Post-disaster reconstruction of road infrastructure: decision making processes in an Australian context

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The rehabilitation and reconstruction of damaged road infrastructure plays a vital role in the recovery of disaster affected regions. The methods and processes adopted by road asset owners during the reconstruction phase influences the longer term effects in disaster hit communities. While the decision making processes are intended to reduce impacts, mistakes at the decision making stage can lead to an increase in social and economic impacts in the longer term. It is thus imperative to understand how decision making takes place with regard to post-disaster reconstruction of road infrastructure. The objective of this paper is to understand how road asset owners assess and prioritise post-disaster reconstruction projects in order to identify how decision making could be improved in Australia and similar regions. The results of in-depth interviews conducted with road infrastructure practitioners in disaster affected regions are presented. The findings show that there is a gap between the research community and practitioners in the use of systematic methods to aid prioritisation and decision making. The interviews also showed that the consideration of only a limited set of engineering and financial elements can lead to unintended consequences that impede resilience. A causal loop diagram was developed to illustrate the interrelationship between factors identified and shows the importance of a systems thinking approach to infrastructure related decision making. These findings suggest that the development of more localised decision making tools can increase their adoption among practitioners.

Keywords: *disaster management, natural hazards, post-disaster decision making, road infrastructure, socio-ecological impacts.*

1. Introduction

With increased climate change scenarios and higher population densities across the globe the adverse socio-economic effects of natural disasters have increased dramatically in recent years. Hydrological disasters such as floods and landslides account for the largest share of natural disaster occurrences globally since 2006 and the largest proportion of life loss and economic losses due to natural events (Guha-Sapir, Hoyois, Wallemacq, & Below, 2016). Road structures

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such as bridges, culverts and flood-ways are designed to cross water-ways and can be severely damaged due to floods. The damage to such critical structures can render large portions of the road network inaccessible and cause knock-on effects. The humanitarian rescue and response efforts soon after a disaster rely heavily on the accessibility in and out of the disaster zone and these efforts could be hindered due to damaged road sections. In the longer term, damaged road infrastructure could exacerbate the socio-economic impacts of the disaster and can affect a wider spatial scale. It has been found that better connected areas tend to recover faster in contrast to areas which are less connected (Zhu, Wang, Liu, & Sui, 2018). It is thus evident that Post-Disaster Reconstruction (PDR) of road infrastructure is a key aspect influencing the recovery of a community affected by a natural disaster.

Post-disaster reconstruction processes of road infrastructure typically differ from routine rehabilitation or new infrastructure projects given the expedited nature of reconstruction required (Le Masurier, Rotimi, & Wilkinson, 2006). PDR processes have been studied by several scholars and it has been found that the availability of resources after a disaster event can be a major influencing factor (Y. Chang, Wilkinson, Potangaroa, & Seville, 2012). Other factors that influence PDR are legislation (Rotimi, Wilkinson, Zuo, & Myburgh, 2009), coordination between government agencies (Le Masurier et al., 2006) and stakeholder engagement processes adopted (Crawford, Langston, & Bajracharya, 2013).

PDR activities are generally carried out based on disaster management and recovery plans, which are specifically designed for this purpose. The lack of a clear disaster management plan can delay the reconstruction activities due to lack of clarity in responsibility and authority (Lin Moe & Pathranarakul, 2006; Pathirage, Seneviratne, Amaratunga, & Haigh, 2012). However, it has been found that most regions or countries develop such plans as a reactionary effort after a major disaster event (Palliyaguru & Amaratunga, 2008).

Even though road networks are considered to be essential public assets, its rehabilitation and reconstruction after a disaster can be delayed due to resource constraints. Financial constraints impact maintenance and replacement of transport infrastructure and have a major influence on how fast a damaged road structure could be brought back to pre-disaster service levels (Vanelslander, Roumboutsos, & Pantelias, 2018). Such constraints could be exacerbated in the event that a number of road structures are damaged or if back-to-back disasters occur in the same area. Under such circumstances the decisions made by the relevant authorities on how to allocate resources for reconstruction and to prioritise specific structures, will affect the recovery of the disaster affected region.

Researchers have proposed several different methods to overcome challenges faced during the PDR stage. The different methods that have been proposed could be categorised as; 1) Policy and legislation 2) Prioritisation and optimisation. Policy and legislation focuses on developing well prepared disaster recovery procedures that need to be implemented after a disaster occurs. These procedures can vary from being general guidelines to legislated regulations and are generally implemented through state or government authorities (Rotimi et al., 2009).

Prioritisation and optimisation methods accept that PDR can be severely hampered by various resource constraints and focus on aiding the practitioners to make the most effective decisions given these inherent challenges. Extensive research has been carried out on developing various models to assist in the optimisation of PDR of road infrastructure. Scholars have used different methods ranging from Analytic Hierarchy Process simulation, deterministic optimisation to stochastic optimisation based on concepts like reliability, robustness and resilience of the transport network for this purpose (Faturechi & Miller-Hooks, 2014).

Although there has been an increased contribution in this area from both policy and theoretical aspects PDR tends to face major obstacles and challenges during implementation. This has resulted in delays in reconstruction, community back lash and even damage to reconstructed infrastructure in later disaster events. Most Australian guidelines on road infrastructure related

PDR tend to pay more attention to the financial and engineering aspects, with less attention on wider socio-economic and ecological factors. This is in contrast to the academic scholarship where numerous models to aid PDR of transport infrastructure have been presented that considers the social and environmental aspects (Dong, Frangopol, & Saydam, 2013; Khaki, Mohaymany, Baladehi, & Gorji, 2013; Tapia & Padgett, 2016). The literature shows that PDR processes are heavily reliant on the expert judgements of the practitioners and the prevailing regulatory requirements (S. E. Chang, McDaniels, Fox, Dhariwal, & Longstaff, 2014; Palliyaguru, Amaratunga, & Haigh, 2010; Zhou & Wang, 2015). However, as most of these studies focus on reconstruction efforts in developing regions or the reconstruction of housing projects it is vital to understand how practitioners approach PDR of road infrastructure in order to identify any gaps between theory and practice, especially from an Australian perspective.

To understand this problem we examined how PDR of road infrastructure is carried out in practical scenarios by interviewing practitioners in disaster affected regions in Australia. The aim of the research was to investigate the methods adopted by practitioners involved in the decision making process of PDR. This paper builds on previous research carried out in interviewing practitioners to understand the decision making processes in a disaster-prone region in Queensland, Australia (Gajanayake, Khan, & Zhang, 2019). Practitioners involved in PDR of road infrastructure in Victoria were interviewed in order to conduct a comparative analysis. The states of Queensland and Victoria were selected for this study as they are two of the most disaster impacted states in Australia.

2. Methodology

Given the exploratory nature of this study a qualitative case study approach was adopted. This involved interviewing practitioners involved in PDR across two different geographical regions, which helped in a comparative analysis of the findings. Qualitative research is used to explore an area of interest where little is known, to obtain a holistic view of a complex system and to investigate social phenomena in the context that it takes place (Karlsson, Dahlstedt, Regnell, och Dag, & Persson, 2007). Such research is constructionist and interpretivist in approach as the findings of the study are based on how ideas generated from the interviews are interpreted and constructed by the researcher (Mulowayi, 2017). A multiple case-study approach increased the generalizability of the research findings beyond the immediate study area (Yin, 2009).

2.1 Interview design
In-depth interviews were chosen as the best method to obtain the relevant information as they are a pipeline to transmitting knowledge (Holstein & Gubrium, 2004) and are intended to tap individual experiences that the researcher may not be aware of (Charmaz, 2003). Exploratory interviews helped broaden and deepen the plan of research by facilitating new dimensions that were earlier not visited by the researchers and to develop ideas and research hypotheses rather than obtaining quantitative facts and statistics (Oppenheim, 2000).

A low degree of structure for the format of the interviews was deemed to be suitable for the purpose of the study. This meant that it was easier to encounter new and unexpected views as the interviewer used a broad range of ideas, experiences and observations (Alvesson, 2010). The questions were designed with a clear theme and fairly limited focus, with more open ended questions, which resulted in gaining deeper understanding and rich descriptions of the issues. The interview questions were designed to obtain information under three broad themes; current practices adopted in PDR, additional aspects that should be considered and how PDR processes could be improved in the future. The interview probed the different factors considered based on three the pillars of social, environmental and economic, which are considered in holistic decision making approaches.

2.2 Interview participants

The first stage of the project involved the interviewing of practitioners from disaster prone regions in Queensland, while a second round of interviews were conducted with practitioners in Victoria. These two states were selected for a comparative study as there were distinct differences in the disaster occurrences between them. Queensland is the most vulnerable State in Australia to disasters and experiences a high number of hydro-meteorological disasters, which can severely affect road infrastructure, while Victoria is prone to more climatological events like bushfires. This allowed for a comparative analysis across interviewees where one group experienced more disaster induced road infrastructure damage in contrast to the other. Participants were selected from both rural and urban organisations from within the two States in order to analyse any differences in practice and opinion based on the geographical setting.

A theoretical sampling technique was adopted to select the potential participants whose work aligned with the research objectives (Robson, 2002). This allowed the selection of respondents with specific characteristics; those employed in organisations involved in post-disaster road reconstruction either directly through decision making processes or indirectly in vetting and stakeholder engagement processes. Typically the responsibility of PDR of roads fall under the local authority or the state roads authority, while funding for such projects is facilitated by the reconstruction agency. A total of eighteen interviewees (Table 1) from local government authorities, road authorities and reconstruction agencies in Queensland and Victoria were identified through previous research work carried out by the authors and were contacted directly by the research team. The snowball interview technique was implemented, where the interviewees were asked if they could recommend any other individuals or organisations relevant to the study. This helped the researchers to confirm that all the different types of organisations involved in PDR had been covered. The majority of the participants were civil engineers overlooking the transport infrastructure, while local government staff working in other divisions were also interviewed to obtain a more diverse opinion on reconstruction efforts.

Table 1.   Interview participants

Participant	Organisational Sector	Work Division	Geographical Jurisdiction
P1	Local Government	Infrastructure Works and Services	Queensland
P2	Local Government	Disaster Management	Queensland
P3	Local Government	Economic Development	Queensland
P4	Local Government	Environment Management	Queensland
P5	Local Government	Environment Management	Queensland
P6	Local Government	Community Development	Queensland
P7	Local Government	Community Development	Queensland
P8	State Government	Reconstruction Operations	Queensland
P9	State Government	Transport operations	Queensland
P10	State Government	Transport operations	Queensland
P11	State Government	Transport Asset Services	Victoria
P12	Local Government	Infrastructure Projects	Victoria
P13	Local Government	Infrastructure Projects	Victoria
P14	Local Government	Construction (New Works)	Victoria
P15	Local Government	Asset Management	Victoria
P16	Local Government	Asset Services	Victoria
P17	Local Government	Asset Management	Victoria
P18	Local Government	Asset Management	Victoria

2.3 Interview process and analysis

The interview questions and a Participant Information Sheet were emailed to the participants a week prior to the interview. This enabled the respondents to get an overview of the project and also to prepare for the questions that would be discussed. The interviews were typically 30-60 minutes in length and were conducted face-to-face at a meeting room at the interviewee's office.

The interviews were audio recorded, using the audio recording function of a smart phone, which was placed on the table. This was a non-intrusive method to record the interviews given the wide-spread use of mobile phones. Careful attention was given to conduct the interviews in a manner that created an atmosphere for the participants to respond with deep perspectives, which opened up new dimensions to be studied (Oppenheim, 2000).

The interviews were analysed using qualitative data analysis principles in order to understand the underlying themes and the processes used by the different participants. Qualitative methods were chosen, as a detailed understanding of the process was needed and as information was required to determine the boundaries and characteristics of the issue being investigated (Bazeley & Jackson, 2013). Data triangulation of the information obtained through the interviews was conducted using relevant institutional documents and systems. This helped in validating the information provided by the participants through more objective sources.

The analysis of the interviews took a two-step approach. The first group of interviews from Queensland were analysed with in-depth focus in order to understand the methods and practices used during PDR. These interviews helped the researchers identify the major factors that were considered, the techniques adopted on the ground and the subtleties that influenced the PDR processes. The analysis of the initial interviews helped in identifying the key issues that were highlighted by the respondents. The second group of interviews were used for comparative purposes and to increase the generalizability of the findings of the previous interviews.

3. Findings and discussion

This section presents the main findings in separate subsections and discusses their influence on PDR activities with reference to relevant literature. Specific quotations from the interviews have also been included in order to draw the reader's attention to important ideas that were mentioned in the interviews. The findings of the interviews are presented according to themes that emerged through the interviews and are different to the themes that were followed during the design phase.

3.1 Consistent use of tacit knowledge

The participants on the whole reported that there were no systematic processes which were followed for prioritisation of PDR. However, there was widespread use of tacit knowledge during the decision making and prioritisation works related to PDR. Such tacit knowledge of the practitioners played an important role in the decision making processes as no systematic methods had been utilized. The most vital aspects that were considered were the practitioners' past experiences and intimate knowledge of the locality. Participants used terms like "*gut-feel*", "*ad-hoc decisions*" and "*grey-matter approach*" to refer to this tacit knowledge.

One benefit of incorporating such tacit knowledge is that the decisions made were considered to be more suitable to the disaster zone. This could be more important in rural areas where state or federal level systems may not be as appropriate. Such measures have been found to benefit the recovery process rather than simply relying on central level, large scale actors (Lyons, 2009; Peng, Shen, Tan, Tan, & Wang, 2013)

"The guys in the field know how important a road is, [if we are asked how we made that decision] we'd be saying, well we made it on gut feel your honour, which isn't very good. But it's all there and it's all in the mind" Participant P1

Practitioners were of the view that communities in disaster-prone areas were much more resilient and adaptable due to generational experiences of living through multiple disaster events. It was considered important to tap into such local knowledge of how the water-ways behave during disaster events in order to re-build a more resilient bridge. This was considered vital in instances where professionals who were not from the locality were involved in PDR. The generational

effects highlighted by the participants were related more to the knowledge of the locality in disaster times rather than experience in dealing with previous disasters from different regions. Practitioners in rural disaster prone areas stressed that some of the infrastructure designs that were done in the past may have been done with such intimate local knowledge in mind. Such decisions are seen to have a heavy influence on the impact to the community and the subsequent ease of recovery after a disaster.

The only systematic process that was utilised in post-disaster decision making was for obtaining funding of reconstruction projects, which were mostly stipulated by state agencies. Such funding proposals tend to focus on the financial cost of reconstruction with minimal consideration given to wider socio-economic and environmental impacts. Data related to road classifications and business types have also been used in such prioritisation processes although no systematic method was utilised to incorporate such information. The interviewees did not seem to think that the decisions that were made in this manner could be completely flawed, but saw the need for a framework that could validate the current decision making processes. It was also highlighted that such a method could be used for numerous purposes including, as an evidence base for funding proposals, prioritisation of projects and the comparison of alternative reconstruction methods.

The interviews showed that there was a mismatch between researchers and practitioners with regard to prioritisation of road infrastructure decision making. Although there have been many models and tools proposed by researchers to aid in road infrastructure reconstruction (Gühnemann, Laird, & Pearman, 2012; Khaki et al., 2013) no evidence for the use of such methods were identified. A possible reason for this could be that most of these methods have not been developed for an Australian context. Since the interviewees mentioned that local nuances were a vital aspect that needs to be considered, the development of such models needs to be localised and context specific as opposed to a more general model. Improving the contextual and scalability of such models may increase the adoption of them in practice.

Opinions on the immediate need of a systematic method to aid PDR, differed based on the disaster vulnerability of the regions that the participants worked in. Practitioners located in more disaster-prone areas saw an immediate requirement for the use of such systems, while those in less disaster-prone areas saw no pressing need to incorporate such tools. Councils that had experienced hydro-meteorological disasters seemed to see a high value in the use of such methods in road infrastructure decision making, confirming the high degree of damage to road structures due to such events. The practitioners expected probability of a disaster occurring explains why disaster management processes are mostly systematized in disaster-prone areas and especially after a major disaster event (Palliyaguru & Amaratunga, 2008).

3.2 Roads viewed as social infrastructure

A majority of the participants were of the opinion that the primary role of road infrastructure was to facilitate the smooth functioning of the society. Most engineering professionals who were interviewed considered road infrastructure as part of the social infrastructure. This was in contrast to the general view among infrastructure engineers in Australia where transport infrastructure is typically classified as economic infrastructure (Infrastructure Australia, 2019). Infrastructure like schools, hospitals and community buildings, which cannot be valued in economic terms, are typically considered as social infrastructure (Jefferies & McGeorge, 2009). This dichotomy in views could be due to the objectives of the organisations that the engineers were employed in. The objectives of the infrastructure services departments in Councils were to ease connectivity purely from a social standpoint, with little or no mention of economic benefits. In general, therefore, it seems that the organisational outlook tends to flow through to the practitioners, and may take precedence during decision making procedures.

"Delay costs and then congestion related issues… [have] a number of health impacts and work-life balance problems. You know if you're stuck in traffic for two hours, it's two hours less with your family."
Participant P12

A diverse set of impacts were identified by different interviewees as the most important type of social impact such as human health issues, access to facilities, inconvenience to communities and traffic related impacts. A very common social impact that was highlighted was that of isolation of people or households due to damaged roads. Isolation of communities was highlighted especially by interviewees working in more rural environments in contrast to those focusing on more urban settings. It was also highlighted that isolation is one of the most critical factors that needed to be considered but is something that is commonly overlooked by practitioners who work in urban areas. A typical reason for this could be that urban areas are better connected, with more alternative routes thus reducing the possibility of isolation when road networks are unusable.

Although social impacts were stated as the most important aspect influencing PDR, no systematic process was used to incorporate such factors in the decision making processes. Given this constraint practitioners have tended to use their tacit knowledge during reconstruction and prioritisation efforts. Some participants, particularly from the infrastructure divisions felt that the road hierarchies and classifications indirectly portrayed the underlying social factors, while others were cautious in relying purely on such quantifiable factors saying that "*need is not always counted by number*".

3.3 Diverse perspectives on socio-ecological factors

Participants expressed a variety of perspectives on the importance and the types of socio-ecological factors influencing decision making. While social impacts were generally identified to be more important than environmental factors no clear distinctions were seen in the categorisation of them. The approach adopted by the researchers were to separate the types of impacts based on economic, social and environmental, which are the typical categorisations in sustainability literature. Participants differed in their opinions on what specific impacts fell into each category. A common view that was found across most participants was that financial factors like cost of reconstruction were confused with economic factors, while some economic factors like, the loss of business revenue were considered to be social factors. The implication of this confusion is potential dismissal of critical economic and social factors which need consideration to undertake a holistic analysis of post disaster recovery strategy and action.

Some participants explained that distinguishing impacts between economic and social could be misleading as economic impacts are within the social system. This portrayed the more contemporary approach of 'strong sustainability', where the economic system is considered to sit within the social system, which in turn is nested within the overarching environmental sphere (Sylva, 2018). The nested approach is in contrast to the initial conceptualisation of sustainability being viewed as three interrelated but separate pillars. We could conclude that practitioners tend to understand this interdisciplinary nature of sustainability without being constrained by theoretical concepts.

"*The more you think about it, everything affects the human social side of it. If they can't get their crops to market, yes it is economic, but at the end of the day it becomes [social].*" Participant P2

A clear distinction was observed among participants on the most important environmental factors that need to be considered. Practitioners in more rural areas thought damage to the natural local environment during PDR to be significant, while practitioners in urban areas mentioned the use of recycled material and carbon emissions to be of significance. The most important environmental impacts that were highlighted in rural disaster-prone areas were soil erosion, effects on water quality and sediment run-off. These impacts were mentioned regardless of the background of the practitioners be they engineers or social workers. The reason for this could be that a link between the natural environment and disasters are directly observable in regional areas and take precedence over global environmental issues. This was in contrast to other studies where the focus of environmental impacts considered during PDR was resource usage and greenhouse gas emissions (Padgett & Tapia, 2013; Schweikert, Espinet, & Chinowsky, 2018), which was similar to the views posed by practitioners in more urban settings.

One interviewee mentioned that damage to heritage listed bridges is a significant environmental impact. Such a classification seemed peculiar at first, as heritage listed architecture would generally fall under the socio-cultural umbrella rather than environmental. However, a reason for this could be that heritage architecture comes under the purview of the Department of Environment in the State of Victoria, which was the jurisdiction of the particular participant. This exemplified that legislative separations could play a more influential role rather than more common academic separations in categorisation of impacts.

3.4 Political and legislative influence

A common theme that emerged from the interviews was that political factors played an influential role in the decision making process. It was mentioned that there may be encouragement given to concentrate on specific areas during the reconstruction processes, purely from a political perspective. In instances where follow up questions were asked, there was hesitance to explain further stating *"you know what I mean"*. It was deduced that political factors could play a decisive role in post-disaster decision making, and was contrary to previous literature, where political and institutional factors have been identified as less important and more of an indirect factor (Pathirage et al., 2012).

Political influence was not always seen as a negative factor. Some participants mentioned that the political influence may indicate some underlying socio-economic factor that may not have been captured otherwise, while another mentioned that political influence was just another element of the tacit knowledge that is considered in the decision making process.

Participants from local councils noted that legislative and funding processes around PDR have a major influence on the type of reconstruction that is carried out. Most funding for reconstruction of infrastructure was available for 'like-for-like' re-building. This has resulted in many of the structures that were reconstructed after a disaster to be damaged in the next disaster event. It was noted that 'building-back-better' with more resilience built into the infrastructure can mitigate future impacts. However, most of the reconstruction did not include any mitigatory elements as funding for such elements were not available, even though the councils knew that such structures are *"not going to stand"* in the next flood event. Funding constraints have been found to negatively impact the resilience of structures due to non-optimal decision making processes in other similar industrial nations as well (Ćirilović, Nikolić, Mikić, & Mladenović, 2018). State level authorities mentioned that these issues have been identified and that measures have been taken to provide funding for more resilient PDR.

It was understood that increased regulations in recent times has had an impact on community level recovery processes and such regulations may be effectively *"legislating resilience away"* from the communities. Such regulations could reduce the adaptive capacity of communities while making them more reliant on Council or State authorities to facilitate recovery. The fact that legislation can have unintended consequences which can impede the resilience of rural disaster-prone communities is an aspect that policy makers should pay close attention to. This of special significance since disaster related regulations are designed to increase community continuity and resilience through institutionalising practices and processes (Britton & Clark, 2000).

"Legislation tells people 'you are not smart enough... so don't even try, we'll tell you how to do it'. But then when a flood hits we try to tell people 'you should be able to look after yourself for three days' and we don't realise that we have disempowered people and it's the legislative approach that has done that."
Participant P7

3.5 Requirements for holistic, systems thinking approach to decision making

The majority of participants mentioned that a more holistic approach to PDR decision making was needed moving away from the current practice of heavy reliance on financial factors. The participants were of the view that a commonly accepted methodology to incorporate wider socio-economic factors will be useful across most organisations. It was revealed that social,

environmental and economic factors were considered during new infrastructure projects but was an area that was lacking during PDR.

Participants from local councils mentioned that there will be higher probability that a holistic approach will be adopted across other organisations if such a method was adopted by the State level authorities. Given the lack of use of PDR specific models in the Councils participants from less disaster affected areas were of the opinion that the current methods used during new infrastructure projects and renewal work will be suitable in post-disaster scenarios. This finding corroborates with similar work carried out in New Zealand where PDR is at times carried out in a similar fashion to routine maintenance work. However, it has been found that routine methods of work can be grossly inappropriate in disaster times (Le Masurier et al., 2006).

Many participants were of the opinion that if a range of practitioners from different disciplines worked together that they would be able to come up with more holistic and previously unexplored solutions to PDR issues. Infrastructure practitioners alluded that they "*selfishly focus on road assets*" during PDR although they do understand the importance of the environmental factors in play. This was a shortcoming that was constantly sighted by socio-environmental practitioners who were of the opinion that both these groups needed to work together if more resilient solutions are to be arrived at.

Some environmental practitioners suggested that the problems with regard to repeated damage to infrastructure could not be resolved from a purely "*engineering thought process*" but needed a more ecological approach. Issues were pointed out to where roads have been built very close to creek bends, the overlapping of road reserves with creek reserves, and an increase of river crossings over the years. This is especially important in a hydrological disaster context as engineering infrastructure can have can have unintended consequences on the socio-ecological systems and have knock-on effects during later disaster events (McCartney et al., 2019).

"*If you've got the opportunity to reintroduce sinuosities to make it more a natural creek system instead of an engineered one… It's not in the infrastructure people's minds. It's a total different set of skills*". Participant P4

This divergence in opinions could be due to the contrasting world views of engineers and ecologists (Raab, 2017). The engineering profession is influenced from a high-modernist ideology (Scott, 1998) and their main role is considered to be transforming natural capital, into human and built capital using technical competence (Mitchell, Carew, & Clift, 2004). The participants were of the view that engineers needed to pay more attention to the ecological aspects because if not "*the impacts of the flood events will continue to become more and more severe*".

It was highlighted that there was disconnect between engineers and ecologists. It was noted that the engineering and environmental departments generally work very much in silos without looking at the bigger picture. Given that most of the PDR of infrastructure is driven by the engineering departments, engineering solutions have taken precedence over ecological solutions, and was seen as a major hurdle to adopting a more holistic decision making approach. It was understood that engineers had more faith that technology could reduce impacts, while ecologists believed that they also had unintended consequences that increased socio-ecological impacts. Most participants were of the view that these two streams of work need to work together in a holistic manner, which would bring about more effective and resilient outcomes in the future.

Similarly there have been instances of disagreements between the residents and the engineers that were contracted for PDR works. Due to high demand for construction work in post-disaster times, there had been many instances where engineers from outside the region were brought into fill this gap. Such workers are worried less about the socio-ecological aspects and are "*really just engineers, purely involved with the technical aspect*" of PDR. It was pointed out that there were instances where engineers did work closely with the local community during reconstruction.

Such work helped to achieve more holistic outcomes as the engineers did not focus on solutions *"purely from an engineering perspective"*.

"There was some resistance from them to listen to local farmers because, [they thought] 'who are you to tell me how to do my job, I'm an engineer what are your qualifications?' But the farmers weren't saying 'this is how you build a bridge'. They were saying 'this is where we need a bridge and this is the order that we need them." Participant P6

The findings show that systems thinking approach is needed in PDR efforts, which involve obtaining the views of a wide variety of stakeholders from different professional backgrounds as well as from communities and businesses. Such a holistic approach may create more resilient outcomes in infrastructure in disaster-prone areas and may also help to reverse negative public opinion where engineers are sometimes seen as part of the problem instead of the solution (Ainger & Fenner, 2014).

3.6 Causal loop diagram of the system studied

Based on the responses of the interviewees a Causal loop diagram (CLD) was developed to identify the interrelationship between factors that influence PDR decision making (Rehman, Sohaib, Asif, & Pradhan, 2019). CLDs are a corner stone of systems thinking approach and represent the dynamic system's causal structure (Schaffernicht, 2010). A typical CLD consists of variables and causal links between the variables that identify feedback loops. The causal links are depicted with arrows showing the direction of causality and symbols to show their polarity. The polarity is presented with (+) or (-) signs representing the relationship of the two variables. Causal relationships between variables can be used to identify closed loops within the system. Closed loops with positive feedback are referred to as reinforcing loops, as a change of one variable propagates through the loop reinforcing the initial deviation. Balancing loops in contrast have negative feedback through the sub-system balancing the initial deviation.

Figure 1 is an illustration of the CLD developed following the analysis of the interview findings. The various factors influencing the PDR process and causal links between them were identified through the analysis of the participant responses. The numerous factors mentioned by all the participants were listed down and then grouped into clusters that are presented as variables in the CLD. The diagram was then used to identify feedback loops within the PDR process and to recommend intervention mechanisms at critical points that could increase resilience of the system. The development of a CLD was the initial step towards analysing the PDR process from a broader point of view so that more holistic intervention could be recommended. Such a method aims to move away from piecemeal solutions, which is typical in organisations that work according to operations silos, towards more sustainable solutions.
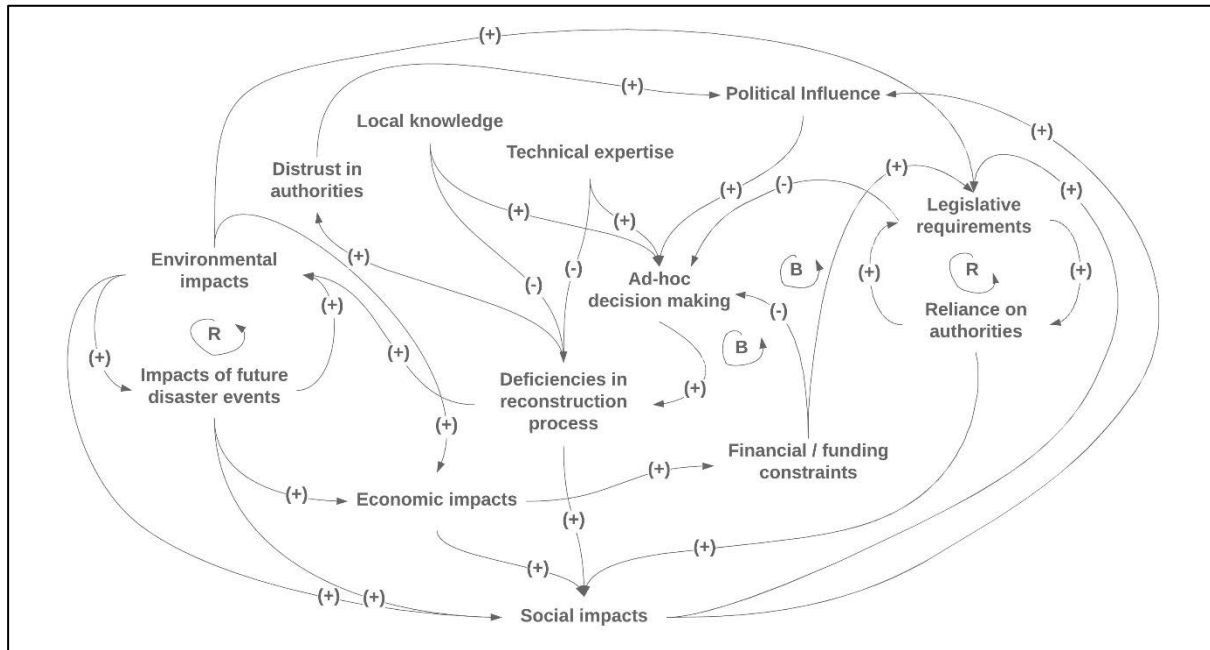
Figure 1.   *Causal loop diagram of PDR process of transport infrastructure*

It can be deduced from this CLD that there are many reinforcing loops within this system. One such reinforcing loop explains how increased legislation can cause a greater reliance on authorities (due to reduced community adaptation capabilities), which in turn increases legislative requirements. Another reinforcing loop was identified where negative environmental impacts can exacerbate impacts of future disaster events. As such environmental consideration during the reconstruction process is a vital aspect that needs to be considered in order to increase the resilience of the transportation system.

An important balancing loop within this system is where legislative or regulatory processes could be used to reduce ad-hoc decision making, which in turn will reduce deficiencies in the PDR process resulting in lower socio-ecological impacts in the future. However, if deficiencies in the PDR process are to be mitigated, socio-ecological factors need to be considered in addition to the techno-financial factors which are being considered currently. It is thus evident that post-disaster decision making processes needs a holistic, systems thinking approach, if more resilient and sustainable infrastructure networks are to be designed.

4. Conclusion

This study, through semi structured interviews with multiple stakeholders in local councils and state authorities, has identified the need for a holistic approach in post-disaster recovery situations. It is important to understand social, economic and environmental impacts in post-disaster recovery situations for example in the context of road infrastructure reconstruction. It has been identified that there is very limited use of any systematic techniques in the PDR process although such methods have been developed by many researchers.

A limited engineering and financial resource allocation approach seems to be the most straight forward choice when it comes to PDR strategy and implementation. This was mainly due to the heavy reliance on the engineering department during PDR, which can minimise collaboration across departments. Nevertheless this is not the most comprehensive and holistic approach as it tends to exclude social, environmental and economic factors from being considered. Reliance on narrow legislative and engineering processes that do not considered wider socio-ecological aspects may lead to unintended consequences that have the negative effect of reducing resilience.

The use of holistic approaches can improve resilience not only of the engineering infrastructure but also of the community in the longer term. When multiple stakeholder views are taken into consideration, various angles relevant to reconstruction emerge, which may usually be ignored. Decisions made with a broader perspective may have an impact on various resource allocations (such as money and time) but can result in better quality outcomes in the longer run. Better quality outcomes include more resilient structures, less environmental impacts and community considerations embedded in recovery decision making and action.

The findings of the study can be used to develop targeted interventions aimed at reducing the socio-ecological impacts and increasing resilience during the PDR process. Further research could explore how best to incorporate the broader socio-ecological aspects during the PDR decision making processes. The results of this study indicate that consideration of local nuances with input from multiple stakeholders will be important in developing such a decision making framework. The adoption of holistic considerations, such as practices and decisions, which are based on multi stakeholder views and expectations, could be encouraged by State and Federal level agencies. Holistic views can be covered in funding proposals and in requirements for granting of funding. Tailor made, holistic considerations can be implemented in data and time constrained situations.

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Appendix A – Interview Schedule

1. Name of Organisation and Department:

2. What are the key objectives and deliverables of your Department?

3. Please explain your department's involvement in post-disaster reconstruction of road infrastructure.

    3.1 Level of involvement: Scale of 1-5

    3.2 Type of involvement: Operational/ Technical/ Financial/Consultation

4. Does your department conduct any type of prioritisation in disaster recovery situations?

    4.1 What processes are followed during PDR?

    4.2 Do the methods change according to:

        4.2.1   Type of disaster

        4.2.2   Type of infrastructure

        4.2.3   Method of reconstruction

        4.2.4   Scale or extent of disaster

5. What aspects / factors are considered by your department in post-disaster reconstruction situations?

    5.1 Social factors

    5.2 Economic factors

    5.3 Environmental factors

6. Are there any additional factors / impact categories that should be considered during PDR?

    6.1 Why aren't these factors considered currently?

7. Are there any set methods used to measure / assess the factors identified in Q4?

    7.1 If yes, what are these methods and how are they used?

    7.2 If no, how are such measurements / assessments carried out?

8. Do you think a framework that measures social, environmental and economic impacts of road structure failure will be useful for your department? Please explain.

9. What type of information should be captured through such a process?

10. What types of impacts / factors should be considered in such a framework?

        10.1   Social factors

        10.2   Environmental factors

        10.3   Economic factors

11. What are the most critical factors/ impacts that you would like included in such a framework?

12. What is the optimal form of output you require from such a framework that will help meet your departmental objectives during PDR?

        12.1   What are the basic objectives it should meet?

12.2   What are the characteristics of performance that it should meet?

12.3   What are the operating conditions it should meet?