University of Southern Queensland

Faculty of Health, Engineering and sciences

Research Topic

Deterioration of Timber Bridges Using a Fault Tree Analysis

A dissertation submitted by

Matthew Wilson

In fulfilment of the requirements of

ENG4111 and 4112 Research Project

Towards the degree of

Bachelor of Engineering (Civil) Honours

Submitted on: 13/10/2016

Abstract

The Department of Transport and Main Roads within the Mackay/Whitsundays region has 62 timber bridges which have progressively deteriorated and are nearing the end of their operational life expectancy. The department is responsible for providing a safe and operational road network which includes the appropriate maintenance of these timber structures. It is expected that within the Mackay/Whitsunday region there is an annual expenditure of approximately 5 million dollars allocated to maintain and rehabilitate timber bridges, which highlights the need for effective and timely maintenance scheduling. This dissertation will identify the probability of conditional state of movement for each structural member of a timber bridge.

The probability of deterioration of these structures are indicative of the deterioration rate over 3 time periods (2, 3 and 5 years). Inspection reports are used for the foundation of the data to identify and track the movement paths for the different condition states. The movement of condition states are then subjected to probability methods (Markov Chain, Fault Tree Analysis) to depict the chance of a member changing condition states over that time period.

A Fault Tree Analysis (FTA) is utilised to investigate the probability over the given time period. The FTA was also used to depict the probability of movement from the timber bridge as a whole, the superstructure and substructure sections. The results indicated the probability of any structural member moving conditional states over the 3 time periods is indicative of the deterioration of timber bridges and this deterioration is indicative of the maintenance required to be performed. The (FTA) is in respect to the data collected within the Mackay/Whitsundays region and local weather/geological conditions, however this may differ depending on the location and conditions to which the timber is exposed.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111 & ENG4112 Research Project

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Matthew Wilson

Student Number: 0061035083

Acknowledgement

Firstly, I would like to acknowledge my supervisor Dr Weena Lokuge (USQ) for the constant support, motivation and immense knowledge throughout this dissertation. Dr Weena Lokuge guided and assisted my learning and development while researching and writing this project. I am extremely thankful and indebted to her for the constant guidance.

In addition, I would like to recognize Nathan Salter, Alan Voll and Tyrell Webster for their constant insight into timber bridges within the Mackay/Whitsundays region. The guidance and expertise supplied by Nathan and Tyrell to help develop my understanding of timber bridges coupled with the assistance to find information needed to complete this project has been invaluable.

I would also like to thank the Department of Transport and Main Roads in Mackay for the access to any information needed and the expertise on hand when needed. The Department of Transport and Main Roads generously provided the information required making access to key data and also providing constant technical support.

Finally, I would like to thank my wife and family for their constant support and encouragement throughout not just this dissertation, but my whole degree.

Table of Contents

List of Figures

List of Tables

Glossary

FTA	Fault Tree Analysis
FTD	Fault Tree Diagram
BIS	Bridge Information System
BAM	Bridge Asset Management
TMR	Department of Transport and Main Roads
USQ	University of Southern Queensland
CS	Condition State
AADT	Annual Average Daily Traffic
UV	Ultraviolet
ARMIS	A Road Management Information System

Chapter 1 Introduction

Introduction

The Department of Transport and Main Roads (Mackay, Queensland) has responsibility for 2,670 kilometres of road network with 297 bridges (62 timber bridges). The majority of timber bridges were constructed in the early 20th century (Figure 1.1) which is indicative of their current Condition State (CS). As depicted in the Bridge Inspection Manual (2004), only 3 bridges have been constructed from timber since 1970 (Figure 1.1). Generally timber bridges have performed well under the conditions to which they are subjected, however due to the age of these structures, the efficient operation of these bridges are nearing their end.

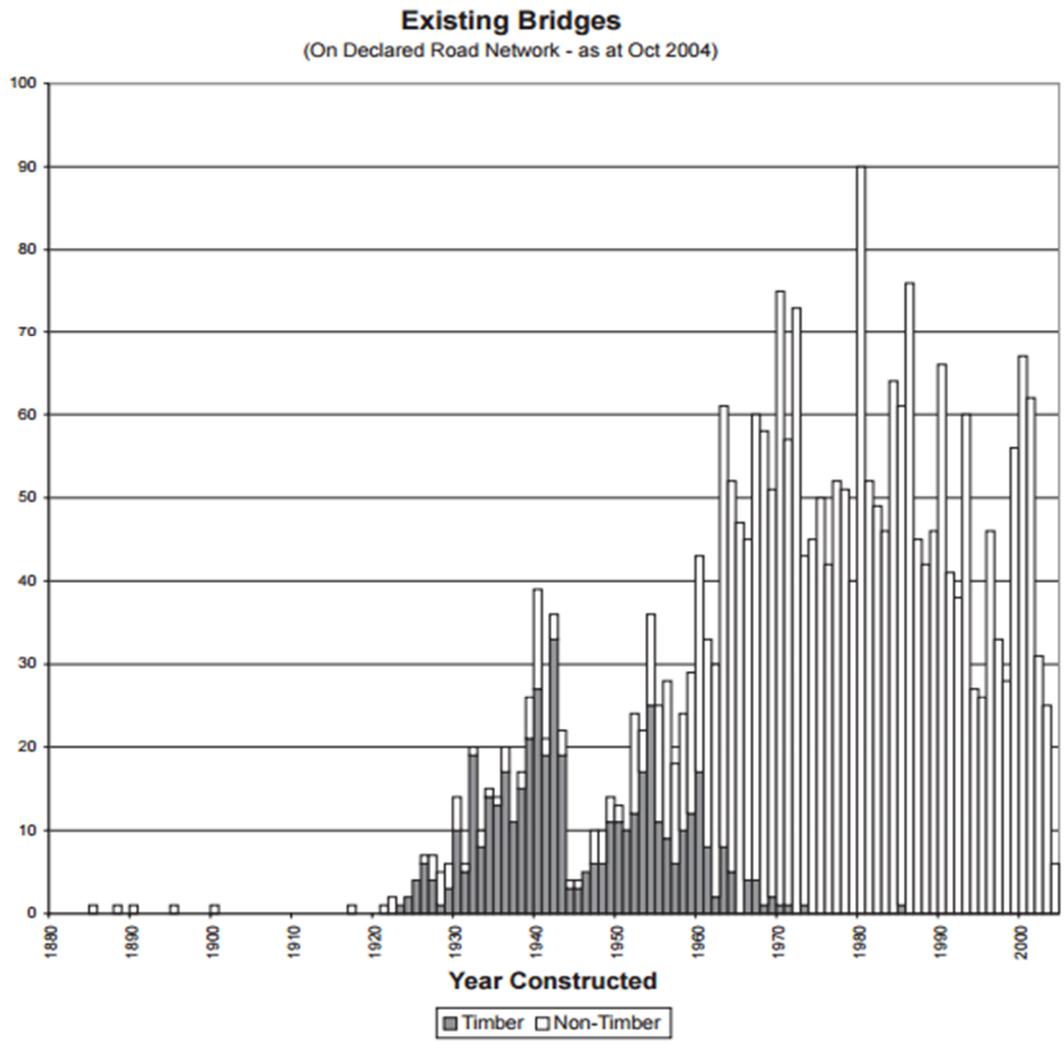


Figure 1.1 – Amount of Bridges Constructed Per Year (Timber bridge Maintenance Manual, 2005)

Timber bridges are constructed with piles, waling, bracing, pile caps, girders, corbels, stringers, decking and balustrades (Appendix. Timber bridge deterioration can be natural (rotting) or human made (new truck suspension system, damage from vehicle impacts), predictable or totally unexpected which has the ability to range from minor to critical which can cause considerable damage and threat to road users and the public. The speed of deterioration of timber bridges can be slowed if correct maintenance is performed, however this can be expensive and time consuming.

Their asset value, operational and strategic importance make these timber bridges a critical components of the state-controlled road network. The Mackay and Whitsundays district road network is limited in comparison to the area of the region (158,167km^2), and therefore if a structure is closed due to failure it is arduous and uneconomical for the local populous. The Annual Average Daily Traffic (AADT) and heavy vehicles depict the safe performance requirements of that structure which is indicative of the maintenance schedule (outlined by Department of Transport and Main Roads).

The Department of Transport and Main Roads (TMR), Queensland is responsible for the maintenance and condition of timber bridges which is conducted through bridge inspection reports, Bridge Asset Management (BAM), Whichbridge and Bridge Information Systems (BIS). Bridge inspection reports are documented and entered into BIS which is controlled by the BAM and analysed by the Whichbridge software. It is predicted that Condition States of timber bridges can be analysed using algorithms, however probability deterioration of these timber bridges cannot be determined until the failure occurs.

A Fault Tree Analysis depicts the possible faults and the likelihood of these faults occurring. In conjunction with inspection reports, case study bridges and a Fault Tree Analysis, it is predicted that a probability factor can be estimated for the deterioration of timber bridges. These probabilities will demonstrate the probability of movement of Condition States over a controlled time period.

1.1 - Project Aims and Objectives

The scheduling and funding provided for timber bridges are limited to inspection reports and the rating given from the Whichbridge program. On this basis, the aim of the project is to provide a relevant probability of timber bridge deterioration using a Fault Tree Analysis of the failing components. Further development of the objectives within this report are:

- Determine the probability of timber bridges to move Condition State
- Identify the possible deterioration mechanisms within the timber structure
- To compare the probability of movement and the causes with deterioration probability software

Deterioration mechanisms vary depending on many factors such as the environment, Annual Average Daily Traffic (AADT) and the maintenance performed. This investigation into the deterioration of timber bridges will result in the probability of the structure moving from a known condition state to a higher rating. These structures will then be examined from the prepared Fault Tree Analysis (FTA) to determine the causes of movement and the failure mechanisms that caused the shift. A comparative analysis will then be undertaken on the model (constructed from excel) which will then be examined with other probability software (e.g. Whichbridge).

While investigating the possibility of movement of the structures with (major) maintenance works will be neglected as this will alter the natural deterioration process. The scope of the project will be limited to the possible failures and their causes; however, an investigation into the protection/maintenance of these faults will be outside of the objectives in this project. Ensuring that the model generated from excel will result in accurate probabilities it will be proposed that as many inspection reports are exploited to ensure that a representative value can be given. The inspection reports will be provided by TMR.

1.2 - Expected Outcomes

The expected outcomes from this dissertation is to identify the probability of movement of condition states over 3 constant time periods. It is expected that a linear change in condition state will be present in accordance with the periods of time. The deterioration of each member to a timber bridge is expected to be constantly declining. The expected outcome is that the probability of condition state movement will constantly change in even intervals (assuming no maintenance has been completed on the member).

A large amount of data available is expected with minimal maintenance within the years of 2001 and 2006. The probability analysis is also expected to be indicative to deterioration over time which depicts a higher probability of deterioration over the longer periods. It is also expected that the period of 5 years will have a higher probability of deterioration/condition state movement than the 2 year time-lapse.

Chapter 2 Literature Review

Introduction

The Department of Transport and Main Roads recognise the essential requirements of managing timber bridge assets and their deterioration to certify that the road network is of the highest level of safety to their customers (road users) as possible. Constant deterioration of timber bridges highlights the importance and requirement to replace and maintain structures so they meet the current standards. Bridge maintenance has a large impact on the department's budget and therefore proactive measures must be implemented by:

- Developing bridge maintenance programs (Whichbridge, BridgeGuide)
- Collating and updating bridge conditions
- Formulating programs that assist in programming maintenance
- Integrating related maintenance and scheduling strategies

Maintenance and management of timber bridge systems involve a rational and systematic approach to ensure correct programming and implementation on a state-wide scale. Bridge Asset Management (BAM) systems will assist in efficient maintenance programming, however correct implementation of maintenance programs must be supervised by a responsible, competent and knowledgeable bridge manager or engineer. In determination of maintenance programs the responsible persons must consider the previous performance, condition state, environment, cost estimates and political, legal and social factors (Local Roads Bridge Management Manual, 2000).

The Department of Transport and Main Roads have a *strategic role* in providing a safe and accessible transport system which depicts a long-term sustainable asset management system to ensure *cost effective* transport and infrastructure (Transport Infrastructure Asset Management, 2012). The policy states that a '*fix first'* approach should be adopted to ensure that a cost-effective asset management process is implemented. As depicted in the Transport Infrastructure Asset Management Policy (2012), the department is committed to continual improvement in asset management practices and continual development of asset management performance. The following is an extract from the Transport Infrastructure Asset Management policy:

"The following principles collectively guide the current management and future development of TMR's transport infrastructure assets:

- Implement international best practice benchmarks for asset management
- The British Standards Institution's (BSI) *Public ally Available Specification (PAS) 55-1:2008 Asset Management* will be the international benchmark used by TMR
- Deliver a 'fix it first' approach
- Use the full potential of existing assets by proactively repairing or rehabilitating networks rather than replacing them to ensure their sustainability
- Ensure whole-of-life costs are factored into transport infrastructure developments
- Capital expansion programs and projects will be accompanied by a clear position on the ongoing funding required to maintain and operate the new assets and services
- Provide 'fit for purpose' transport solutions
- Maintain existing assets to a 'fit for purpose' condition that is sustainable
- TMR will define appropriate, affordable levels of service which balance performance, costs and risks over the asset's life to ensure the transport network is sustainable."

Maintenance scheduling of timber bridges is a continually evolving within TMR, with existing methodologies, reports and data requirements providing a platform for further development in automating the process of maintenance programming and budgeting. Ideally, the analysis of Condition State (CS) movement can be predicted which will enable better scheduling and budgeting for the Department of Transport and Main Roads.

2.1 - Asset Deterioration Terminology

Asset deterioration and asset maintenance terminology with their definitions is portrayed in the Transport and Main Roads 'Engineering Policy Statement (1999)' which is depicted in Table 2.1.

Road Asset	The road asset consists of pavements, bridges, surfaces, formation and drainage structures, traffic control systems, signage, and other associated infrastructure.
Road Asset Maintenance	Management of the ongoing performance and condition of the road asset. Specifically for bridges, maintenance is defined as preservation of the serviceability, load carrying capacity and safety of a structure throughout its designated service life and beyond. Figure 2.1 shows the asset life cycle. Maintenance involves little or no increase in the current level of service of the bridge. Road asset maintenance can be separated into rehabilitation, programmed maintenance, and routine maintenance activities.

Table 2.1 – Transport and Main Roads Terminology and Definitions

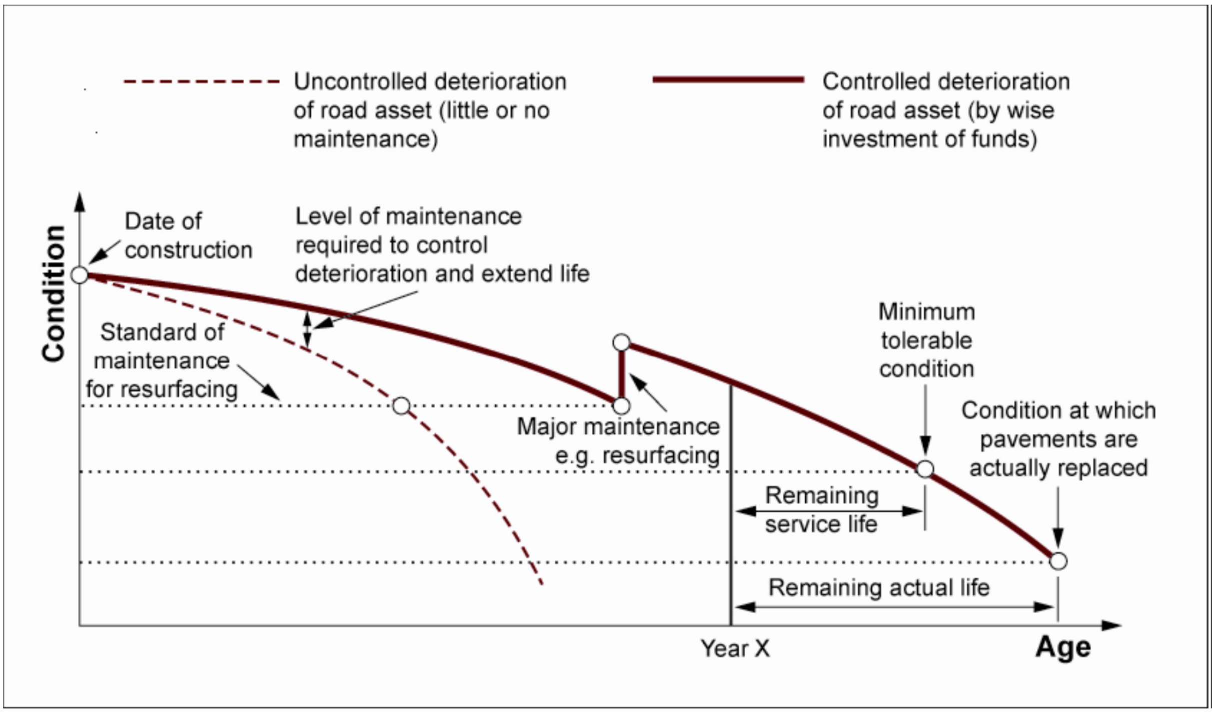


Figure 2.1 – Asset Life Cycle

(Source: Austroads, Guide to Asset Management, 2009)

During the operational stage of the bridges life cycle, it is essential to predict the rate and extent of any future deterioration, which is indicated by inspection reports, service/maintenance frequency and the monitoring of assets. To enhance the assets life, maintenance can be performed (as per TMR policy fix-it-first).

2.2 - Asset Management

Asset management is essential for the effective and efficient operation of TMR and it is essential to monitor and document assets and their condition. Depicted by Austroads 'Guide to Asset Management Part 1: Introduction to Asset Management' (2009):

To ensure a safe and operation road network it is essential to have a strategic view to manage demand and match this demand through ongoing provision of new and upgraded links and maintenance of existing stock. To limit the long term cost to the community and road users this system must be efficient.

To ensure efficient and effective asset management a guide can be established to offer guidance and best practices, which can be defined by Austroads 'Guide to Asset Management Part 1: Introduction to Asset Management' (2009):

- adoption of a rigorous, and cyclic process-based approach which is policy-driven and results oriented and customer focused
- manages current assets and provides for future assets
- provides a defined level of service
- develops cost-effective programs for the long-term
- manages risks associated with asset failures
- requires performance monitoring, audit and feedback
- employs appropriate quality information and decision support tools
- encourages continuous improvement in asset management practices and human resource skill development
- encourages development of clear business processes and organisational accountabilities.

To ensure achieving effective asset management is plausible, the above must be satisfied for continued monitoring and development of the department's timber bridges.

2.3 - Risk Management and Legal Liability

The Department of Transport and Main Roads are the authority for the state-controlled road networks and its assets. TMR has a duty of care to the public and its road users which is implemented through maintenance, repairs and replacements. The Queensland government may be liable for injuries and losses if the road authority did not provide a safe and appropriate operational network, however depending on the situation, the evidence will determine the extent (if any) of liability.

In order for TMR to satisfy its duty of care to road users, TMR must demonstrate and execute a reasonable schedule for the inspection of the road network (including timber bridges) to identify any failures or defects. Additionally, the road authority must also implement a reasonable and responsible schedule for planning, repairs, maintenance, replacements and upgrades.

To manage the risks associated with timber bridges it is essential to log and track assets (Heywood, Karagania and Baade, 2003). The Department of Transport and Main Roads depicts that assets must be tracked and maintained for the Timber Bridge Maintenance Manual. To ensure compliance with legislative requirements, procedures must be implemented to ensure the requirements of the Timber Bridge Maintenance Manual are adhered to with inspections done by qualified inspectors (Bridge Inspection Manual, 2004).

2.4 - Inspections

The majority of bridges built prior to the middle of the 1900's were constructed from timber with the majority of these only present on low volume roads. Although these structures are present on low AADT roads, the heavy vehicle usage and environment conditions effect the condition and rating of these bridges. To ensure the safe operation and to adhere to the duty of care undertaken by TMR, frequent inspections are required to establish if there are any defects or failures or if any are imminent or likely to occur.

Bridge inspection reporting is a method of controlling the safety and condition of structures throughout road networks. A three level hierarchy system is used to control the safe operation of bridges throughout the state which was introduced in March 1998. The scope of each level of inspection reports are depicted below (Bridge Inspection Manual, 2004):

Level 1 – Routine Maintenance Inspection

Inspection of approaches, waterway, deck/footway, substructure, superstructure and attached services to assess and report any significant visible signs of distress or unusual behaviour, including active scours or deck joint movements.

Check of miscellaneous inventory items, including the type, extent and thickness of the bridge surfacing as well as details of existing services.

Recommendation of a Bridge Condition Inspection if warranted by observed distress or unusual behaviour of the structure.

Identify maintenance work requirements, and record on the Structure Maintenance Schedule form (M1).

Verification of the "Structural Inventory" data held in the BIS as part of the initial inspection and as required thereafter (standard forms can be produced from the BIS for this purpose).

Level 2 – Bridge Condition Inspection

Compiling, verifying and updating inspection inventory element items as appropriate.

Visual inspection of the principal bridge components (including measurement of crack widths, etc.) and an assessment of condition using a standard condition rating system as defined in the inspection procedures.

Visual inspection to identify any suspected asbestos containing material.

The inspection of timber bridges will be supplemented by a drilling investigation, and will also include the identification and reporting of undersized timber members.

'Soundings' to determine the presence of active scour.

Reporting the condition of the principal bridge components and determining an aggregate rating of the structure as a whole.

Identifying and programming preventative maintenance requirements and recording on the Structure Maintenance Schedule form (M1). If access equipment is required to conduct the inspection, then routine / preventative maintenance may also be completed in conjunction with the inspection.

Requesting a detailed bridge inspection by a bridge engineer if warranted by apparent rapid changes in structural condition and/or apparent deterioration to condition state 4.

Development of "Structure Management Plans" in conjunction with Structures Division for all defective structures. Refer to Appendix F for plan guidelines.

Underwater inspections of those elements in permanent standing water at the specified frequency.

Recommending requirements for the next inspection and nominating components for closer monitoring as appropriate.

Recommending supplementary testing as appropriate.

Completion of the "Design Inventory" data held in the BIS as part of the initial inspection and as required thereafter (standard forms can be produced from the BIS for this purpose)

Level 3 – Inspection

Undertake numerical modelling or other calculations.

To prepare a Structural Management Plan based on Level 2 inspection data that the engineer believes is comprehensive and adequately describes the structure. This occurs where it is considered that the risk can be adequately managed with known data without visiting the site again.

Management of Potentially Structurally Deficient Bridges based on Level 2 inspection and other data that the engineer believes is comprehensive and adequate to determine if the theoretical deficiency is consistent with the observed condition of the bridge component. This occurs where it is considered that the risk can be adequately managed with known data without visiting the site again.

Each inspection level is restricted to a scope, however for the purpose of this dissertation level 2 inspection reports will be used due to the information available and required. The bridge inspection reports document (photos, drill reports and noting) any deterioration of the structure in the field which is then entered into BIS. All inspections are scheduled in accordance with the condition state depicted from the previous inspection report (depicted in Table 2.1) or immediately after flooding, fire or accident damage events (Bridge Inspection Manual, 2004). Depicted in Table 2.2 is the description of each Condition State which depicts the deterioration/defects required to be graded that rating (Bridge Inspection Manual, 2004).

Structure type	Condition state of structure	Inspection Frequency (years)
Timber or Steel Culverts in wet environments	1-2 3	2 1**
Other	1-2 3	5 3
Components under water	1-2 3	8 1
All	4	1** with "Structures Management Plan"

Table 2.2 – Inspection Frequency

** Level 1 and Level 2 inspection cycles to be staggered by six months to ensure that the structure is inspected every six months

Condition State	**Subjective Rating**	**Description**
1	**GOOD** (“as new”)	Free of defects with little or no deterioration evident
2	**FAIR**	Free of defects affecting structural performance, integrity and durability. Deterioration of a minor nature in the protective coating and/or parent material is evident.
3	**POOR** (monitoring required)	Defects affecting the durability/serviceability which may require monitoring and/or remedial action or inspection by a structural engineer. Component or element shows marked and advancing deterioration including loss of protective coating and minor loss of section from the parent material is evident. Intervention is normally required.
4	**VERY POOR** (Remedial Action Required)	Defects affecting the performance and structural integrity which require immediate intervention including an inspection by a structural engineer, if principal components are affected. Component or element shows advanced deterioration, loss of section from the parent material, signs of overstressing or evidence that it is acting differently to its intended design mode or function.
5	**UNSAFE** (Immediate Remedial Action Required)	This state is only intended to apply to the "whole structure" rating. Structural integrity is severely compromised and the structure must be taken out of service until a structural engineer has inspected the structure and recommended the required remedial action

Table 2.3 – Description of each Condition State

2.5 - Timber Bridge Deterioration Mechanisms

Considering timber bridges were constructed up until the middle of the 1900's it could be construed that they have performed adequately, however due to the nature of timber these structures are inevitably deteriorating. The majority of timber bridges are on low volume trafficable road networks with just under one quarter of all structures being constructed from timber. The deterioration of timber bridges can be in many forms including (Bridge Inspection Manual, 2004):

1. Fungal (rotting) - decay of timber by fungi from internal and external growth (Figure 2.2).
2. Termites - identified as subterranean termites that consume dead timber which leave the bridge components weak and brittle (Figure 2.3).
3. Shrinkage and Splitting - due to the timbers (green/new) drying below its fiber saturation point the components start to shrink and/or split (Figure2.5).
4. Marine organisms - underwater timber is damaged via marine borers (Figure 2.6).
5. Corrosion of Fasteners - a chemical reaction causing rusting and 'loss of section' causing significant strength loss.
6. Fire damage – when timber burns the density starts to decay causing the structure to become weak and brittle.
7. Weathering – exposure to the elements (sun, wind and rain) the timber gradually starts to deteriorate (Figure 2.7).

Figure 2.2 - Termite Damage in Deck Planks

Figure 2.3 - Fungal Fruiting Body and Decay of Girder

(Source – Timber Bridge Maintenance Manual, 2005)

Figure 2.4 - Splitting in Girder

Figure 2.5 - Rotted Ends of Deck Planks

(Source – Timber Bridge Maintenance Manual, 2005)

Figure 2.7 – Rotting of Abutment pile below ground level (possible marine deterioration)

Figure 2.6 - Weathered and Rotted Timber deck Planks

(Source – Timber Bridge Maintenance Manual, 2005)

COMPONENT		
Standard Component No	Description	Significance Rating (SR)
1	Fill/Wearing Surface	2
2	Bridge Barriers	1
3	Bridge Kerbs	1
4	Footways	1
10	Pourable Joint Seal	2
11	Compression Joint Seal	2
12	Assembly Joint Seal	2
13	Open Expansion Joint	2
14	Sliding Joint	2
15	Fixed/Small Movement Joint	2
20	Deck Slab/Culvert Base Slab Joints	3
21	Closed Web/Box Girders	4
22	Open Girders	4
23	Through Truss	4
24	Deck Truss	4
25	Arches	4
26	Cables/Hanger	4
27	Corbels	3
28	Cross Beams/Floor Beams	3
29	Deck Planks	3
30	Steel Decking	3
31	Diaphragms/Bracing (Cross Girders)	3
32	Load Bearing Diaphragms	4
33	Spiking Plank	1
40	Fixed Bearings	2
41	Sliding Bearings	2
42	Elastomeric/Pot Bearings	2
43	Rockers/Rollers	2
44	Mortar Pads/Bearing Pedestals	1
45	Restraint Angles/Blocks	2
50	Abutment	3
51	Wingwall/Retaining Wall	3
52	Abutment Sheeting/Infill Panels	2
53	Batter Protection	1
54	Headstocks	4
55	Pier Headstocks (Integral)	4
56	Columns, Piles or Pile Encasements	4
57	Piles Bracing/Walls	3
58	Pier Walls	3
59	Footing/Pile Cap/Sill Log	3
60	Wing Piles	3
70	Bridge Approaches	2
71	Waterway	2
72	Approach Guardrail	1
80	Pipe Culverts	2
81	Box Culverts	2
82	Modular Culverts	2
83	Arch Culverts	2
84	Headwalls/Wingwalls	1

Table 2.4 – Significance Rating for Component (Bridge Inspection Manual, 2004)

Each component of the structure can be classified according to its significance within the bridge (Table 2.4). The higher the weighting the more significant that component has on the integral structure, and subsequent risk of failure. Deterioration of timber bridges can vary depending on the environment and conditions to which the structure is subjected. It is therefore imperative that a systematic interpretive system be established to reasonably predict the probability and possible cause of failure. Deterioration from fungal growth is evident in timber with more than 20% of moister with a serious decay occurring between 28-30 percent (Wacker, 2015). If the structure is subjected to this moisture content for an extended period, the fungal growth has a considerable impact on the integrity of the timber (Wacker, 2015, White, Ross, 2014). Fungi growth in timber structures will thrive when the following conditions are present (Main Roads 2008):

- Moisture >20%
- Oxygen (submerged timber greater then 600mm is rarely attached)
- Temperature >25˚C to <40˚C is ideal for deterioration with temperatures 5˚C to 40˚C retarding growth
- Food source (e.g. minerals and carbohydrates)

Additionally, termite protection is essential in timber bridges which can be controlled by careful design, good workmanship and appropriate asset management (Main Roads, 2008). In the conditions above with the deterioration (from termites) the timber can fail rapidly (Mackenzie, 2005). Termite exposure hazard levels can be depicted from H1 to H5 (Table 2.5) depending on the structures locations and it exposure (Main Roads, 2008). Subterranean termites are commonly present on timber bridges in the Mackay/Whitsundays region due to the conditions present and the direct access from their nests and food sources (Main Roads, 2008).

Exposure	In Service Conditions	Insect or Fungal Hazard	Possible Uses	Defined Hazard Level (H)
Interior – not in ground contact	Dry, well ventilated, no termite hazard	Lyctid (only affects hardwood sapwood) or anobium borer (softwood sapwood)	Wall, floor and roof framing, interior joinery	1
Interior – not in ground contact	Not completely protected from dampness or other hazard	Termites, borers or moderate decay	Roof, wall and floor framing and decorative timbers, particularly adjoining wet areas	2
Exterior – above ground	Occasionally exposed to moderate wetting	Moderate decay, termites and borers	Cladding, all decking and sub-frames	3
Exterior – in ground contact	Regular and excessive wetting and leeching	Severe decay, termites or borers	Girders, timber abutments and sheeting	4
Exterior – in ground contact or in fresh water	Exposed to severe and regular to constant wetting or were the cost of failure indicates a requirement for a high level of protection	Severe decay, termites or borers	Building poles, piers and piles, retaining walls, transmission poles	5
Marine – salt and fresh water exposure	Extreme exposure in a marine environment	Marine borers and decay	Bridge piers, wharf piles, and ancillary timbers subject to tidal inundation and boat hulls	6

Table 2.5 – Hazard Levels for different service conditions (Main Roads, 2008)

Weathering is the process of wetting, drying, and exposure to ultraviolet (UV) radiation which decays timber and other components. If timber is untreated/maintained the structure can deteriorate rapidly and cause major structural faults (Timber Bridge Maintenance Manual, 2005, Main Road, 2008). Untreated/maintained timber can cause splitting in components, corrosion of fasteners and weakening of microstructure (Main Road, 2008, Timber Bridge Maintenance Manual, 2005, Faber, 2006). The exposure to weather is dependent on the location of the structure, therefore asset management should reflect this (Main Roads, 2008, Timber Bridge Maintenance Manual, 2005).

Fire in the Mackay/Whitsunday area is a high risk due to the majority of the locations of timber bridges (located near farm land), therefore regular inspections should be undertaken (Bridge Inspection Manual, 2004). Clearing of any debris caught by the structure should be cleared to remove the risk of fire (Bridge Inspection Manual, 2004). To ensure protection to fire damage, a zone of maintenance is required every 12 months (Figure 2.8) which include clearing of vegetation around, under and on the structure (Timber Bridge Maintenance Manual, 2005):

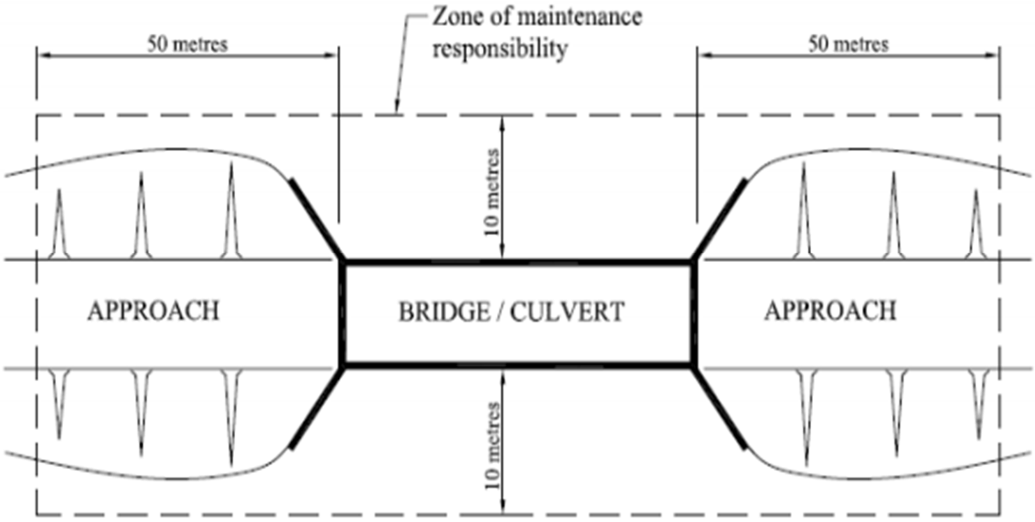


Figure 2.8 – Extent of servicing/maintenance envelope

In the case a fire impacts a timber bridge, inspection and testing must be carried out to ensure the microstructure of the component is sound (Bridge Inspection Manual, 2004). Fire damage can weaken timber by deteriorating the density of the components which cause the strength to decrease and intern the structure. If the timber component has sign of deterioration (e.g. fungi, weather, termite) the temperature of ignition will become lower causing the structure to be at risk.

The deterioration of timber bridge components can be subjected to many different factors, however the type of load can impact the severity of the defect/failure. Depicted in Figure 2.4, each component has a Significance Rating (SR) which indicates the importance of that component compared to the whole structure.

2.6.1 Deterioration Mechanisms Summary

Timber bridge deterioration can occur from a single or the combination of many factors which will affect the severity and life of each component. Deterioration mechanisms which will affect timber bridges are predominately induced by natural causes, however it is the asset management which effects the limits of damage. Ideal conditions of above 20% of moisture in the timber, between 25˚C and 40˚C with oxygen and timber present possess perfect foundation conditions for timber deterioration. The addition of fire and/or weather damage with these conditions can rapidly increase the rate of condition state movement of components. Correct maintenance and asset management is essential to ensure the duty of care is achieved by The Queensland Government.

2.7 - Fault Tree Analysis

Fault Tree Analysis (FTA) was developed by H.A. Watson of Bell Laboratories who was directed by the United States Air Force to create a risk assessment tool (Ericson, 1999). FTA consists of both qualitative and quantitative risk assessments. Qualitative analysis depicts a visual model of events prior to failure/defect their relationships (Ericson, 1999). FTA depicts a 'top' symbol (e.g. Timber Bridge) and uses gate and event symbols to illustrate possible faults/defects of each component in the analysis. This analysis (for timber bridges) can be used for individual components or whole structures.

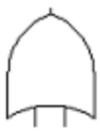
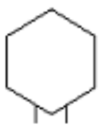
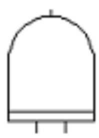
Gate Symbol	**Gate Name**	**Description**
	OR	Output event occurs if one of the input events occurs
	AND	Output event occurs if all the input events occurs
	EXCLUSIVE OR	Output event occurs if one but not both of the input events occurs
	INHIBIT GATE	Output event occurs if a single input event and a conditional event occur
	PRIORITY AND	Output event occurs if all input events occur in a specific sequential order

Table 2.6 – Fault Tree Gate Symbol and Descriptions (Ericson, 1999)

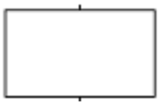
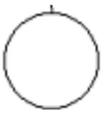
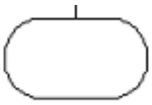
Event Symbol	Event Name	Description
	INTERMEDIATE	An event that results from one or more preceding events acting through logic gates
	BASIC	Initiating event which cannot be further developed
	UNDEVELOPED	An event that cannot be further developed due to insufficient information
	CONDITIONAL	A specific condition applied to an INHIBIT or PRIORITY AND gate
	HOUSE	An event which is expected to occur or not occur

Table 2.7 – Fault Tree Event Symbols and Descriptions (Ericson, 1999)

Cut sets are developed to depict the unique combination of faults/failures that cause the top event to take place. Applying probabilities in a quantitative analysis to all undeveloped, basic, conditional and house events using Boolean algebra and probabilistic mathematics to solve the probability of top events and minimal cut sets where minimal cut sets are the shortest path to the highest event (Ericson, 1999).

Deterioration of timber bridges can be exploited using the FTA to depict the failure mechanism and the path the failure took to reach a certain condition state. Utilizing the FTA will allow for a clear and concise path to why a timber bridge moves condition states and the path the deterioration took. While investigating the deterioration of a timber bridge, a FTA can be undertaken to depict the cause of movement of condition states based on the failure. The FTA will be used to illustrate the behavior of the case bridge (Davis-Mcdaniel et al, 2013; LeBeau and Wadia-Fascetti, 2007; Sianipar and Adams, 1997) and how movement of condition states are conducted.

The main difference between the FTA of concrete (Setunge et al, 2015) and timber bridges will be the basic events that lead to the final failure, therefore the cause of failure can be identified using case studies. To ensure an accurate development of the FTA, deterioration of timber bridges and the probability of occurrence of contributing factors must be established and identified (Lebeau and Wadia-Fascetti. 2000).

Chapter 3 Methodology

Introduction

The Management of all information associated with timber bridges is a complex and difficult task which is ideally suited to a computerized management system. Therefore, it is essential to program these systems (Whichbridge, BridgeGuide) to correctly represent timber bridges. To ensure the accuracy of this research, it is imperative that all input information is accurate and timely.

3.1 - Dissertation phasing

3.1.1 Phase 1 – Start Up

To ensure that the correct procedures are implemented and TMR are notified of the intention to investigate deterioration of timber bridges on state controlled roads, informing staff and managers must be completed. An investigation and plan has been conducted to ensure the information required by TMR (BIS, inspection reports) will be made available for the purpose of the dissertation.

To achieve optimal efficiency, the appropriate staff must be notified of the detailed action plan and the information/outcome required. Authorised staff are to be notified, as it is essential to apply and be given approval to collect, investigate and report on the findings (inspection reports). If required, the correct procurement processing must be followed as per TMR standards which depicts the requirement to receive approval.

Access to ARMIS (A Road Management Information System), is necessary for the dissertation. This is the database holding the applications which are approved. The BIS (Bridge Information System) will also be a crucial asset to this dissertation as it will be where all inspection reports will be accessed. In addition to these specific TMR programs, the latest version of Microsoft office (word, excel, Visio) will be required to produce the analysis, reporting and Fault Tree Analysis.

3.1.2 Phase 2 – Data Collection

The dissertation is dependent on the information acquired from TMR and therefore it is essential to collect all inspection reports necessary and any other information (Whichbridge models and methodology). This collection phase will be conducted internally with access being previously obtained to BIS, BAM and all inspection reports. Constant discussions are essential between Project Managers and inspectors to identify any structures which conform to the requirements of the dissertation (timber).

Collecting inspection reports require expertise of what will be analyzed and the required outcome of the project. During the analysis phase it is anticipated that each component will be investigated individually. It is imperative that the timber components of the structure be specifically examined as this is the material most likely to show signs of fatigue or potential failure. Inspection reports and the coding of each component will depict the material and the condition state. Within the Bridge Information System, inspection reports can be split into 13 sections which depict the different components of that report (e.g. condition rating, timber drill report).

When collecting inspection reports it is essential to only 'download' the condition rating section of the years necessary. When conducting the analysis of the condition rating of each bridge, each component's code must be the same as depicted in Table 3.1 with an addition to the material used (e.g. timber – t). Depicted in Table 3.1, all timber bridges within the Mackay/Whitsundays district was investigated and subjected to the required criteria for the three time periods (2001, 2003 and 2006). This report was created from consultation with the structures project manager, level 2 inspector and the BIS.

ID	STRUCTURE NAME	MATERIAL	ROAD	CHAINAGE	CS	LENGTH	WIDTH	SPANS
7243	Mcgregor Creek	TIMB	536	14.483	2	15.2	7.4	2
7385	Lonely Creek	TIMB	33B	13.421	4	38	7.2	4
7384	Fiery Creek	TIMB	33B	9.962	4	45.7	7.3	5
7223	Rock Creek	TIMB	517	23.75	4	25.1	5.5	3
7212	Prospect Creek	TIMB	512	208.691	4	41.1	6.7	5
7572	Carpet Snake Creek	TIMB	88B	0.596	4	15.24	5.49	2
7412	Suttor River	TIMB	88B	68.085	3	27.43	3.66	4
7244	Dalrymple Creek	TIMB	536	23.16	4	42.7	5.5	4
1151	Bottletree Creek	TIMB	512	55.776	4	24.7	7.3	3
7206	Boothill Creek	TIMB	512	180.822	4	27.4	3.7	3
7238	Cattle Creek	TIMB	532	61.945	4	49.4	7.9	6
7265	Isaac River	TIMB	5122	12.975	4	42	3.7	5
7220	Bell Creek	TIMB	517	12.725	4	33	5.5	4
7279	Fursden Creek	TIMB	5302	4.108	4	54.9	5.5	6
1152	Plumtree Creek	TIMB	512	57.645	3	16.5	7.3	2
1157	Clarke Creek	TIMB	512	83.046	4	36.6	7.3	4
7268	Main Creek	TIMB	5124	38.635	4	18.3	3.7	2
7390	Kirkup Bridge	TIMB	33B	78.183	4	36.6	6.8	4
7254	Victor Creek	TIMB	854	12.875	3	15	3.7	2
7245	Murray Creek	TIMB	536	24.92	4	36.6	5.5	4
7246	Silent Grove Ck	TIMB	536	33.06	4	9.1	3.7	1
7280	Unnamed Creek	TIMB	5302	21.865	3	8	3.7	1
7273	East Funnel Creek	TIMB	5126	22.474	4	27.4	3	3
7386	Boundary Creek	TIMB	33B	16.681	4	38	7.2	4
7387	Cut Creek	TIMB	33B	24.212	4	56	7.2	6
7276	Jubilee Creek	TIMB	5127	6.465	3	9	3.7	1
7236	Palm Tree Creek	TIMB	532	41.392	4	53.3	6.8	5
7274	Mango Creek	TIMB	5127	0.098	4	16	3.7	2
7275	Scrubby Creek	TIMB	5127	4.991	4	21	3.7	2
7277	Hut Creek	TIMB	5127	8.554	3	21	3.7	2
8314	Miclere Creek	TIMB	98A	19.528	2	24.3	6.6	3
8223	Belyando River	TIMB	552	103.121	4	18.3	3.7	3
1158	Yatton Creek	TIMB	512	94.531	4	45.7	7.3	4
1349	Sheepskin Creek	TIMB	512	127.734	4	28	7.3	4
2189	Connors River	TIMB	512	139.031	4	79.6	3.7	9
1159	Two Mile Creek	TIMB	512	99.176	4	18.4	7.3	2
1153	Clive Creek	TIMB	512	62.359	4	42.65	7.3	5
8699	Spring Creek	TIMB	512	91.955	4	19	7.3	2
1154	Stockyard Creek	TIMB	512	72.475	3	45.7	7.3	5
1156	Grave Gully	TIMB	512	82.023	4	24.69	7.3	3
7247	Parnells Gully	TIMB	536	34.485	2	9	3.7	1
7269	Station Creek	TIMB	5126	1.094	3	23	3.6	3
7203	Horse Creek	TIMB	512	160.2	4	16.5	7.3	2
7205	Kennedy Creek	TIMB	512	164.307	4	36.6	7.3	4

7209	Three Mile Creek	TIMB	512	192.967	4	36.6	5.5	4
7210	Back Creek	TIMB	512	195.442	4	36.56	6.7	4
7211	Stony Creek	TIMB	512	208.14	4	24.7	6.7	3
7201	Plain Creek	TIMB	512	150.39	2	15.2	7.3	2
7202	Main Range Creek	TIMB	512	157.663	2	17.1	7.3	2
7278	Prospect Creek	TIMB	5127	12.327	4	32	3.7	3
7288	Mcnamaras Gully	TIMB	5342	4.037	4	18	3.7	3
7219	Alligator Creek	TIMB	517	6.747	4	24.69	5.5	3
7221	Spring Creek	TIMB	517	13.35	4	10.7	5.5	1
7286	Broken River	TIMB	5324	5.338	4	32	3.7	3
7239	Sandy Creek	TIMB	533	12.807	4	27.4	7.3	3
7284	Seven Mile Creek	TIMB	5323	8.11	4	27	3.7	4
7207	Funnel Creek	TIMB	512	187.489	4	73.2	3.7	8
7241	Dows Creek	TIMB	536	10.695	4	21.3	5.5	4
7248	Ossa Creek	TIMB	536	36.505	2	15.2	3.7	2
7253	Cluney Creek	TIMB	854	11.051	2	15	3.7	2
7242	Unnamed Creek	TIMB	536	14.005	2	9.1	6.3	1
1160	Lotus Creek	TIMB	512	119.455	2	45.75	3.7	5
7272	Dents Gully	TIMB	5126	19.722	2	9	3.7	1

Table 3.1 – Timber Bridges in the Mackay/Whitsundays Region (TMR)

		Year 2001					Year 2003															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	56T	83.3	5.6	11.1	0.0	100.0	44.4	27.8	11.1	16.7	100	44.44	27.78	5.56	5.56	0.00	5.56	11.11	0.00	0.00	0.00	100.00
7209	56T	50.0	12.5	18.8	18.8	100.0	68.8	12.5	18.8	0.0	100	68.75	0.00	0.00	0.00	12.50	6.25	0.00	6.25	6.25	0.00	100.00
1158	56T	52.9	23.5	23.5	0.0	100.0	41.2	5.9	35.3	17.6	100	29.41	11.76	5.88	11.76	0.00	11.76	5.88	17.65	5.88	0.00	100.00
1153	56T	60.0	10.0	20.0	10.0	100.0	26.7	16.7	36.7	20.0	100	26.67	10.00	23.33	10.00	6.67	3.33	0.00	10.00	3.33	6.67	100.00
2189	56T	64.0	24.0	12.0	0.0	100.0	52.0	0.0	16.0	32.0	100	52.00	0.00	16.00	8.00	0.00	0.00	12.00	0.00	12.00	0.00	100.00
7242	56T	21.4	7.1	35.7	35.7	100.0	21.4	7.1	21.4	50.0	100	14.29	0.00	0.00	14.29	7.14	0.00	0.00	21.43	35.71	7.14	100.00
7385	56T	86.7	10.0	3.3	0.0	100.0	56.7	23.3	10.0	10.0	100	56.67	23.33	6.67	0.00	0.00	3.33	6.67	0.00	3.33	0.00	100.00
7241	56T	48.0	20.0	20.0	12.0	100.0	48.0	24.0	20.0	8.0	100	48.00	4.00	0.00	0.00	20.00	0.00	0.00	20.00	0.00	8.00	100.00
7243	56T	81.3	6.3	6.3	6.3	100.0	31.3	12.5	12.5	43.8	100	18.75	6.25	12.50	43.75	6.25	0.00	0.00	0.00	12.50	0.00	100.00
																						0.00
Total		547.62	118.98	150.69	82.71	900.00	390.38	129.80	181.75	198.06	900.00	359.0	83.1	69.9	93.4	52.6	30.2	35.7	75.3	79.0	21.8	900.0

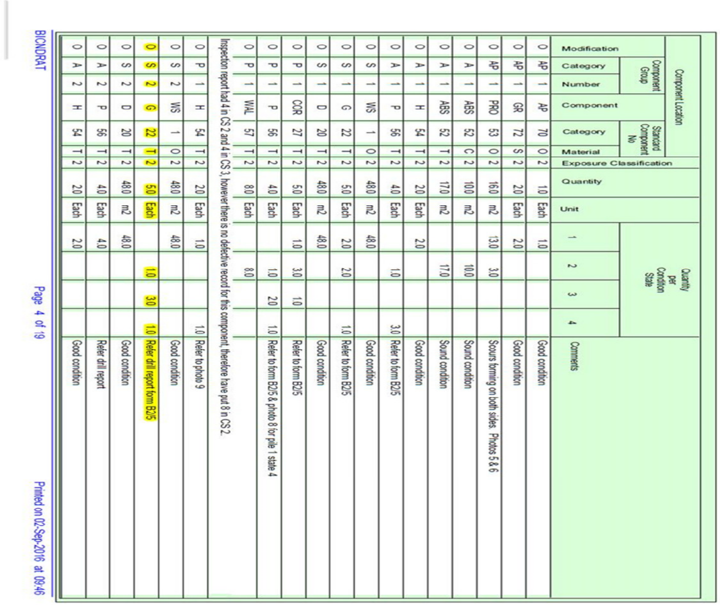
P1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.7	0.2	0.1	0.2	0.0	0.4	0.3	0.3	0.0	0.0	0.5	0.5	0.0	0.0	0.0	1.0
65.6	15.2	12.8	17.0	0.0	44.2	25.4	30.0	0.0	0.0	50.0	52.4	0.0	0.0	0.0	100.0

Table 3.2 – Piles Excel model from Inspection Reports Data

STANDARD COMPONENT MATRIX

	Codes	Significance Rating	Abutments	Piers	Spans/Cells	Approach
			A1,2	P*n*	S*n*	AP1,2
Abutment	A	3	50			
Abutment Sheeting	ABS	2	52			
Approach	AP	2				70
Arch	ARH	4			25	
Batter Protection	PRO	1	53			53
Bearings	B	2	40-43	40-43		
Bearing Pedestals	PED	1	44	44		
Bracing Wale	WAL	3	57	57		
Bridge Barriers	BR	1	2		2	
Columns	C	4	56	56		
Corbels	COR	3	27	27		
Cross Beam	XB	3			28	
Cross Girder**	XG	3			31, 32	
Deck	D	3			20, 29, 30	
Footing	F	3	59	59		
Footway	FY	1			4	4
Girders	G	4			21, 22	
Guard Rails	GR	1				72
Hanger	HR	4			26	
Headstock	H	4	54	54, 55		
Headwall	HW	1	84		84	
Joints*	J	2	10-15, 20	10-15, 20	10,11,13-15	
Kerb	K	1	3		3	
Mortar Pad	MP	1	44	44		
Pier Wall	PW	3		58		
Piles & Encasements***	P	4	56, 60	56		
Pilecap	CAP	3	59	59		
Restraint Angle	RA	2	45	45		
Retaining Wall	RW	3			51	51
Sill Log	SL	3	59	59		
Spiking Plank	SP	1			33	
Through Truss	TT	4			23, 24	
Waterway	W	2			71	
Wearing Surface/Fill	WS	2			1	
Wingwalls	WW	3	51			
Arch Culvert	AC	2			83	
Box Culvert	BC	2			81	
Modular Culvert	MC	2			82	
Pipe Culvert	PC	2			80	
Culvert Base Slab	CBS	3			20	

Table 3.3 – Standard Component Matrix (Bridge Inspection Manual, 2004)



2001

Queensland Government

Bridge Information System
Condition Rating

Modification	Category	Number	Component	Category	Material	Exposure Classification	Quantity	Unit	1	2	3	4	Comments
O	AP	1	AP	70	O	2	1.0	Each	1.0				Good condition
O	AP	1	GR	72	S	2	2.0	Each	2.0				Good condition
O	AP	1	PRO	53	O	2	16.0	m2	13.0	3.0			Scours forming on both sides. Photos 5 & 6
O	A	1	ABS	52	C	2	10.0	m2		10.0			Sound condition
O	A	1	ABS	52	T	2	17.0	m2		17.0			Sound condition
O	A	1	H	54	T	2	2.0	Each	2.0				Good condition
O	A	1	P	56	T	2	4.0	Each		1.0		3.0	Refer to form B2/5
O	S	1	WS	1	O	2	48.0	m2	48.0				Good condition
O	S	1	G	22	T	2	5.0	Each	2.0	2.0		1.0	Refer to form B2/5
O	S	1	D	20	T	2	48.0	m2	48.0				Good condition
O	P	1	COR	27	T	2	5.0	Each	1.0	3.0	1.0		Refer to form B2/5
O	P	1	P	56	T	2	4.0	Each		1.0	2.0	1.0	Refer to form B2/5 & photo 8 for pile 1 state 4
O	P	1	WAL	57	T	2	8.0	Each		8.0			
Inspection report had 4 in CS 2 and 4 in CS 3, however there is no defective record for this component, therefore have put 8 in CS 2.													
O	P	1	H	54	T	2	2.0	Each	1.0			1.0	Refer to photo 9
O	S	2	WS	1	O	2	48.0	m2	48.0				Good condition
O	S	2	G	22	T	2	5.0	Each		1.0	3.0	1.0	Refer drill report form B2/5
O	S	2	D	20	T	2	48.0	m2	48.0				Good condition
O	A	2	P	56	T	2	4.0	Each	4.0				Refer drill report
O	A	2	H	54	T	2	2.0	Each	2.0				Good condition

BICNDRAT Page 4 of 19 Printed on 02-Sep-2016 at 09:46

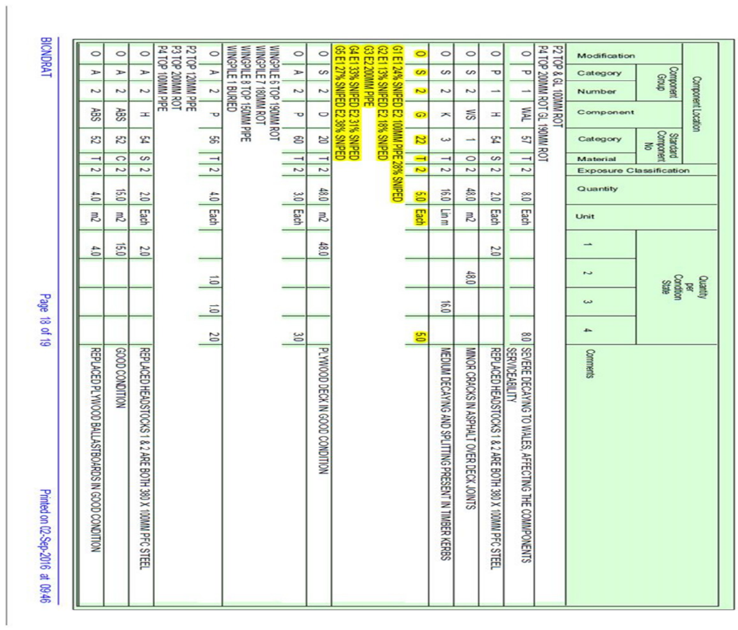
2003

Queensland Government

Bridge Information System
Condition Rating

Modification	Category	Number	Component	Category	Material	Exposure Classification	Quantity	Unit	1	2	3	4	Comments
O	S	2	K	3	T	2	16.0	Lin m	16.0				
O	S	2	G	22	T	2	5.0	Each		1.0		4.0	
G1 st4 100 rot 140 snipe 52%. G2 st4 110 rot 30 snipe 37%. G3 st4 40 rot 140 snipe 40%. G4 st4 170 snipe 36%.													
O	S	2	D	20	T	2	48.0	m2	48.0				
O	A	2	P	56	T	2	8.0	Each	2.0		2.0	4.0	
P1 st4 (wing pile) 100 rot 36%. P2 st4 (abut p1) 120 rot 38%. P3 (abut p2) 150 rot 41%. P4 st3 100 rot 29%. P6 (wing pile) st3 70 rot 24%. P8 (wing pile) 270 rot 90%													
O	A	2	H	54	T	2	2.0	Each	2.0				
O	A	2	ABS	52	C	2	15.0	m2		15.0			
O	A	2	ABS	52	T	2	4.0	m2				4.0	Ballast boards rotten
O	AP	2	AP	70	O	2	1.0	Each		1.0			Approx 30mm drop onto bridge.
O	AP	2	GR	72	S	2	2.0	Each				2.0	4m each side fishtail ends hex head bolts (not cup head) posts at 4m spacings.
O	AP	2	PRO	53	O	2	16.0	m2	16.0				

BICNDRAT Page 9 of 19 Printed on 02-Sep-2016 at 09:46



2006

Queensland Government

Bridge Information System
Condition Rating

Modification	Category	Number	Component	Category	Material	Exposure Classification	Quantity	Unit	1	2	3	4	Comments
P2 TOP & GL 100MM ROT P4 TOP 200MM ROT GL 190MM ROT													
O	P	1	WAL	57	T	2	8.0	Each				8.0	SEVERE DECAYING TO WALES, AFFECTING THE COMMPONENTS SERVICEABILITY
O	P	1	H	54	S	2	2.0	Each	2.0				REPLACED HEADSTOCKS 1 & 2 ARE BOTH 380 X 100MM PFC STEEL
O	S	2	WS	1	O	2	48.0	m2		48.0			MINOR CRACKS IN ASPHALT OVER DECK JOINTS
O	S	2	K	3	T	2	16.0	Lin m			16.0		MEDIUM DECAYING AND SPLITTING PRESENT IN TIMBER KERBS
O	S	2	G	22	T	2	5.0	Each				5.0	
G1 E1 24% SNIPED E2 100MM PIPE 28% SNIPED G2 E1 13% SNIPED E2 18% SNIPED G3 E2 200MM PIPE G4 E1 33% SNIPED E2 31% SNIPED G5 E1 27% SNIPED E2 38% SNIPED													
O	S	2	D	20	T	2	48.0	m2	48.0				PLYWOOD DECK IN GOOD CONDITION
O	A	2	P	60	T	2	3.0	Each				3.0	
WINGPILE 5 TOP 190MM ROT WINGPILE 7 180MM ROT WINGPILE 8 TOP 150MM PIPE WINGPILE 1 BURIED													
O	A	2	P	56	T	2	4.0	Each		1.0	1.0	2.0	
P2 TOP 120MM PIPE P3 TOP 200MM ROT P4 TOP 100MM PIPE													
O	A	2	H	54	S	2	2.0	Each	2.0				REPLACED HEADSTOCKS 1 & 2 ARE BOTH 380 X 100MM PFC STEEL
O	A	2	ABS	52	C	2	15.0	m2	15.0				GOOD CONDITION
O	A	2	ABS	52	T	2	4.0	m2	4.0				REPLACED PLYWOOD BALLASTBOARDS IN GOOD CONDITION

BICNDRAT Page 18 of 19 Printed on 02-Sep-2016 at 09:46

Figure 3.1 - Tracking of Condition State Movement

3.1.3 Phase 3 – Data Analysis

Microsoft excel will be used to enter the data recorded from the inspection reports where each component will be allocated into different tabs. Each component will be analyzed via 2, 3 and 5 year periods to highlight the deterioration over time. The movement of condition states is then indicative of the deterioration of that member over that time period. To ensure the input of the inspections are correct, the condition rating for each component is tracked individually from one inspection to the next. All members which are maintained or are replaced with another material are disregarded which will limit the amount of inspection reports available for all three time periods.

Once each members condition state has been tracked over the three periods, an analysis is made to calculate the probability of movement from one condition state to another (only deterioration has been reported as improvement of condition state is disregarded). The Markov Chain equation 1 (Ranjith, Sujeeva, Gravina, Vankatesan, 2013) is then used to depict the probability of movement of condition states for each movement (for example, CS 1 to 2). The probability from the Markov Chain is then subjected to graphical representation and the average taken to find the probability of movement for each year period.

$$P_{ij} = \frac{n_{ij}}{n_i} \qquad eq.1$$

Where n_{ij} is the number of transitions from state i to j within a given time period and n_i is the total number of elements in state I before the transition.

The Fault Tree Analysis (FTA) will be designed with the assistance and knowledge from the literature review. The FTA will adhere to the conventional design with a top item and splitting into sub-items to depict the failure mechanism. Possible faults and failures will be identified in conjunction with inspection reports, inspectors and TMR engineers.

The FTA will have a top element of the structures deterioration followed by a gate to the substructure and superstructure. Each element will then be linked to the required structures component with an average of deterioration. The FTA will be allocated into 3 periods of time which will depict the probability of movement (indirectly the deterioration) of each element. The FTA will follow the outlined model depicted in Figure 3.2

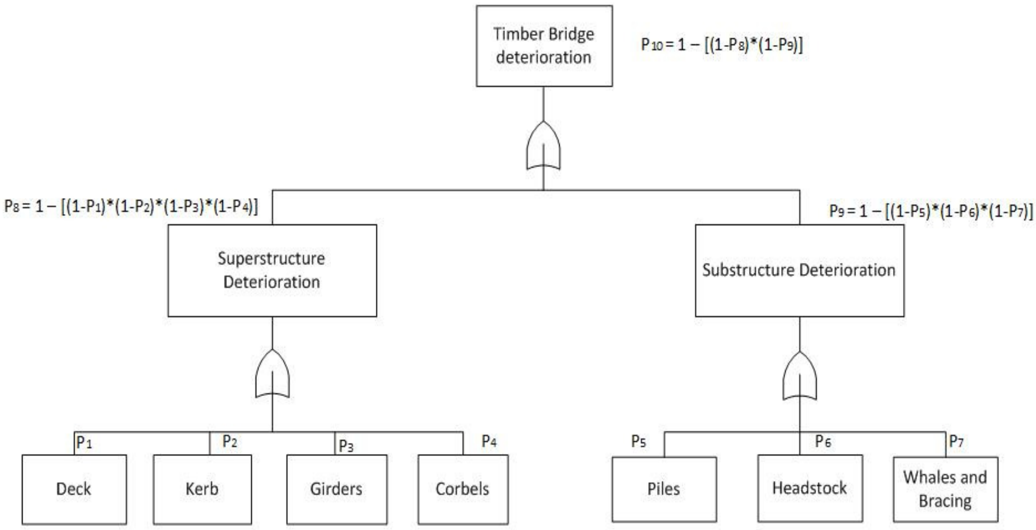


Figure 3.2 – Fault Tree Analysis model

3.1.4 Phase 4 – Implementation

The FTA will be constructed from the data gathered from inspection reports and results of meetings of appropriate personnel. This data will be traced from final fault through to the construction of the bridge (no failures). A deterioration path will follow the typical design of FTA with specific information being formed from data collected. This FTA will then be subjected to the excel model which will then generate the probability of movement.

Appendix C and Table 3.2, illustrates the models used for each member of the timber bridge with the tracking process. Depicted in Appendix D from the model in Figure 3.2 are the results produced in the inspection reports (FTA). The final phase of the dissertation is the *"write up"* phase which consisted of implementation and interpretation of the results which is depicted throughout this dissertation.

Chapter 4 Results and Discussion

In this chapter the results of the data from inspection reports are represented and presented. The problems and issues detailed in chapter 1 are subjected to the methodology outlined in chapter 3. The fundamental objectives to collect the data from inspection reports were to ensure all members were timber throughout the 3 time periods indicated in the methodology and that the data was tracked correctly throughout its life (changes to condition states). The combination of both of these goals made the availability of data minimal and difficult to report on, however representative. These goals were accomplished and presented within this chapter to demonstrate the probability of condition state movement from a theory and practice.

The investigation from the inspection reports required examination of all 62 timber bridges within the Mackay/Whitsundays district in the years of 2001, 2003 and 2006. These bridge inspection reports were then subjected to the criteria stated within chapter 4 (Methodology), where 10 bridges were found to be acceptable for the 3 time periods for each of the timber members. The 10 inspection reports which were acceptable were then subjected to the criteria over the 3 periods where this number dropped down to 3 for 2003 and 2006 due to change of material/maintenance.

4.1 - Findings

4.1.1 Inspection reports

The 10 inspection reports investigated depicted that deterioration of timber bridges were predominately rapid when subjected to natural weathering conditions (e.g. deck, whales, bracing), however the rate was slower when away from these elements (e.g. corbels, girders). The reports also indicate that workmanship of the installation impacted the condition state/deterioration of that member (highly evident in corbels from over sniping). Inspection reports were examined in conjunction to all 3 periods at the same time to ensure that the condition state movement could be tracked (Figure 3.1).

The inspection reports which were consistent over the 3 time periods depicted that within the Mackay/Whitsundays region had been replaced which is limited the investigation (headstocks, whales and bracing). In the situation that no inspection reports were available for that member a probability of movement of 0 is given to allow consistent representation of the whole sub/super structure.

4.1.2 Excel Model

The excel model of the deterioration of timber bridges within the Mackay/Whitsunday district was a visual and mathematical representation of the inspection reports. Each excel model was subjected to the methodology in chapter 4 which depicts the average percent of movement of condition states. All three periods for each element has been investigated separately from the FTA to represent the probability of each component moving.

The results depicted in Appendix C represent the chance of moving from one condition state to another (e.g. 1 to 2) for each component. These results are individual tracking of inspection reports (condition states) to depict the probability of movement over set given periods of time (2, 3 and 5 years).

The data entered which depicts a positive change to condition states are disregarded which also is representative of the maintenance which Mackay/Whitsunday's TMR have completed on those structures. This data also depicts the rapid initiative to change the deteriorating Headstocks in 2002/2003 which is indicative of the data available from 2003 onwards for timber Headstocks.

4.1.3 Deck

The probability of movement of the deck on timber bridges is depicted in Figure 4.1 which demonstrates the likelihood of condition state change over the 3 time periods. The deck is depicted to have a higher chance of moving condition states with the more deteriorated of the member. The data available for decks were concentrated to represent the whole deck as a one member when the member became more deteriorated. It is also evident that the maintenance completed on these structures were completed before deterioration had passed condition state 3.

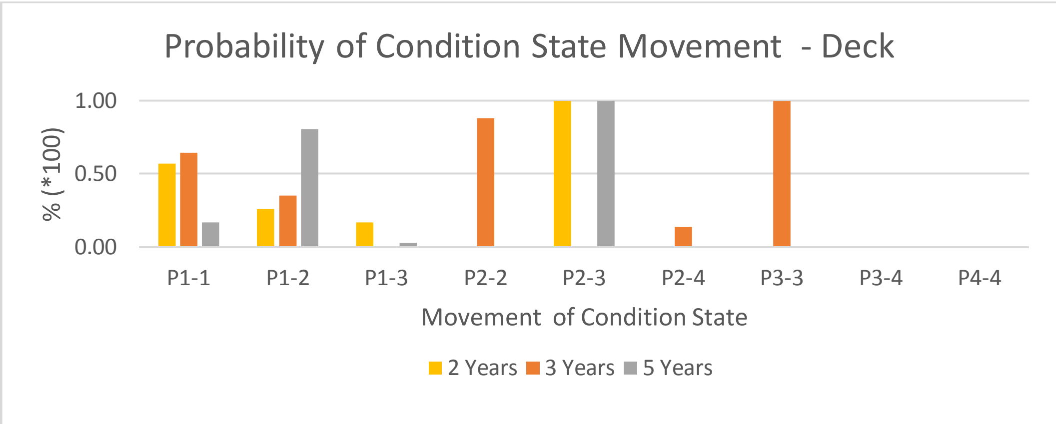


Figure 4.1 - Probability of Condition State Movement – Deck

4.1.4 Kerb

Depicted in Figure 4.2, the probability of condition state movement for kerb over the 3 time periods and the chance the kerb will change condition state. The kerb depicted in Figure 4.2, there is a higher chance of the member remaining in the same condition state over the 2, 3 and 5 year periods. The 5-year period illustrates that the probability of movement of condition states increase as the member deteriorates.

When isolating the kerb into condition state 2, the 2-year period depicts that minimal probability of change is present, whereas the 5-year period illustrates more of a probability of movement than remaining in the same state. This is indicative to the deterioration of members over a greater period of time.

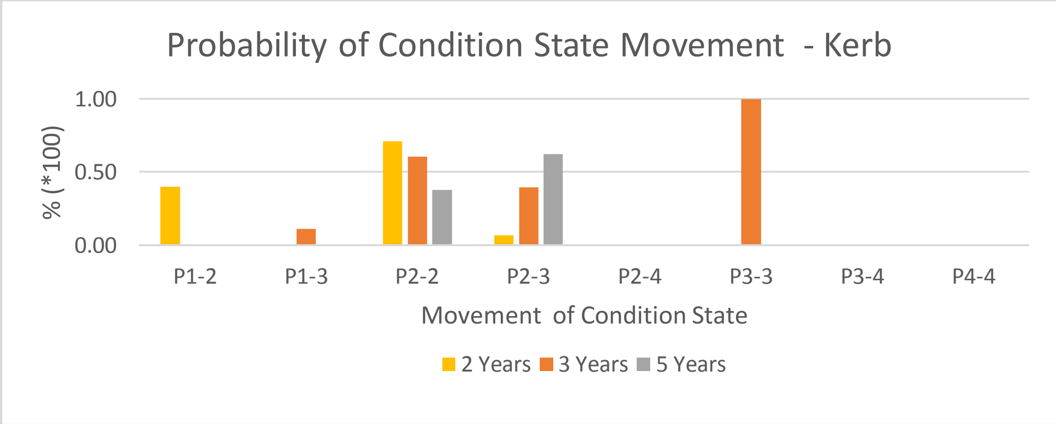


Figure 4.2 – Probability of Condition State Movement – Kerb

4.1.5 Girder

The girder data collected from inspection reports and represented in Figure 4.3 is a good representation of the condition of girders due to the amount of data available and the maintenance performed. The 3 time periods illustrated in Figure 4.3 depicts that the probability of condition state movement is significate from CS 1 to 2, 2 to 3/4 and 3 to 4.

The 5-year period depicts that when the member is in a condition state of 1 or 2 that deterioration is minimal, however when the structure reaches CS 3 the girder has a high potential to deteriorate and move condition states. The 2 and 3 year periods are similar to the 5 year, however the probability is lower (65% and 61% respectively).

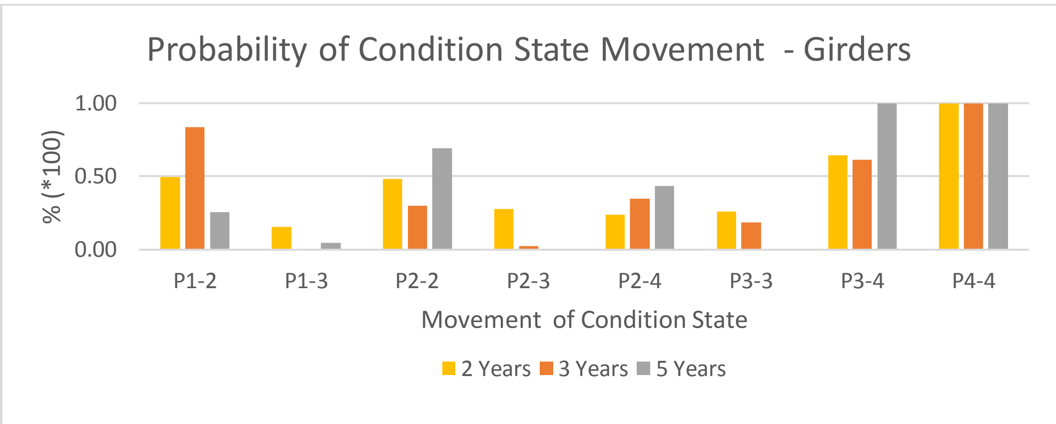


Figure 4.3 – Probability of Condition State Movement – Girders

4.1.6 Corbels

The probability of condition state movement is indicative to the time period illustrated in Figure 4.4. Depicted in Figure 4.4, the probability of deterioration over 2 years is seen to be small movements (1 to 2), however when deteriorated this probability becomes high. The 3-year period has minimal change to condition states, however has a higher chance of sever deterioration than 2 years. This is indicative to the probability of movement from CS 1-3 (40%). The deterioration from the 5-year time period is depicted to be the most sever in respect to the highest deterioration movement (CS 2 to 4 to be 63%). This data suggests that maintenance is minimal on girders within Mackay/Whitsundays district, however the time period can directly relate to the deterioration.

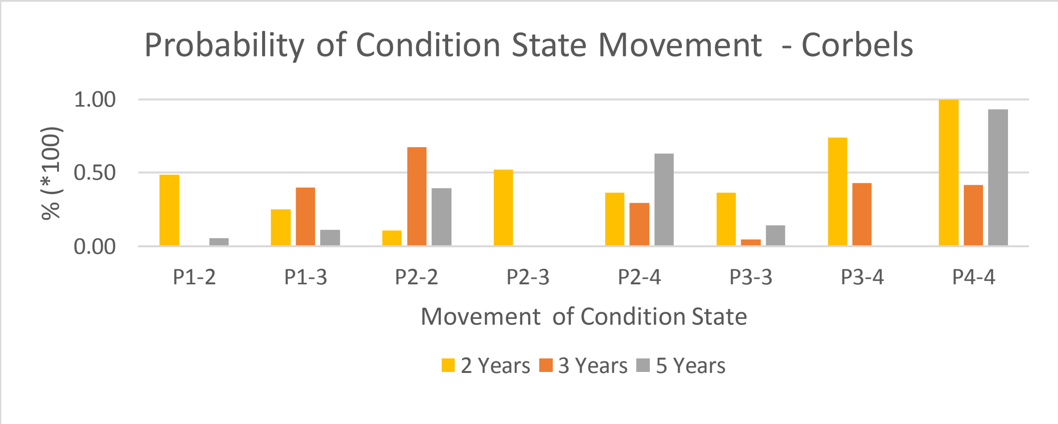


Figure 4.4 – Probability of Condition State Movement - Corbels

4.1.7 Piles

Depicted in Figure 4.5, the probability of condition state movement changes depending on the time period. The deterioration represented in Figure 4.5 is indicative to the environment the pile is subjected to (e.g. marine deterioration) which would speed the decaying rate. This is indicative to the change of condition states having the highest probability at the 3-year time period (CS 2-3 at 79% and 2-4 at 71%). The change of condition for the 2 and 5 years are consistent with deterioration over time. It can be depicted that maintenance on piles would be best performed within the 2 and 3 year periods.

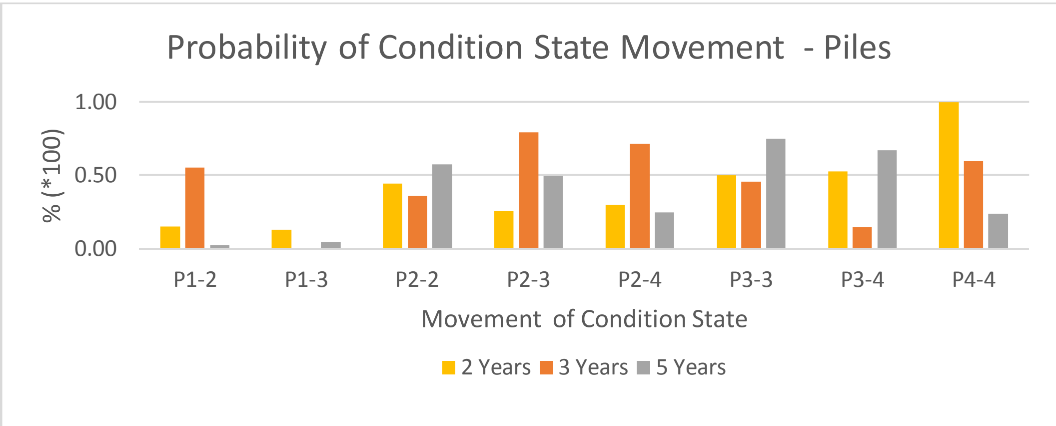


Figure 4.5 – Probability of Condition State Movement - Piles

4.1.8 Headstocks

The data available for headstocks within the Mackay/Whitsundays district is limited as indicated in Figure 4.6. The time period of 3 years all depicted that there was a 100% chance of headstock remaining in CS1 over 3 years, however the time period of 2 years illistrated that the chance of movement was high when the member was in CS 2. The 2 year period depicted that the probability of movement has a medium (35%) chance of moveing from CS1 to 4, however when the headstock is already in a a CS of 2 a 50% chance is present to move from CS 2 to 3.

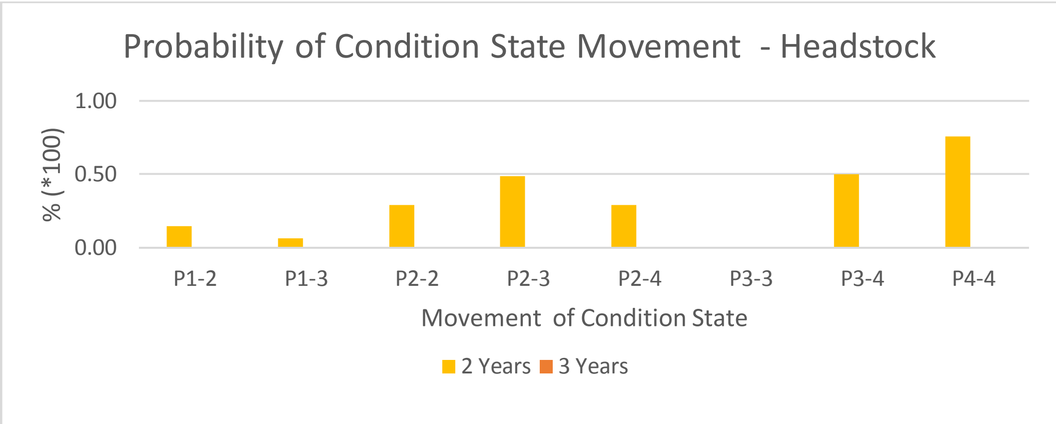


Figure 4.6 – Probability of Condition State Movement - Headstock

4.1.9 Whales and Bracing

The whales and bracing data collected from inspection reports are similar to the availablility of headstocks. It has been established that the data available for whales and brace is limitied due to the ease of replacement. It has been concluded that whales and bracing is a component which can be changed to another material simply and therefore is one of the first components to be replaced when maintenance is scheduled. Depicted in Figure 4.7, the chance of deterioration of whales and bracing is minimal, however in one case it was found to be significant (3 year CS 2 to 4 of 20%). This could be indicitive of the situation if the maintenance was not performed within the 3 year period.

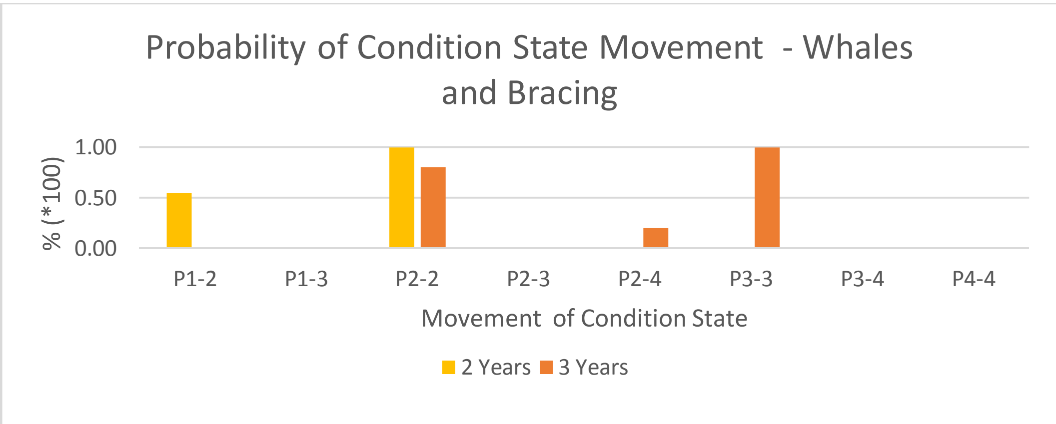


Figure 4.7 – Probability of Condition State Movement – Whales and Bracing

4.2 - Fault Tree Analysis

The Fault Tree Analysis is used to graphically model the probability of movement of condition states over the 3 different time periods. Depicted in Table 4.1 is the overview of the FTA for each condition state movement illustrated in Appendix D. The top element in the deterioration FTA depicts that the probability of each of these cases (e.g. 1-2, 1-3, 1-4) will happen over each time period. An example can be used for 2 years with a probability of failure (CS4) is 56%. The results in Table 4.1, depicts the probability of the whole member moving these condition states.

Fault Tree Analysis Probabilities										
	P1-1	P1-2	P1-3	P1-4	P2-2	P2-3	P2-4	P3-3	P3-4	P4-4
2 Years	0.96	0.93	0.57	0.56	0.95	0.88	0.76	0.77	0.98	1
3 Years	1	0.95	0.47	0.11	1	0.88	0.91	1	0.81	1
5 Years	0.97	0.87	0.21	0.39	0.95	1	0.85	0.79	1	1

Table 4.1 - FTA Probabilities

The probability of movement can be tracked for 2, 3 and 5 year periods for a timber bridge moving from a condition state 1 to 4 (probability of failure of a timber bridge). Figures 4.8, 4.9 and 4.10 depict the Fault Tree Analysis for probability of failure of each timber member over the three time periods.

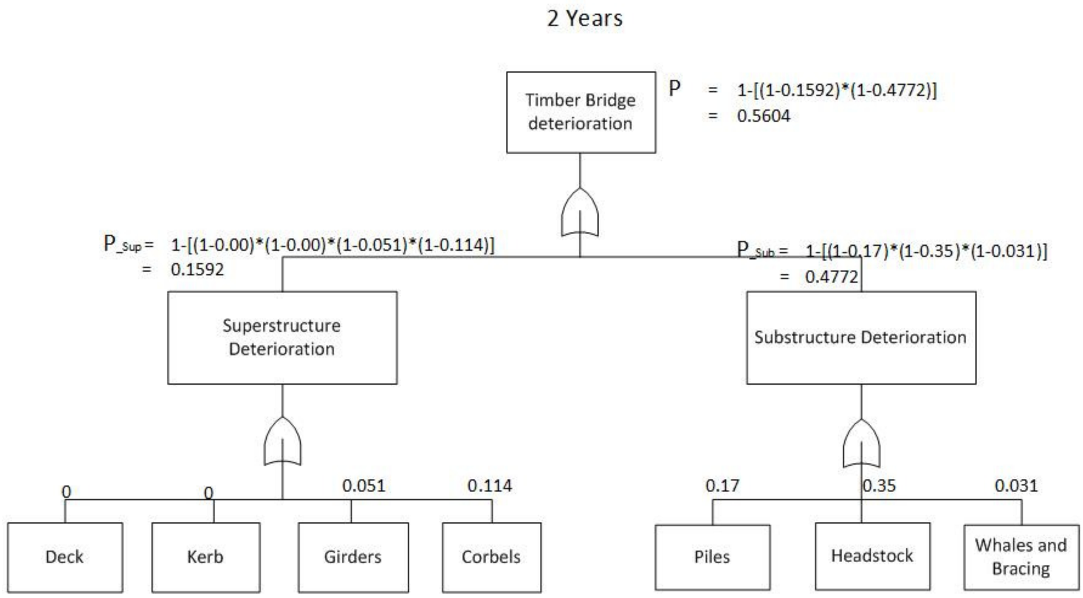


Table 4.2 – FTA for 2 Years for CS movement 1-4

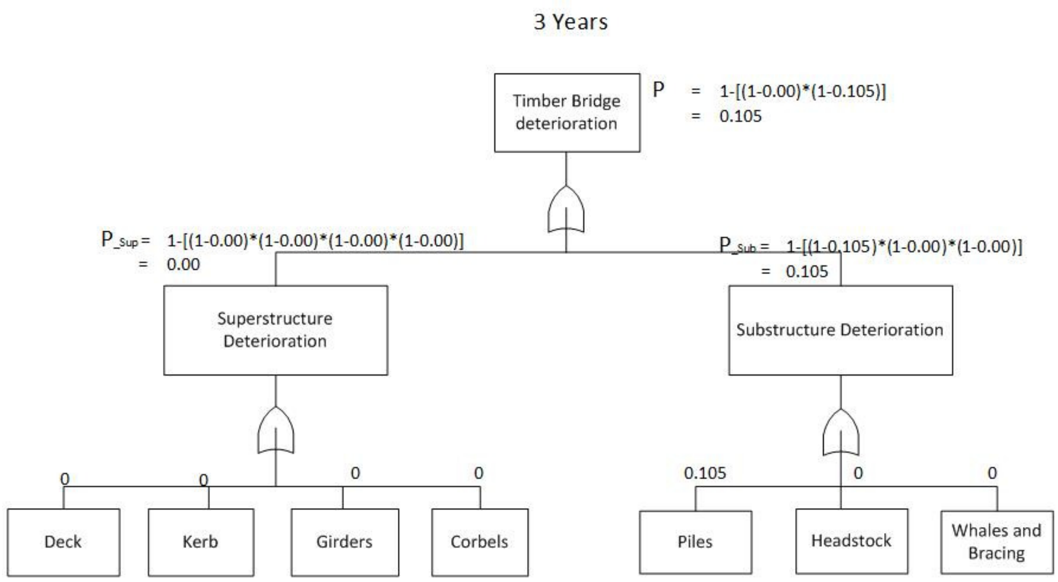


Table 4.3 – FTA for 3 Years for CS movement 1-4

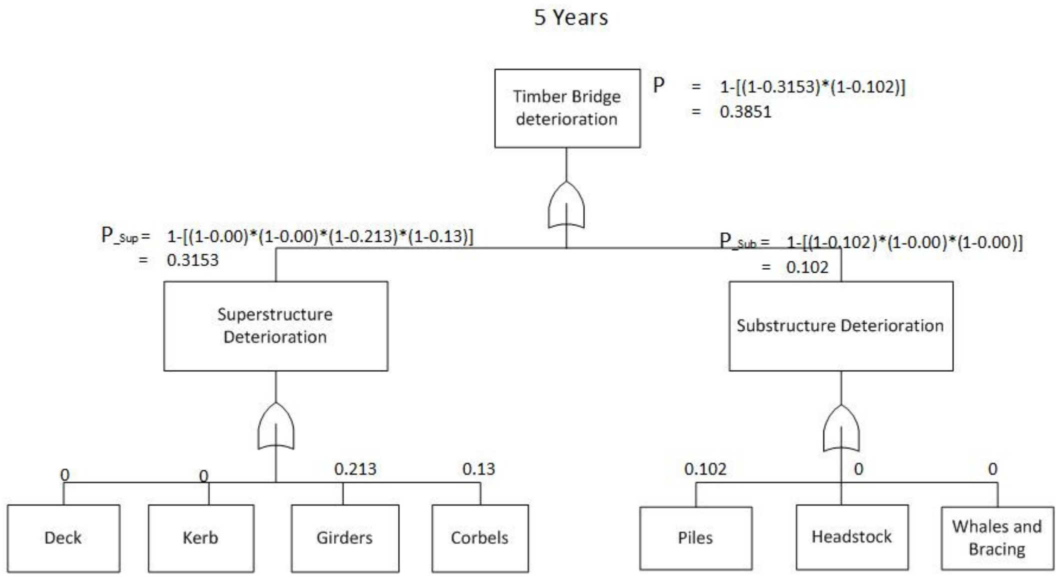


Table 4.4 – FTA for 5 Years for CS movement 1-4

Chapter 5 Conclusion and Further Recommendation

The data recorded from inspection reports were adequate to support a firm conclusion that deterioration is directly related to time. The probabilities found from the FTA were also consistent with the estimated outcomes, however the probability is higher than anticipated. The information presented throughout this dissertation can draw the following conclusions:

- Super and substructure deterioration are consistent with all both sections of the timber bridges deteriorating simultaneously.
- Preventative maintenance scheduling can be done with probabilities.
- Probability of movement of condition states is high for movement from lower states to higher states when the time period increases.
- Each member should be investigated individually to depict the probability deterioration.

The model produced from this dissertation provides a method to determine the probability that each member will deteriorate and change condition states. This method can be applied to every member of a timber bridge where an analysis can be done on the probability that member will be in CS 1, 2, 3 and 4 within the 2, 3 and 5 year periods. The application of the Fault Tree Analysis allows a quick reference for each member and their movement probability.

5.1 - Future Recommendation

Recommendations for further research would be to investigate other districts to determine the extent the geography has on the different timber members. In addition, an investigation into the following could add more validity to this dissertation:

- The different deterioration causes and draw a probability connection of same
- How the different timbers used throughout the state deteriorate at varying rates
- Investigate the AADT relationship with deterioration of timber members
- Research additional time periods (e.g. 8, 10, 14)

In conclusion this research allows scheduling and maintenance on timber bridges to be completed prior to the fault. Application of this method can be used for any timber bridge members if the current condition state is known. This model can then predict the probability that member will deteriorate and the extent.

Chapter 6 References

Agrawal, AK & Kawaguchi, A 2009, *Bridge element deterioration rates: final report*, project C-01–51, New York State Department of Transportation, New York, NY, USA.

Ataei, N., Stearn, M. and Padjett, J.E. (2010), "Response Sensitivity for Probabilistic Damage Assessment of Coastal Bridges under Surge and Wave Loading", Transportation Research Record: Journal of the Transportation Research Board, Vol. 2202, pp. 93-101.

Austroads (2009), Austroads Guide to Bridge Technology-Part 7 Maintenance and Management of Existing Bridges, Austroads Publication, Sydney, Australia.

AUSTROADS, 1991, Bridge Management Practice, AP-13/91. pp 118, Austroads, Sydney, NSW.

AUSTROADS. 2004, *Summary of Austroads Strategy for Improving Asset Management Practice*, http://www.austroads.com.au/assetmgmtstrategy.php.

Becker, A, Toilliez, J, Mitchell, T, 2015, *Considering Sea Level Change When Designing Marine Civil Works: Recommendations for Best Practices*, Handbook of Coastal Disaster Mitigation for Engineers and Planners, Chapter 32.

Bootle, K.R. (1983), Wood in Australia. Types, properties and uses, McGraw-Hill Book Company.

Brites, R.D., Neves, L.C., Machado, J.S., Lourenco, P.B. and Sousa, H.S. (2013), "Reliability analysis of a timber truss system subjected to decay", Engineering structures, Vol. 46, pp. 184-92.

Bulusu, S, Shinha, K, 1997, *Comparison of Methodologies to Predict Bridge Deterioration,* Transport Research Board.

C-H, Wang, RH, Leicester, 2008, *A Probabilistic Procedure for Design of Timber Above-ground under Attack of Decay Fungi,* Australian Structural Engineering Conference.

Committee, TM-006, T.P.A.D. 2003, *Australian Standard® Timber – Natural durability ratings standards*. Australian International Ltd, Sydney.

Davis-McDaniel, C., Chowdhury, M., Pang, W. and Dey, K. (2013), "Fault-Tree Model for Risk Assessment of Bridge Failure: Case Study for Segmental Box Girder Bridges", Journal of infrastructure systems, Vol. 19, pp. 326-34.

Department of Transport and Main Roads, Queensland, June 2004, *Bridge Inspection Manual, Second Edition,* Bridge Asset Management, Structures Division, Road System and Engineering.

Department of Transport and Main Roads, Queensland, February 2005, *Timber Bridge Maintenance Manual,* Bridge Asset Management, Structures Division, Road System and Engineering.

Ejechi, B.O. (2003), "Microbial deterioration of partially submerged service timbers in a tropical inter-tidal zone", International biodeterioration & biodegradation, Vol. 51, No. 2, pp. 115-8.

Enright, M.P. and Frangopol, D.M. (1998), "Probabilistic analysis of resistance degradation of reinforced concrete bridge beams under corrosion", Engineering structures, Vol. 20, No. 11, pp. 960-71.

Ericson, C.A. (2005), Hazard Analysis techniques for system safety, John Wiley & Sons.

Ericson, C. A., II., 1999, *Fault Tree Analysis – A History,* System *Safety at the Dawn of a new Millennium,* System Safety Society, Orlando, FL.

Faber, M.H. (2006), Risk and Safety in Civil, Surveying and Environmental Engineering, https://www1.ethz.ch/ibk/emeritus/fa/education/ws_safety/Safety07/Web_Lecture_14.pdf

FHWA (2011), Framework for improving resilience of bridge design, Publication No. FHWA-IF-11-016. U.S. Department of Transportation, Federal Highway Administration.

Flyvbjerg, B. (2006), "Five misunderstandings about case-study research", Qualitative Inquiry, Vol. 12, No. 2, pp. 219-45.

Giummarra, G.J., McInerney, R. & Styles, E.T. 2003, *'Risk Assessment For Road Networks and Bridges'*, IPWEA (Qld) 2003 State Conference, Mackay.

Johnson, P.A. (1999), "Fault tree analysis of bridge failure due to scour and channel instability", Journal of infrastructure systems, Vol. 5, No. 1, pp. 35-41.

Kleiner, Y, 2001, Scheduling inspection and renewal of large infrastructures assets, Journal of Infrastructure Systems, .7, pp. 136-143.

Kurz, J.H. and Boller, C. (2015), "Some background of monitoring and NDT also useful for timber structures", Journal of Civil Structural Health Monitoring, Vol. 5, pp. 99-106.

LeBeau, K. and Wadia-Fascetti, S. (2000), 'A fault tree model of bridge deterioration', in 8th ASCE Specialty Conference on Probabilistic Mechanics and Structural Reliability.

LeBeau, K. and Wadia-Fascetti, S. (2007), "Fault tree analysis of Schoharie Creek Bridge Collapse", Journal of Performance of Constructed Facilities, ASCE, Vol. 21, No. 4, pp. 320-6.

Liu, M. and Frangopol, D.M. (2005), "Time-dependent bridge network reliability: Novel approach", Journal of Structural Engineering, Vol. 131, No. 2, pp. 329-37.

Lopez-Anido, R, Michael, A, Goodell, B, Sandford, T, 2004, *Assessment of wood pile deterioration due to marine organisms.* Journal of Waterway, Port, Coastal and Ocean Engineering, 130. 70-76.

Mackenzie, C, 2005, *Timber service life design, Design guide for durability,* Wood Solutions, design and build.

Madanat, S, Mishalani, R, and Ibrahim, W, 1995, *Estimation of Infrastructure Transition Probabilities from Condition Rating Data,* Journal of Infrastructure Systems, 1, 120-125.

MainRoads-Queensland (2004), Bridge Inspection Manual, Department of MainRaods, Queensland.

Mainroads (2014), Detailed Visual Bridge Inspection Guidelines for Timber Bridges, Main roads, Western Australia.

Main Roads. 1999, *Engineering Policy Statement No. EP109 – Road Asset Maintenance Policy and Strategy*, Main Roads.

Morocus, G, 2013, *Life-Cycle Assessment of Nebraska Bridges,* Nebraska Department of Roads (NDOR).

National Vocational Education and Training Content NVETC, 2014, *Introduction to hazards and risks, http://nationalvetcontent.edu.au*.

Radford, D.W., Van Goethem, D., Gutkowski, R.M. and Peterson, M.L. (2002), "Composite repair of timber structures", Construction and Building Materials, Elsevier, Vol. 16, pp. 417-25.

Ranjith, S. (2010), 'Tools for diagnosis and prediction of deterioration of timber bridges in Australia', Masters thesis, RMIT University, Melbourne.

Ranjith, S., Setunge, S., Gravina, R. and Venkatesan, S. (2013), "Deterioration Prediction of Timber Bridge Elements Using the Markov Chain", Journal of Performance of Constructed Facilities, Vol. 27, No. 3, pp. 319-25.

Sangree, R.H. and Schafer, B.W. (2008), "Field experiments and numerical models for the condition assessment of historic timber bridges: Case study", Journal of Bridge Engineering, ASCE, Vol. 13, No. 6, pp. 595-601.

Setunge, S., Zhu, W., Gravina, R. and Gamage, N. (2015), "Fault-Tree-Based Integrated Approach of Assessing the Risk of Failure of Deteriorated Reinforced-Concrete Bridges", Journal of Performance of Constructed Facilities, pp. 04015058-1-12.

Shellshear, M, 2008b, '*Urban stormwater treatment using chitosan',* ENG4111/4112 research project dissertation, Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba.

Ranjith, S, Sujeeva, S, Gravina, R and Vankatesan, S. (2013), *Deterioration Prediction of Timber Bridge Elements Using the Markov Chain,* Journal of Performance of Constructed Facilities, May/June ed.

Sianipar, P.R. and Adams, T.M. (1997), "Fault-tree model of bridge element deterioration due to interaction", Journal of infrastructure systems, Vol. 3, No. 3, pp. 103-10.

Sorensen, J.D. (2011), "Framework for robustness assessment of timber structures", Engineering structures, Vol. 33, pp. 3087-92.

Van de Kuilen, J.W.G. (2007), "Service life modelling of timber structures", Materials and Structures, Vol. 40, pp. 151-61.

VicRoads (2006), VicRoads Bridge Maintenance Repair and Strengthening Guidelines., Roads Corporation, Victoria Australia.

Wacker, J.P., Brashaw, B.K. and Jalinoos, F. (2015), 'A field Assessment of timber highway bridge durability in United States', in Structures Congress: USA.

Wallace, L. (2015), New technology set to ease timber bridge crisis., https://www.engineersaustralia.org.au/portal/news/new-technology-set-ease-timber-bridge-crisis.

Weena, L, Nirdosha, G, Sujeeva Setunge, (2006), "*Fault tree analysis method for deterioration of timber bridges using an Australian case study",* Build Environment Project and Management, Vol. 6 Iss 3 pp. 332 – 344.

White, R. H.; Ross, R.J. (2014). '*Wood and Timber Condition Assessment Manual'*, 2nd edition. General Technical Rpt. FPL-GTR-234. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Wilkinson, K., Thambiratnam, D.P. and Ferreira, L. (2005), 'Capacity of notched timber girders', in 9th International Conference on Inspection, Appraisal, Repairs and Maintenance of Structures: Fuzhou, China.

Wilson, P.J. 2004, *Programme for Replacement of Timber Bridges,* Wide Bay District, Bundaberg.

Yin, R.K. (2009), Case study research: Design and methods, Thousand Oaks, CA.

Zhu, W., Setunge, S., Gravina, R. and Venkatesan, S. (2008), 'Estimation of Residual Capacity and Time-dependent Reliability of Reinforced Concrete Bridges after Initiation of a Deterioration Mechanism and Subsequent Rehabilitation', in Australian Structural Engineering Conference: The Meeting Planners, pp. 087-1--8.

Appendix A - Project Specification

University of Southern Queensland

FACULTY OF HEALTH, ENGINEERING AND SCIENCES

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	Matthew Wilson
Major:	Civil Engineering
TOPIC:	Deterioration of Timber Bridges Using Fault Tree Analysis
SUPERVISOR:	Dr Weena Lokuge
ENROLMENT:	ENG4111 - S1, 2016 ENG4112 – S2, 2016
PROJECT AIM:	This project seeks to investigate the causes of deterioration in timber bridges and the categorising of each failure. Analysis will be undertaken to depict the different faults and the probability of deterioration.
PROGRAMME:	Issue A, 23rd January 2016

1. Conduct a literature review on the possible deteriorations in timber bridges and gather inspection reports relating to the change of condition states of those bridges
2. Design a model to depict the probability of movement from different condition states
3. Develop a Fault Tree Analysis to depict the effect different failure mechanisms have on timber bridges
4. Evaluate the case studies and implement into models to predict the probability of the change of conditions states and incorporate it into the Fault Tree Analysis

As time and resources permit:

5. Compare the method developed with the results obtained from the Whichbridge software

AGREED

Matthew Wilson (Student) ________________________________(Supervisor)

Appendix B – Risk Assessment

To ensure the safe efficient operation of the project, two perspectives are analyzed. The two methods include the NVETC (2014) matrix which will be subjected to each objective (depicted from Table 4.2) and potential risks which may alter the efficiency of the project. The matrix outlined in Table 4.2, depicts a likelihood of occurrence vs. consequence of that event occurring. Each activity (Table 4.2) will be subjected to this matrix to determine the personal risk involved (Table 4.3). Once the risk is depicted for each activity, control measures can be implemented (if required).

Legend		
Low Risk	Medium Risk	High Risk

		Consequence			
		A Minor **First Aid or some medical treatment**	**B Moderate** **Increased medical attention**	**C Major** **Severe health outcome or injury**	**D Extreme** **Intensive care or death**
Likelihood of Occurrence	**1 Rare**	A1	B1	C1	D1
	2 Unlikely	A2	B2	C2	D2
	3 Likely	A3	B3	C3	D3
	4 Almost certain	A4	B4	C4	D4

Appendix B 1 – Personal Risk, Likelihood and Consequence Matrix

Task	Hazard	Risk	Minimisation
1	Injury by slips, trips, falls when walking.	**Low Risk**	Be aware of where walking and only walk on even ground.
2	If given in paper copy, be sure to use correct carrying techniques.	**Low Risk**	Use a correct bag to carry, don't lift heavy objects.
3, 4, 5	Poor circulation from sitting long periods. Muscle aching. Fatigued.	**Low Risk**	Take regular breaks, stretch and take regular walks.

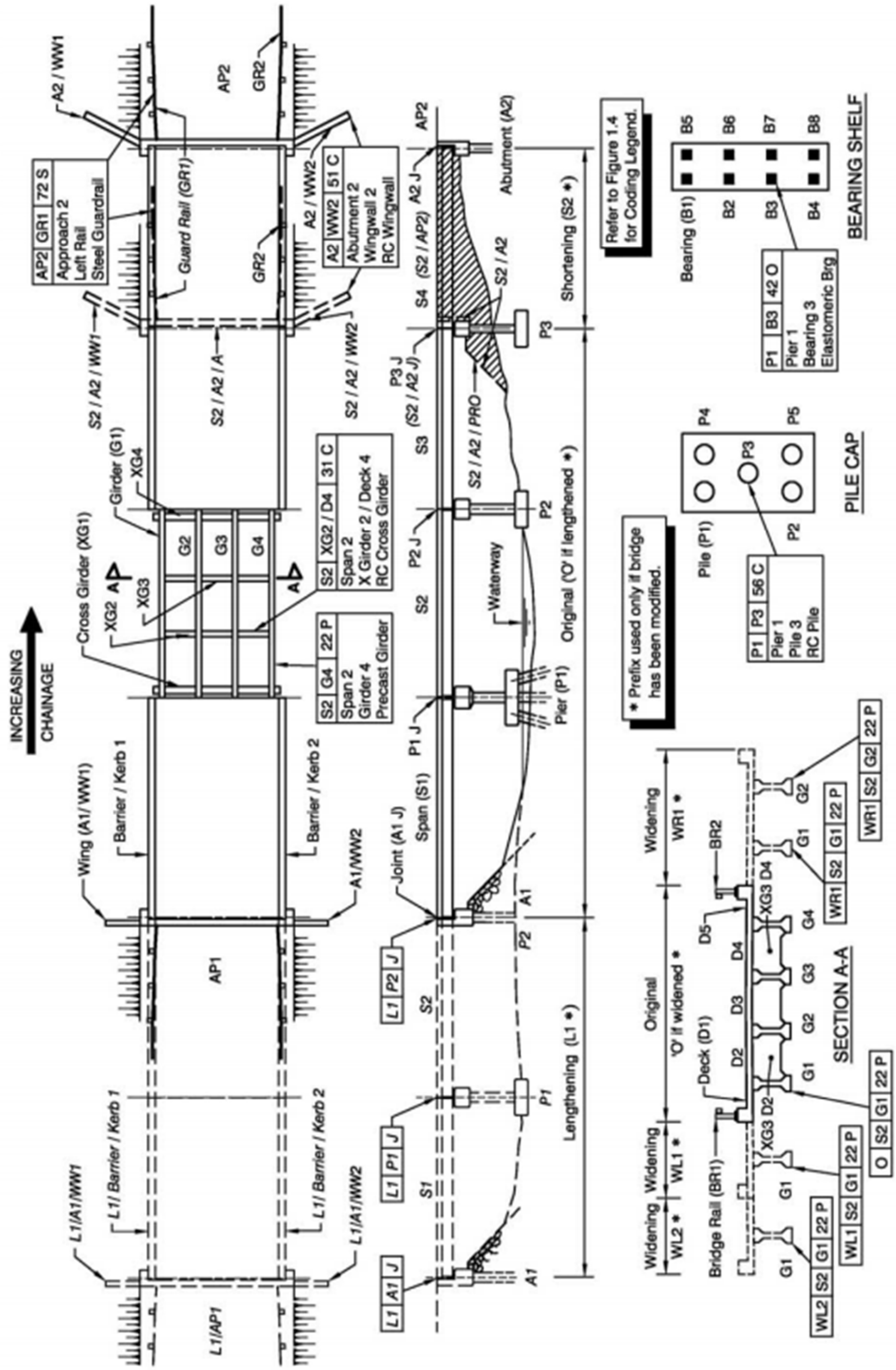
Appendix B 2 – Personal Risk Assessment for Each Activity

Illustrated above there is no high or medium risk to person when undertaking this project as the majority of the dissertation will be undertaken in a controlled environment/office. Although there is minimal threat to person, the project however will have a higher risk due to the time constraint. Due to the information needed to complete the dissertation is supplied by external sources, the time taken is unpredictable with a high level of likelihood.

Task	Hazard	Risk	Minimisation
1	Required TMR staff is on leave.	Low Risk	Allow a minimum of 6 weeks to inform TMR. Informing stage already completed.
	Resources are not readily available.	Medium Risk	Ensure the correct procedures have been implemented to gain access to both inspection reports and Whichbridge software (BIS).
	TMR system is unavailable.	Low Risk	Ensure adequate time is allocated. Acquire training with BIS.
2	BIS system is unavailable or access has been denied.	High Risk	Ensure phase 1 is implemented correctly and adequate time is allocated.
	Whichbridge software is unavailable of access has been denied.	High Risk	Ensure phase 1 is implemented correctly and adequate time is allocated.
3, 4	Excel is unavailable, input data is not accessible.	Medium Risk	Ensure Excel is downloaded on other systems and that phases 1 and 2 are implemented correctly.
3, 4, 5	Word is unavailable, input data cannot be accessed.	Medium Risk	Ensure Word is downloaded on other systems and that phases 1 and 2 are implemented correctly. All relevant information is researched and documented in the literature review.
5A	Supervisor is busy or on leave and is not accessible.	Medium Risk	Leave adequate time for consultation with supervisor and ensure frequent communication.

Appendix B 3 – Project Risk Assessment

Appendix C – Bridge Cross Section



Appendix C 1 – Cross-Section of Timber Bridge

Appendix D – Data analysis from inspection reports

Piles

		Year 2001					Year 2003																
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	56T	83.3	5.6	11.1	0.0	100.0	44.4	27.8	11.1	16.7	100	44.44	27.78	5.56	5.56	0.00	5.56	11.11	0.00	0.00	0.00	100.00
7209	56T	50.0	12.5	18.8	18.8	100.0	68.8	12.5	18.8	0.0	100	68.75	0.00	0.00	0.00	12.50	6.25	0.00	6.25	6.25	0.00	100.00
1158	56T	52.9	23.5	23.5	0.0	100.0	41.2	5.9	35.3	17.6	100	29.41	11.76	5.88	11.76	0.00	11.76	5.88	17.65	5.88	0.00	100.00
1153	56T	60.0	10.0	20.0	10.0	100.0	26.7	16.7	36.7	20.0	100	26.67	10.00	23.33	10.00	6.67	3.33	0.00	10.00	3.33	6.67	100.00
2189	56T	64.0	24.0	12.0	0.0	100.0	52.0	0.0	16.0	32.0	100	52.00	0.00	16.00	8.00	0.00	0.00	12.00	0.00	12.00	0.00	100.00
7242	56T	21.4	7.1	35.7	35.7	100.0	21.4	7.1	21.4	50.0	100	14.29	0.00	0.00	14.29	7.14	0.00	0.00	21.43	35.71	7.14	100.00
7385	56T	86.7	10.0	3.3	0.0	100.0	56.7	23.3	10.0	10.0	100	56.67	23.33	6.67	0.00	0.00	3.33	6.67	0.00	3.33	0.00	100.00
7241	56T	48.0	20.0	20.0	12.0	100.0	48.0	24.0	20.0	8.0	100	48.00	4.00	0.00	0.00	20.00	0.00	0.00	20.00	0.00	8.00	100.00
7243	56T	81.3	6.3	6.3	6.3	100.0	31.3	12.5	12.5	43.8	100	18.75	6.25	12.50	43.75	6.25	0.00	0.00	0.00	12.50	0.00	100.00
																						0.00
Total		547.62	118.98	150.69	82.71	900.00	390.38	129.80	181.75	198.06	900.00	359.0	83.1	69.9	93.4	52.6	30.2	35.7	75.3	79.0	21.8	900.0

P1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.7	0.2	0.1	0.2	0.0	0.4	0.3	0.3	0.0	0.0	0.5	0.5	0.0	0.0	0.0	1.0
65.6	15.2	12.8	17.0	0.0	44.2	25.4	30.0	0.0	0.0	50.0	52.4	0.0	0.0	0.0	100.0

		Year 2003					Year 2006															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	56T	44.4	27.8	11.1	16.7	100.0	42.86	0.00	28.57	28.57	100.00	42.86	0.00	0.00	0.00	0.00	28.57	14.29	0.00	14.29	0.00	100
7209	56T	68.8	12.5	18.8	0.0	100.0	61.54	15.38	23.08	0.00	100.00	61.54	15.38	0.00	0.00	7.69	0.00	0.00	15.38	0.00	0.00	100
1158	56T	41.2	5.9	35.3	17.6	100.0	33.33	33.33	8.33	25.00	100.00	33.33	25.00	0.00	0.00	8.33	0.00	0.00	8.33	0.00	25.00	100
1153	56T	26.7	16.7	36.7	20.0	100.0	20.00	60.00	20.00	0.00	100.00	20.00	60.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	0.00	100
7243	56T	31.3	12.5	12.5	43.8	100.0	33.33	16.67	8.33	41.67	100.00	33.33	16.67	0.00	0.00	0.00	0.00	8.33	8.33	0.00	33.33	100
8699	56T	66.67	33.33	0.00	0	100.0	44.44	11.11	11.11	33.33	100.00	44.44	0.00	0.00	22.22	11.11	11.11	11.11	0.00	0.00	0.00	100
1159	56T	60	40	0	0	100.0	40	20	20	20	100.00	40	20	0.00	0.00	0.00	20	20	0.00	0.00	0.00	100
Total		212.29	75.33	114.32	98.06	500.00	191.06	125.38	88.32	95.24	500.00	191.06	117.05	0.00	22.22	27.14	59.68	53.73	52.05	14.29	58.33	500.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.90	0.55	0.00	0.10	0.00	0.36	0.79	0.71	0.00	0.00	0.46	0.15	0.00	0.00	0.00	0.59
90.00	55.14	0.00	10.47	0.00	36.03	79.23	71.33	0.00	0.00	45.53	14.57	0.00	0.00	0.00	59.49

Year 2001 Year 2006

Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4			% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	56T	83.3	5.6	11.1	0.0	100.0	116.7	42.86	0.00	28.57	28.57	100.00	42.86	0.00	14.29	0.00	0.00	14.29	0.00	0.00	28.57	0.00	100.00
7209	56T	50.0	12.5	18.8	18.8	100.0	150.0	61.54	15.38	23.08	0.00	100.00	61.54	0.00	0.00	0.00	15.38	0.00	0.00	23.08	0.00	0.00	100.00
1158	56T	52.9	23.5	23.5	0.0	100.0	147.1	33.33	33.33	8.33	25.00	100.00	33.33	0.00	0.00	0.00	33.33	0.00	0.00	8.33	25.00	0.00	100.00
1153	56T	60.0	10.0	20.0	10.0	100.0	140.0	20.00	60.00	20.00	0.00	100.00	20.00	0.00	0.00	0.00	60.00	0.00	0.00	20.00	0.00	0.00	100.00
7243	56T	81.3	6.3	6.3	6.3	100.0	118.8	33.33	16.67	8.33	41.67	100.00	33.33	8.33	0.00	33.33	8.33	0.00	0.00	8.33	0.00	8.33	100.00
Total		327.52	57.83	79.64	35.00	500.00	672.48	191.06	125.38	88.32	95.24	500.00	191.06	8.33	14.29	33.33	117.05	14.29	0.00	59.74	53.57	8.33	500.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.58	0.03	0.04	0.10	0.00	0.58	0.49	0.25	0.00	0.00	0.75	0.67	0.00	0.00	0.00	0.24
58.34	2.54	4.36	10.18	0.00	57.64	49.41	24.70	0.00	0.00	75.02	67.27	0.00	0.00	0.00	23.81

Girders

Structure ID	Component	Year 2001 % in CS1	% in CS2	% in CS3	% in CS4		Year 2003 % in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	22T	80.00	20.00	0.00	0.00	100	0.00	100.00	0.00	0.00	100	0.00	80.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	0.00	100
7209	22T	95.00	5.00	0.00	0.00	100	95.00	0.00	5.00	0.00	100	95.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	100
1158	22T	95.24	0.00	4.76	0.00	100	4.76	52.38	38.10	4.76	100	4.76	52.38	38.10	4.76	0.00	0.00	0.00	0.00	0.00	0.00	100
1153	22T	50.00	21.43	7.14	21.43	100	0.00	17.86	39.29	42.86	100	0.00	14.29	28.57	7.14	3.57	7.14	10.71	3.57	3.57	21.43	100
2189	22T	86.11	13.89	0.00	0.00	100	33.33	52.78	11.11	2.78	100	33.33	44.44	8.33	0.00	8.33	2.78	2.78	0.00	0.00	0.00	100
7242	22T	60.00	40.00	0.00	0.00	100	0.00	80.00	0.00	20.00	100	0.00	60.00	0.00	0.00	20.00	0.00	20.00	0.00	0.00	0.00	100
7243	22T	20.00	30.00	30.00	20.00	100	0.00	20.00	30.00	50.00	100	0.00	10.00	10.00	0.00	10.00	20.00	0.00	0.00	30.00	20.00	100
7241	22T	60.00	25.00	10.00	5.00	100	55.00	20.00	15.00	10.00	100	55.00	5.00	0.00	0.00	15.00	5.00	5.00	10.00	0.00	5.00	100
7385	22T	95.83	4.17			100	4.17	54.17	20.83	20.83	100	4.17	54.17	16.67	20.83	0.00	4.17	0.00	0.00	0.00	0.00	100
Total		642.18	159.48	51.90	46.43	900.00	192.26	397.18	159.33	151.23	900.00	192.3	320.3	101.7	32.7	76.9	44.1	38.5	13.6	33.6	46.4	900.0

P1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.30	0.50	0.16	0.05	0.00	0.48	0.28	0.24	0.00	0.00	0.26	0.65	0.00	0.00	0.00	1.00
29.94	49.87	15.83	5.10	0.00	48.22	27.64	24.14	0.00	0.00	26.15	64.68	0.00	0.00	0.00	100.00

		Year 2003					Year 2006															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	22T	0.00	100.00	0.00	0.00	100	40.00	20.00	0	40.00	100	0.00	40.00	0.00	0.00	20.00	0.00	40.00	0.00	0.00	0.00	100.00
7209	22T	95.00	0.00	5.00	0.00	100	55	45.00	0	0	100	55.00	45.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
7243	22T	0.00	20.00	30.00	50.00	100	0	0	0	100	100	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	30.00	50.00	100.00
2189	22T	33.33	52.78	13.89	0.00	100	31.81818	54.54545	13.63636	0	100	31.82	22.73	0.00	0.00	31.82	4.55	0.00	9.09	0.00	0.00	100.00
Total		128.33	172.78	48.89	50.00	400.00	126.82	119.55	13.64	140.00	400.00	86.82	107.73	0.00	0.00	51.82	4.55	60.00	9.09	30.00	50.00	400.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.68	0.84	0.00	0.00	0.00	0.30	0.03	0.35	0.00	0.00	0.19	0.61	0.00	0.00	0.00	1.00
67.65	83.94	0.00	0.00	0.00	29.99	2.63	34.73	0.00	0.00	18.60	61.36	0.00	0.00	0.00	100.00

Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	22T	80.00	20.00	0.00	0.00	100	40.00	20.00	0	40.00	100	40.00	0.00	0.00	40.00	20.00	0.00	0.00	0.00	0.00	0.00	100.00
7209	22T	95.00	5.00	0.00	0.00	100	55	45.00	0	0	100	55.00	40.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	100.00
7243	22T	20.00	30.00	30.00	20.00	100	0	0	0	100	100	0.00	0.00	0.00	20.00	0.00	0.00	30.00	0.00	30.00	20.00	100.00
2189	22T	86.11	13.89	0.00	0.00	100	31.82	54.55	13.64	0.00	100	31.82	31.82	13.64	0.00	22.73	0.00	0.00	0.00	0.00	0.00	100.00
Total		281.11	68.89	30.00	20.00	400.00	126.82	119.55	13.64	140.00	400.00	126.82	71.82	13.64	60.00	47.73	0.00	30.00	0.00	30.00	20.00	400.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.45	0.26	0.05	0.21	0.00	0.69	0.00	0.44	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00
45.11	25.55	4.85	21.34	0.00	69.28	0.00	43.55	0.00	0.00	0.00	100.00	0.00	0.00	0.00	100.00

Headstocks

Structure ID	Component	Year 2001 % in CS1	% in CS2	% in CS3	% in CS4		Year 2003 % in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	54T	75.00	0.00	0.00	25.00	100	0.00	0.00	50.00	50.00	100	25.00	0.00	25.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	100
7209	54T	90.00	0.00	0.00	10.00	100	30.00	40.00	0.00	30.00	100	30.00	30.00	0.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00	100
1158	54T	83.33	0.00	0.00	16.67	100	33.33	0.00	0.00	66.67	100	33.33	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	16.67	100
1153	54T	70.59	0.00	11.76	17.65	100	5.88	29.41	0.00	64.71	100	5.88	23.53	0.00	35.29	0.00	5.88	0.00	0.00	5.88	23.53	100
2189	54T	100.00	0.00	0.00	0.00	100	94.44	0.00	5.56	0.00	100	94.44	0.00	5.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
7242	54T	25.00	75.00	0.00	0.00	100	0.00	50.00	25.00	25.00	100	0.00	25.00	0.00	0.00	25.00	25.00	25.00	0.00	0.00	0.00	100
7243	54T	83.33	0.00	0.00	16.67	100	66.67	0.00	0.00	33.33	100	66.67	0.00	0.00	16.67	0.00	0.00	0.00	0.00	0.00	16.67	100
7241	54T	87.50	0.00	0.00	12.50	100	50.00	0.00	12.50	37.50	100	50.00	0.00	12.50	25.00	0.00	0.00	0.00	0.00	0.00	12.50	100
7385	54T	66.67	11.11	0.00	22.22	100	22.22	22.22	11.11	44.44	100	22.22	22.22	0.00	22.22	0.00	11.11	0.00	0.00	0.00	22.22	100

Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7273	54T	100	0	0	0	100	100	0	0	0	100	100	0	0	0	0	0	0	0	0	0	100
7241	54T	100	0	0	0	100	100	0	0	0	100	100	0	0	0	0	0	0	0	0	0	100
						0					0											0
Total		200.00	0.00	1.26	0.00	236.80	200.00	0.00	0.00	0.00	200.00	200.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0

Corbels

Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7209	27T	66.67	20.00	6.67	6.67	100	40.00	33.33	26.67	0.00	100	40.00	33.33	0.00	0.00	0.00	20.00	0.00	6.67	0.00	0.00	100
1158	27T	80.95	0.00	14.29	4.76	100	0.00	19.05	47.62	33.33	100	0.00	19.05	47.62	14.29	0.00	0.00	0.00	4.76	9.52	4.76	100
1153	27T	66.67	14.81	3.70	14.81	100	3.70	14.81	25.93	55.56	100	3.70	14.81	25.93	22.22	0.00	0.00	14.81	0.00	3.70	14.81	100
2189	27T	53.13	15.63	28.13	3.13	100	3.13	25.00	40.63	31.25	100	3.13	21.88	25.00	3.13	3.13	3.13	9.38	12.50	15.63	3.13	100
7243	27T	20.00	60.00	20.00	0.00	100	0.00	20.00	40.00	40.00	100	0.00	20.00	0.00	0.00	0.00	40.00	20.00	0.00	20.00	0.00	100
7241	27T	50.00	10.00	20.00	20.00	100	20.00	30.00	20.00	30.00	100	20.00	20.00	0.00	10.00	10.00	0.00	0.00	10.00	20.00	10.00	100
7385	27T	100.00	0.00	0.00	0.00	100	5.56	83.33	11.11	0.00	100	5.56	83.33	11.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
Total		437.41	120.44	92.78	49.37	700.00	72.38	225.53	211.95	190.14	700.00	72.38	212.40	109.66	49.63	13.13	63.13	44.19	33.93	68.85	32.70	700.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.17	0.49	0.25	0.11	0.00	0.11	0.52	0.37	0.00	0.00	0.37	0.74	0.00	0.00	0.00	1.00
16.55	48.56	25.07	11.35	0.00	10.90	52.41	36.69	0.00	0.00	36.57	74.21	0.00	0.00	0.00	100.00

		Year 2003					Year 2006															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7209	27T	40.00	33.33	26.67	0.00	100	80.00	20.00	0.00	0.00	100.00	80.00	0.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	0.00	100
1153	27T	3.70	14.81	25.93	55.56	100	52.17	26.09	21.74	0.00	100.00	52.17	0.00	17.39	0.00	26.09	0.00	0.00	4.35	0.00	0.00	100
7243	27T	0.00	20.00	40.00	40.00	100	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	40.00	40.00	100
Total		43.70	68.15	92.59	95.56	300.00	132.17	46.09	21.74	100.00	300.00	132.17	0.00	17.39	0.00	46.09	0.00	20.00	4.35	40.00	40.00	300.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.33	0.00	0.40	0.00	0.00	0.68	0.00	0.29	0.00	0.00	0.05	0.43	0.00	0.00	0.00	0.42
33.07	0.00	39.79	0.00	0.00	67.63	0.00	29.35	0.00	0.00	4.70	43.20	0.00	0.00	0.00	41.86

		Year 2001					Year 2006														
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7209	27T	66.67	20.00	6.67	6.67	100.00	80.00	20.00	0.00	0.00	100.00	80.00	0.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	0.00	100.00
1153	27T	66.67	14.81	3.70	14.81	100.00	52.17	26.09	21.74	0.00	100.00	52.17	8.70	17.39	0.00	17.39	0.00	0.00	4.35	0.00	0.00	100.00
7243	27T	20.00	60.00	20.00	0.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	20.00	0.00	0.00	60.00	0.00	0.00	20.00	100.00
Total		153.33	94.81	30.37	21.48	300.00	132.17	46.09	21.74	100.00	300.00	132.17	8.70	17.39	20.00	37.39	0.00	60.00	4.35	0.00	20.00	300.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.86	0.06	0.11	0.13	0.00	0.39	0.00	0.63	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.93
86.20	5.67	11.34	13.04	0.00	39.44	0.00	63.28	0.00	0.00	14.32	0.00	0.00	0.00	0.00	93

Deck

Structure ID	Component	Year 2001 % in CS1	% in CS2	% in CS3	% in CS4		Year 2003 % in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	29T	0	100	0	0	10 0	0	0	100	0	10 0	0	0	0	0	0	10 0	0	0	0	0	10 0
1158	20T	100	0	0	0	10 0	93.33 333	6.666 667	0	0	10 0	93.33 333	6.666 667	0	0	0	0		0	0	0	10 0
1153	20T	100	0	0	0	10 0	100	0	0	0	10 0	100	0	0	0	0	0	0	0	0	0	10 0
2189	20T	100	0	0	0	10 0	0	0	100	0	10 0	0	0	10 0	0	0	0	0	0	0	0	10 0
7242	20T	100	0	0	0	10 0	0	100	0	0	10 0	0	100	0	0	0	0	0	0	0	0	10 0
7243	20T	100	0	0	0	10 0	50	50	0	0	10 0	50	50	0	0	0	0	0	0	0	0	10 0
7241	20T	100	0	0	0	10 0	100	0	0	0	10 0	100	0	0	0	0	0	0	0	0	0	10 0
																						0
Total		600	100	0	0	70 0	343.3 333	156.6 667	200	0	70 0	343.3 333	156.6 667	10 0	0	0	10 0	0	0	0	0	70 0

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.57	0.26	0.17	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57.22	26.11	16.67	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		Year 2003					Year 2006															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	29T	0.00	0.00	100.00	0.00	100.00	0.00	0.00	100.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00		0.00	100.00	0.00	0.00	100.00
7209	29T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
1158	29T	93.33	6.67	0.00	0.00	100.00	0.00	92.09	7.91	0.00	100.00	0.00	92.09	0.00	0.00	0.00	0.00	7.91	0.00	0.00	0.00	100.00
1153	29T	100.00	0.00	0.00	0.00	100.00	0.00	100.00	0.00	0.00	100.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
7243	29T	50.00	50.00	0.00	0.00	100.00	50.00	50.00	0.00	0.00	100.00	50.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	100.00
8699	29T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
1159	29T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
																						0.00
Total		543.33	56.67	100.00	0.00	700.00	350.00	242.09	107.91	0.00	700.00	350.00	192.09	0.00	0.00	50.00	0.00	7.91	100.00	0.00	0.00	700.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.64	0.35	0.00	0.00	0.00	0.88	0.00	0.14	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
64.42	35.35	0.00	0.00	0.00	88.24	0.00	13.95	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00

		Year 2001					Year 2006															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	29T	0	100	0	0	100	0.00	0.00	100.00	0.00	100.00	0	0	0	0	0	100	0	0	0	0	100
1158	20T	100	0	0	0	100	0.00	92.09	7.91	0.00	100.00		92.09	7.91								100
1153	20T	100	0	0	0	100	0.00	100.00	0.00	0.00	100.00		100									100
7243	20T	100	0	0	0	100	50.00	50.00	0.00	0.00	100.00	50	50	0	0	0	0	0	0	0	0	100
Total		300.00	100.00	0.00	0.00	400.00	50.00	242.09	107.91	0.00	400.00	50.00	242.09	7.91	0.00	0.00	100.00	0.00	0.00	0.00	0.00	400.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.2	0.8	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.7	80.7	2.6	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Kerb

		Year 2001					Year 2003															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	3T	0	100	0	0	100	0	0	100	0	100	0	100	0	0	0	0	0	0	0	0	100
7209	3T	100	0	0	0	100	100	0	0	0	100	100	0	0	0	0	0	0	0	0	0	100
1158	3T	0	100	0	0	100	0	100	0	0	100	0	0	0	0	100	0	0	0	0	0	100
1153	3T	100	0	0	0	100	100	0	0	0	100	100	0	0	0	0	0	0	0	0	0	100
2189	3T	0	100	0	0	100	0	100	0	0	100	0	0	0	0	100	0	0	0	0	0	100
7242	3T	0	100	0	0	100	0	70	30	0	100	0	0	0	0	70	30	0	0	0	0	100
7241	3T	50	50	0	0	100	50	50	0	0	100	50	0	0	0	50	0	0	0	0	0	100
Total		250	450	0	0	700	250	320	130	0	700	250	100	0	0	320	30	0	0	0	0	700

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
1.00	0.40	0.00	0.00	0.00	0.71	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100.00	40.00	0.00	0.00	0.00	71.11	6.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		Year 2003					Year 2006															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	3T	0.00	0.00	100.00	0.00	100.00	0.00	0.00	100.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	100
7209	3T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
1158	3T	0.00	100.00	0.00	0.00	100.00	0.00	75.51	24.49	0.00	100.00	0.00	0.00	0.00	0.00	75.51	24.49	0.00	0.00	0.00	0.00	100
1153	3T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
7243	3T	50.00	25.00	25.00	0.00	100.00	0.00	0.00	100.00	0.00	100.00	0.00	0.00	50.00	0.00	0.00	25.00	0.00	25.00	0.00	0.00	100
8699	3T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
1159	3T	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
Total		450.00	125.00	125.00	0.00	700.00	400.00	75.51	224.49	0.00	700.00	400.00	0.00	50.00	0.00	75.51	49.49	0.00	125.00	0.00	0.00	700.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.89	0.00	0.11	0.00	0.00	0.60	0.40	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
88.89	0.00	11.11	0.00	0.00	60.41	39.59	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00

		Year 2001					Year 2006														
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7221	3T	0	100	0	0	100.00	0.00	0.00	100.00	0.00	100.00	0	0	0	0	0	100	0	0	0	0	100
7209	3T	100	0	0	0	100.00	100.00	0.00	0.00	0.00	100.00	100	0	0	0	0	0	0	0	0	0	100
1158	3T	0	100	0	0	100.00	0.00	75.51	24.49	0.00	100.00	0	0	0	0	75.51	24.49	0	0	0	0	100
1153	3T	100	0	0	0	100.00	100.00	0.00	0.00	0.00	100.00	100	0	0	0	0	0	0	0	0	0	100
Total		200.00	200.00	0.00	0.00	400.00	200.00	75.51	124.49	0.00	400.00	200.00	0.00	0.00	0.00	75.51	124.49	0.00	0.00	0.00	0.00	400.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
1.0	0.0	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100.0	0.0	0.0	0.0	0.0	37.8	62.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Whales and Bracing

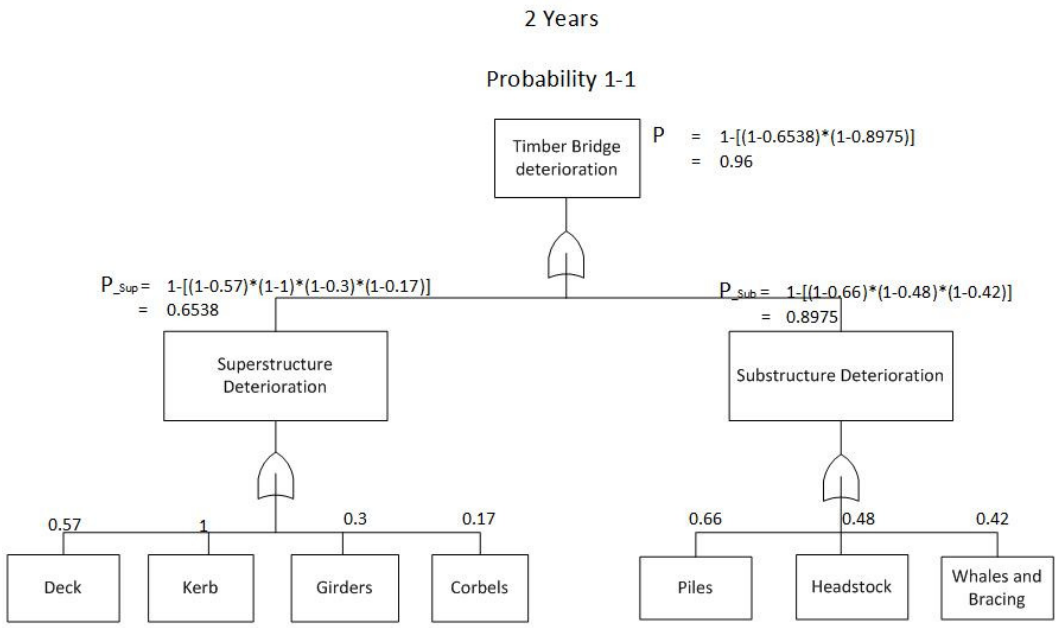
		Year 2001					Year 2003															
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7209	57T	100	0	0	0	100	100.00	0.00	0.00		100	100.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	100
1158	57T	100	0	0	0	100	0.00	96.55	0.00	3.45	100	0.00	96.55	0.00	3.45	0.00	0.00	0.00	0.00	0.00	0.00	100
1153	57T	100	0	0	0	100	0.00	87.50	0.00	12.50	100	0.00	87.50	0.00	12.50	0.00	0.00	0.00	0.00	0.00	0.00	100
2189	57T	20	80	0	0	100	20.00	80.00	0.00	0.00	100	20.00	0.00	0.00	0.00	80.00	0.00	0.00	0.00	0.00	0.00	100
7241	57T	100	0	0	0	100	100.00	0.00	0.00	0.00	100	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
7385	57T	100	0	0	0	100	0.00	100.00	0.00	0.00	100	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
Total		520.00	80.00	0.00	0.00	600.00	220.00	364.05	0.00	15.95	600.00	220.00	284.05	0.00	15.95	80.00	0.00	0.00	0.00	0.00	0.00	600.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
0.42	0.55	0.00	0.03	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42.31	54.63	0.00	3.07	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

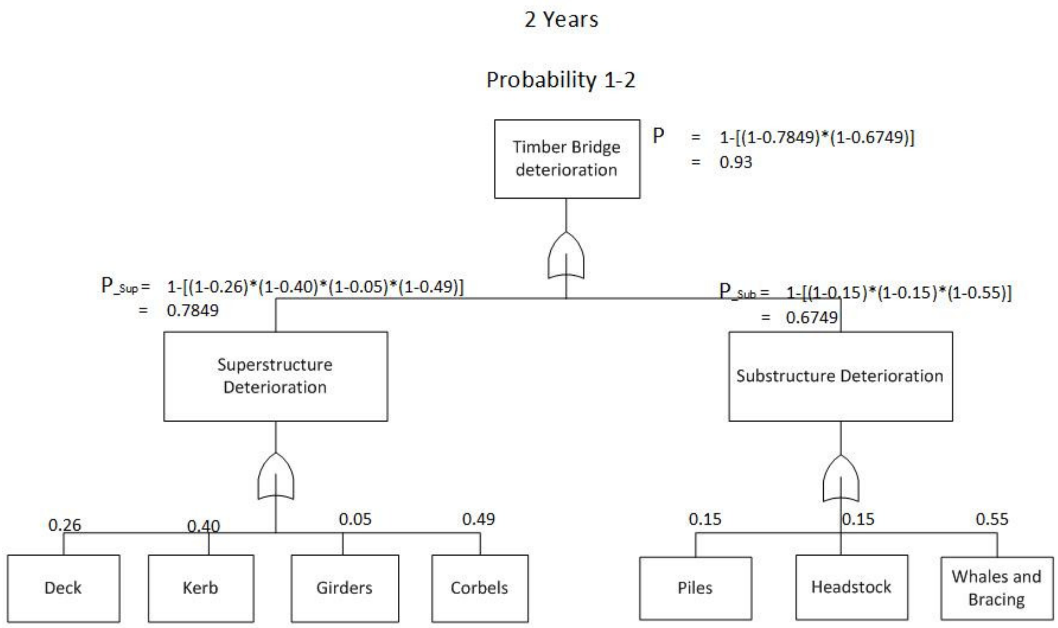
		Year 2003							Year 2006												
Structure ID	Component	% in CS1	% in CS2	% in CS3	% in CS4		% in CS1	% in CS2	% in CS3	% in CS4		1-1'	1-2'	1-3'	1-4'	2-2'	2-3'	2-4'	3-3'	3-4'	4-4'	
7209	57T	100	0	0	0	100	100	0	0	0	100	100	0	0	0	0	0	0	0	0	0	100
1158	57T	0	100	0	0	100	0	100	0	0	100	0	0	0	0	100	0	0	0	0	0	100
7243	57T	0.00	50.00	50.00	0.00	100	0	0	0	100	100	0	0	0	0	0	0	50	0	50	0	100
1159	57T	0	100	0	0	100	0	100	0	0	100	0	0	0	0	100	0	0	0	0	0	100
Total		100.00	250.00	50.00	0.00	400.00	100.00	200.00	0.00	100.00	400.00	100.00	0.00	0.00	0.00	200.00	0.00	50.00	0.00	50.00	0.00	400.00

P 1-1	P1-2	P1-3	P1-4	P2-1	P2-2	P2-3	P2-4	P3-1	P3-2	P3-3	P3-4	P4-1	P4-2	P4-3	P4-4
1.0	0.0	0.0	0.0	0.0	0.8	0.0	0.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
100.0	0.0	0.0	0.0	0.0	80.0	0.0	20.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0

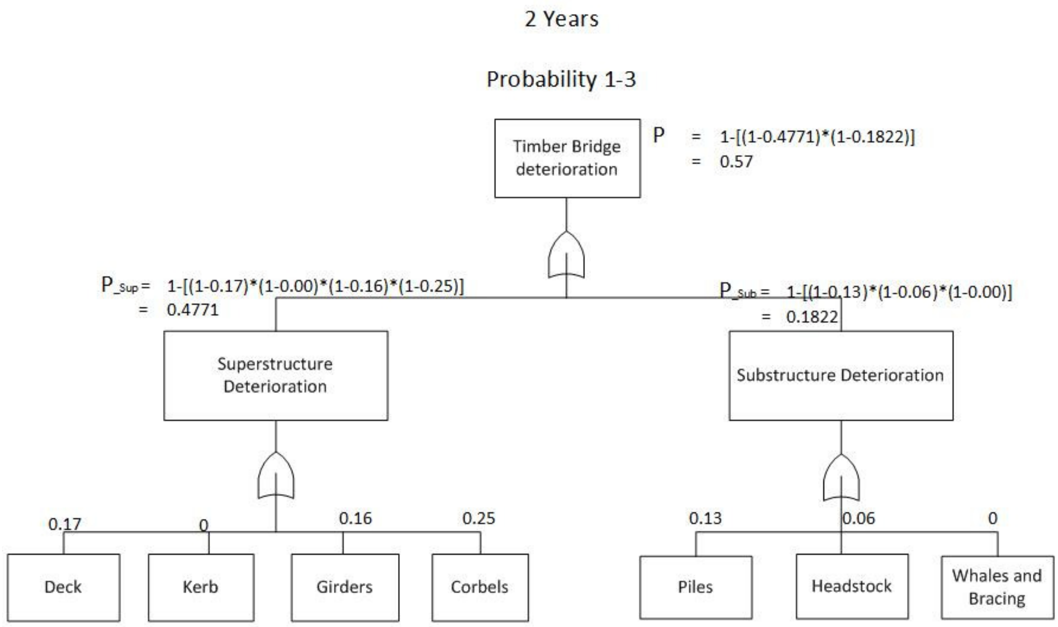
Appendix E – Fault Tree Analysis



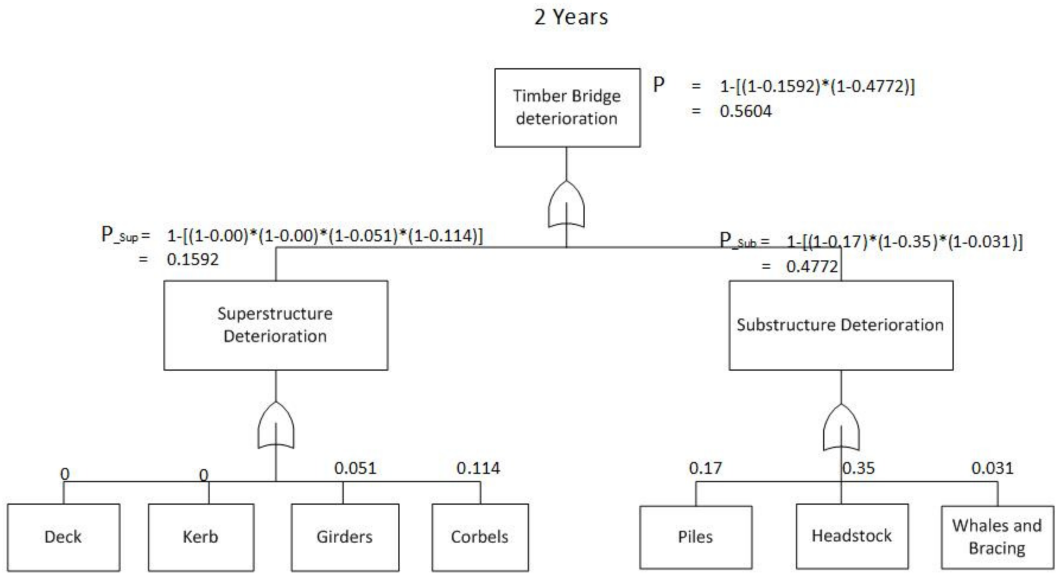
Appendix E 1 – FTA 2 Years 1-1



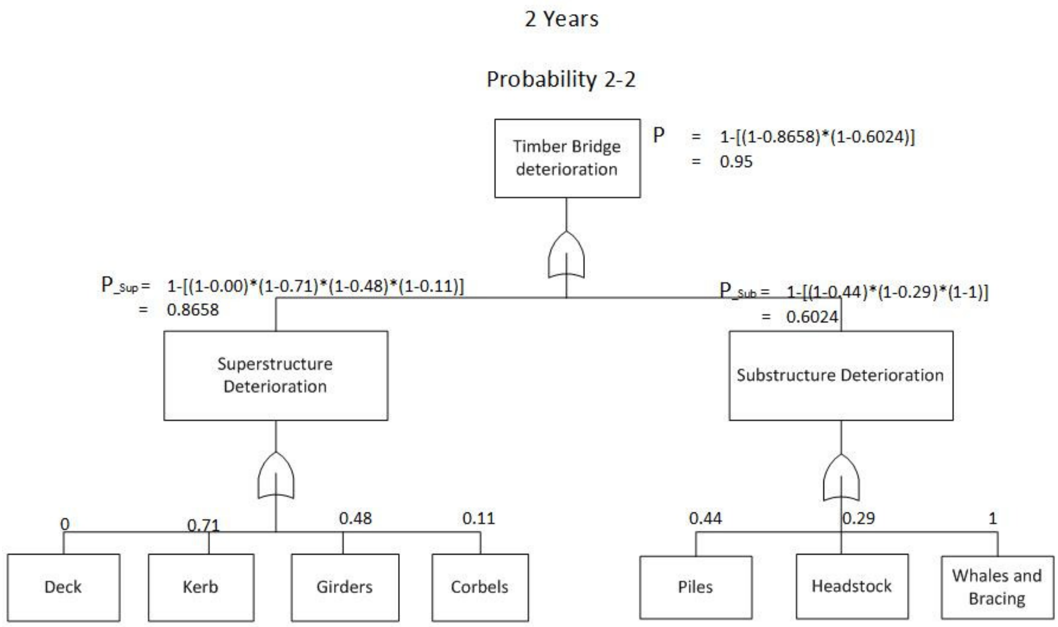
Appendix E 2 – FTA 2 Years 1-2



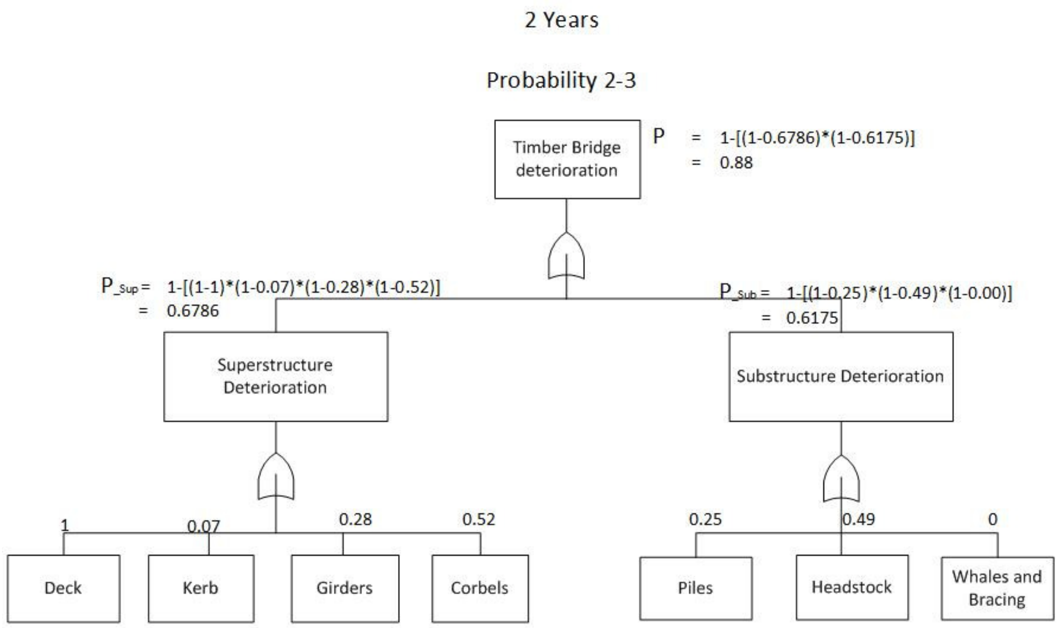
Appendix E 3 – FTA 2 Years 1-3



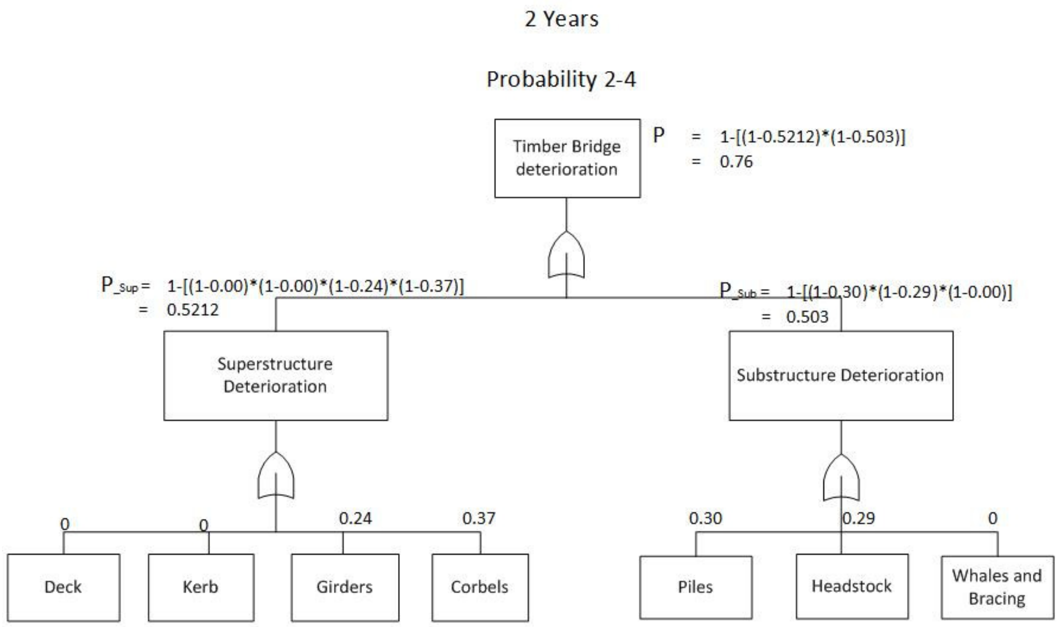
Appendix E 4 – FTA 2 Years 1-4



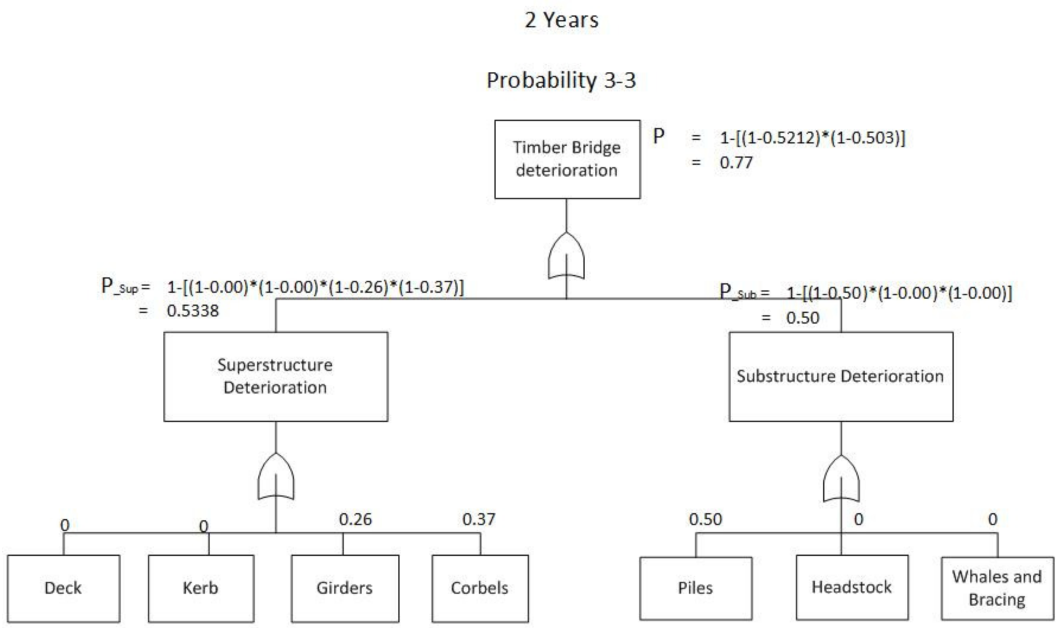
Appendix E 5 – FTA 2 Years 2-2



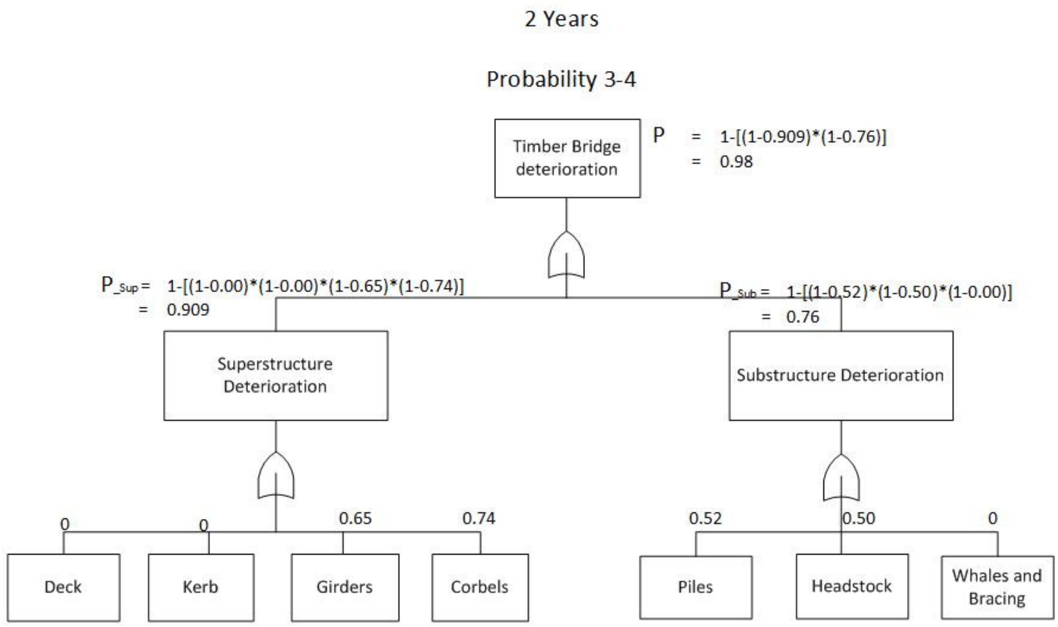
Appendix E 6 – FTA 2 Years 2-3



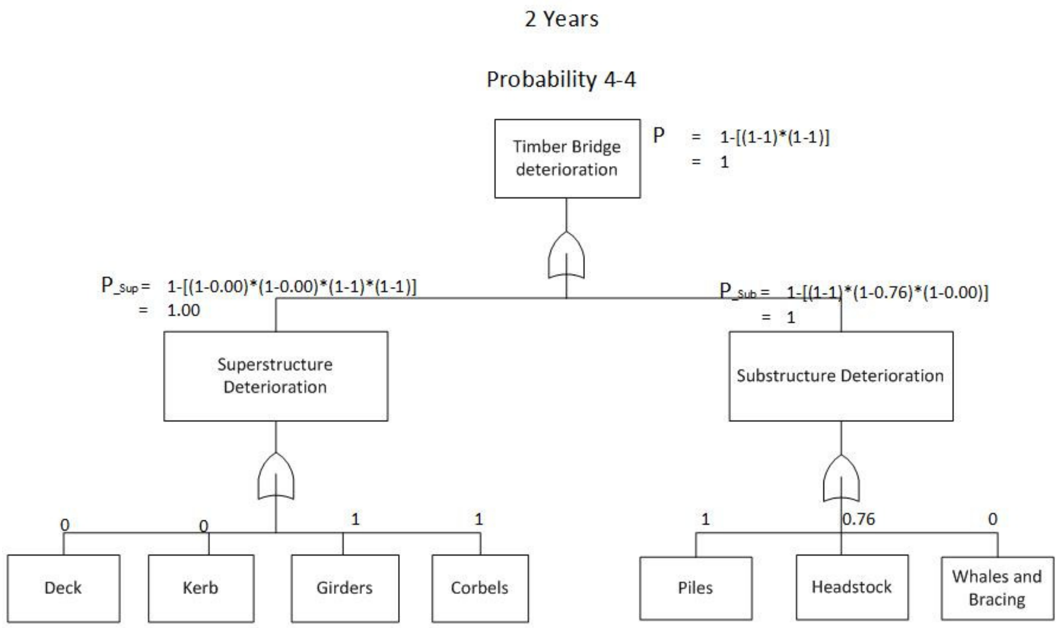
Appendix E 7 – FTA 2 Years 2-4



Appendix E 8 – FTA 2 Years 3-3



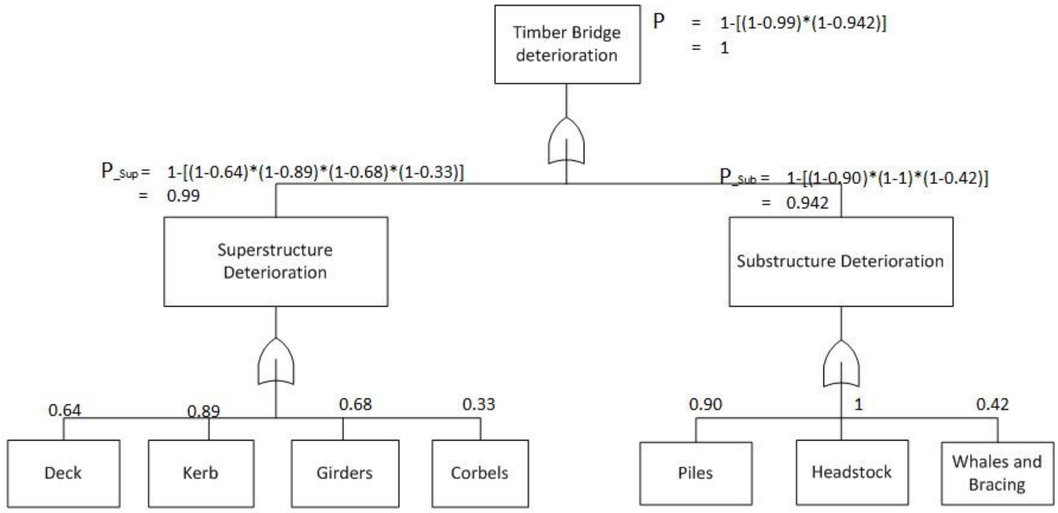
Appendix E 9 – FTA 2 Years 3-4



Appendix E 10 – FTA 2 Years 4-4

3 Years

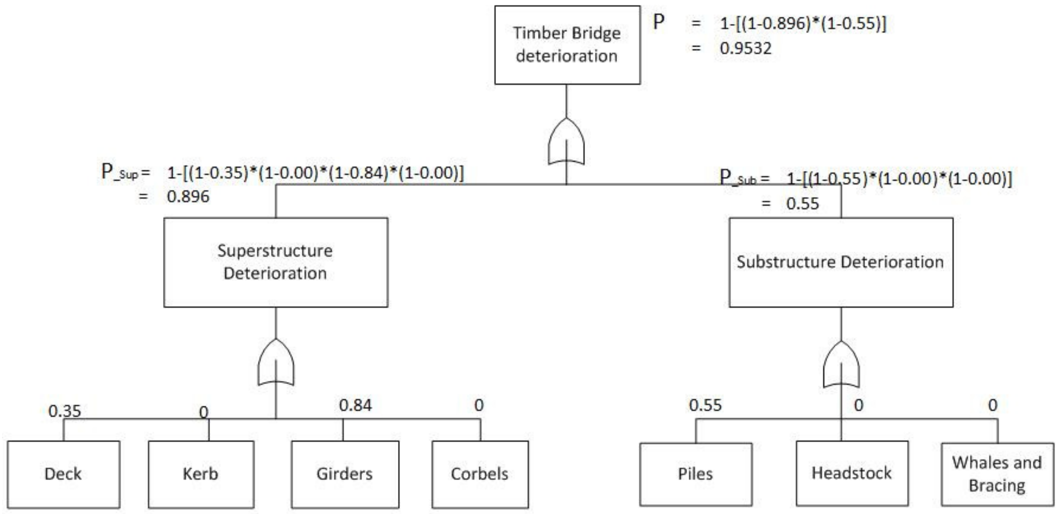
Probability 1-1



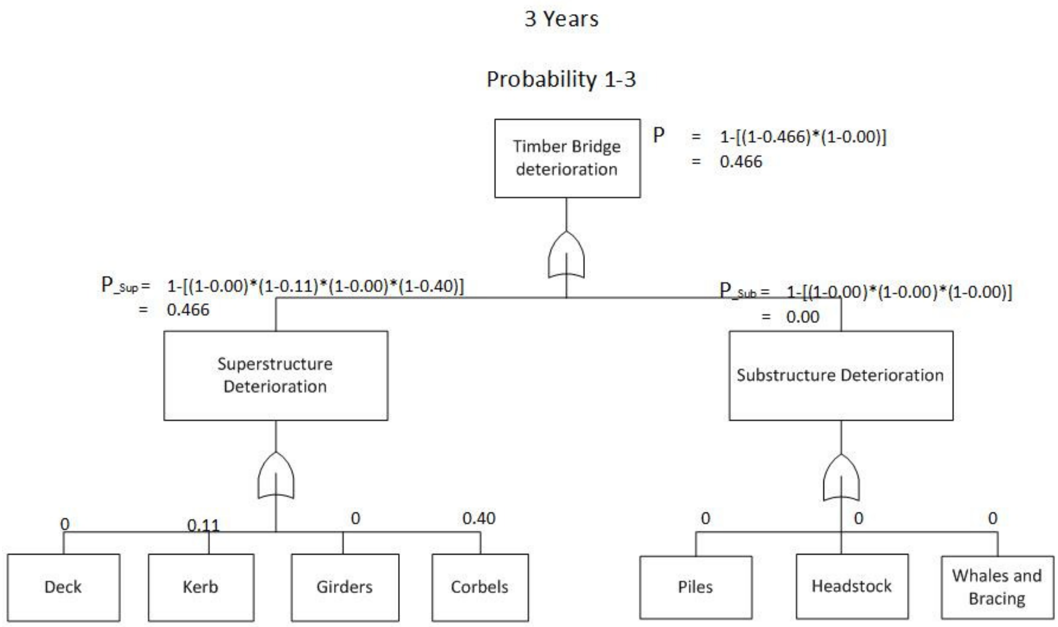
Appendix E 11 – FTA 3 Years 1-1

3 Years

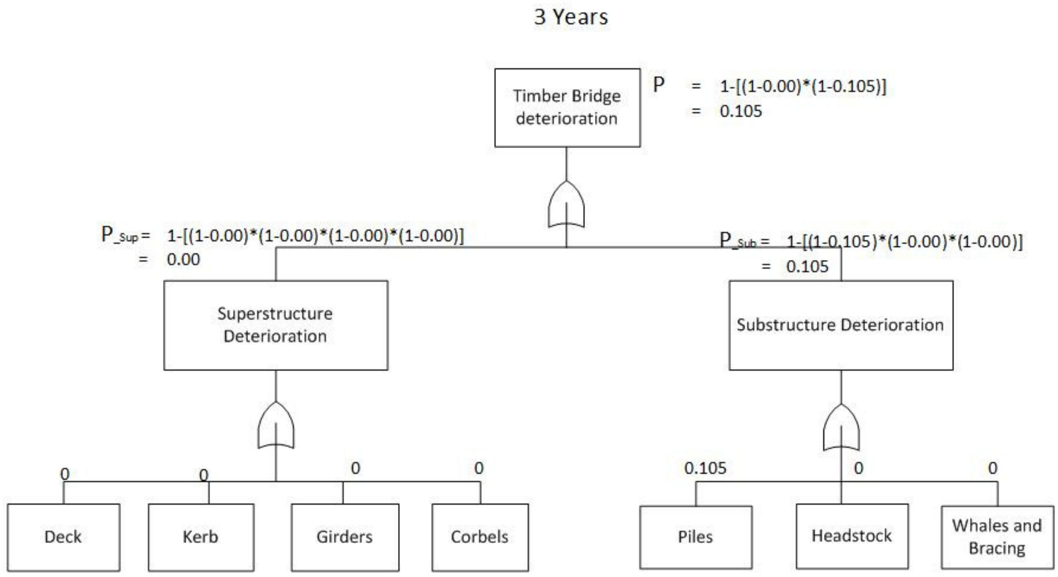
Probability 1-2



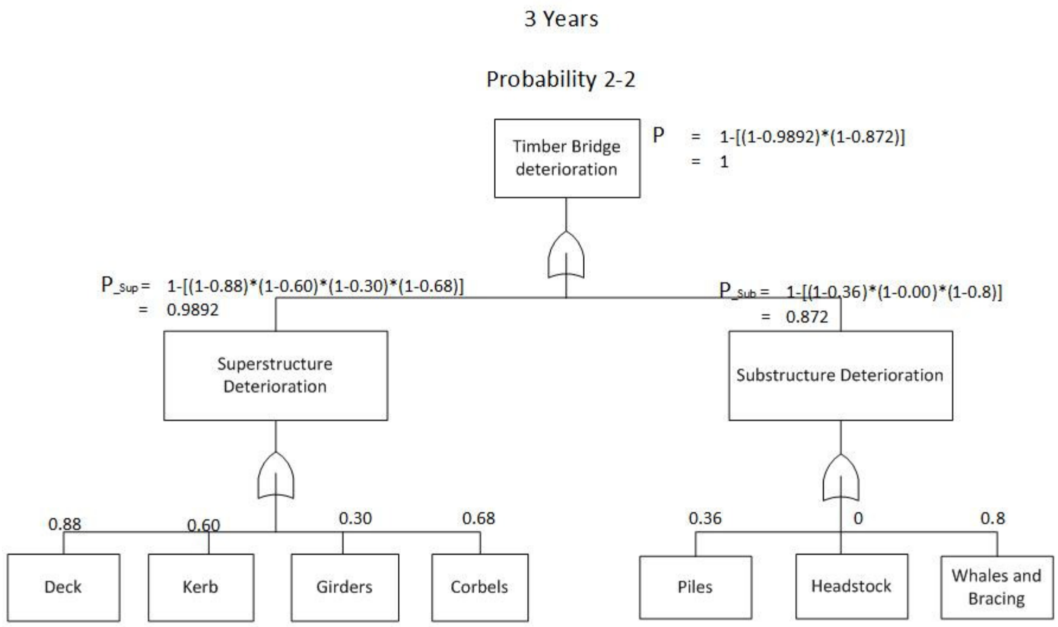
Appendix E 12 – FTA 3 Years 1-2



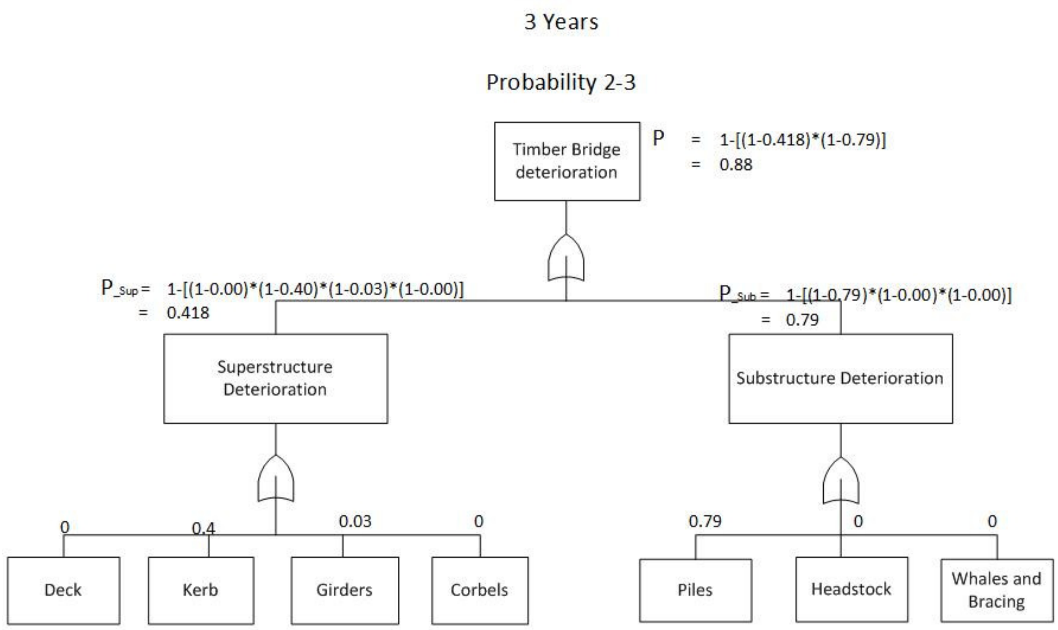
Appendix E 13 – FTA 3 Years 1-3



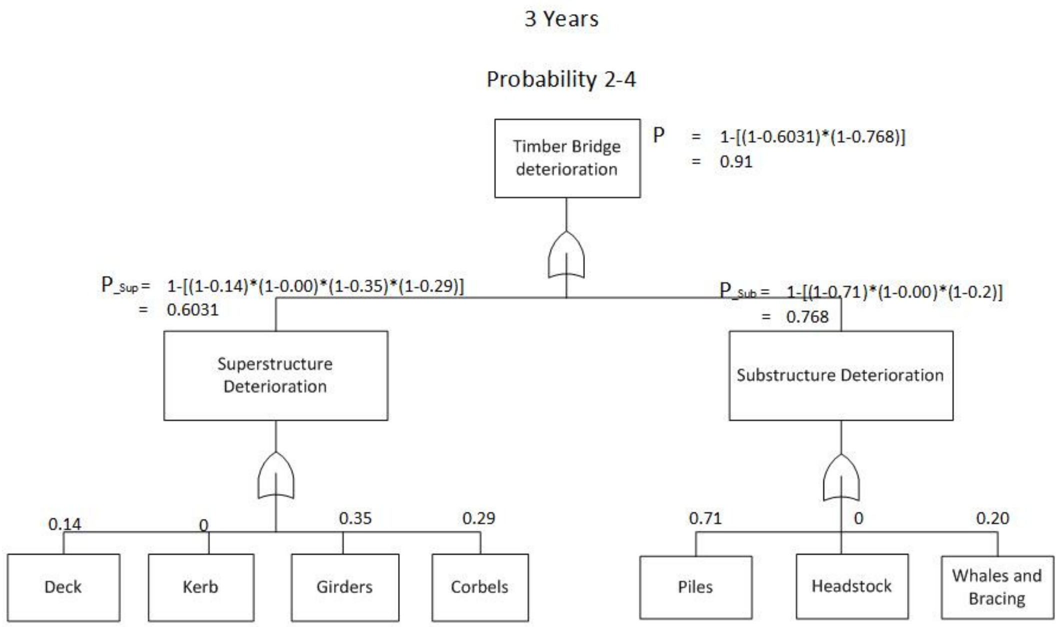
Appendix E 14 – FTA 3 Years 1-4



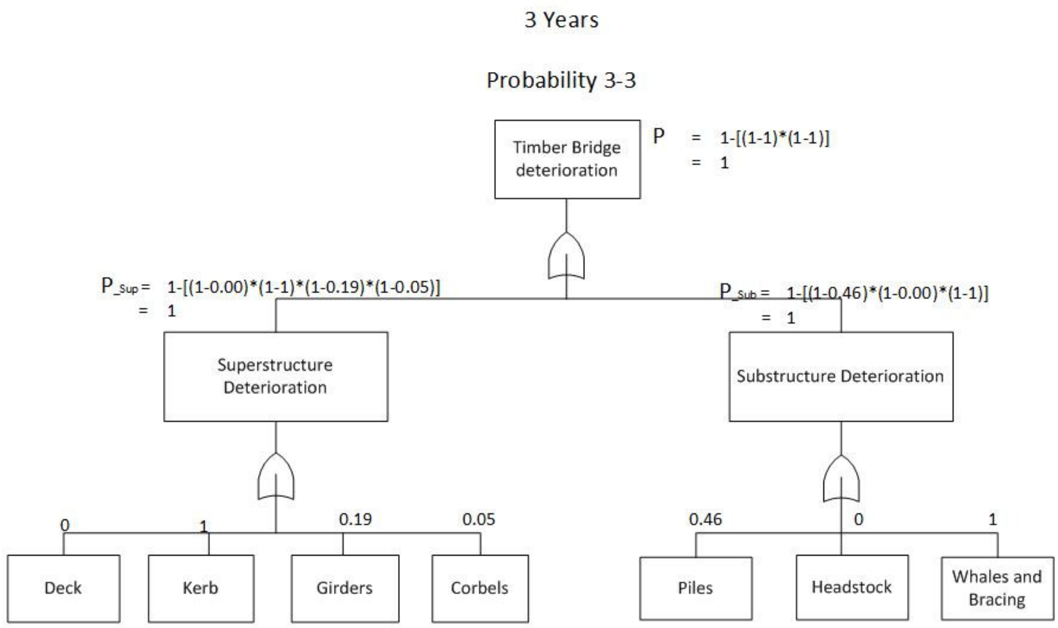
Appendix E 15 – FTA 3 Years 2-2



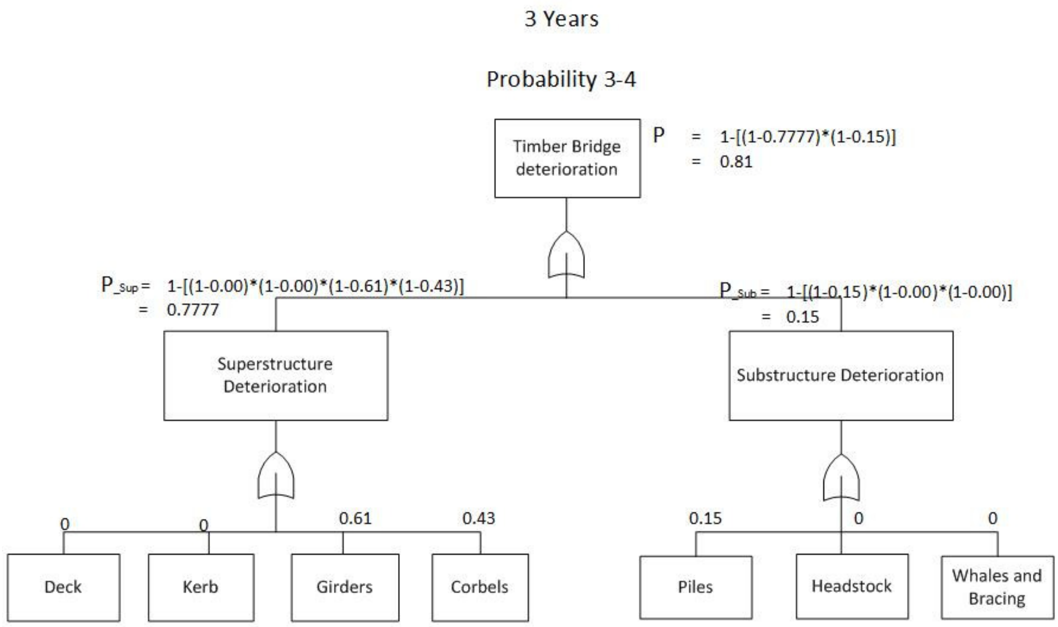
Appendix E 16 – FTA 3 Years 2-3



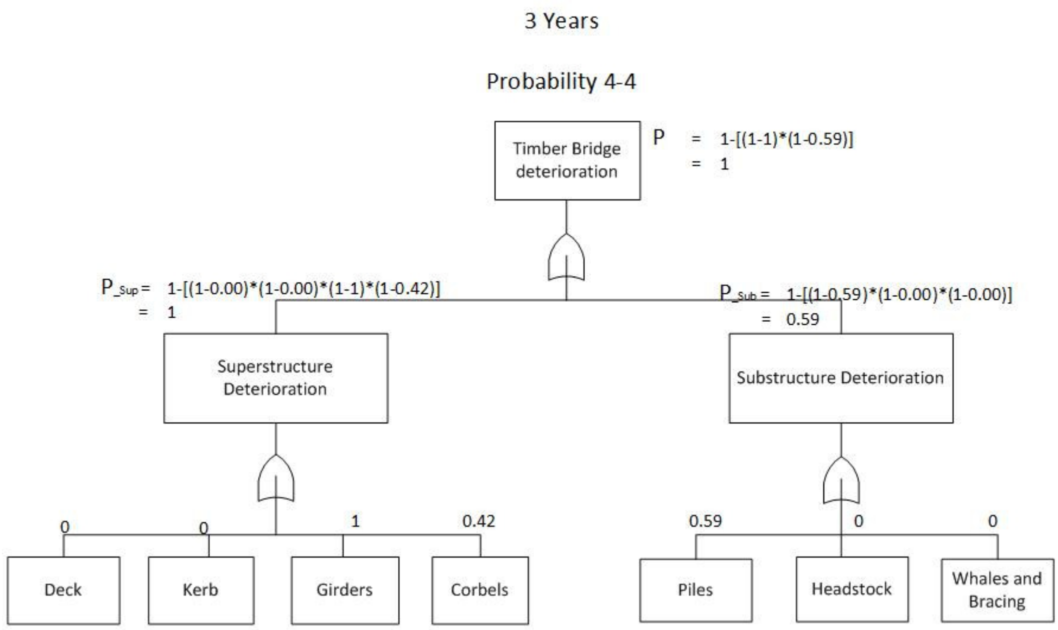
Appendix E 17 – FTA 3 Years 2-4



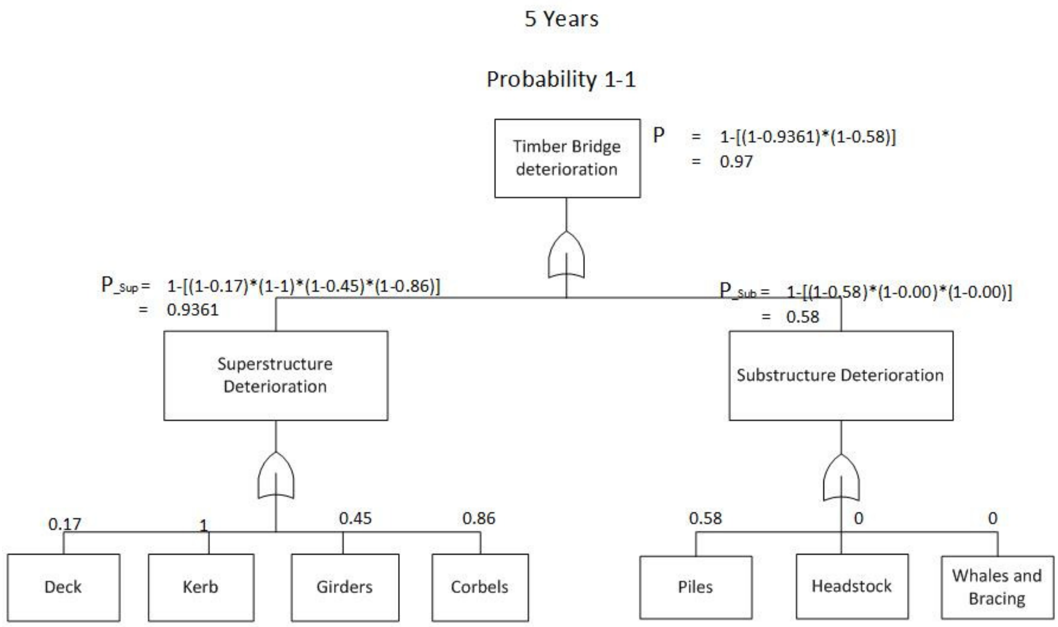
Appendix E 18 – FTA 3 Years 3-3



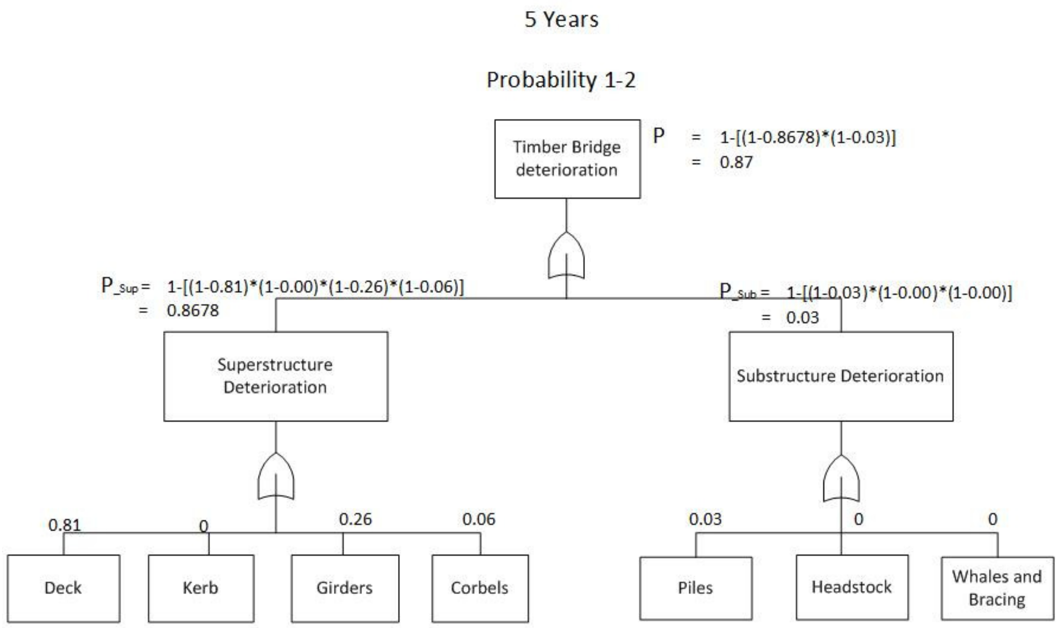
Appendix E 19 – FTA 3 Years 3-4



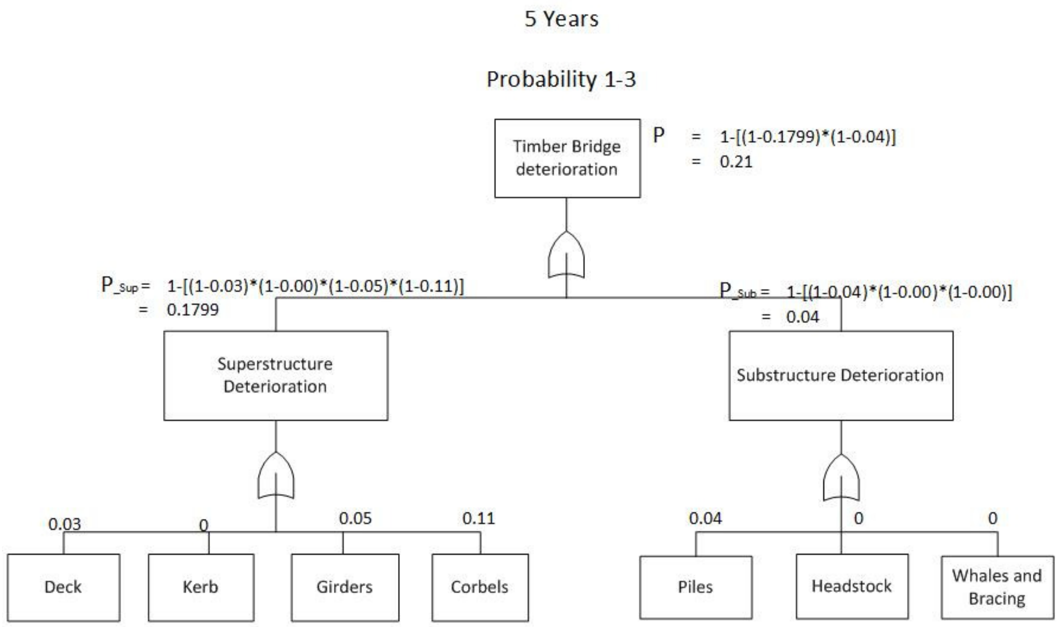
Appendix E 20 – FTA 3 Years 4-4



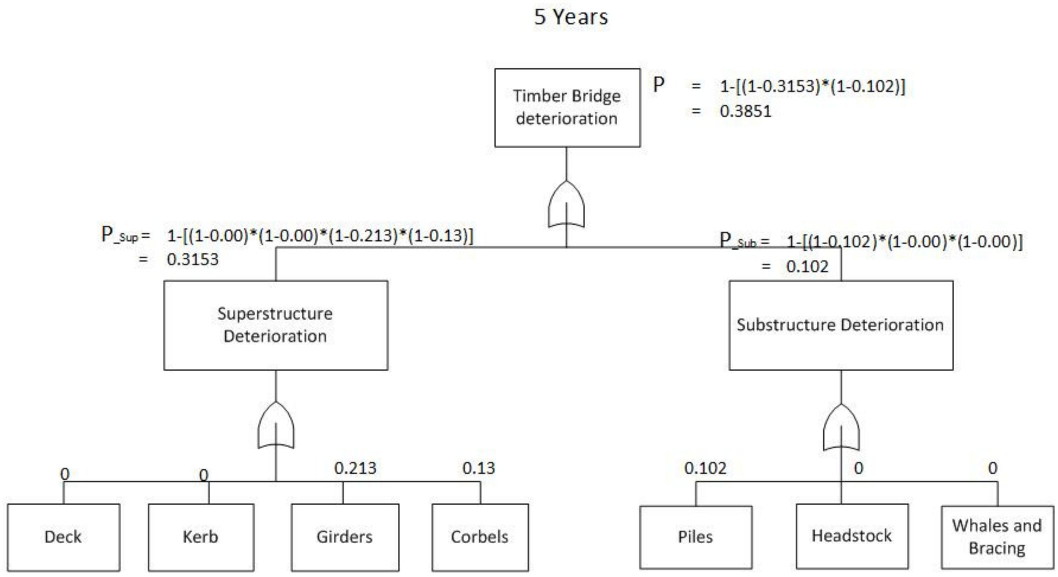
Appendix E 21 – FTA 5 Years 1-1



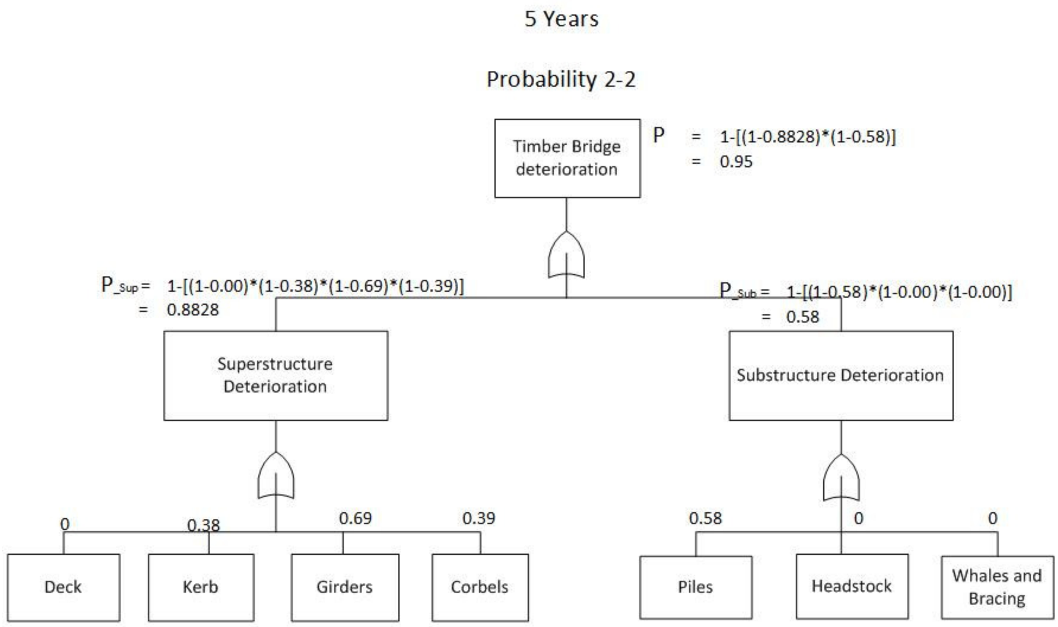
Appendix E 22 – FTA 5 Years 1-2



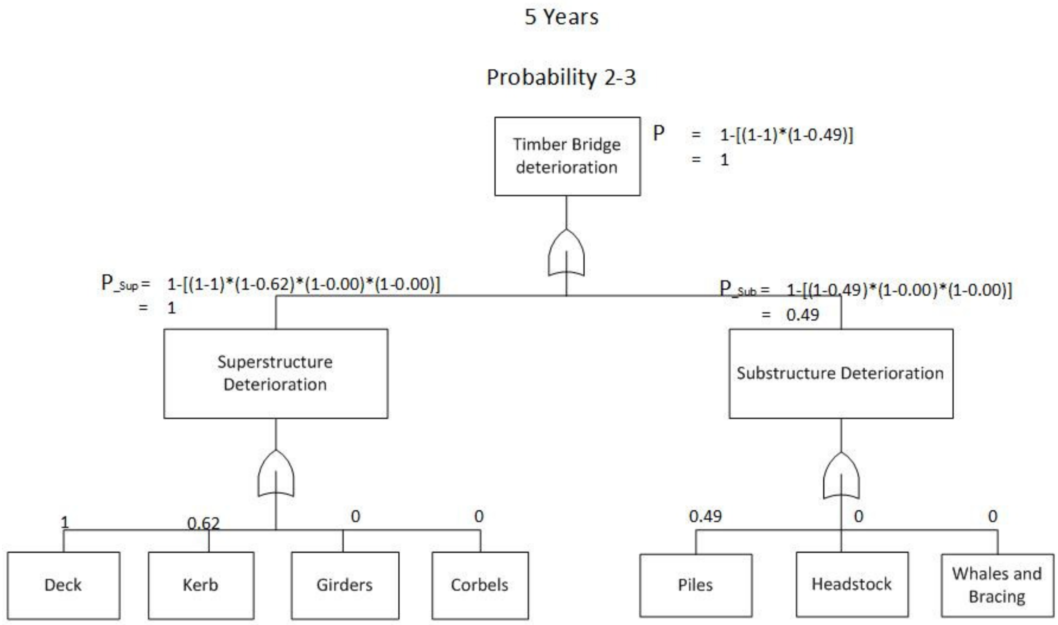
Appendix E 23 – FTA 5 Years 1-3



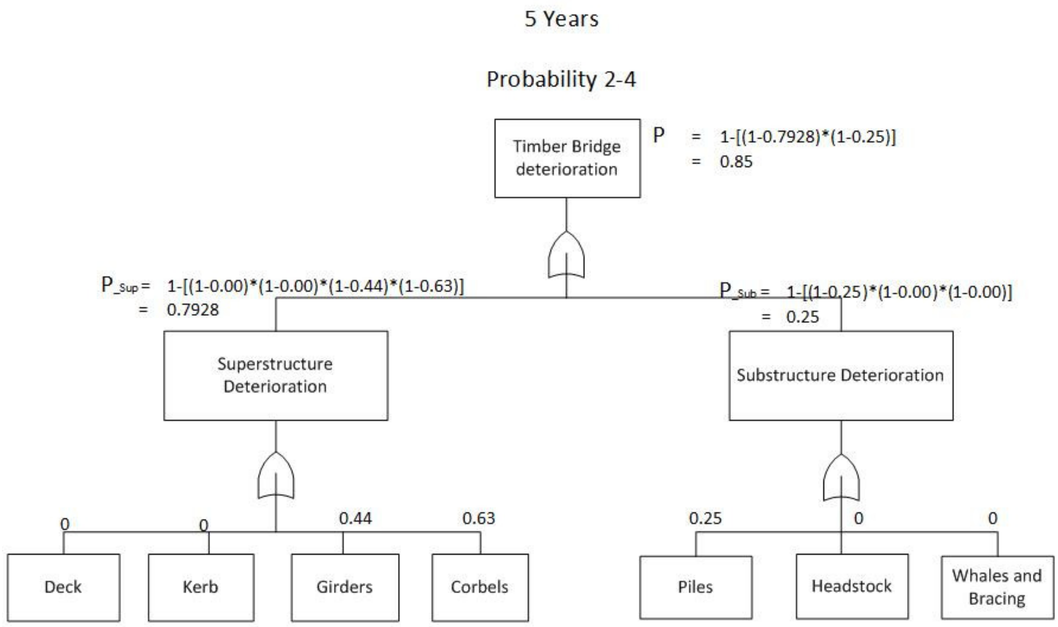
Appendix E 24 – FTA 5 Years 1-4



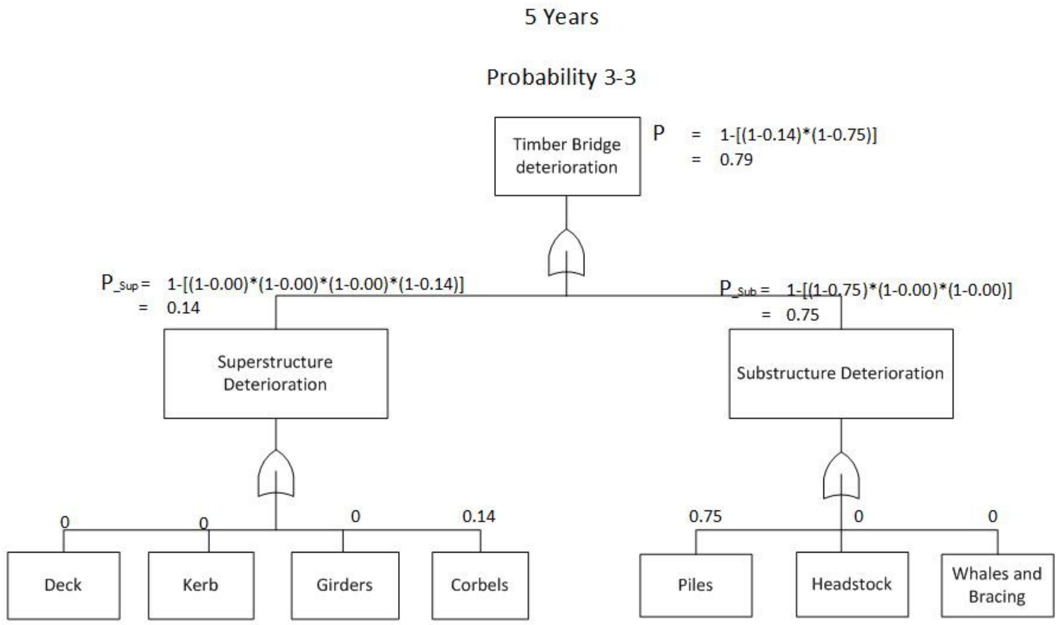
Appendix E 25 – FTA 5 Years 2-2



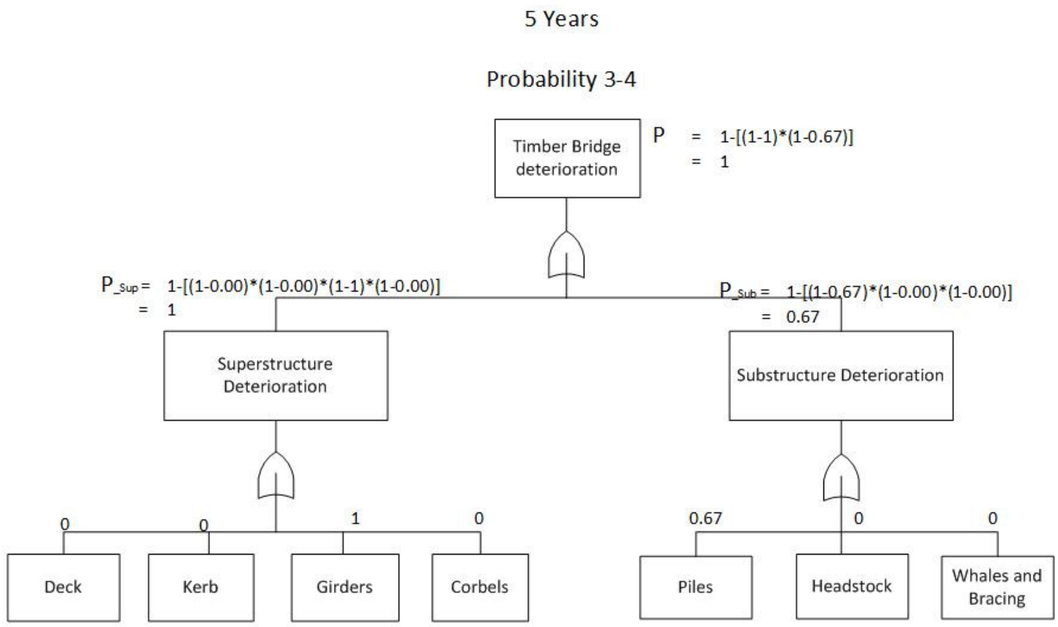
Appendix E 26 – FTA 5 Years 2-3



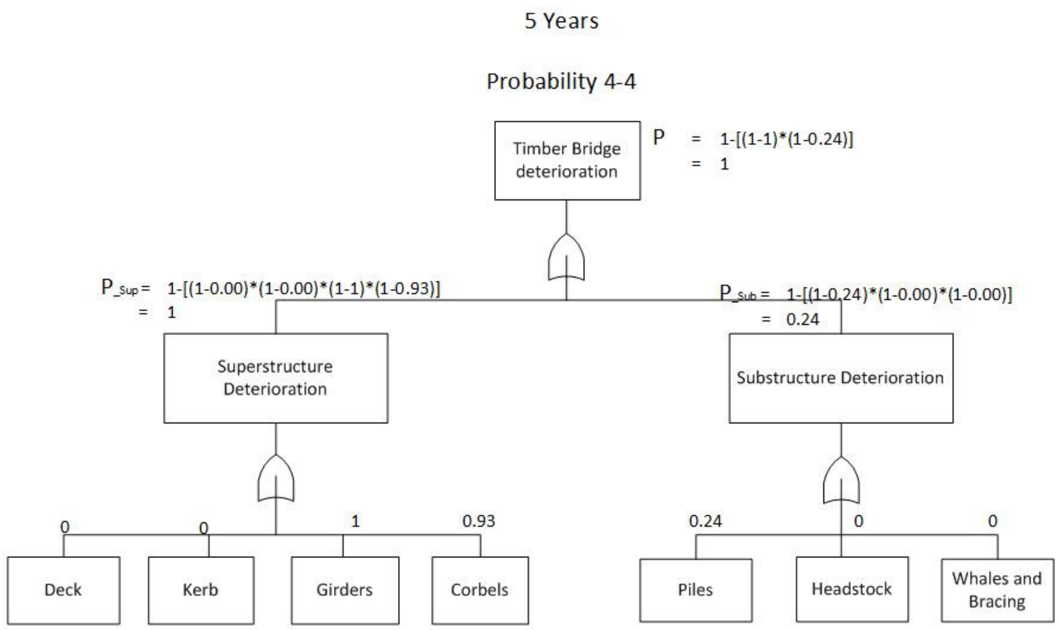
Appendix E 27 – FTA 5 Years 2-4



Appendix E 28 – FTA 5 Years 3-3



Appendix E 29 – FTA 5 Years 3-4



Appendix E 30 – FTA 5 Years 4-4