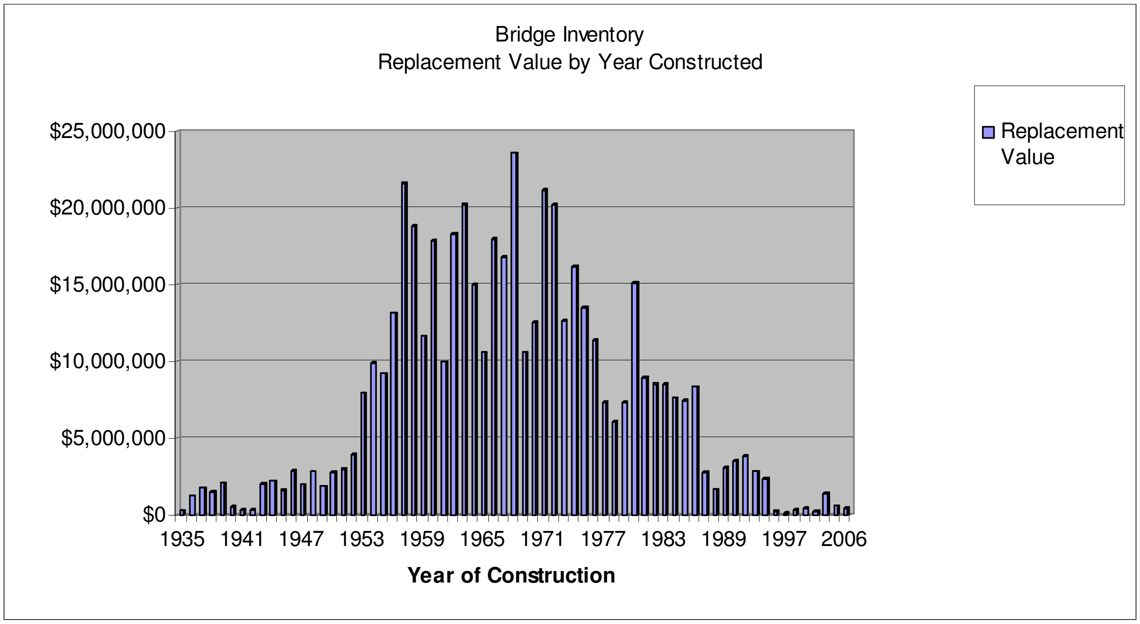
Culvert inventory records were examined for available attributes to support the costing of culvert listing. Replacement costs for structures less than or equal to 3000mm in diameter are shown in the following Table.

Culvert Replacement Costs
By Diameter / Unit Metre

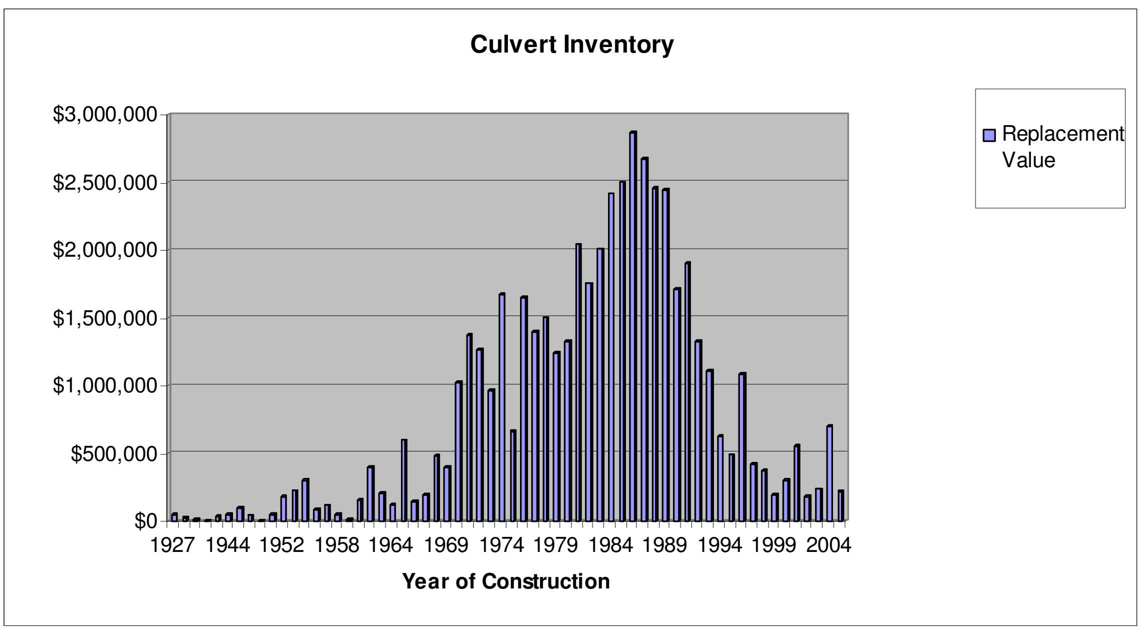
Size (mm)	Material Cost ($/m)	Labour Cost ($/m)	Total Cost ($/m)
800	175	700	$875
900	190	800	$990
1000	220	900	$1,120
1200	275	1000	$1,275
1400	340	1200	$1,540
1600	385	1400	$1,785
1800	440	1600	$2,040
2000	500	1800	$2,300
2200	535	2000	$2,535
2400	585	2200	$2,785
2700	880	2300	$3,180
3000	975	2400	$3,375

Non circular, culverts greater than 3000mm in diameter and those with no definitive size and shape information were valued on an individual basis and included in the derived financial calculations. SHT staff requested that subsequent financial calculations include a life span estimate of 40 years.

The following figures indicate the total replacement value, in today's dollars, by construction year for bridges and culverts respectively. These figures provide an overall view of the distribution of the value of the network by year of construction.



The above figure indicates that the bulk of the bridge network value was built between approximately 1953 and 1970.



In contrast the culvert replacement value by year indicates a much larger proportion of assets being constructed in recent years.

Replacement Life Cycle Financing

The entire bridge and culvert inventory was examined in the context of operating all structures to their point of failure based on the described life spans. This “operate to failure” assumptions means that any given structure has no implicit service level or value after it has reached an age equal to its expected life.

As mentioned in the previous section, two iterations of the calculations were required as alternative life expectancy estimates were provided by SHT staff. These values are lower than those derived from **AE** research however they did reflect many years of SHT staff’s personal experience.

In order to effectively determine both the short and long term financial needs, from a capital replacement perspective, the project database was structured to perform the following calculations based on the available asset inventory:

- Total value of the asset inventories expressed in terms of today’s dollars.
- Depreciated value was assigned using a standard linear depreciation method equating to the purchase price in today’s dollars multiplied by the remaining life divided by the useful or expected operating life.
- Future replacement value was defined via a compound interest equation with the annual rate of inflation assumed to be 3% based on a seventy year actuarial average. Each asset’s future replacement value was calculated to the year of replacement based on the installation or purchase date plus estimated useful life.
- Investment capital reserve required was calculated using a compound interest equation assuming an annual 6% rate of return, a seventy year actuarial average, indexed to the future replacement value as defined above.
- Backlog is defined as the total value in today’s dollars of all assets whose age was beyond the estimated useful life.

These calculations were employed using industry standard/actuarial based long range average rates of inflation, interest and depreciation. All calculations are applied on a live basis allowing for subsequent analysis on the inventory on an ongoing basis.

Results of these analyses are shown in the following tables for bridges and culverts respectively with the AE and SHT supplied life spans applied.

Bridge Valuation Scenarios

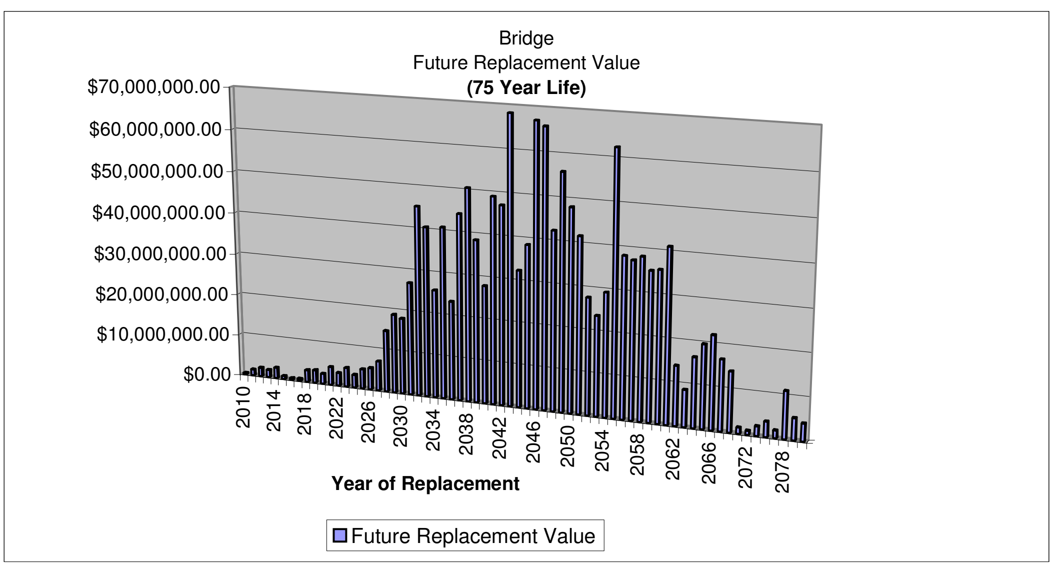
Life	Total Replacement Value	Depreciated Value	Future Replacements	Backlog	Capital Investment Required
75 year	$536,195,671	$239,952,750	$503,514,081	$32,681,590	$190,498,517
60 year	$536,195,671	$175,629,279	$484,608,328	$49,607,418	$271,099,057

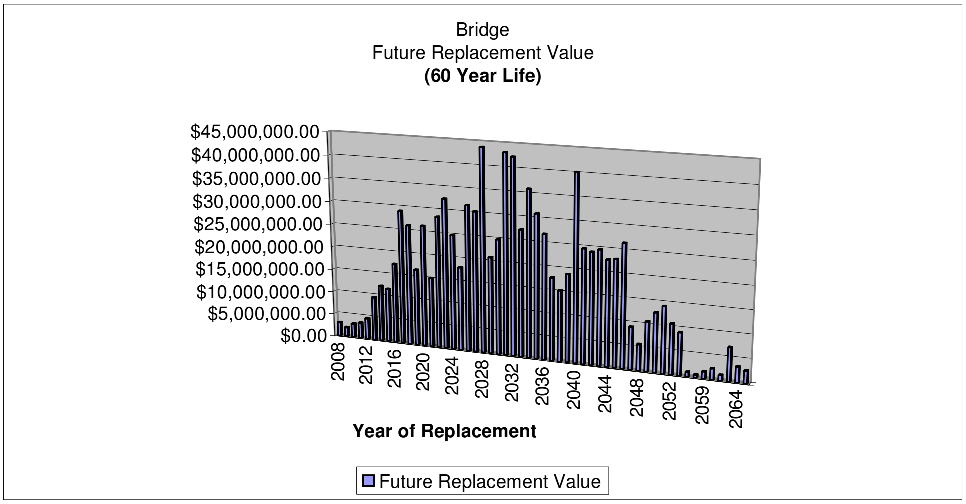
Culvert Valuation Scenarios					
Life	Total Replacement Value	Depreciated Value	Future Replacements	Backlog	Capital Investment Required
50 year	$61,000,000	$28,700,000	$56,600,000	$5,100,000	$28,400,000
35 year	$61,000,000	$18,000,000	$46,900,000	$14,900,000	$32,700,000

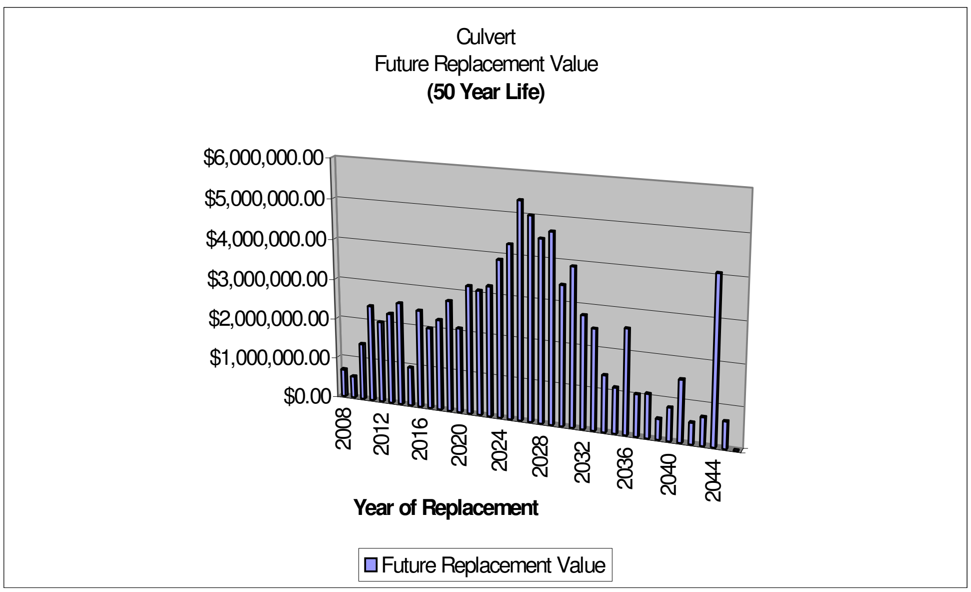
All values shown are expressed in today's dollars. A brief explanation of each column value follows:

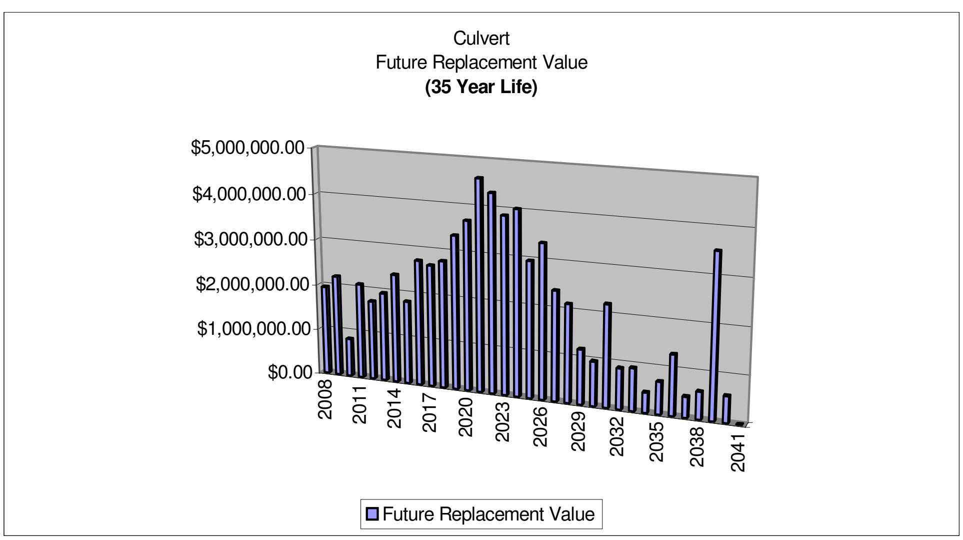
- Life: Life expectancy of asset based on AE research or SHT Staff input.
- Total Replacement Value: Total estimated value of all assets in today's dollars.
- Depreciated Value: Total depreciated value assuming a straight line depreciation of cost based on expected life span.
- Future Replacements: Total value in today's dollars of future replacements with no inflation factor applied.
- Backlog: Total value in today's dollars of those assets older than the quoted life span.
- Capital Investment Required: Value in today's dollars of the investment capital required to fund one life cycle of replacements assuming removal of backlog.

The required cash flows for the both networks, based on an operate to failure management regime, are shown in the following figures. The cash flows shown below assume removal of the existing structure backlog as indicated above and are expressed in inflated or tomorrow's dollars at the time of replacement based on individual structure anniversary dates.



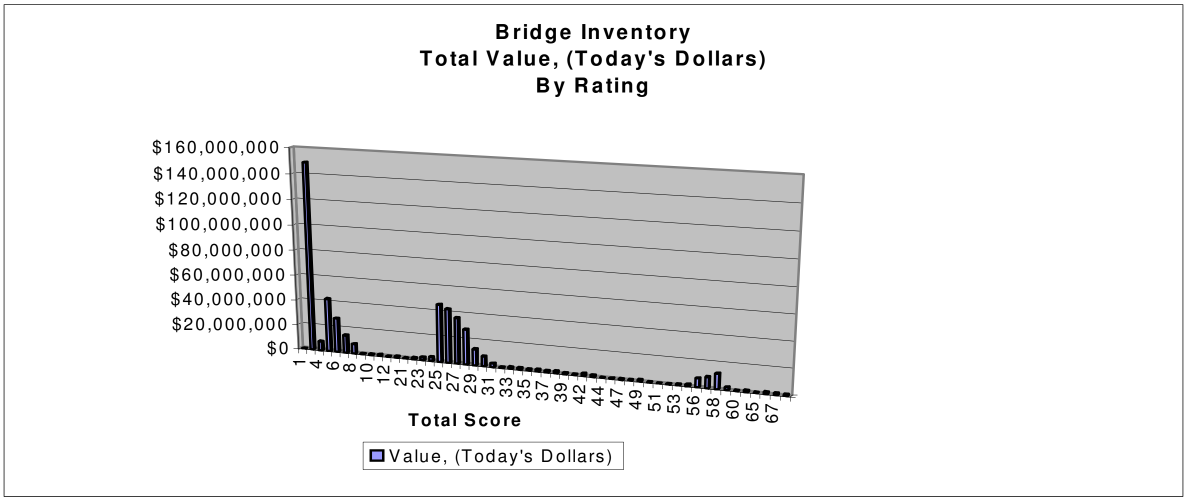

Bridge
Future Replacement Value
(60 Year Life)
$45,000,000.00
$40,000,000.00
$35,000,000.00
$30,000,000.00
$25,000,000.00
$20,000,000.00
$15,000,000.00
$10,000,000.00
$5,000,000.00
$0.00
2008
2012
2016
2020
2024
2028
2032
2036
2040
2044
2048
2052
2059
2064
Year of Replacement
Future Replacement Value


Culvert
Future Replacement Value
(50 Year Life)
$6,000,000.00
$5,000,000.00
$4,000,000.00
$3,000,000.00
$2,000,000.00
$1,000,000.00
$0.00
2008
2012
2016
2020
2024
2028
2032
2036
2040
2044
Year of Replacement
Future Replacement Value


Culvert
Future Replacement Value
(35 Year Life)
$5,000,000.00
$4,000,000.00
$3,000,000.00
$2,000,000.00
$1,000,000.00
$0.00
2008
2011
2014
2017
2020
2023
2026
2029
2032
2035
2038
2041
Future Replacement Value

The preceding figures illustrate the total costs associated with replacement by calendar year expressed in tomorrow's or future dollars. These costs are inflated to the year of replacement on the respective structure anniversary dates.

The calculated aggregate replacement costs were then analyzed in aggregate form, for the bridge network, against the individual priority and level of service rankings assigned in the initial phases of the project. Aggregate values of the bridge network were presented on a priority scale from a minimum value of 1 to maximum value of 67. The following figure and table illustrate the results of this analysis. A corresponding examination of the culvert inventory could not be performed due to ambiguity in the data record.



Total Replacement Value
By Group Rating

Score Range	Total Value*	Percentage
0 to 10	$248,925,290	51%
11 to 24	$9,145,635	2%
25 to 33	$177,542,665	36%
34 to 55	$17,217,090	4%
56 to 73	$35,266,096	7%
Total	$488,096,776	100%

The groupings shown indicate the replacement value of the network versus the assigned cumulative score. In general a significant portion of the inventory expressed as a total cost, ~$ 250M, appears to be, relative to the remainder of the network, insignificant in relation to the rating scheme applied. This grouping is indicated in red in the above 5.0. This group, by virtue of this examination and limited funding, should not be a priority in any capital replacement or repair program.

The issue of affordability to the end user is primarily the largest single determinant in the adoption of a uniform service level. The above and detailed listing provided in the project database was provided as a guide for the inspection, repair and replacement priorities of both SARM and SHT. Recommendations pertaining to the sustainability and further refinement of this rating system as new and more detailed information becomes available was provided.

Given the relevant costs presented, bridge removal (inventory reduction) based on a uniform and defensible rationale was evaluated as a method to reduce the apparent financial liability shown.

Project Summary and Recommendations

It was recommended based on the project analyses that consideration be given to: the update of the bridge inventory database via a comprehensive summary level inspection program at an approximate cost of $700,000 to mitigate risk relative to bridge condition, reduction of bridge inventory to limit future financial liability, establishment of service level standards across the structure network to better manage bridge replacement needs relative to service level and the creation of a formal communications protocol between SARM, Saskatchewan Highways and Transportation and funding agencies to ensure that inventory records are consistent throughout the entire rural municipal structures network.