Rework Causation: Emergent Theorectical Insights and Implications for Research

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Abstract: Rework is a chronic problem in construction and engineering projects. A plethora of studies examining the nature of rework have been undertaken since Burati *et al*. (1992) examined quality deviations. Early studies initially focused on identifying the causal factors and costs of rework to quantify the severity of the problem. These initial studies recognized that because rework causes are both interdependent and complex, techniques such as Cognitive Mapping and System Dynamics were introduced to model this phenomena. These models provided invaluable insight needed to stimulate theory development – yet despite this advance in knoweldge, rework remains a pervasive issue. Several factors have have exacerbated the prevailing causal ambiguity, for example, the epistemological underpinning used to construct the nature of causes and the subsequent use of analysis tools and techniques. Evidence of this ambiguity is presented in recent studies that have failed to acknowledge the interdependency of rework causes. Indeed, research has regressed to identifying causality of singular nature using one-dimensional tools such as questionnaire surveys. Consequently, such research continues to stymie progress toward reducing and containing rework and a moratorium for such approaches to examine rework causation is suggested. With this in mind, insights into the extant rework literature and causation philosophy are examined and recommendations to improve the understanding necessary to establish a theory for rework causality are proposed.

Keywords: Causal ambiguity, epistemology, questionnaire surveys, rework, causation theory

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Introduction

> *"We think of a cause as something that makes a difference, and the difference it makes must be a difference from what would have happened without it. Had it been absent, its effects — some of them, at least, and usually all — would have been absent as well."* (Lewis, 1973b, p.161)

Rework remains a chronic problem in construction and engineering projects (e.g. Burati *et al*., 1992; Barber *et al*., 2000; Li and Taylor, 2014). Various definitions of rework have been propagated, which has resulted in significant discrepancies in reported costs. For example, Rogge *et al*. (2001) defined rework as: *"activities in the field to be done more than once in the field or activities which remove work previously installed as part of the project."* Love (2002a) defined it as the: *"unnecessary effort of re-doing a process or activity that was implemented incorrectly the first time, which accommodates design and construction errors, omission and changes, which may arise."* Conversely, Robinson-Fayek *et al*. (2004) refers to rework as the: *"total direct cost of re-doing work in the field regardless of initiating cause."* Robinson-Fayek *et al*. (2004) specifically state that their definition excludes change orders and errors due to off-site manufacture, which are not considered as rework. Such differences have been further compounded by the methods used to quantify rework costs, and naturally this also impacts upon determining its causal nature (Love and Sing, 2013). For example, case study based-research that relied upon close interaction with contractors and establishment of a formal measurement system revealed that direct rework costs during construction ranged from 2% to 5% of contract value (e.g. Love and Li, 2000; Robinson-Fayek *et al*., 2004; Kakitahi *et al*., 2014; Taggart *et al*., 2014). When indirect costs of are considered (Barber *et al*., 2000) rework increased to 16% and 23% of contract value. These estimates included an allowance for the cost of delays that were incurred. If these were removed, then rework costs would have equated to 3.6% and 6.6% of contract value. Love (2002b) suggested that indirect rework can have a 'multiplier effect' of up to six times the actual (direct) cost of rectification. Case study research undoubtedly has its merits however, the number of cases presented in studies has been limited and thus only stimulated research to be repeatedly exploratory instead of being explanatory, which is essential for developing theory of rework causation in construction (Love *et al*., 2002)

With tight profit margins and the need for higher productivity levels, clients and their project teams cannot ignore rework as ultimately business survival is jeopardized. Despite considerable research undertaken to date, there is a clear paucity of evidence to confirm that rework is being reduced or contained in projects despite similar costs and causes being identified more than 25 years ago (e.g. Aiyetan, 2013; Hwang *et al*., 2014; Kakitahi *et al*., 2014; Taggart *et al*., 2014; Jingmond and Ågren, 2015). Building upon knowledge accrued to date, this paper provides insights into rework causation and specifically calls for a moratorium for future studies to provide a contextual backdrop via which to better understand the rework connundrum. The research culminates with the philosophical stance that past research may have maligned our ability to delevop a deeper and richer awareness as to ‘why’ and ‘how’ rework arises in projects; this in turn has impeded the development of a ‘theory’ for its causation.

Rework Causation

A plethora of rework related studies have focused on identifying specific causation factors and how they influence the cost and schedule performance of projects (e.g. Love and Li, 2000; Love *et al*., 2004; Love and Edwards, 2004; Hwang *et al*., 2009; Love *et al*., 2009a,b: Aiyetan, 2013; Hwang *et al*., 2014; Kakitahi *et al*., 2014). For example, Ye *et al*. (2014) concluded that:

> *“Because the majority of rework causes identified in this study confirm those found in previous work, the findings from this study consolidate existing knowledge with new evidence from China. New causes, such as contract management, active reworks, and scope management, are also identified, which helps expand existing knowledge for the global construction community”*

A closer examination of the literature by Ye *et al*. (*ibid*) reveals that the purported ‘new’ causes were identified in previous studies more than decade ago (e.g. Rodrigues and Bowers, 1996; Love *et al*., 1999; Josephson *et al*., 2002; Love and Edwards, 2004). Similarly, the work of Hwang *et al*. (2014) and Kakitahi *et al*. (2014) were previously reported upon by Burati *et al*. (1992) and a abundance of other studies conducted in the 1990s (e.g. Abdul-Rahman, 1995; CIDA, 1995; Love *et al*., 1999). Within hindsight, the rework related research of Ye *et al*. (2014), Hwang *et al*. (2014), Kakitahi *et al*. (2014), Taggart *et al*. (2014) and Jingmondand Ågren (2015) has either unwittingly regressed knowledge to historical milestones already firmly established within the extant literature or has been subject to conscienous-raising. Ye *et al*. (2014) provide an exemplar to support this assertion when they simply list rework causes derived from a questionnaire and then use ‘Factor Analysis’ from a heterogeneous sample to add statistical rigor to determine a commonality of groupings for variables without defining the context regards how rework arose in the projects they sampled. Love *et al*. (2009a), undertook similar work but produced a *Structural Equation Model* without providing the underlying knowledge needed to be able reduce and contain rework (Love *et al*., 2015a).

Notably, seeking opinions about rework causes from heterogeneous samples through questionnaires is considered to provide uncertain results (e.g. Love and Edwards, 2004; Ye *et al*., 2014). This is because respondents rarely view the same event at the same time and therefore, inconsistencies arise with the testimonies/ responses of other participants who are involved with the same project. Ye *et al*. (2014), for example, identify *“poor communication path of project instructions”* as a cause of rework, but this observation simplifies the complexity associated with how people interpret information. In explaining this complexity, Busby (2001) suggests that problems do not arise because X does not communicate Z to Y, but the way Y interprets Z in light of some prior experience (or lack of), which X does not know about. Thus, X fails to make allowances for Z, and Y does not realize X does this as Y thinks that both their experiences are representative. In short, improving communication practices via technology or using Building Information Modeling (BIM) will not reduce the incidence of rework *per se*. Fundamentally, work processes, policies, procedures and behaviours need to change in concert if rework is to be reduced (Love *et al*., 2011a). Suggesting that *"unclear and ambiguous project process management"* and *"poor quality of construction technologies used"* result in rework (Ye *et al*., 2014) are 'conditional' not 'casuality' statements, especially as an infinite number of possible outcomes may arise from these declarations. An important distinction is that statements of causality require an antecedent or coincidence with the consequent events, whereas conditional statements do not require this temporal order. Thus, the epistemological underpinning used to draw conclusions of causality is misplaced in this instance.

Several case studies have also derived 'singular' causal factors (*c.f.* Love and Li, 2000; Josephson *et al*., 2002). While such studies have attempted to provide a context to explain 'why' and 'how' rework arose, the views of those participants involved in the chain of events that lead to its occurrence are generally limited to specific points in time. Thus, the determination of causation is narrowly defined and potentially leads to bias being reported. Construction researchers have defined the 'root cause' of rework as a point in a causal chain which facilitates intervention that changes performance and/ or prevents an undesirable outcome. However, 'the root cause' often merely represents the place in a point of time where a researcher decided to complete their investigation (Dekker, 2002; Hollnagel, 2004; Dekker, 2006). Consequently, sub-optimal rework-mitigation solutions have been identified (Love *et al*., 2011a). This arrogant certainty of science has allowed notions to be constructed about rework yet the means of actively reducing it alludes the scientific community (Love *et al*., 2015b,c).

Human Error and Rework

Rework predominately arises due to human error, such as mistakes (rule or knowledge based), slips and lapses of attention, and acts of omission and commission (Love and Josephson, 2004; Love *et al*., 2011a; Love and Li, 2000; Taggart *et al*., 2014). However, many rework studies have not consulted the error literature to understand why people performed the acts that lead to their occurrence and how they could have prevented the event from occurring (e.g. Ye *et al*., 2014; Kakitahi *et al*., 2014; Jingmond and Ågren, 2015).

Observations of the conditions contributing to human error are drawn from Love *et al.*'*s* (e.g. 2009b; 2012a,b) phenomenological research and are presented in Table 1. Two observations are repeatedly identified by Love and his colleagues; namely: (1) people breaking rules because of the belief that such augments efficiency, which is akin to procedural violations and omission errors;

and (2) organizations breaching specified work practices and procedures. When combined with project delivery strategies (that are risk averse for clients and place emphasis on competitive tendering), the propensity for risk-taking by consultants and contractors increases in order to maximize both their margins (Love *et al*., 2011b).

Ford and Sterman (2003) provide an invaluable insight into what transpires when rework negatively influences an organization's bottom-line and suggest that employees may conceal it to avoid informing managers of 'bad news' and/ or present information that does not adhere to their beliefs. According to Ford and Sterman (2003) the practice of hiding mistakes is institutionalized in many organizations and is akin to an error or omission. In fact, Roth and Kliener (1996) observed a cultural mandate within engineering organizations of not informing people about problems unless solutions are forthcoming. Thus, concealing problems becomes standard practice (Ford and Sterman, 2003) which results in a 'Prisoner's Dilemma'. This wall of silence enables project team members to abrogate their direct responsibility thereby preventing any form of reprimand from their immediate manager. Regards the Prisoner's Dilemma scenario, managers may question team members about project's progress without being provided with all the necessary information. Team members can: *"cooperate with one another by concealing the problems that they know exist, or defect by revealing"* the issues that need to be addressed to the project manager (Ford and Sterman, 2003:p.215). If the project team members cooperate by concealing known problems, project costs and schedule will remain the same and they avoid blame. Revealing problems caused by others, may increase project cost and could led to schedule slippage, giving them the opportunity to attend to these issues. However, most people are reluctant to become a 'whistleblower', given the the acrimony attached to such activity.

Table 1. Observations of the conditions contributing to human error

Observation	Comment
• No one had a clue, they had different understandings of the same event	Parties involved in a rework event all had differing opinions as to 'how' and 'why' it occurred, as demonstrated in the example presented in Table 1. Basically, what may be apparent to one individual will differ to another. People select information to make sense of a situation as they perceive it to occur. It is deemed to be easier for people to seek confirming evidence for their current undertstanding than to test it and risk having to invest in significant time and effort in devising another explanation.
• People filter out most of the information around them	In this instance, people are only interested in the information required to undertake their task. If information is missing, then they may request it, though this will often depend on the 'level'

	that is required. People possess a hierarchy of mental filters and thus select the information that best suits their needs.
• Cultural differences increase the likelihood of different interpretations of the same event	Differing parties involved in a delivery of a project have differing goals and objectives which are crafted as a result of their organization's culture. What is considered relevant to one person may not be relevant to another as a result of the task they are undertaking and thus socio-political and organizational pressures can shape their perceptions and memory of an event.
• Problems arise when the goals of people in the same organization start to diverge	Organizations involved with delivering construction projects tend to have differing goals. A lack of understanding of each participating organizations roles and capabilities leads to divergence and problems arising.
• People break rules to make work more efficient	Time and cost are innate features of construction projects. Thus, within this context people make trade-offs between efficiency and thoroughness, which is guided by the experience and training a person has been given.
• People's decisions are a trade-off between the available information and the available time	People often do not have enough time to complete their tasks. As a result, they rely on an alternative approach to produce the best decisions using the available nformation within the time they have. In addition, within construction there is a great deal of uncertainty and complete information is often not made available.
• People make mistakes. Organizations make it possible for the mistakes to be really serious	Inadequate time, design, staffing and the lack of good management that contribute to errors may combine to make a situation even worse. For example, building failure, which may result in injury or even deaths.

For reasons of self-preservation, it is better to allow other project team members to be blamed for the cost and schedule overruns that may occur. Should all team members reveal the problems known, project costs increase and the schedule slips, but all are apportioned blame from management – a *lose-lose* outcome for all. Refusing to admit to a negative outcome and to continue a course of action can contribute to rework and is referred to 'defensive avoidance' (Love *et al*., 1999; Janis and Mann, 1977). Shaw (1981) provides several explanations for this phenomenon. First, people pursue a course of action in spite of negative feedback; this suggests that people value tenacity, or perseverance, as they generally admire those who stick to their principles (Shaw, 1981). Second, people will forsake a more rational approach to difficult decision situations out of the concern with establishing consistency, a valued characteristic.

Systemic Approach

The identification of singular causes (which in most cases only describe the proximal causes i.e. those nearest in time to the event) is counterintuitive, as rework causation can only be understood by considering the whole project system holistically and how variables dynamically inter-react (Taylor and Ford, 2006; Aljassmi and Han, 2013; Han *et al*., 2013; Li and Taylor, 2014). Causality governs the relationship between events and its formalization enables a system to be constructed that has a set of observable causal variables (Goodman *et al*., 2011). Techniques such as Cognitive Mapping (CM) and System Dynamics (SD) have been used to observe the behavior and determine the interdependency of causal rework events. However, these techniques have limitations and therefore an alternative epistemological underpinning to examining this phenomenon is proposed in this paper. Prior to introducing this alternative agenda, systemic approaches presented in the literature are first examined.

Cognitive Mapping

Cognitive mapping (CM) enables people to process their environment, solve problems and use memory. It is derived from Kelly's (1955) theory of personal constructs, which suggests that: *"we make sense of the world in order to predict how, ceteris paribus, the world will be in the future and to decide how we might act or intervene to achieve what we prefer within that world: a predict and control view of problem solving"* (Ackermann *et al*., 1992: p.1). Operations Researchers have extensively used this qualitative technique as a tool to construct, organize and analyse data related to project performance and disputes by enabling a structured account of the problem to be created (e.g. Ackermann *et al*., 1997; Williams *et al*., 2003; Ackermann and Eden, 2005; Ackermann, 2012). In addressing issues associated with project performance and disputes, rework was identified as major contributor and has been accordingly mapped. However, creating a cognitive map for rework is a time-consuming process for the person charged with undertaking the task of comprehending information presented, typically in an interview or focus group format, while having to simultaneously remember the guidelines required to produce the influence diagram. As a result, salient issues that contributed to events that lead to the rework event may be overlooked.

While CM provides a graphical structure for addressing the 'messiness' associated with understanding rework causation, a number of factors such as cognitive perspectives, cognitive reference points, and the specific rotation to a frame of reference, can distort the memory and judgment of the person being interviewed (Tversky, 1993). Hence, when utilizing CM it is important to obtain multiple views that can explain the rework events occurrence (Tversky, 1993). Addressing this issue may create an overly complicated diagram that is difficult to understand, particularly for practitioners who may have limited knowledge of the concept. Notwithstanding this limitation, CM is a useful tool for understanding the complexity associated with rework causation (Jingmond and Ågren, 2015).

System Dynamics

System dynamics (SD) has been used extensively to model the dynamic and complex nature of projects, particularly errors and rework (e.g. Lynies and Ford, 2007; Han *et al*., 2013). Both the qualitative (e.g. influence and causal loop diagrams (CLD)) and quantitative (e.g. stock-flow and simulation) dimensions of SD have been utilised to develop models that explain the behavior and impact of rework on project performance (Ackermann *et al*., 1997). Copper's (1993a; b) influential work provided the platform for examining the systemic nature of rework and is core to understanding how SD is applied to projects. The 'Rework Cycle' provides a description of workflow that incorporates rework and undiscovered rework. Work rate is determined by staff skills, productivity and availability, and as project time advances, the amount of work remaining reduces. Work is then completed to a specified standard or becomes undiscovered rework that contains errors that have yet to be identified but are perceived to have been undertaken. Latent errors are often not immediately identifiable and only transpire after a period of incubation in the system. After some time these errors are eventually detected, or they arise in due course and rework is identified, which increases the amount of work to be undertaken (Cooper, 1993; Rodrigues and Williams, 1998). Akin to CM, CLDs have invariably been based upon interview data and thus a participant's memory and judgment is predominantely relied upon to give an account of what transpired. Moreover, conditional statements are used to create an association or determine an influence and while plausible, the issue of causation remains an unaddressed issue. A lack of real life industry specific data (such as design errors) to create and simulate the dynamic nature of rework using stock-flows also diminishes the accuracy, validity and reliability of SD models (Tombesi, 2000).

Context: Judgement and Counterfactual Alternatives

When constructing graphical causal diagrams, it should be noted that people's thoughts about the causal relationships between rework events influence their judgments of the plausibility of 'counterfactual alternatives'. Equally, their 'counterfactual thinking' about how a situation could have turned out differently can change their judgments of the causal role of events as well as those responsible (Roese and Olson, 1995; Roese, 1997). Yet according to Bryne (2005) identifying the cause of an event and the counterfactual thoughtdo not always correspond. This is due to participants in projects distinguishing between the various type of causes and making different inferences from dissimilar causes (Miller and Johnson-Laird, 1976; Love *et al*., 2015a). In addressing this shortcoming, a contractor, who is preparing a rework claim may sieve through the available evidence and look for fragments of information that seem to point to a common cause in developing *a priori* explanation. While this approach is common, it is also problematic as (Dekker, 2006) notes:

- details that are relevant to explaining the actions and behaviors of people can be overlooked; and

- the information collated is meaningless outside the context where it originated. Invariably the pieces of information obtained are combined with those of a similar nature, though it may have its own context and *raison d'etre.* In fact, when the data was produced it may be divorced from other fragments of information which it has been combined with.

Taking information out of context by selecting and combining it together in hindsight or micro-matching it with a view that the contractor knows now to be true is misleading as the original context and meaning becomes redundant and a new sense adopted. The construction of a rework 'cause' is dependent upon the experience and views of those who are involved with the event. For example, Love *et al*. (1999) sought to explain 'why' and 'how' the pitch of a structural steel framed roof for a residential building failed building regulations and subsequently had to be re-designed and re-engineered. Drawing from the vignette presented in Love *et al*. (1999), the differing points of view as to the contributing causes of rework, from the perspective of the contractor and architect, are presented in Table 2.

Table 2. Differing points of view: Contributing causes for the same rework event

Contractor	**Architect**
• Errors in contract documentation provided by the architect • Inadequate design audits and design review by the architect and structural engineer • Inadequate use of technology to coordinate the architectural and engineering design • Over-reliance by the architect to ensure the contractor would identify errors prior to construction	• Limited time provided by the client to document the design • Structural engineer's design did not 'actively' coordinate and integrate with the architectural design • Workload increase due to discrepancies in the architectural and structural engineering drawings • Contractor did not plan and coordinate works on site with other trades

Unsurprisingly, the factors identified by both parties contributed to the rework that materialized but in this instance, the parties may have selectively chosen those that have contributed to the event. Invariably socio-political, cultural and organizational pressures rather than the context within which they arose may have driven their selection in this instance. Considering this scenario, Dekker (2006) suggested that a: *"cause is not something you find. Cause is something you construct. How you construct it and from what evidence, where you look, what you look for, who you talk to, what you have seen before, and likely on whom you work for."*

Understanding of Causation: Issues and Challenges

Studies examining rework causation have not been based upon a theory. The establishment of relationships have been based upon people's innate ability to infer the causal structure of a project system is derived from the individual's organisational culture and relationships. As for any inductive task, causal inference is an ill-posed problem: the data that is viewed undermines the true causal structure (Tenebaum and Griffth, 2003). This is a statistician's dilemma as a 'correlation does not imply causation'; a mere association exists (*ibid*). The assumption, that correlation proves causation, is considered to be a 'questionable cause fallacy' whereby two events occurring together are taken to have a cause-and-effect relationship (Cavender and Kahne, 2010). Essentially, a causal connection is assumed without proof. This fallacy is also known as *cum hoc ergo propter hoc*, (i.e. *"with this, therefore because of this"*, and 'false cause' A similar fallacy whereby an event that follows another is necessarily a consequence of the first event, is described by Damer (1995) as *post hoc ergo propter hoc* (i.e. *"after this, therefore because of this"*).

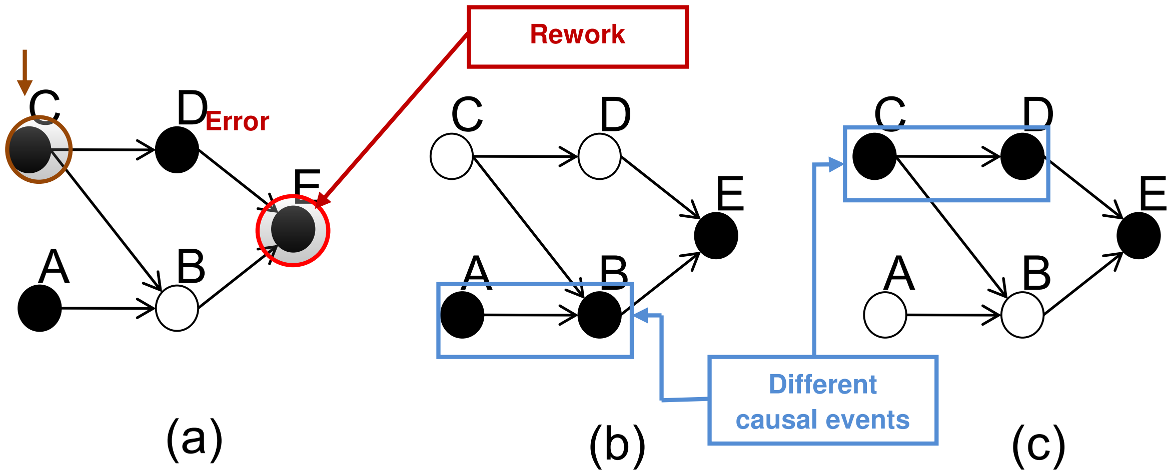
A range of causality theories are categorized according to the way they address key questions (e.g. Russell, 1913; Salmon, 1998; Pearl, 2000; Hitchcock, 2012; Williamson, 2009). One question often posed is 'are the causal relata single-case or generic'? A philosophical theory of causality might hold that a cause or effect concerns a single occasion and so either obtains or fails to obtain, for example, an contractor's presentation of a claim to a client may cause them to a great deal of angst. Alternatively, it may hold that causes and effects can obtain and fail to obtain on different occasions: errors cause rework. In the former case, cause and effects are called *single-case*, *particular* or *token-level* and for the latter, they are *generic*, *repeatedly instantiable* or *type-level* (Williamson 2009). Another perspective of causation examines the causal relata at the individual or population level (*ibid*). At the population-level, a cause or effect concerns a group of individuals, for example, an increase in the number of change-orders in a project causes a reduction in the project team's morale. The individual-level cause or effect concerns only one person at a time, for example, long working hours causes stress. According to Williamson (*ibid*): *"such causal relata occur in our causal claims, so any theory that considers one kind to the exclusion of others provides only a partial account of causality."*. With this in mind, the causal relata of a rework event should then be determined from the perspectives of the individual, organization and project through an epistemological lens that accommodates varying perspectives to provide a thorough and balanced account of its causation.

Several questions have also been raised concerning the causal relationship itself. For example, *"is causality some kind of physical connection between cause and effect?"* or is "it purely mental in the sense that it is a feature of some individual's epistemic state?" (Williamson, 2006a,b; Williamson, 2009). Other questions seek to address *"whether causal relationships are objective?"* or "does the theory in question attempt to understand actual or potential causality"? In the former case, if two agents disagree to causal relationships, then at least one of them must be wrong or is it subjective, admitting a degree of personal choice? (Williamson, 2009). In addressing the latter, the general case is referred to as *potential* or *possible causation*, while the factual is called *actual causation.* Such questions are pivotal to the on-going discourse about the philosophical theory of causality.

A prominent approach to the study of causation has been to analyze it in terms of counterfactual conditionals (Paul, 2009); these represent a subjunctive conditional sentence, whose antecedent is contrary-to-fact (Hitchcock, 2012). For example *"if a structural engineer had not specified reinforcement in concrete column, the building would have not collapsed."* In the case of indeterministic outcomes, it may be appropriate to use probabilistic consequents: *"if a structural engineer had not specified reinforcement in the concrete columns, the probability of the building not collapsing would be 0.1."* Several studies have analyzed causation in terms of such probabilistic counterfactuals (e.g. Balke, 1995; Di Tillio *et al*., 2012; Schacter *et al*., 2013). However, counterfactuals refer to specific events at particular times, thus such theories of causation are singular in nature (Hitchcock, 2012). Consider the research of Ye *et al*.(1994) where the relationship of *"poor communication path of project instructions"* with rework, implicitly assumes causality in terms of counterfactual dependence of the effect on the cause: the cause is rendered counterfactually necessary for the effect (Love *et al*., 2012). Ye *et al*.'s (2014) presupposition infers that if poor communication had not occurred, then the rework would not have ensued. Causality can be defined by reference to a causal chain of counterfactually dependent events, where a sequence of events (*C*, *E*, *F*, ...) is a chain of counterfactual dependence if *E* counterfactually depends on *C*, *E* counterfactually depends on *F*, and so on. Lewis (1973) asserted that *"one event is a cause of another if and only if there exists a causal chain leading from the first to the second."*

Various forms of counterfactual dependence have been adopted through the application of structural equations (e.g. Hitchcock, 2001) whereas limited studies have applied structural equations to examine the causal factors that contribute to rework (e.g. Love *et al*., 2009a). While such studies have provided a valuable contribution to understanding causal inferences through generalization, they have not provided a nomologically possible context. Such context would provide detail about how events unfold according to an underlying 'event theory', a set of background laws that define the outcome of events (Bell, 2004; Bell, 2007).

Figure 1 illustrates three nomologically different contexts where strategic misrepresentation *A* and/ or optimism bias *C* could give rise to a cost and/ or time overrun *E*. Each node represents an event. In this instance the occurrence of event *A* or *C* or both (at some implicit point in time) is the cause of the occurrence of event *E* (at a later point in time). In the context of (a), *C* and *D* are proximate (as are *A* and *D*), and *C* and *E* are remote. The occurrence of *C* stimulates *D*, in this case a error, but inhibits *B*. The occurrence of *D* then results in *E* (i.e. rework). Besides, poor communication or inappropriate use of technology (Ye *et al*., 2014), pathogenic influences can give rise to *C* and *A*, which can then trigger a series of events that result in *E*, rework (Love *et al*., 2012).



Adapted from Love *et al*. (2012b)

Figure 1. Nomologically different contexts each represent a different history

Nonetheless, it has been widely acknowledged that Lewis's theory (*c.f.* 1973) possesses several limitations (Menzies, 2014):

- *Context-sensitivity* – assumes that causation is an absolute whose nature does not vary from one context to the another. According to Lewis (1973) every event has an objective causal history consisting of a vast structure of events ordered by causal dependence. Hence, the human mind may select parts of the causal history for attention, perhaps different parts for different purposes of enquiry.
- *Temporal asymmetry* – assumes that time is fundamentally asymmetrical and there is a profound difference between the past and the future. Even if the notions of 'cause' and 'effect' are stripped of their directional bias, there is no evidence to suggest that the resulting causal relation is always exemplified asymmetrically in time. As a result, this difference is in no way indicative of a qualitative difference between the direction of time from earlier to later and *vice versa*.
- *Transitivity* - assumes chains of causal dependence to ensure causation is transitive; a key focus of counterfactuals. However, other possible events that do not have a direct cause are not addressed and therefore the issue of preemption is not addressed; and
- *Preemption* – is the root idea of causation. However, preemption does not explain how a preempting cause qualifies as a 'cause' when the effect does not causally depend on it. This

is akin to the example presented above that discounted the notion of identifying a root cause for rework.

Menzies (1989) proffered a revision to Lewis's original theory (1973) by specifying attention to the continuous processes that are linked to causes and effects. This account is designed to handle cases of probability-raising from non-causes. Menzies (1996) concedes that this account remains problematic with certain types of pre-emption, and discarded it opting in favor of causation as a 'Concept of a Theoretical Entity', which treats it as an intrinsic relation between events. Thus, causation is defined by Menzies (1999) as: *C* causes *E* only if the intrinsic relation that typically accompanies causal dependence holds between *C* and *E*. In dealing with preemption and additional problems that relate to causes that affect the time at which an event occurs, Noordhof (1999) developed a counterfactual probabilistic '*ceterbis parabis'* theory where causes increase the probabilities of their effects. Building on this theory, Schaffer (2000) provides an explanation attending to causes that raise the probability of specific processes, rather than individual events, which have been motivated by the problems of preemption and probability-lowering causes.

To address the limitation of Lewis's (1973) theory, Lewis (2000) developed a 'Theory of Causation as Influence', although it does not accommodate deterministic causation and so does not address probabilistic pre-emption (Menzies, 2014). The central notion of the Lewis's (2000) 'Theory of Causation as Influence' is expressed as:

> Where *C* and *E* are distinct events, *C* influences *E* if and only if there is a substantial range of *C*1, *C*2, … of different not-too-distant alterations of *C* (including the actual alteration of *C*) and there is a range of *E*1, *E*2, … of alterations of *E*, at least some of which differ, such that if *C*1 had occurred, *E*1 would have occurred, and if *C*2 had occurred, *E*2 would have occurred, and so on.

Where one event influences another, there is a pattern of counterfactual dependence of *whether*, *when*, and *how* upon *whether*, *when*, and *how*. In this instance causation is defined as an *ancestral relation* whereby *C* causes *E* if and only if there is a chain of stepwise influence from *C* to *E*. An ancestral relation is essentially a relation that stands to another as 'ancestor of' stands to 'parent of': an ancestor is a parent, or parent of a parent, and so on (Frege, 1879). However, the counterfactuals employed in Lewis's (2000) new theory do not state dependences of *whether* one event occurs on *whether* another event occurs. Instead, the counterfactuals state dependences of *whether*, *when* and *how* one event occurs on *whether*, *when*, and *how* another event occurs (Menzies, 2014). A key idea underpinning the formulation of these counterfactuals is that of an *alteration* of an event. This is an actualised or unactualised event that occurs at a marginally different time or in a dissimilar manner from the given event. Menzies (2014) states that an alteration is a fragile event that could not occur at a different time, or in a dissimilar manner without being an altered event. Lewis (2000) intended that the derived terminology be neutral on the issue of whether an alteration of an event is a version of the same event or a numerically different event. Notably, Lewis's (2000) new theory does accommodate cases of late as well as early pre-emption and therefore addresses, only to some extent, the issue of temporal asymmetry.

Through counterfactual thinking, people can reason how past changes affect the present and use such reasoning for cognitive tasks including social judgments, causal attribution, problem solving and learning (Roese, 1997; Byrne, 2002). Kahneman and Tversky (1982) suggest that people reason counterfactually by using a 'simulation heuristic', whereby events are altered in their mind (via recurrent ruminations) and a simulation run of how things would have gone otherwise, given these changes. A point to consider at this juncture is the 'conjuction fallacy' whereby people tend to assume specific conditions are more probable than a single general one (Kahneman and Tversky, 1983), rendering the complex task of assessing probabilities and predicting values to judgmental operations (Kahneman and Tversky, 1982). The subjective assessment of probability, often aligned with the use of qualitative diagrammatic aids such as CM and CLD to explain and examine rework causation are based on data with limited validity and therefore processed using heuristic rules and baises (Tversky and Kahneman, 1974).

The preceding discussion, illustrates that research examining rework causation is immature and lacks a robust theorectical foundation, which has therefore inhibited its reduction in construction and engineering projects. A significant amount of ambiguity prevails as to 'why' and 'how' rework occurs, its causal structure and ways in which to effectively contain and reduce its occurrence.

Implications for Research

Science aims to determine whether a set of axiomatic events or propositions can be accepted as true and validate the complex facts that establish causal relationships. According to Wold (1954) *"the concept of causality is indepensablee and fundamental to all sciences."*. Yet, in the pursuit of determing rework causation, a lack of a theorectical foundation or acknowledgement of complexity associated with its context, temporal asymmetry, transitiveness and preemptive nature has stagnated research and discernable improvements in practice. Future research should therefore place emphasis on establishing the counterfactual relationships between may exist between conditions. The notion of pathogenic influences providing the conditions for rework to materialize provides the basis for the use of counterfactual causation (Love *et al*., 2009b). The limitations of Lewis's (2000) theory, need to be considered together with the heuristic rules and biases that form an integral part of people's consciousness. In accommodating these issues, it is suggested that the development of theory based upon probabilistic causation and generalizations could provide underlying impetus to establish a setting for rework causation to be determined. Explicitly, to understand causal generalizations, there is a need to understand 'how' and 'why' participants in projects generalize about the rework they encounter and the circumstances that lead to its occurrence. Hence, the metaphysical task is to clarify the causal relevance of variables within homogeneous contexts (Hausmann, 2010). The works of Noordhof (1999), Williamson (2009), Hausmann (2010), and Di Tillio *et al*. (2012), provide fundamental building blocks for testing and developing a probabilistic theory of rework causation.

To generate generalizations for rework, however, it suggested that epistemological-based notion of sensemarking (Weick, 2001) can provide essential information needed to unearth probabilistic causation. Sensemaking is retrospective and grounded in identify construction and thus can be used to re-conceptualize and re-contextualize people's mechanistic and positivistic notions of the social reality that lead to rework (Love *et al*., 2015a). By gaining an understanding of the individual's role and views, plausibility extends beyond immediately observable phenomena; an attempt in this instance is made to fit together the evidence available to complete a puzzle despite not having some of the pieces. Thus, it is necessary to acquire multiple viewpoints from the causal chain. Obtaining such views will be a time-consuming, yet necessary validation process that will assist in the development of new theory. Without a valid and reliable theory of probabilistic causation, or variant thereof, for rework, empirical induction cannot provide researchers and practitioners with the needed rules to reject causal relationships and develop effect rework mitigation strategies.

Conclusion

This paper sought to highlight that the determination of rework causation research conducted to date, has had limited theoretical underpinning and is conceptually flawed. Having a theory to explain rework causation serves as a benchmark upon which the means of effectively mitigating its presence can be developed for construction and engineering projects. Relating to a theory of rework causation, may increases its ability to solve other problems in different times and places.

The comprehensive literature review conducted demonstrates that research into rework causation has stagnated. Factors identified decades are still being identified, yet rework remains a prevailing and chromic problem. Tools such as questionnaire surveys used to identify and rank a list of single causal factors have contributed to this stagnation because they provide no explanation of causality; thus, it is recommendation a moratorium being placed on such studies. Moreover, recent research has discounted the notion that rework causes arise from a chain of causal conditions and a seemingly counterfactual in nature with pathogens providing being preemptive. The limitations of assuming counterfactual causation are identified and thus need to be accommodated in a theory that can explain rework causation.

The braiding of an epistemological-based notion of sensemaking with probabilistic causation accommodates both the qualitative and quantitative aspects of rework causation needed to develop a balanced and robust theory. Future research should place emphasis on constructing a theory that can accommodate nomologically different contexts but also be generalizable and parsimonious. This is and will continue to be a challenge, but this paper provides the valuable insights needed to move research forward in rework causation.

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