DYNAMIC TEMPORAL RISK ALLOCATION IN COMPLEX HAZARD MANAGEMENT

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Abstract

Dynamic temporal risk allocation (DTRA) has been used in other research domains, notably in the predation theory on prey animals as part of ecology research and risk management in economic markets, as part of financial research. In both cases risk has been judged in the temporal domain. When a new sub-system is added to any complex system – ecology, finance or transport, it brings with it some residual risk. Its insertion into the system-of-systems brings another hazard source to the risk profile. However, the overall risk may be judged to remain broadly the same because the new source cannot bring a new temporal unit of risk exposure – it has to replace some other item's temporal unit. The existing research on this subject in parallel domains needs to be brought to the safety industry domain to be reviewed for value and benefit.

1 Introduction

Fixed risk apportionment of a risk budget across the entities that make up complex system-of-systems is a difficult process to go through, involving multiple analysis steps including event-tree analysis, fault-tree analysis and expert judgement. The determination of key binary characteristics and the yes/no probabilities can be difficult to carry out, explain and provide auditable evidence of suitability and proportionality. The results can sometimes be very sensitive to relatively small changes in probabilities. It also becomes increasingly difficult to justify when new sub-system items are added, swapped or replaced to the system-of-system capability. Significant re-work can sometimes be required to re-apportion the risk budget when 'n' sub-systems become 'n+1' or 'n+m' sub-systems.

One method of utilising risk allocation that appears to be very suitable to a complex system is the concept of DTRA, where each item in the system composition receives one packet of fixed, equally sized risk budget of the whole system. The number of equal risk packets 'p' is significantly less than the number of sub-systems 's', expressed as $p \ll s$. It is the number of items influencing the total risk that varies dynamically with time rather than acting together in accumulation. Similar concepts have been used in other research domains, notably in the predation theory on prey animals [2, 5] and risk management in economic markets [1, 3], where risk is judged in the temporal domain. The rest of this paper discusses the application of DTRA to the safety domain by drawing on its use in other research domains.

2 Temporal Risk Variation in Ecology

It is an unavoidable aspect of nature that individual prey animals experience temporal variations in predation risk. Predator presence varies routinely with seasons, moon phases and on a moment-to-moment basis [2]. However, until recently no theory in ecology had focussed explicitly on the effects of dynamic temporal risk variation on the behaviour of the prey animals. It is suggested that because theory and experiments had not addressed these temporal effects, standard protocols for considering risk might systematically err in estimating the importance of predation risk in nature [ibid.].

There have been hundreds of experimental studies [ibid.], which have been used to quantify the effects of predators on prey behaviour. Most studies have shown strong relationships between increasing risk and prey behaviour in terms of refuge use, feeding, vigilance and mating. But few studies have gone on to look at the temporal variation in predator presence modifies prey behaviour For example, exposing the prey to predator risk for brief pulses of threat after long periods of no-threat, or using higher frequency threats, or even long duration medium threats from multiple predator types [ibid.].

There are several concerns on the research in this area of ecology [ibid.]. The current risk allocation hypotheses make several simplifying assumptions e.g. there are thresholds beyond which there are no further (lower-risk) benefits; and that the prey animals have a perfect knowledge of the residual risk situation at all times; and that response to the addition and withdrawal of predators is the same and rational [ibid.]. These perhaps over-simplifying assumptions transfer all too well into the human safety domain, so it might appear reckless to adopt a DTRA concept. However, it is clear that dynamic risk is a real factor in the natural environment and there may be strong benefits by researching this area.

Research in this area of ecology has been in progress [5], where models have been developed based on the concept that prey adaptively allocate their foraging and anti-predator efforts across high- and low-risk situations, depending on the duration of high- vs. low-risk situations and the relative risk associated with each of them. A predictable risk should lead to prey displaying minimal vigilance behaviours during predictable low-risk periods and the strongest anti-predator behaviours during risky periods. Conversely, an unpredictable predation risk should result in prey displaying constant vigilance behaviour, with suboptimal foraging rates during periods of safety but anti-predator behaviours of lower intensity during periods of risk [ibid.].

The referenced research has shown that frequency of risk (i.e. exposure to alarm cues) is an important variable influencing the behaviour of prey animals (in this case it was cichlids – a type of fish). It was found that cichlids exposed to the high-frequency risk environments responded with a lower intensity of anti-predator response than those in the low-frequency environments. Moreover, when given predation cues, cichlids in the low-frequency treatments reduced their foraging effort more than cichlids in the high-frequency treatments. These responses are consistent with the behaviour predicted by the research model [ibid.].

3. Temporal Risk Variation in Economics

Many economic-based service providers face the problem of meeting instantaneous and variable performance demands; several services embed a high cost of non-delivery [3]. The parallels with the safety industry are surprising.

Wholesale power is increasingly being produced and traded via exchanges as an energy commodity, but its dynamic characteristics and risks are fundamentally influenced by its use and delivery as an essential service to consumers. As a consequence, with companies facing substantial uncertainties about their operations as well as costs, the development of optimization models that allow managers and duty holders to make appropriate production and trading decisions to maximize their benefits within specific risk constraints, presents an exceptional situation for analysis [ibid.].

In risk management in this financial domain, much of earlier research has focused on extreme risks that are often related to "maximum amount of money that may be lost on an investment portfolio over a given period of time, with a given level of confidence" [ibid]. Much of the research has been undertaken by applying use cases to existing market data and using this to predict the future performance of a given market situation.

Much of the understanding of financial risk management is based on static models that describe how various capital market imperfections give companies the incentive to manage and reduce risk [1]. However, they provide few predictions about how firms utilise the incentives to actually manage the risk into useful decisions on the choice of risk management strategies and importantly, how these strategies dynamically morph over time. Treating risk as a static dimension restricts the opportunity to recognise the potential value of dynamic risk management as the market conditions and operating characteristics change – sometimes rapidly.

Modelling of dynamic risk is seen with great importance in the economic world and efforts have been made to develop a continuous-time, infinite horizon model of an electricity supplier that can then be allowed to endogenously and dynamically adjust its risk management strategies and financial contracts [ibid.]. The strategies are driven by the need of the shareholders to maximise the value of their equity stake.

In these financial risk models the hypothetical firm can enter into or withdrawal from a risk management position in order to reduce risk related to the product's future priced uncertainty. The risk management contract guarantees a predetermined price for some proportion of the firm's future product. This is the 'hedge' ratio and it is used in financial domains to offset future undesired impacts – in the safety domain we would call them – accidents!

Again there are several concerns relating to the simplification of the risk management models in this area of research. The modelled firms do not themselves change dynamically with time – they do not grow or contract, i.e. all profits are paid out in dividends and not re-invested. One of the models researched on a gold producer only allowed a single risk management strategy in any one time unit [1]. The other researched model on electricity supplies [3] allowed variable sizes of commodity to be traded, where as in the real market there are usually fixed sizes of energy packets available.

The financial research reviewed indicates that while static models do provide some valuable insight as to why firms need to manage risk, the dynamic modelling generates many new implications and research areas as compared with the static models [1]. The researchers propose that their dynamic risk model could serve as a basis for developing normative decision support tools for practitioners of financial risk management strategies [ibid.].

The model on the electricity commodity firm indicated that the dynamic optimization method is much more efficient than periodic optimization or fixed allocation for risk management. In their hypothetical extrapolation of the results to the national level in Finland, they suggested that dynamic optimization (instead of fixed allocation) would result in savings of approximately 200 million Euros annually [3].

4. Benefits of Dynamic Temporal Risk Allocation in Safety Engineering

The extensive research programmes underway in other scientific domains would seem to indicate that a dynamic approach to risk has some benefits.

The ecology-based research indicates that risk is a dynamic property in nature, and that it is dynamic with respect to time.

Thus allowing risk assessment models to include the temporal dynamic variables creates a closer match between the models and actual empirical observation i.e. the models are constructed correctly and are constructed of correct elements. This is a close definition of the models becoming valid and verified. The benefits of using a dynamic approach might also mitigate a systematic error is the static treatment of risk [2, 5]. The goal of this domain's research appears to be a better understanding of the character of risk as a natural science, rather than for financial or human safety benefits.

The financial modelling of dynamic risk has a very specific purpose – to increase net wealth, but it appears to do this through reduction in loss rather than increase in income. The financial research also indicates that risk is a dynamic property of financial markets, and also suggests that it is dynamic with respect to time. The benefits highlighted are the provision of more accurate models such that there is better (investment and purchasing) decision support in financial trading. Further that the dynamic-based models offer a more efficient use of resources such that significant savings in costs can be made in a future purchase stream [1, 3].

5. The Wider Use of Dynamic Temporal Risk Allocation

One area where DTRA has already been presented is in the defence arena where military operations are built up from multiple service systems which are added to and taken away from the operational use case as the live operation dictates. That is to say, as the operational picture changes dynamically with time, so does the residual risk profile [4]. The programme it was linked to was to assess and procure a network enabled capability to integrate multiple sensor products in order to provide actionable data and to provide interoperability between UK and coalition assets, whilst enhancing situational awareness and contributing to the development of the Joint operational picture.

Instead of allocating a fixed risk packet from an overall Health and Safety Executive-derived target that has been spread arbitrarily and equally among 'n' elements with risk, the quantitative targets were developed using a temporal unit much shorter than the operational mission that allowed dynamic re-allocation of risk among the network elements actually providing risk to the operation, in that time packet. So, within the use cases developed to carry out programme assessments and option choices, the risk profiles could be better used as decision support measures. For example, one of the use cases involved some 25 assets in a coalition network across the military sensor-to-shooter operational profile. A traditional fixed budget risk allocation could have started by giving each asset 1/25 of the total risk budget. However, when the operational profile was assessed in the time domain, with the ∂t interval much less that the overall T for the mission, it became obvious that only around half of the mission assets could influence the risk in any ∂t interval. So a more appropriate risk budget could be given to each asset that was judged to provide a residual risk to the whole use case. This provided the justification for why the total risk budget could be shared out in <n packets; why the total summed residual risk of all elements that could make a contribution to the whole coalition network risk, was greater than the overall risk target; and, why the various elements could be tolerated with higher risk profiles.

There is also opportunity to utilise this concept in the domain of societal risk. Insurance companies are already aware of the temporal analysis of risk. Cheaper insurance is offered for less risk exposure as measured in the temporal domain – number of days skiing, length of non-occupancy of a house and even the number of years of no-claims!

As societal risk becomes more of a political issue, with pandemics, terrorism and climate change, there is an ongoing discussion in Government think tanks [6] that there should be a more unified approach to managing societal risk, using the temporal domain as the main risk measuring unit.

6. Cautionary Notes

In the more generic sense, DTRA could lead to a more efficient use of risk budgets across a much wider industry domain. However, the assumptions cited in the referenced research give pointers to the areas where the use of this concept is unproven or too complicated at present.

This would include assumptions based on full knowledge of the dynamic risk profile, as in the ecology prey animals; the use and knowledge of the effects of multiple mitigation strategies, as in the gold producer; and the existence of multiple (and often conflicting) requirements, rather than a single need of increased wealth or finding enough food. The ecology research gets closer on this last point, as in nature there are conflicting requirements on time – feeding, sleeping and mating and yet they are linked in that without enough food or sleep the animal will not have enough energy to find or fight for a mate.

7. Conclusions

It is the author's opinion that the arbitrary apportionment of risk targets across a system, or system-of-systems, based on engineering judgement does usually works out OK. This uses a rough rule of thumb that engineers have thought about and discussed for a very long time, but not yet been able to identify any particular theoretical grounding for why this is acceptable. The use of DTRA might actually provide the basis for safety arguments using targets developed with some foundation of scientific principles, rather than on best 'guestimate'.

DTRA appears to hold significant benefits for efficient use of risk budgets. Other industries are showing competitive advantage is possible, and even natural if a dynamic approach to risk can be taken. This should provide the spur to additional research in this area.

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[6] See:
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