

Assessing VoLL
for
High Impact Low
Probability Events

Report prepared for
Transpower Ltd

February 2009

Prepared by: G.H. Thorpe & L.J. Hoch

Oakley Greenwood Pty Ltd

ABN 37 133 921 212

GPO Box 4345 Melbourne Vic 3001, Australia

www.oakleygreenwood.com.au

February 2009

DISCLAIMER

Oakley Greenwood and its authors make no representation or warranty as to the accuracy or completeness of the material contained in this document and shall have, and accept, no liability for any statements, opinions, information or matters (expressed or implied) arising out of, contained in or derived from this document or any omissions from this document, or any other written or oral communication transmitted or made available to any other party in relation to the subject matter of this document.

February 2009

TABLE OF CONTENTS

1.	EXECUTIVE SUMMARY	1
1.1.	BACKGROUND	1
1.2.	VALUING INTERRUPTIONS: TANGIBLE AND INTANGIBLE ISSUES	1
1.3.	SETTING UPPER AND LOWER BOUNDS ON VALUE FOR HIGH IMPACT EVENTS	2
1.4.	SETTING VoLL FOR WIDE SCALE, HIGH IMPACT EVENTS WITHIN UPPER AND LOWER BOUNDS	3
2.	INTRODUCTION.....	4
3.	QUANTIFYING VoLL	4
3.1.	MODELLING BASED APPROACHES	5
3.2.	SURVEY-BASED APPROACHES	6
3.3.	EXAMPLES OF THE USE OF THE VARIOUS TECHNIQUES.....	8
3.4.	CHALLENGES FACING ALL SURVEY APPROACHES.....	9
4.	HIGH IMPACT EVENTS AND SOCIAL DISRUPTION	10
4.1.	THE IMPACT OF SCALE	10
4.2.	ESTIMATION OF SOCIAL DISRUPTION COSTS BY VENCORP	11
5.	FRAMEWORK FOR EVALUATING WIDE AREA COST EFFECTS ON WILLINGNESS TO PAY	12
6.	CONCLUSION	15
	APPENDIX A SURVEY METHODS.....	17
A.1	DIRECT COST METHODS.....	17
A.2	INDIRECT METHODS	18
A.2.1	Contingent valuation (open-ended version).....	18
A.2.2	Contingent valuation (referendum version)	19
A.3	CHOICE MODELLING.....	20
A.4	CONJOINT ANALYSIS.....	21
A.5	ECONOMIC PRINCIPLE OF SUBSTITUTION.....	23

1. EXECUTIVE SUMMARY

1.1. BACKGROUND

Transpower is investigating the assessment of economic benefit of potential investments that reduce the level of unserved energy using the Henderson to Otahuhu (HEN-OTA) 220kV line as a case study for High Impact Low Probability (HILP) situations. This line forms part of the supply to Auckland combinations of outages affecting this line can lead to widespread interruptions in parts of Auckland and surrounding areas. This paper reports on issues in evaluating the economic value that should be assigned to changes in unserved energy that can be achieved by additional investment. A separate report is examining the probability of failure of this line.

The Electricity Commission (Commission) has previously sought to establish a sound economic base for approving network investment. It has indicated a preference for evaluations of regulated network investments to be based on probabilistic, cost-benefit techniques. However, the Commission also has included provision for a deterministic safety net for core elements of the main grid, but indicated an intention to review this arrangement.

1.2. VALUING INTERRUPTIONS: TANGIBLE AND INTANGIBLE ISSUES

The basic premise of a cost benefit analysis is that if benefits are greater than costs then a rational person would be willing to proceed with the investment - assuming the particular investment offered the highest benefit.

The cost side of such an analysis is relatively straight forward and based on estimates of cost to build a new network asset or to arrange for generation or demand side alternatives. Benefit is far more complex. Assessment of benefit requires an understanding of the probability of an event that will result in interruption of supply, an understanding of the characteristics of the interrupted customer load - such as the type of customer, amount and duration, and the value that should be ascribed to interruption, or rather to reducing or avoiding it.

A number of approaches are used to assess the value of reducing the level of interruption and each has limitations. Surveys that assess the effects on individuals and modelling approaches rely on data about industry sectors and regions. Neither is well equipped to assess intangible values that are sometimes called social disruption costs related to inconvenience nor do they readily identify costs that are more likely in wide scale events that are inevitably high impact.

There are costs in a wide scale interruption due to the aggregation of effects on individuals that exceed the sum of the individual impacts, for example disruption to commerce across a wide area, traffic management, health services and the higher level of inconvenience that raises willingness to pay. Wide-scale interruptions are also more likely when other forms of disruption are occurring and this also raises likely costs. For example a widespread interruption due to major storm activity that requires the community and emergency services to deal with the consequences of both events. The quantitative approaches also do not assess willingness to pay for additional network based on attitudes about relative levels of interruption with equivalent communities and this is especially so in the case of wide scale events.

1.3. SETTING UPPER AND LOWER BOUNDS ON VALUE FOR HIGH IMPACT EVENTS

We submit that::

- Because the mix of customer types, economic activities and probability of events that may result in an interruption (of any scale) are different in each situation, it is important to ensure that valuations are fit for purpose;
- Surveys of individuals and macro modelling are most useful as measures of the minimum direct economic impact and willingness of individuals to mitigate small scale effects and are thus a lower bound on VoLL for wide area, high impact events;
- Wide area, high impact events, especially where impacts compound, will inevitably result in additional costs arising from the aggregation of effects on individuals and business sectors that are not readily assessed by quantitative survey and modelling – for example customer attitudes about how much inconvenience is too much;
- A reasonable upper level of willingness to mitigate the effects of very high impact events may be formed by benchmarking against the reliability available to equivalent communities. This is similar to the situation in many other industry sectors including health and education and is consistent with principles of *regret*. It also highlights the complexity of assessing HILP VoLL.

This current work is using the supply to Auckland as a case study and therefore we would expect any benchmarking activity to compare Auckland to international cities: many of these use deterministic “n-1” and “n-2” performance standards. In saying this we recognise the Commission has previously noted justified concern that simplistic application of such standards may lead to unwarranted outcomes, and we would concur.

However, we do consider that more sophisticated benchmarking against both performance and cost is justified as the measure of an upper bound on value in the relatively few cases of very wide scale, high impact situations that may occur. Cost benchmarks would involve comparison of the actual and proposed costs to meet different levels of benchmarked performance elsewhere.

1.4. SETTING VoLL FOR WIDE SCALE, HIGH IMPACT EVENTS WITHIN UPPER AND LOWER BOUNDS

Central authorities are best placed to make the final judgement about VoLL for HILP events in the knowledge of potential upper and lower bounds. They will have knowledge of overall resource objectives and constraints across the broader economy and are ultimately responsible for major policy trade-offs in a number of sectors. Our expectation is that this is a trade-off that needs to be made for only a few genuinely high impact situations. Clearly, the smaller the difference between the upper and lower bounds the higher the confidence there can be in the ultimate choice that is made.

In the time available to us for this work we have not undertaken quantitative analysis of direct or indirect costs that may arise from the Henderson to Otahuhu (HEN-OTA) 220kV line. However, assessments of value for Victoria, Australia using a survey approach in 2007 resulted in an overall value of A\$47,850/MWh for direct costs - a significant increase from under A\$30,000/MWh from a similar survey in 2002. The 2007 study also developed a minimum value for social disruption but only considered direct service provider costs and thus was conservative. Equivalent values for Auckland would require detailed assessment of the customer base in Auckland. We are also aware of a modelling based assessment undertaken for Auckland in 2002 that indicated an overall value in a range under NZ\$10,000/MWh: clearly much lower than was obtained from fairly exhaustive study of only the measurable survey costs for Victoria. At the very least the differences between these results should be examined.

The differences between similar approaches for different times and for different techniques evident in these other studies serves to highlight the inherent difficulty in quantifying value for wide scale, multi sector, non linear HILP events. Our view is that an understanding of upper and lower bounds formed from a combination direct and indirect means to assess value of network investment to electricity consumers can form the basis for the unavoidable policy decisions in respect of the relatively few HILP situations that are likely.

2. INTRODUCTION

Transpower is investigating the assessment of economic benefit of potential investments that reduce the level of unserved energy using the Henderson to Otahuhu (HEN-OTA) 220kV as a case study. This line forms part of the supply to Auckland. This paper reports on issues in evaluating the economic value that should be assigned to changes in unserved energy. A separate report is examining the probability of failure of this line.

Under the Grid Code all economic benefits are currently based on a default value of \$20,000/MWh unless specific evidence of a different value can be developed in particular circumstances.

The Commission has previously sought to establish a sound economic base for approving network investment. Although the Commission has indicated a preference for evaluations of regulated network investments to be based on probabilistic economic techniques, the Commission has included the concept of core and non core network with different evaluation criteria in the current Grid Code. Investment in core grid assets is evaluated against a safety net based on a traditional industry “n-1 criterion”. Investment in assets that deliver greater than “n-1” reliability can be approved on the basis of a probabilistic assessment. All non core asset parts of the grid are subject to probabilistic economic assessment.

Probabilistic assessments compare the probability weighted economic benefit of reducing energy not served (Expected Unserved Energy) and the cost of the potential investment, and if the benefits outweigh the costs then the investment is able to proceed. We have been asked to advise Transpower about techniques to quantify the value that should be ascribed to unserved energy, commonly termed the Value of Lost Load (VoLL), especially where alternative investments deliver different forms of benefit, for example different level of diversity.

3. QUANTIFYING VOLL¹

The role of VoLL in this context is to express the willingness to pay for an additional investment that will reduce the level of expected unserved energy. There are a number of approaches including evaluations of economic value lost from an interruption through to questions to individuals that directly survey how much each consider they would pay for this purpose.

All are attempting to find the economic utility of reduced levels of unserved energy. This section reviews the different techniques and their advantages and disadvantages.

¹ Parts of this section of the report is adapted from a report by Charles River Associates entitled *Value of Customer Reliability Discussion Paper*, which was prepared for the South Australia Electricity Supply Industry Planning Council in October 2004. The authors of this paper were two of the three authors of that earlier work.

In general value is multi dimensional. There are many examples of work done to assess household and individual business and service provider costs and these show variations by:

- Type/location
- Time: Time of day/year, duration and frequency of interruption

A range of methodologies exists for quantifying the value customers ascribe to reliability. Table 1 shows this range in terms of the two basic approaches: survey-based and modelling-based methods. The table also shows examples of the specific assessment methods associated with each approach, and the specific customer sectors to which each approach is generally applied.

Table 1: Typology of approaches and methods for estimating outage costs

Approach	Methods	Customer Sectors
Modelling-based	Income proxy	Residential
	Case studies of blackouts	All
	Backup generator proxy	Commercial and industrial
	GDP per kWh proxy	Commercial and industrial
Survey-based	Direct cost	Commercial and industrial
	Contingent valuation (WTP/WTA)	Residential
	Choice modelling	Residential
	Conjoint analysis	Residential
	Economic principle of substitution	Residential

Each of the methods outlined in Table 1 is discussed in further detail in the following sections.

3.1. MODELLING BASED APPROACHES

Modelling or analytical-based approaches use readily available secondary data sourced from existing research, rather than directly from customers through surveys to develop outage cost estimates. A model is typically developed to fit the available data sets, which are sourced from third parties. Examples of analytical-based approaches include:

- Income proxy – Outage cost estimates are developed based on the assumption that the inconvenience and lost time experienced by residential consumers during an outage can be valued in terms of the income that would have been earned in an equivalent amount of time.

- Case studies of blackouts – Case studies that have measured the economic costs of actual blackouts in terms of their duration, number of customers affected and direct costs incurred by those affected, are reviewed and used to provide indicative costs for other situations. A limitation with this method is that detailed case study information is likely to be available for only a limited number of outages, and information from any particular case study may not be easily transferable to a different outage in another region or country.
- Standby generator proxy – In this method commercial and industrial customers are assumed to purchase standby generators. However the method is heavily dependent on accurate information on generator costs, operating hours, fuel costs, etc.
- GDP or GSP per kWh proxy – The value of the energy not consumed by commercial and industrial customers is valued at the local ratio of GDP (or GSP) per kWh that characterises the local economy.

Modelling-based approaches, however, suffer from a number of limitations. Firstly, they cannot provide 'fine grained' results in terms of addressing, for example, time-of-day and seasonal differences in outage costs. Secondly, these methods do not reflect actual customer valuations. Finally, numerous assumptions need to be made in the development of the model algorithms, and in filling any data gaps. The consequence of these limitations is that analytical models are only able to provide general insights and broad indicators of outage costs. They generally do not provide sufficient detail and insight into customer preferences and value to provide guidance for transmission investment decision-making.

3.2. SURVEY-BASED APPROACHES

Survey-based methods can be classified into two broad groupings – direct cost and indirect cost methods. Direct costs methods seek to determine the actual costs a customer would incur as a result of an outage. Where intangible costs that are difficult or impossible to quantify are present, one of a number of indirect cost survey approaches can be used as an alternative. Contingent valuation, contingent ranking, choice modelling and the principle of economic substitution are examples of indirect methods that can be used to estimate outage costs.

The selection of approach needs to be made in recognition of the fact that it is more difficult for some customers to identify and quantify the real costs of an outage. For a business, the approach is relatively straightforward. The cost of an outage can be estimated by the sum of all the costs that business would incur due to the occurrence of that outage. Such costs would be likely to include (but would not necessarily be limited to):

- lost revenue;
- payments to staff for non-productive time;

- maintenance, shut down and start up costs, including any costs incurred for clean-up and/or reset of equipment shut down at short notice;
- spoiled inputs or products; and
- any costs incurred to mitigate the impact of outage on operations, such as the purchase and operating costs of a UPS or standby generator).

For residential customers, it may be more difficult to identify and quantify the costs of an outage. Households do not lose revenue from an outage, and many may not have undertaken specific investments to mitigate the impact of outages. Some actions that the householder might have already undertaken in response to previous outages or would be likely to undertake in the event of an outage can be checked relatively easily, such as:

- the cost of buying dinner out during an outage;
- the cost of candles or a lantern for lighting; and
- the cost of wood for heating.

However, there are a number of other costs – many of them intangible – that are significantly harder to quantify for households that experience outages, such as:

- the ‘cost’ or inconvenience of rearranging plans;
- the ‘cost’ of having to have cold showers or a cold (or hot) house (depending on the season in which the outage occurs); and
- the ‘cost’ of not having access to household entertainment amenities such as television, stereos, and/or desktop computer.

As is illustrated by the simple cases above, different methods may be needed to survey different customer groups in an efficient and accurate manner. Further details on the available direct and indirect costs methods are provided in Appendix A.

3.3. EXAMPLES OF THE USE OF THE VARIOUS TECHNIQUES

CRA's 2004 review of approaches to the value of customer reliability identified the following examples of studies that had been undertaken:

Table 2: Approaches taken in a sample of other VCR studies

Organisation	Date	Approach / Comments
VENCorp	1997, 2002, 2007	Each of these studies used the same approach: <ul style="list-style-type: none"> Residential: economic principle of substitution All other segments: direct cost estimation
Powercor and KBA	1999	Study used choice-based modelling and adaptive conjoint analysis to measure customer willingness to pay for higher levels of service in electricity supply in 1999.
NSW Treasury	2002	Study utilising choice modelling was commissioned - results were never published
SA Independent Industry Regulator	2002	Study using similar methodology commissioned in NSW was undertaken, but results were never published
ActewAGL	2002	Study used a combination of focus groups, face-to-face questioning, computer-aided telephone interviews and stated preference choice modelling. No further public information is available.
Power System Research Group Canada	Unknown	A series of studies using contingent valuation, direct costing and indirect costing to ascertain the value of reliability of electricity supply.
Lawrence Berkley National Laboratories	Unknown	Combined data from 8 available outage studies to form a 'mega-dataset' on VCR. All 8 VCR studies were based on surveys using the following approaches <ul style="list-style-type: none"> Residential: economic principle of substitution All other segments: direct cost estimation

Source: CRA, *Value of Customer Reliability Discussion Paper*, October 2004

The results from the VENCorp 2007 study are discussed below for the sole purpose only of providing an example of the type and level of results provided by these approaches.

All three rounds of the VENCorp studies were conducted using the same approach, though alterations were made to the specific survey questions used across the three studies. Some key findings included:

- VCR values by customer sector did not change much between 1997 and 2002, but were seen to increase markedly between 2002 and 2007;
- On an un-weighted basis, the value of unserved energy is highest in the agricultural and commercial sectors, and lowest in the residential sector;
- The state-wide value of customer reliability was calculated as \$47.85/kWh on a sector- and interruption probability-weighted basis.

As noted, this value is based on the average value of reliability calculated from the sample of customers surveyed in each sector, the proportion of each customer segment's electricity consumption as a proportion of total Victoria electricity consumption, and the probability of outages of different durations as determined from statistics for the previous three years. This makes the calculated value a unique outcome of the population and recent outage history in Victoria, and as such is not readily transferable to other areas.

What may be more useful for consideration in the present instance are the un-weighted sectoral reliability values calculated for each customer segment in the 2007 VENCORP study, which are shown in Table 3 below.

Table 3: Unweighted sector values of customer reliability (\$/kWh of unserved energy)

Interruption duration	Residential	Agricultural	Commercial	Industrial
20 minutes	Not assessed	\$87.07	\$213.76	\$86.47
1 hour	\$24.48	\$47.10	\$130.92	\$40.41
2 hours	Not assessed	\$203.98	\$46.98	\$28.95
4 hours	\$12.38	\$128.59	\$44.51	\$25.01
8 hours	\$8.69	\$120.78	\$42.87	\$28.45
24 hours	\$4.84	\$78.95	\$22.46	\$29.30

Source: CRA, *Assessment of the Value of Customer Reliability (VCR)*, prepared for VENCORP, August 2008.

These figures simply show the costs that various types of electricity users in Victoria individually said they would incur during electricity outages of different durations. Although the values for New Zealand customers would almost certainly be different, these figures could be used to provide a very crude estimate of the equivalent responses about the electricity supply interruptions in New Zealand.

3.4. CHALLENGES FACING ALL SURVEY APPROACHES

This section briefly notes the particular challenges in undertaking surveys of the value of unserved energy including:

- there needs to be statistically robust coverage of all segments for which the value of reliability or its distribution over relevant parameters is likely to materially differ and need to consider sample sizes, response rates and any self-selection bias;
- a variety of scenarios need to be tested to cover the multi dimensional nature of the value,
 - for example combinations of frequency, duration and geographic spread of the outages.

- surveys need to be designed knowing that the actions customers are likely to take to mitigate the problems may differ across different combinations of the relevant parameters;
- whether customers can provide meaningful answers about outage situations they haven't faced;
- whether answers will vary based on recent experience; and
- whether responses are biased by unresolved "outrage" (see below)

4. HIGH IMPACT EVENTS AND SOCIAL DISRUPTION

High impact events are distinguished by:

- Generally wide geographic affect (in special cases high impact could be associated interruption to a major high value load but it is assumed costs and benefits in these cases are more readily assessed and treated on a case by case basis); and
- Very low probability of occurrence and hence scant data available about social or community effects.

A wide geographic spread implies many individual loads, a range of types of load, involves infrastructure and limited opportunity for substitution. Accordingly the scale of effect becomes a relevant additional dimension.

4.1. THE IMPACT OF SCALE

Wide scale effect leads to potentially significant social/community disruption costs that occur because of the wide spread nature of the events. In economic terms a wide scale event is likely to lead to reduction in utility that is disproportionately greater than effects on only a single residence or business. As a result the aggregation of willingness to pay from effects on individuals does not account for the implied willingness to pay by the community at large for a wide scale event.

For example where a limited scale outage would allow a branch office to transfer activities to another office a city wide event will mean this is not possible. Transfer of business activity to another city may be limited by communications and availability of staff, and if the business is to serve local customer needs then the customers themselves may be unable to function and could not be served from another city in any event. On the other hand loss on one day may be made good later in some cases. Wide scale effects can also create costs within major utilities such as water and sewage providers, public transport, police (traffic management and looting). Case by case analysis is needed to quantify these effects and as noted earlier can often only deliver approximate results.

4.2. ESTIMATION OF SOCIAL DISRUPTION COSTS BY VENCORP

The 2007 VENCORP study sought to address social disruption costs. It did so by investigating the costs that would be incurred by community and social service agencies due to electricity outages of relatively longer durations and geographic spread. It therefore measured direct costs and did not examine attitudes that may affect willingness to pay and did not examine resource limitations or the effects of correlated events such as how the services would cope with major storms at the same time as major power interruption. The types of organisations included in the sample were:

- Emergency services – Ambulance services, Victoria Police, Fire services (MFB/CFA), Emergency Service Telecommunications Authority
- Health care – Public and private health care services including hospitals
- Transport / Air / Public / Roads / Communications -- Connex, VicRail, VLine, Yarra Trams, bus companies, Vic Roads, airlines
- Water and sewerage / waste disposal – Water authorities, Melbourne Water (sewerage), municipal authorities, waste companies.

The approach employed essentially constituted an assessment of the direct costs these organisations would incur in performing their activities during an extended and/or widespread outage. These included costs in areas such as:

- Costs resulting from changes to operating procedures and staffing levels during power outages, or from additional deployment of emergency infrastructure (eg fire trucks or ambulances);
- Increased costs of consumables such as fuel or wear and tear on vehicles;
- Limitations to staffing levels or deployment of emergency vehicles needed to manage emergency calls associated with widespread interruptions to Victoria's electricity supply; and
- Plans to invest in other technologies or to implement new business procedures to improve service provision during emergencies, and associated costs.

The study concluded that the costs incurred in these areas during outages ranging from 20 minutes to 24 hours was approximately \$1/kWh on a duration and probability weighted basis, which the study acknowledged is "relatively small compared to the VCR of \$47.85 per kWh". However, the study also stated that the costs identified in the study had to be thought of a lower bound to the social disruption costs, because:

- The bottom up methodology that was employed may have missed some cost impacts from service and infrastructure providers that were not interviewed or were interviewed but were unable to quantify the impacts of power outages.

- The approach does not take into account the potential unmet demand for services in the event of an outage that service providers may be unable to satisfy due to resource constraints. For example, during a significant wide area power outage, twenty additional ambulances may be required within a short space of time to meet demand, however ambulance services may only be able to deploy ten additional vehicles and crews, representing the limit of their available resources.
- Finally, and most importantly, the cost estimates developed in the study related only to the service providers and do not take into account economic flow on costs, non-quantifiable effects of outages on individuals and communities. Such impacts include but are not limited to:
 - disruptions to leisure and study time; social and sporting events; and the activities and programs of schools, universities, public administration, and government and non-government community services;
 - additional healthcare costs due to interruptions water and sewage services, and trauma related to injuries/mortalities; and
 - increased incidence of crimes, and related costs such as an increase in the demand for private security and protection services.

It was acknowledged that quantification of the full range of these costs would be both logistically and methodologically difficult. The amount should be considered as part of the lower bound of costs proposed in this report.

5. FRAMEWORK FOR EVALUATING WIDE AREA COST EFFECTS ON WILLINGNESS TO PAY

If the quantitative approaches provide a lower bound there is a question of what should the value be? Is there an upper bound? If wide area effects are not well accounted for in probabilistic assessments what approach can be used to robustly settle on a value? This section provides a framework to answer these questions. It also concludes that the final evaluation in respect of wide scale HILP events requires policy judgements alongside quantitative economic and engineering analysis.

Probabilistic techniques assume that a rational person will be willing to pay the demonstrable economic benefit that can be achieved from a network investment. This assumption implies that the economic costs of inconvenience and inefficiency should be included in the analysis. This is the case even though these intangible costs are more difficult and complex to assess compared to assessing costs associated with lost production, spoiled food, or the purchase and installation operation and maintenance of a standby generator. The inclusion of many intangible costs is certainly achievable in principle even though in practice it may be expensive, time consuming and complex - or all three.

At this point it is useful to consider that, although it is unlikely to have been intended, when applied to wide scale events deterministic standards implicitly account for broader social and community costs. But they do so in an approximate and sometimes inconsistent manner. For example the same deterministic standard applied in two locations may involve markedly different cost and therefore imply markedly different willingness to pay and economic cost. The concept of a distinction between core and non core grid elements in the current arrangements in NZ based on the amount of load at risk implies a very approximate recognition of wide area social/community costs not addressed by current probabilistic methodology.

In other locations there are more graded approaches, for example in South Australia there is a 6 tier deterministic standard ranging from “n-2” in the capital city to less than “n-1” in at the edges of the transmission network. A number of cities use a flat n-2 criterion, for example Sydney CBD, the main grid of Great Britain and in the US.²

Our intention here is not to argue for deterministic standards per se, but to highlight the concept of social/community value as different to direct and measurable cost and the inherent difficulty of quantifying it for wide area events. At this point we submit that it is fair to say that:

- Standard techniques for probabilistic assessments are likely to be better at developing floor or minimum valuations and do not readily assess wide area (high impact) effects; and
- Traditional industry practice has very approximately and often inconsistently recognised wide area effects using ad hoc deterministic engineering standards.

Empirical evidence from other areas suggests willingness to pay is more complicated than can be found from cost based economic analysis. This finding was the basis for the development of *regret theory*. In a regret situation the question is: *If a widespread interruption occurs will I/we regret not having spent more to avoid or reduce its effects?* The challenge for regulators and network businesses is to determine how this should affect decisions about new investment and how to determine the appropriate dollar value to be invested. The question is thus one of policy and how to quantify an attitude to an event that most respondents will not have experienced.

² International Review of Transmission Reliability Standards, KEMA 2008. Published by the Australian Energy Market Commission. See <http://www.aemc.gov.au/pdfs/reviews/Transmission%20Reliability%20Standards%20Review/consultancy/000KEMA%20Final%20Report%20-%20International%20Review%20of%20Transmission%20Reliability%20Standards%20-%20Parts%201%20to%203.pdf>

A regret framework can, however, assist in retrospectively explaining why, in principle, aspects of deterministic standards are intellectually supportable. Deterministic standards are readily understood and highly transportable and are relatively easy to use to benchmark investment in and performance of networks. As a result, networks that provide “n-1” or “n-2” levels of redundancy can easily be compared to each other. We submit that, all else being equal, the level of regret within the broad public and policy making community about the effects of a wide-scale interruption will be low if the local network can be shown to match the level of redundancy commonly provided in comparable cities. But to repeat an earlier point, a simplistic application of “n-1” or “n-2” can lead to clearly uneconomic and inconsistent outcomes and should not be supported. However, this leaves open the option of a more sophisticated benchmarking approach using both performance and cost as a part of the derivation of value.

It is notable that many industry sectors face similar issues. For example in health, how many hospital beds or pieces of diagnostic equipment should be provided? In education, how much money should be spent on school facilities or teacher training? In transport, how many safety devices should be mandated? And in national parks, how much land should be acquired? Regret and benchmarking are common issues in all of these areas. Further, standards and community choices change over time: for example, willingness to pay for facilities and equipment in residential buildings and in transport has increased significantly in the last 50 years. In economic terms the higher level of facilities increases utility and can be afforded as a result of changing economic efficiency, in lay terms it would be fair to say we do this because we can now, but couldn't before.

For the present purpose, however, we can refine our earlier summary and state:

- Standard techniques for probabilistic assessments provide floor or minimum valuations of the effect of interruptions; and
- Benchmarking of redundancy and associated implied cost against comparable networks elsewhere provides a reasonable upper limit on the likely willingness of the community to pay for network investments and may be particularly important for wide scale, HILP events.³

Having proposed a means to set upper and lower bounds on value, the obvious question is how to settle on a value within the range? This is a question that is difficult to answer in the abstract. There will be only a limited number of locations and situations in New Zealand where wide scale high impact effects will be an issue and until further analysis is completed the magnitude and materiality of the decision will be uncertain.

³ Where risk factors vary between networks it may be possible to apply techniques such as those used in Wood, M. Review of HILP Risks – Prepared for Transpower Ltd, February 2009, to ensure that the use of different networks still provides a relatively level playing field for the purposes of benchmarking..

However, the final choice is a policy matter - as it is in the other industries that must also deal with similar questions. Clearly the more information and “hard evidence” that is available the more confidence there can be in a final decision. However, while the regulatory process provides for consultation with interested individuals a central policy body is best equipped to establish the appropriate balance between cost, performance and more broadly the distribution of resources across different sectors within the community. For example the best means to mitigate the effect on, say, the cost of health services, might be by reallocating resources into the health sector rather than increase expenditure on the electricity network. Our view is that an understanding of upper and lower bounds formed from a combination direct and indirect means to assess value of network investment to electricity consumers can form the basis for decisions in respect of the relatively few HILP situations that are likely.

6. CONCLUSION

1. VoLL is a complex concept and should reflect the overall willingness of the community to pay for network capability. It is generally a multi dimensional and often non linear quantity as it is affected by the type of customers, the location of customers, the timing, scale and impact of interruptions.
2. Readily available quantitative methods for assessing economic costs as a basis for setting VoLL:
 - are best suited to identifying direct and measurable costs for individuals and individual organisations;
 - involve different approximations and require assumptions that lead to uncertainty about outcomes for the factors they measure; and
 - are less well suited to identifying the compound effects in a wide scale high impact interruption or intangible willingness to pay based on attitudes;
3. Available quantitative methods should be regarded as providing a lower bound on VoLL.
4. An upper bound on VoLL will be influenced (but not necessarily set) by benchmark comparisons with equivalent situations; in the case of Auckland by relevant comparisons with other cities.
 - Benchmarks should consider both commercial and physical performance, although the majority of international benchmarks for HILP situations are based on physical criteria related to levels of duplication (diversity).

5. Robust assessment of investment proposals can be made without quantifying an upper bound precisely, providing it can be demonstrated that a proposal would not exceed the likely value of an upper bound - for example a proposal that implies only modest cost due to HILP conditions over and above quantifiable costs derived from individual impacts.
6. Wide scale HILP events, although relatively rare in NZ, represent the most complex circumstance for determining VoLL and will generally involve more than the electricity sector and thus require broad policy considerations to be taken into account.

APPENDIX A SURVEY METHODS

A.1 DIRECT COST METHODS

Direct costing methods seek to quantify the actual costs facing the customer as a direct result of a change in the 'quality'⁴ of the service or the cost arising from absorbing this risk. In the case of an electricity outage, the direct costs method would seek to determine:

- the economic damage the outage would inflict on the customer's business; and/or
- the cost of the steps the customer would take to mitigate the risk of outage, or its impacts.

Under the direct costs methods surveys are generally undertaken to describe to customers a number of hypothetical outage scenarios that include variations in the timing, duration and frequency of supply outages. Variations in geographic spread are also sometimes addressed. For each scenario, customers are prompted with a series of questions that ask them to estimate the costs they would incur in a number of operational areas. The categories probed attempt to be comprehensive and would typically include⁴:

- lost sales;
- product or input spoilage;
- damage to plant equipment;
- increased equipment operations or maintenance costs;
- wages paid to staff unable to work, and
- cost of operating back-up generation equipment.

The primary problems with this approach are that:

- it does not adequately accommodate costs that are hard to quantify in financial terms;
- it requires a significant amount of time per respondent, and therefore can be quite expensive;
- it is not applicable in the residential sector, because outages generally pose inconvenience rather than direct financial costs on these customers;

⁴ The term quality here is used in its broadest sense

- it requires a good working knowledge of the processes of different business types in order to provide the level of effective probing that avoids missing categories of cost that are applicable to a particular customer or customer segment; and
- it is extremely difficult to verify the completeness or accuracy of the responses.

As intimated above, this approach is generally implemented with business customers, as they are much more likely to conceptualise and be able to express the impacts of an outage in financial terms.

A.2 INDIRECT METHODS

Indirect methods of valuing reliability were developed to address situations where customers are not able to conceptualise or quantify the costs they incur due to an electricity supply interruption. Such methods aim to infer a valuation on costs that are difficult to quantify, (inconvenience for example), by finding acceptable substitutes of a known value, or trade-offs that customers are willing to make. Several indirect costing methods are discussed below.

A.2.1 Contingent valuation (open-ended version)

Under Contingent Valuation (CV), value estimates are derived by gathering responses to a hypothetical scenarioⁱ. Originally, this method used open-ended questions in which respondents were asked to nominate a monetary value representing their Willingness To Pay for (WTP) or Willingness To Accept (WTA) a particular change in service quality. This data is then treated in one of two ways:

- A mean WTP or WTA can be calculated across all respondents; or
- The data can be linked to a series of demographic parameters by regression analysis.

For example:

How much money would you be willing to accept to compensate you for a 4-hour outage?

The open-ended version of this method has limited credence because it is believed to be too susceptible to cognitive burdenⁱⁱ; that is, the fact that respondents are being asked to estimate the value of, or their willingness to pay for, a good (e.g., electricity reliability) that they have no market experience in purchasing or valuing, is likely to introduce significant inaccuracy in their responsesⁱⁱⁱ.

The difficulty in achieving cohesive results can be illustrated by the fact that surveys using WTP and WTA generally do not provide equivalent results^{iv}. Although it might be expected that the amount of money a customer is willing to pay for an improvement in service of magnitude x would be equivalent to the money that same customer is willing to accept to compensate for a decrease in service of magnitude x , this equivalence does not hold in practice. Rather it is generally the case that the WTA compensation requirement will exceed the WTP amount for an equivalent, but opposite, change in service quality^v.

This apparently irrational result can be explained in part by income and substitution effects, and in part by consumer sensitivity to cash flows⁵, but regardless, creates some doubt about which is the 'better' survey approach to use and the accuracy of these approaches altogether.

It also underscores the importance of choosing the approach that most closely matches what the survey is seeking to determine. For example, a survey seeking to design an interruptibility program to defer network augmentation would probably provide better estimates of customers' participation requirements by using a WTA approach. Valuation of a network augmentation might be more closely approximated by a WTP approach.

A.2.2 Contingent valuation (referendum version)

The referendum version of the CV method aims to overcome some of the difficulties associated with the cognitive burden of the open-ended CV method by getting respondents to make a discrete choice whether to accept a specified change in service quality for a specified amount of money (WTP or WTA).

For example:

Would you be willing to accept \$50 to compensate you for a 4-hour outage?

The proposed change in service quality and the proposed amount of money are varied across respondents to develop a broad picture of customer preferences. This binary information is then used to derive the effective utility function (how a customer's level of satisfaction changes with changes in service) subject to a budget constraint^{vi}.

While it has improvements on an open-ended CV approach, in terms of cognitive burden, the referendum CV approach has some limitations of its own such as^{vii}:

⁵ In that customers will overstate how much they would need to be compensated and understate what they should need to pay – this is irrational because they should state a value at which they are indifferent to the change in service or the money.

- Only one aspect of service quality (such as frequency of interruption) can be modelled per survey. Although this may be acceptable in some instances, the method will not be appropriate if trade-offs between possible improvements need to be considered or if embedding effects are present⁶. However, this approach has been used to predict customer outage costs in VCR studies.
- The questions and the scenarios used in the survey are intrinsically hypothetical, and therefore respondents may find it difficult to accurately estimate their valuation of goods or services for which they are not used to paying, even when given discrete choices between alternatives. It should be noted that this is slightly different to the cognitive burden associated with the open-ended CV model of nominating values in unfamiliar context because the survey provides the valuation. In addition, there have been attempts to take consideration of any customer uncertainty in the standardisation of survey responses by factoring up or down the significance of individual responses by the level of certainty they feel they had about their response.
- If each respondent is asked about his/her willingness to accept a series of values, the survey runs the risk of strategic behaviour from the respondents. If each respondent is limited to one value, very large sample sizes may be needed to cover the range of possible values.

Some researchers feel that CV models are open to manipulation by respondents who have an incentive to act strategically by falsely representing their valuation of a service depending on whether they believe they will be required to foot the bill. Such an effect is mitigated in other approaches, for example in Choice Modelling, by asking respondents to make choices based on a grouping of attributes.

A.3 CHOICE MODELLING

Choice modelling (CM)^{viii}, like the Referendum CV model, is based on using Random Utility theory to build a profile of customer preferences. However, CM, unlike the Referendum CV model, is non-binary – i.e. respondents are asked to choose between three or more alternatives. Also, whereas Referendum CV can deal with only one-dimensional changes in service quality, CM can accommodate a number of different service attributes at once⁷, and implicitly accounts for all embedding and trade-offs between the attributes.

⁶ Embedding effects are where the sum of the valuations of a series of possible changes does not equal the valuation of the collection of changes as a whole. This effect can occur if synergies are gained from the combination of some of the measures; or if some of the measures cancel each other out to an extent.

⁷ Generally no more than six attributes are tested at once as experimental results have shown that it is difficult for respondents to make effective trade-off decisions among that many attributes at once.

An example of a CM might be to show consumers a sheet that contains 3 alternatives. Each alternative has different values for a number of variables on it – (X interruptions per year, Y duration of interruption, Z decrease in call centre support, and P change in average bill). Respondents are simply required to choose their most preferred option.

<i>Please indicate the alternative you most prefer</i>			
	Alternative 1	Alternative 2	Alternative 3
Interruptions per year	1	2	4
Duration of Interruption	4 hours	1 hour	30 minutes
Hours per day of call centre support	12	8	24
Price increase in average bill	\$40	\$30	\$10

A series of such choice sets is shown to each respondent, and by varying the values of the different variables, a deep understanding of customer preferences, including their interrelationships, can be achieved. So long as one of the variables can be measured in dollars (i.e. price), values can be attributed to each of the other variables^{ix}. Due to the relative complexity of the surveying, respondents are less likely to effectively manipulate survey results by strategic behaviour. This method, however, tends to be more costly than other options because the surveys do not lend themselves to anything but face-to-face surveying, and require significant computational analysis.

A.4 CONJOINT ANALYSIS

Conjoint analysis, like CM, is a technique that can be used to determine how customers make trade-offs in benefits or in attributes. It is a particularly robust technique for calibrating the precise level of service quality or reliability that customers desire. *Conjoint rating, conjoint ranking and paired comparisons* are examples of conjoint analysis survey techniques.

In conjoint rating surveys, respondents are asked to give a numerical rating to a series of alternatives, one by one. Each alternative will have, like CM, a number of service attributes. Respondents do not need to compare alternatives or to choose between them (although it could be argued that this happens to a degree anyway – meaning that starting point bias needs to be managed).

For example, a respondent would be shown a series such as:

<i>Give a rating of your strength of preference for the below option</i>	
Interruptions per year	1
Duration of Interruption	4 hours
Hours per day of call centre support	12
Price increase in average bill	\$40
Weakly Preferred	1 2 3 4 5 Strongly Preferred

This method has two major problems:

- Data from these surveys has traditionally been analysed using Ordinary Least Squares (OLS) regression techniques. More recently this approach has been determined to be inappropriate given the fact that the data provided by the survey is ordinal rather than interval, and OLS regression requires interval data; and
- Respondents often have trouble accurately representing their hypothetical choice behaviour outside a 'market type' situation (one where customers choose one product over others).

Conjoint Ranking surveys are similar to Conjoint Rating except that respondents are asked to give a relative numerical ranking to several alternatives at one time (i.e., first choice, second choice, third choice) thus linking the scenarios. As it also produces ordinal data it is generally no longer used because of the inappropriateness of using its data in a regression algorithm^x.

<i>Please rank the alternatives in order of preference</i>			
	Alternative 1	Alternative 2	Alternative 3
Interruptions per year	1	2	4
Duration of Interruption	4 hours	1 hour	30 minutes
Hours per day of call centre support	12	8	24
Price increase in average bill	\$40	\$30	\$10
Ranking (1,2 or 3)			

Paired Comparison surveys involve respondents being asked to rate their level of preference for one alternative scenario over another. Like CM, each alternative can have a number of attributes, but in this case, the respondent doesn't just have to say which alternative they prefer, but also by how much (or if they consider them to be equivalent). This provides the interval level data upon which the regression analysis can legitimately be undertaken.

For example

<i>Please rank the alternatives in order of preference</i>			
	Alternative 1		Alternative 2
Interruptions per year	1		4
Duration of Interruption	4 hours		30 minutes
Hours per day of call centre support	12		24
Price increase in average bill	\$40		\$10
Which alternative do you prefer ? (circle your preference)	Strongly prefer left		Strongly prefer right
	1	2 3	4 5

More recently, several advanced conjoint-related approaches have been developed to try to reduce the level of survey burden and improve accuracy. To our knowledge, none of these have been applied to electricity reliability as yet.

A.5 ECONOMIC PRINCIPLE OF SUBSTITUTION

Another approach for estimating outage costs indirectly is based on the Economic Principle of Substitution (EPS). The approach can be applied in surveys to evaluate the cost of a good or service without a known value – such as a reliable power supply – by asking customers to choose one or more options with known costs as substitutes. The principle can be readily applied in customer surveys to estimate outage costs. Acceptable substitutes that customers might choose could include insurance policies to cover the cost of damage or one or more preparatory actions that they might take to mitigate the inconvenience of an outage such as purchasing a generator or a portable gas cooker or even a night out at a restaurant. The importance of the substitutes is that they provide a “known context” for the cost, and therefore for the value of reliability.

For example:

<i>Select one or more of the following actions you may take in the event of a 6 hour outage</i>	
Action	Cost
Purchase candles	\$5
Purchase a torch and supply of batteries	\$15
Purchase a gas lantern	\$75
Purchase a portable gas cooker	\$100
Purchase a UPS	\$250
Lease a generator	\$500

The EPS approach provides reasonable outage cost results provided extreme care is taken in formulating the survey questions and particularly the list of preparatory actions and options offered to customers to choose from. If the quality of survey design is poor, the outage costs developed from the survey results can be misleading and potentially overstated. For example, if customers are presented with an option to purchase a high quality battery powered lantern at \$100 instead of a torch at \$15, this would result in highly overstated outage cost estimates.

Similarly, care needs to be taken to avoid the situation where the nature of the option interferes with the number of customers selecting it. For example, if one of the choices shown is going out to dinner at a cost of \$100, some respondents may be drawn to the solution, but feel that the price is not an accurate representation of what they would do. In this case, the context – the solution – would interfere with the selection of the appropriate value. This again reinforces the importance of careful thought regarding the substitutes to be presented.

Moreover, customers need to be presented with a large continuum of options that range from nil/low cost actions to high costs options to cater for the spectrum of affordability and lifestyle preferences. A wealthy consumer, for example, accustomed to an expensive lifestyle may place a different value on the cost of an outage than say a socially disadvantaged consumer. The wealthy consumer may well be prepared to purchase or lease a generator to maintain his lifestyle, while a low income consumer on the other may be more than satisfied with opting for nil or low cost mitigation actions.

It is also important that options are selected such that increments in price from one option to the next are relatively small. For example presenting customers with the following three options; purchase of candles (\$5), a lantern (\$75) or lease of generator (\$500 a day) is likely to yield poor outage cost results because of the large price increments between each option.

Another issue to consider in valuing customer reliability via the EPS method is that the cost of the substitutes, and hence the interruption, is dependent on whether the respondent is considering the long-run, or short-run, marginal cost. For example, should residential customers include the costs of switching their electric water heaters to gas if interruption is to be a frequent occurrence, or just the cost of candles because the event is likely to happen rarely. Suddenly, the issue of evaluation of costs (and therefore the value of reliability) becomes a complex one with many more ways of viewing 'value' and, at best, a dynamic solution set.⁸

The best way to address this potential problem is to provide (and periodically repeat) within the survey the context in which the substitution decision is to be made. This involves providing the respondent with a clear statement about the expected frequency, duration and timing of the supply interruption the substitute is meant to address.

-
- i Review of Willingness-to-Pay Methodologies – Prepared for IPART – Centre for International Economics – 17 August 2001
 - ii Hanemann, W.M.; Contingent Valuation and Economics – Department of Agricultural and Resource Economics – University of California – Berkley - 1994
 - iii Review of Willingness-to-Pay Methodologies – Prepared for IPART – Centre for International Economics – 17 August 2001
 - iv Review of Willingness-to-Pay Methodologies – Prepared for IPART – Centre for International Economics – 17 August 2001
 - v Shogren, J.F. et Al; Resolving differences in WTP and WTA – The American Economic Review pp 255-270 - 1994
 - vi Louviere, J.J.; Analysing Decision Making: Metric Conjoint Analysis – 1988 – Sage Publications
 - vii Review of Willingness-to-Pay Methodologies – Prepared for IPART – Centre for International Economics – 17 August 2001
 - viii Revelt, D. and Train, K.; Mixed Logit with Repeated Choices: Households' Choices of Appliance Efficiency Level – Review of Economics and Statistics - 1998
 - ix Review of Willingness-to-Pay Methodologies – Prepared for IPART – Centre for International Economics – 17 August 2001
 - x Louviere, J.J. and Timmermans, H.; Stated Preference and choice models applied to recreation research: a review; Leisure Sciences 12 - 1990

⁸ Dynamic in the sense that, for example, if a customer was to switch their water heating to gas in response to interruptions, clearly their value of reliability has changed because they are now somewhat insulated from the effects of future supply events