

We're trialling a new version of this page and we'd like your opinion.

[Take a look](#)



Article

Annals of Operations Research

February 2016, Volume 237, *Issue 1*, pp 281-300

First online: 10 February 2015



Optimizing enterprise risk management: a literature review and critical analysis of the work of Wu and Olson

- Yongrok Choi
- , Xiaoxia Ye
- , Lu Zhao
- , Amanda C. Luo

10.1007/s10479-015-1789-5

[Copyright information](#)

Abstract

Risks exist in all aspects of our lives. Using data in both Scopus and ISI Web of Science, this review paper identifies pioneer work and pioneer scholars in enterprise risk management (ERM). Being ranked the first based on the review data, Desheng Wu has been active in this area by serving as a good academic network manager on the global research network. His global efforts with diverse networking have enabled him to publish outstanding papers in the field of ERM. Therefore, this paper also conducts a literature review of his papers and critical analysis of the work of Wu and Olson, from the perspective of the ERM, to glean implications and suggestions for the optimization and customization of the ERM.

Keywords

Enterprise risk management (ERM) Risk elements W-O ERM model Value at risk (VaR) Customization

1 Background of the risk management analysis

Facing a great deal of daily environmental changes, we are exposed to new opportunities as well as threats. In this rapidly changing world, risks exist in all aspects of our lives, which can be viewed as threats in general. Nevertheless, businesses exist to cope with risks (Olson and Wu 2008). Since risks are rather difficult to quantify, different disciplinary research approaches have different ways of dealing with risks. Companies, in particular, are confronted with the need to accelerate their growth cycles as a result of increased production complexity, rapid technological changes, shorter product life cycles, and rapidly changing market trends. In order to handle these risks from an enterprise perspective, there are various studies dealing with enterprise risk management (ERM). Most of these papers analyze how to measure, control, and manage the inevitable risks that arise from environmental changes in an enterprise.

The concept of ERM was developed in the mid-1990s, with an emphasis on management. The ERM is a systematic and integrated approach to manage all risks that an organization faces (Dickinson 2001). This concept has gained popularity since the recent traumatic 9/11/2001 incident in New York, and the global economic crisis since 2008 (Baranoff 2004; Wu and Olson 2010c). Of late, sustainable management with certain level of risk constraints has become a core strategy for an enterprise to make profits in a rapidly changing economy. Risks in an enterprise should be, and can be, quantified and managed using various theories and modeling techniques.

Figure 1 presents the number of journal publications on “enterprise risk” since 2000. The trend figure was created by using the key words “enterprise risk” in both Scopus and ISI Web of Science. Data we used from Scopus is obtained by searching subject areas “Social Sciences & Humanities” and “health science”. Data we used from ISI Web of Science includes three data sources: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI) and Arts & Humanities Citation Index (A&HCI). All trend curves suggest that ERM have been popularized by the recent financial crisis during the last decade and continue to keep as a hot research area.

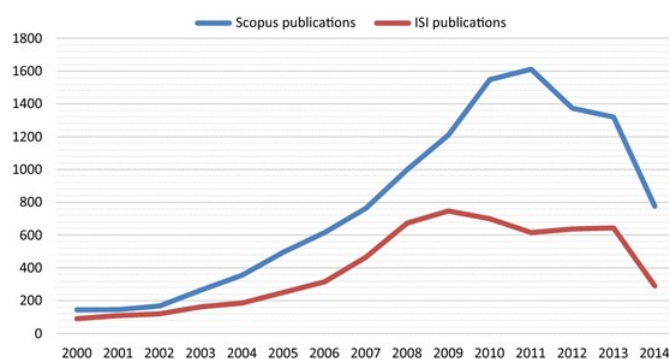


Fig. 1

Publication trends on “enterprise risk” since 2000

It is very interesting how the ERM theories applied across diverse fields can be systematically integrated into the general ERM theories. Among the proponents of previous research studies, Desheng Wu has made a concerted effort to promote ERM in diverse fields using different methodological approaches. In this literature survey, we do not only get an overview of existing studies on ERM in multiple disciplines, but also intend to systematically integrate most of Wu's papers surrounding the debate on appropriate risk measurement issues, and propose challenging suggestions from his research.

Desheng Wu has been a good network manager on the global research network. He has organized many international conferences on risk management and related fields. Based on this network, he took several guest-editors for the special edition on the same theme of the studies. His great efforts with global networking have enabled him to publish outstanding papers in the field of risk analysis and risk management. However, his research has been considered to be insufficient as most of his papers lack the categorical content for specific journals. Therefore, it is necessary to conduct a literature review of his papers, especially with regard to the ERM. As Choi and Lee (2009) state, the role of a network manager is important in terms of creating value for the good governance of the collaborative network. Therefore, the literature survey on the papers of Desheng Wu will shed light on the future challenges in the paradigm shift of the ERM.

2 Conceptual characteristics of enterprise risk management

In general, risk management is defined by the International Organization for Standardization (ISO) as a coordinated activity to direct and control an organization with regard to risk, where risk refers to "an uncertain event or set of events which, should it occur, will have an effect on the achievement of objectives". The most widely used ERM standard is defined by the Committee of Sponsoring Organizations of the Treadway Commission (COSO 2004) as follows:

Enterprise risk management is a process, effected by an entity's board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives.

The ERM is founded on the notion that companies can succeed on the basis of risk management, much as companies compete in terms of efficiency, costs, labor, location, and other dimensions (Walker 2013). The risks in the daily operations of a company seem much more definite, often catastrophic, and look more like shocks to the companies. Therefore, competing on risk management requires discipline, a commitment to using information, recognizing shocks, and acting upon them to redistribute assets (Walker 2013). Wu et al. (2010a) specify enterprise risks in detail by showing a cyclical interrelationship among these risks in Fig. 2, which shows that the source of enterprise risks could be external, internal, or procedural. Their impacts are interdependent.

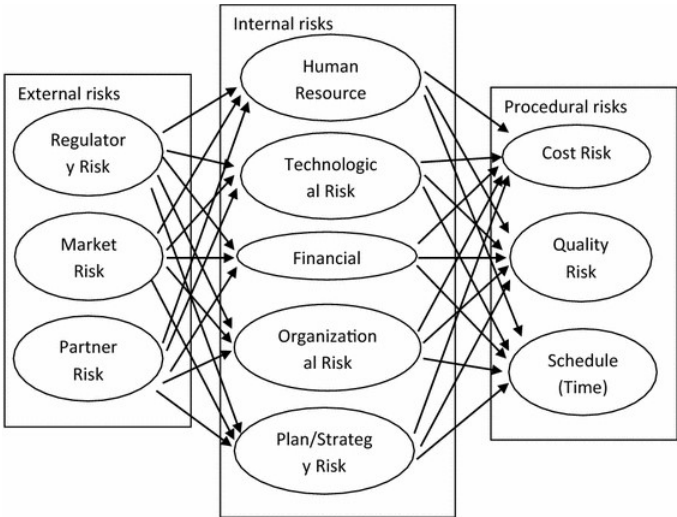


Fig. 2

The causal relationship between enterprise risks *Source:* modified by the author based on Wu et al. (2010b)

By identifying and managing risks, their impact on an enterprise will be minimized, because risk itself is the potential loss or undesirable outcome. Here, risk is strongly related to uncertainty, and thus ERM can be defined as an activity used to identify, assess, and evaluate potential outcome, and thereby suggest the optimal path for risk management, as shown in Fig. 3. ERM is essentially based on the procedural approach, rather than the structural approach of the economics paradigm, or the functional approach of the business management paradigm, because the core of ERM is to mitigate uncertainty along the time path and its effect on the possible outcome. As shown in the Fig. 3, the core of risk analysis consists of identification, assessment, and evaluation, which should be optimized and customized based on different internal and external conditions of risks.

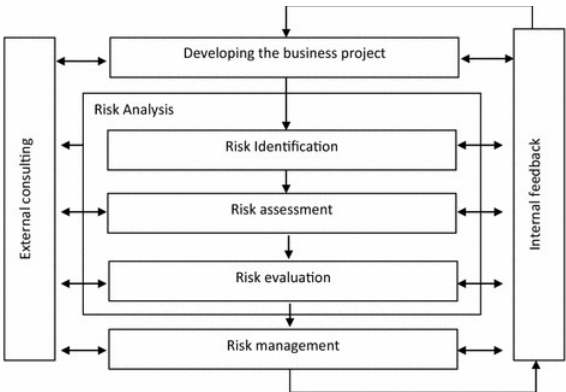


Fig. 3

Enterprise risk management procedural approach *Source:* modified by the author based on Walker (2013)

Therefore, ERM with a procedural approach includes procedural activities of a company such as engineering, finance, and banking. Moreover, ERM is very sensitive as an analytical tool or a set of methodologies to achieve the optimal solution. There are various theories and case studies to quantify these procedural activities.

3 Review of enterprise risk management literature and methodology

This section aims to review some important studies in the ERM literature, as well as methodologies that are commonly used. Table 1 gives disciplinary trend on ERM on “enterprise risk” by demonstrating publications since 2000 from five disciplines: Computer Science/Information Systems, Economics, Operations Research/Management Science, Engineering Industrial, and Management. The figure was created by searching for the words “enterprise risk” in ISI Web of Science including dataset of Science Citation Index Expanded (SCI-EXPANDED), and Social Sciences Citation Index (SSCI). The Operations Research and Management Science is a key area to accommodate ERM research besides the more science area such as Computer Science and Engineering Industrial and the more social science area such as Economics and Management. It is therefore timely to conduct such a review on ERM at ANOR journal.

Table 1

Disciplinary trend on ERM

Year	Computer science information systems	Economics	Operations research management science	Engineering industrial	Management	Total
2000–2001	29	34	23	27	21	200
2001–2002	49	47	37	30	26	229
2002–2003	63	55	40	32	25	282
2003–2004	67	55	44	33	39	348
2004–2005	80	55	51	39	99	436
2005–2006	104	62	78	76	159	565
2006–2007	125	143	154	105	281	780
2007–2008	214	269	288	117	487	1,138
2008–2009	246	306	368	174	528	1,420
2009–2010	200	258	317	156	474	1,447
2010–2011	168	195	185	89	409	1,316
2011–2012	139	176	84	74	283	1,253
2012–2013	96	182	61	53	211	1,280

Based on the COSO’s definition, the ERM framework is extensively discussed in the literature and widely applied in the industry. The implementation of the ERM is closely related to firm characteristics. Using data gathered from 123 US and international organizations, Beasley et al. (2005) find the stage of ERM implementation to be positively related to the presence of a chief risk officer, board independence, CEO and CFO apparent support for

ERM, the presence of a Big Four auditor, entity size, and entities in the banking, education, and insurance industries. Based on a sample of 112 US firms that disclose the implementation of their ERM activities within their 10Ks and 10Qs filed with the US Securities and Exchange Commission, Gordon et al. (2009) find empirical evidence supporting the argument that the relation between ERM and firm performance is contingent upon the appropriate match between ERM and the following five factors affecting a firm: environmental uncertainty, industry competition, firm size, firm complexity, and board of directors' monitoring. Therefore they suggest that firms should consider the implementation of an ERM system in conjunction with contextual variables surrounding the firm. Liu et al. (2011) compare Enterprise Risk Management and Project Risk Management, and evaluate the ERM implementation status in the Chinese construction industry through a questionnaire survey. Paape and Speklè (2012) specify the factors that determining the extent of ERM implementation, and show empirical evidence of the design choices of ERM systems which can influence risk management effectiveness.

In addition, it is commonly accepted in the literature that the ERM is beneficial to firms' management in general. For example: Beasley et al. (2008) study the costs and benefits of ERM using equity market information. Based on a sample of 120 announcements from 1992 to 2003, they find that there are significant relations between the magnitude of equity market returns and certain firm specific characteristics: especially for nonfinancial firms, announcement period returns are positively associated with firm size and the volatility of prior periods' reported earnings and negatively associated with leverage and the extent of cash on hand relative to liabilities. They therefore conclude that the costs and benefits of ERM are firm-specific; Pagach and Warr (2011) also provide evidence supporting the hypothesis that firms adopt the ERM for direct economic benefit rather than to merely comply with regulatory pressure; Based on data of US insurers, Hoyt and Liebenberg (2011) study the impact of the implementation of the ERM on firm value. They find a positive relation between firm value and the use of ERM. The ERM premium of roughly 20 % is statistically and economically significant; McShane et al. (2011) find that firm value increases as the sophistication of traditional risk management tools increase and firms move from traditional risk management approaches to ERM, but no further improvement by achieving higher levels of ERM.

Finally, there are studies focusing on different activities, organizational dynamics, and new techniques of the ERM: Koutoupis and Tsamis (2009) analyze critically the Risk Based Internal Auditing approaches through case studies of three Greek banks, and propose potential improvement; Arena et al. (2011) present actual uses of the ERM in a panel of nine Italian companies from different industrial fields and legislative. Their analysis highlights the existence of different activities that are supported by the ERM tool and also different types of use (i.e. responsive, discursive and prospective) corresponding to a different contribution of ERM to managerial action; Arena et al. (2010) study the organizational dynamics of the ERM. They find that the ERM introduces a new scientific rationality, marking a potential rupture in the company's risk history and sensitivity, but its organizational translations diverge as they encounter pre-existing centers of control and practices; Wu et al. (2014a) provide a review on the use of business intelligence in the ERM. This new direction will likely open a fruitful research area within the ERM literature.

In Table 2, we provide a comprehensive review of the recent methodological development on the ERM. We categorize the papers into different fields using the classification of risk fields proposed by Wu and Olson (2013). Specifically, within the ERM framework, we focus on operational risk, credit risk, market risk, and nonfinancial risk. Over the past decade, we witness a strong wave of progress in the area of methodological development on the ERM. One prominent observation from Table 2 is that there are four papers that are authored by Wu and Olson among the most important 23 papers. Apparently, Wu and Olson have made a significant contribution to the literature of the ERM.

Table 2

Literature review on the ERM

Paper	Risk field	Country	Field of contents	Methodology
Mills (2009)	Nonfinancial risks	US	Climate risk	Catastrophe modeling (CAT)
Huang et al. (2011)	Operational risk	Taiwan	Information technology general control (ITGC)	AHP
Kuhn Jr. and Sutton (2010)	Operational risk	US	Continuous auditing	Embedded audit modules (EAM) and monitoring control layer (MCL)
Wu and Olson (2010a)	Operational risk	US	Supply chain management	DEA VaR
O'Donnell (2005)	Operational risk	Canada	Event identification	Systems-thinking
Wu and Olson (2010c)	Credit risk	Canada	Account creditworthiness	Scorecard
Gatzert et al. (2008)	Credit risk	Europe	Default probabilities	Copula
Wu and Olson (2009a)	Operational risk	Canada	Organizational performance	Business scorecard
Sutton (2006)	Operational risk	US, Europe, Canada, and Australia	Supply chain management	Extended-enterprise systems
Xu et al. (2011)	Operational risk	US	Competitive intelligence	Conditional random fields (CRF)

Paper	Risk field	Country	Field of contents	Methodology
Olson and Wu (2011a)	Operational risk	Australia	IT risk	Multiple criteria analysis
Raiborn et al. (2009)	Operational risk	US	Outsourcing	Committee of Sponsoring Organizations of the Treadway Commission (COSO ERM)
Mikes (2009)	Operational risk	US	ERM models	Calculative cultures
Blome and Schoenherr (2011)	Operational risk	Europe	Supply Chain Risk Management	Multiple case-study approach
Zhao et al. (2013)	Operational risk	Singapore	ERM maturity model	Fuzzy set theory
Yow and Sherris (2008)	Credit risk, market risk, operational risk	Global	Firm value maximization, frictional costs	Statistical method, numerical optimization
Kretschmar et al. (2010)	Credit risk	Europe	Capital allocation in Banking industry	Statistical method
Diers (2011)	Credit risk	Germany	Multi-year ERM	DFA, value-at-risk, simulation
Gatzert and Schmeiser (2011)	Credit risk	Not country-specific	Financial conglomerates	Simulation
Wunder (2009)	Operational risk	Global	Internal control of tax-related risk	Survey, statistical method
Arnold et al. (2011)	Operational risk	US	Companies completed SOX 404 reporting	Field survey, statistical method

As shown in the table, the scope of ERM can be sorted out using the five perspectives of risk content: financial risk management, accounting, supply chain management (SCM), information systems, and disaster management (Olson and Wu [2008](#)). The methodologies cover statistical methods, data envelopment analysis (DEA), the analytic hierarchy process (AHP), fuzzy set theory, grey relationship analysis, balanced scorecards, and financial risk measures, all of which is of help in risk management. Since the ERM is very sensitive to the chosen methodology, it is crucial to understand each of the seven modeling approaches. Ho et al. ([2009](#)) summarized the fundamental theories behind these seven modeling approaches, and detailed their advantages and disadvantages when applied to performance evaluation.

First, statistical methods, used to quantify complex issues or events, are placed in the multivariate statistical analysis category. The strength of these methods lies in the traditional approaches that are backed by solid theoretical foundations. However, and methods that do not include statistical testing cannot be used systematically, which hampers further interpretation of the results.

The second method is data envelopment analysis (DEA) based on the concept of Pareto optimality. The outstanding quality of DEA is the fact that it can be used to handle empirical tests with multiple inputs and outputs without the need for much of a theoretical background. However, it yields the efficient frontier, too large to capture the reliable relationship between the variables.

Third, the analytic hierarchy process (AHP) is an approach to quantify subjective estimates for complex and/or non-systematic issues. It is easy to utilize and to generalize results, and has a sound theoretical foundation. However, it has its disadvantages: when there are great differences in opinions among experts, their diverse results yield little value. Like DEA, AHP also fails to find the relationship between factors (variables).

Forth, the fuzzy set theory provides an overall evaluation of events or phenomenon influenced by a number of factors, as well as by way of building up subordinate functions. Since it is a simulation of human thought and decision process, it is quite compatible with realized human behavior. However, the degree of subordination is indicated by a value between 0 and 1, and therefore, the results of the evaluation could influence the choice over the subordination function.

The fifth method is grey relationship analysis based on the homogeneity or heterogeneity of the trend development of factors, which determines whether there is a grey relationship between two indicators and what the extent of the relationship is. As there is no rigid requirement for the sample size, it is applicable even when the distribution is uncertain. However, it has a disadvantage in that it cannot directly handle quantitative issues, because it is essentially non-quantifiable.

The sixth method is the balanced scorecard (BSC) approach. Based on four components of finance (customer, internal process, learning and growth), it evaluates systems that could help companies translate strategies into actions. It is a strong approach since it can integrate information and put various key factors for the success of an organization into one report. The weakness of the balanced card approach is that the procedure for the application of BSC is complex and time consuming.

The seventh approach, financial statement analysis is based on the belief that the results of business activities of a firm would be reflected in its financial statements. They reflect the actual events objectively, and quantify data in a concrete manner. However, the weakness lies in the fact that financial statements cannot express qualitative information, such as the degree of morale and trust.

Unfortunately, it is very difficult to generalize all previous studies, because ERM utilizes the procedural approach, but not the structural or functional approach, which makes it procedure-specific for each individual field of research. Therefore, it is necessary to first compare Wu and Olsen's studies more in detail, and subsequently categorize their unique contributions in Sect. 5.

4 Who are leading scholars in ERM?

Table 3 gives a ranking of the leading scholars in the area of ERM based on their publications on "enterprise risk" between 2005 and 2014. The figures are calculated by searching for the words "enterprise risk" in ISI Web of Science and retaining those publications that indeed present techniques for managing various enterprise risks. 2,280 records are found by using data from ISI Web of Science, which includes two data sources: Science Citation Index Expanded (SCI-EXPANDED), and Social Sciences Citation Index (SSCI). We show the top ten most productive scholars in Table 3.

Table 3

Top ten scholars in the area of ERM

Rank	Researcher's name	Number of records	Percentage of 2,280	Institution
1	Desheng Wu	13	0.570	Stockholm University, Sweden (and University of Toronto)
1	David Olson	13	0.570	University of Nebraska-Lincoln, US
2	Akinori Nakata	8	0.351	NIOSH, Div Appl Res & Technol, Cincinnati, US
3	Andrew Moore	7	0.307	CSIRO Plant Ind, Australia
3	Alfredo Jimenez	7	0.307	Universidad de Burgos, Spain
4	Masaya Takahashi	6	0.263	National Institute of Industrial Health, Japan
4	So Young Sohn	6	0.263	Yonsei University, South Korea
4	Scott JM	6	0.263	University New England, Australia
4	Robertson MJ	6	0.263	CSIRO Plant Ind, Australia
4	Ikeda T	6	0.263	NIOSH, Cincinnati, US

These top ten scholars in total publish 64 important papers with 636 citations from 2005 to 2014. Figures 4 and 5 respectively, present the numbers of publications and citations over the years.

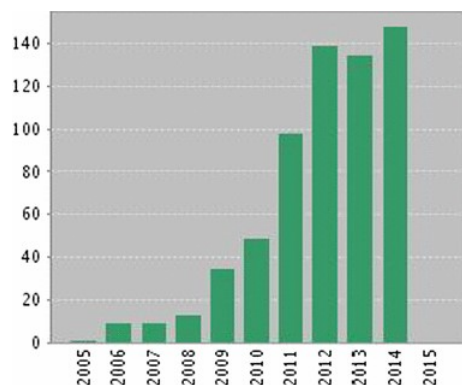


Fig. 4

Citations in each year

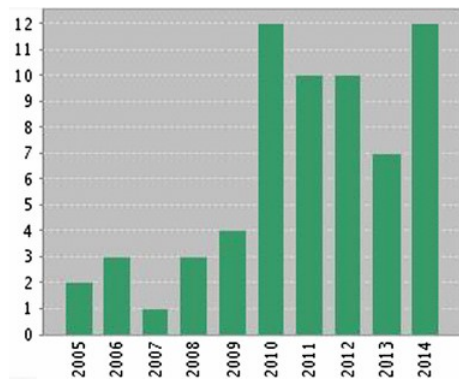


Fig. 5

Publications in each year

Correspondingly, Table 4 presents top ten most cited articles of the above top ten researchers. From Table 4, we find that Wu and Olson are ranked first in terms of the most cited articles using the metric of both Total Citations and Average Citations per Year. Wu and Olson publish top three most cited articles. The top ranked article titled “Enterprise Risk Management: Coping with Model Risk in a Large Bank” was awarded “10 big impact articles” from the 2010 and 2011 volumes of Journal of the Operational Research Society, and was ranked first (see http://www.palgrave-journals.com/jors/highly_cited_articles.html). One half of the most cited articles were produced by Wu, Olson, and their coauthors. All these five publications yield more than 20 % of the total citations. Wu and Olson (2010c) is ranked first in the area of ERM using operations research and management science approaches, yielding an average number of citations of 10.80 per year. A further important support to this observation is from the widely recognized Thomson’s Web of Knowledge database Essential Science Indicators (ESI) that provides comprehensive aggregate citation analysis. We use the keyword “enterprise risk management” at ESI database to search for Highly Cited Papers which represent the top 1 % of articles by total citations in each annual cohort from each of the 22 ESI-defined field. Two papers are found: one titled “Enterprise risk management: a DEA VaR approach in vendor selection” published at International Journal of Production Research, and the other titled “Enterprise risk management: coping with model risk in a large bank” published at Journal of the Operational Research Society. Both were written by Wu and Olson. Besides these two work, we found another ESI Highly Cited Paper by Wu and Olson: “Supply chain risk, simulation, and vendor selection” published at International Journal of Production Economics.

Table 4

Top ten most cited work in ERM (time: December 20, 2014)

Authors	Journal title	Publication year	Total citations	Average per year	2010	2011	2012	2013	2014
Wu and Olson	J of the Operational Research Society	2010	54	10.80	4	7	16	16	11
Wu and Olson	Human and Ecological Risk Assessment	2009	53	8.83	6	16	15	12	4
Wu and Olson	I J of Production Research	2010	50	9.40	0	11	16	13	10
Nakata et al.	Industrial Health	2005	38	3.80	8	2	3	1	7
Wu et al.	Technological Forecasting and Social Change	2010	31	6.20	1	3	10	10	7
Nakata et al.	American J of Industrial Medicine	2006	28	3.11	4	3	1	5	5
Wu and Olson	Production Planning & Control	2009	24	4.00	2	3	8	6	4
Robertson et al.	Crop and Pasture Science	2010	20	4.00		2	9	3	5
Moore et al.	Animal Production Science	2009	19	3.17	1	3	1	5	7

Authors	Journal title	Publication year	Total citations	Average per year	2010	2011	2012	2013	2014
Bell and Moore	Agricultural Systems	2012	17	5.67	0	0	0	3	14

5 Review and discussion of Wu and Olson's work

As discussed above, most of the ERM-related research can be conducted using the five categories of risks and seven groups of methodologies. Since ERM is based on the procedural paradigm, which is quite different from the structural paradigm of economics and functional paradigm of business management, it is quite important to determine the procedural implications of Wu and Olson's articles for this complex empirical experiment. Wu and Olson make tremendous progress in this area with many outstanding research works. They have not only published many papers in well-known journals, but also participated in international conferences as organizers as well as guest editors for the special edition of these journals. A literature survey on their articles is arguably imperative, given the fact that Wu and Olson showcase not only diverse content and methodologies, but also comparative studies of many previous studies at the conferences and/or in the special issues of the well-known journals. Since papers by Wu, Olson, and their coauthors shed light on the procedural paradigm of ERM, we summarize their articles (see Table 5), examine their theoretical contributions, and suggest policy implications based on their works. We will meanwhile generalize Wu and Olson's ERM Work and Methodology in a theoretical framework. To acknowledge their theoretical contributions, we use the first letter of both scholars' last name and call it "W-O" ERM theory.

Table 5

Literature review on ERM by Wu and Olson

Author	Risk elements	Country	Field of contents	Methodology
Wu and Olson (2008)	Cost, quality, and time risks	Global	Partner selection on SCM	CCP, DEA, MOP
Ho et al. (2009)	Financial risk	USA	Stock market	DEA
Chen et al. (2010)	Credit risk	China	Information systems	Adjusted KMV model
Wu et al. (2010c)	Cost, quality, and time risks	Global	Partner selection on SCM	Fuzzy multi-objective model
Wu et al. (2010a)	Risk perception, value perception, and risk preference	China	Car manufacturing industry (SCM)	System dynamics: risk-based decision making (RDM)
Wu and Olson (2010c)	Credit risk and model risk	Canada	Banking finance	Balanced scorecard approach
Wu and Olson (2010b)	Technological risk	Not country-specific	Editorial comparison	Comparative review
She et al. (2010)	Value, probability, and time	Global	Risk (time)-value tradeoff on decision tree type information system	Intertemporal risk-value (IRV) model
Wu (2011)	Field-based and property-based risks	Not country-specific	Editorial comparison	Comparative review
Wu and Birge (2012)	Financial risk: merger efficiency (harmony and scale effect)	Canada	Banking operations (finance)	Sequential DEA
Wu et al. (2010b)	Product development risk	China	Car manufacturing industry (SCM)	Graphical evaluation and review technique (GERT)
Olson and Wu (2011b)	Financial risk	Global	Portfolio investment (Finance)	Value at risk (VaR) model (mean-variance approach)

Author	Risk elements	Country	Field of contents	Methodology
Olson and Wu (2011b)	Outsourcing risk in SCM: recall risk	China	Partner selection on SCM	DEA
Olson and Wu (2013b)	Volcanic incident risk	Not country-specific	Book review	N.A.
Wu et al. (2013)	Outsourcing risk (random and fuzzy uncertainty)	Global	Order under uncertainty on SCM (disaster management)	Fuzzy multi-objective model
Wu et al. (2014a , b , c)	Operational risk	Canada	Operational efficiency in banking mergers	BLP, DEA, case study
Zhao and Dash (2014)	Financial risk	Not country-specific	Multi-period cash flow risk in dual-channel supply chain	Simulation
Wu and Olson (2014)	Financial risk	USA	Banking accounts receivable risk management	System dynamics modelling
Wu et al. (2014c)	Risk perception, price volatility	China	investors' investment decision making and financial review	sentiment analysis, machine learning, GARCH
Wei et al. (2015)	Work safety risk	China	Work-related accidents	Grey theory

Most importantly, Wu and Olson emphasize that a customized ERM model depends on risk elements, external and internal risk contents, as well as the methodologies shown in Fig. 1. Even for a similar field of research in supply chain management (SCM), their show several differences by applying customized approaches to individual cases. To verify this, they consider three types of vendor selection methodologies in supply chains with risks: chance constrained programming (CCP), data envelopment analysis (DEA), and multi-objective programming (MOP), in one paper for comparison (Wu and Olson [2008](#)). As demonstrated in Toyota's global recall incident in 2008, appropriately selecting a global outsourcing partner in SCM is crucial. The CCP can directly incorporate probabilities into models. The DEA can guarantee nondominated solutions, but does not incorporate decision makers' preferences, which enable the identification of preferred solutions. The MOP provides flexibility for decision makers to reflect their preferences for different criteria. Different preferences for different criteria lead to selecting different vendors (Wu and Olson [2008](#)).

In their paper on the credit risks of small and medium enterprises (SMEs), Wu and his coauthors modify the original KMV model for the credit warning system to make ERM more firm and process-specific (Chen et al. [2010](#)). They found that the predictive accuracy of the adjusted KMV model is more stable and accurate than that of other models, when predicting defaults of Chinese listed SMEs. Their study concludes that the credit risks are relatively high and tend to increase during the period of 2004–2006, implying that the credit situation with regard to SMEs is not optimistic in China. Moreover, their point out that some financial information disclosed by the Chinese listed SMEs may have been fabricated.

In another paper on financial institutions (Wu and Olson [2010c](#)), Wu and Olson verify that all risks in an enterprise can, and should be, quantified and managed using various models. They show that the predictive scorecard approach could obtain better performance than other alternatives, such as credit bureau scores and Beacon data.

Most of the previous risk-value models ignored the time factor, even though time and probability are fundamental attributes of any non-degenerate decisions that involve making a decision on a tradeoff between an immediate or sure outcome and delayed or uncertain outcome. Wu and his coauthors extend the risk-value model to incorporate the time factor and build an intertemporal risk-value (IRV) model (She et al. [2010](#)). In three fundamental aspects of ERM: value, probability, and time, they integrate the risk-value trade-off, the probability-time tradeoff, and the time-value tradeoff into the general IRV model. Furthermore, by using lottery simulations, they find that an individual psychological decision process could be molded as a tool for a decision maker to determine his or her time preference and reasonably evaluate future risky events.

Many ERM approaches may be mutually exclusive, related, or independent of each other, depending on the circumstances. Therefore, there is not a generalized version of ERM for all cases. In financial markets, investors choose stocks for investment. A major concern for investors is whether their investment has a potential for higher returns. Most of the previous studies on the risks of this type of stock investment are based on return on equity (ROE), profit margin, total asset turnover, and financial leverage. Since multiple indicators are considered, the DEA approach could be used to evaluate the investment risks (Ho et al. [2009](#)). Based on an integrated approach combining ROE and DEA, the empirical results in Ho et al. [2009](#) show that for the internet industry, company effectiveness is more important than operating efficiency. It implies that companies should control their expenses to increase their net income effectively.

The financial transaction for a mortgage operation could be viewed from a SCM perspective, where the primary and secondary markets are upstream and downstream chain members, respectively (Wu and Birge [2012](#)). With an emphasis on the time factor in this stepwise financial merger, Wu and Birge develop a serial-chain-merger DEA model to assess potential gains from the merger of different chain operations. They conclude that the merger of operations can result in an overall improvement on efficiency in the banking industry, provided all the sub chain members are efficient.

Value-at risk (VaR) is one of the most widely used methods in ERM, especially in the financial market. Based on the return-risk tradeoff due to Markovitz ([1952](#)), VaR can be characterized as a maximum expected loss in a given time horizon and confidence interval (Olson and Wu [2013a](#)). Olson and Wu verify the presence of fat tails distribution of the financial return data, and suggest that logistics distribution is better in describing financial risks. This implies that the previous studies based on the normal distribution may underestimate financial risks, and each field of risk should be treated differently and with much more caution.

In interdependent economies with borderless competition, the selection of suppliers in a global market could be very hard to deal with due to the complex systems, because supply chain outsourcing risk management is subject to both random and fuzzy uncertainty. To accommodate both stochastic and fuzzy aspects of the optimization process, a novel stochastic fuzzy multi-objective programming model (SFMOP) is developed (Wu et al. [2010c](#)). Three traditional key factors: cost, time, and quality are considered for enterprise risks. Wu and his coauthors also include a broader set of SCM risks, such as internal and external risks, based on certain level of controllability. Their computational results suggest that a less risk-averse customer prefers more for times of uncertainty and risk.

The above research has been expanded to incorporate the game theoretic stepwise decision approach and has been verified by simulation. It is neither easy nor convincing to clarify the risky decision process of the SCM by integrating the quantifiable risks with the qualitative fuzzy risks on the SCM. However, by using the SFMOP, Wu and his coauthors expand the model to include the three-stage decision process in the SCM. Using simulation, they find that the results of trade-off game analysis support the points on the trade-off curve. The finding is very useful for decision makers to identify proper weighting schemes in which the Pareto optimum is achieved to select preferred suppliers.

Global borderless competition induces rapid technological changes and shortens the product life cycle in companies in a rapidly changing environment. Concurrent engineering (CE) provides a tool for companies to reduce the time taken to reach the market and achieve overall cost savings under these circumstances. In Wu et al. ([2010a](#)), Wu and his coauthors develop a three-dimensional early warning system for monitoring the product development risks on CE by integrating graphical evaluation and review technique (GERT), failure modes, and effective analysis (FMEA) on product database management (PDM). Since CE diversifies risks, the three-dimensional integrated approach will improve the optimization of the ERM. Based on three key risk indicators: scheduling risk, cost risk, and quality risk, they show that a project manager could use the integrated model to conduct the optimal control for the three-dimensional risks on the CE process.

In general, a business project consists of three successful determinants: technology, business strategies, and fund financing. Among these three factors, as a starting point the technological innovation on research and development (R&D) or on the manufacturing process is most critical for a business project. Thus, continually technological innovation has been playing a vital role in ensuring the sustainable management of an enterprise. With regard to technological innovation with enterprise risks, there are three major factors affecting an individual's risk-based decision making (RDM): risk perception, risk preference, and the value perception from a risky decision. From an agent's perspective, the team play for the R&D decision process may differ from one to one. Therefore, Wu and his coauthors simulate the technological innovation in RDM from a point of view of an entrepreneurial "team" (Wu et al. [2010b](#)). Using a system dynamics approach for team decision making, they show that supports from government and/or society result in better performance than just using a company's resources to deal with risks in China.

A key factor involved in supply chains is the priori evaluation of potential partners, not only in terms of expected cost (which includes exchange rate risk), but also other risks. Based on DEA simulation, a risk-adjusted decision process for selecting an appropriate partner is conducted by Olson and Wu ([2011b](#)). From this empirical research in China, they find that vendors from China are preferred over those from western nations, owing to lower risk-adjusted costs and higher efficiencies. This implies that the most important factor for partnerships in global outsourcing is the risk-adjusted efficiency that arises from trust in global standard.

In the review of all the papers in special issues of the journals, Wu first made it clear that different disciplines should have a different ways of classifying and treating risks. He proposed two categories of risk management approaches: field-based and property-based (Wu [2011](#)). The field-based approach takes into account the diverse content in the field of risks, while the property-based research is based on three properties of risks: probability, time dynamics, and dependence. Based on these paradigms, he comparatively reviews the four papers in the special issue of Stochastic Environment Risk Analysis. From these papers, he concludes that qualitative models could be effective for managing risks, and procedural approaches of gathering data, developing an action plan, and organizing the team should be more consistently harmonized. In another survey paper in the special issue on "risk and technology," Wu and Olson claim that a number of psychological-based researchers have emphasized that the role of human preference expands the interest of the ERM from objective data concerning probabilities to the more complex judgmental forum requiring subjectivity (Wu and Olson [2010b](#)). Therefore, the transformation of objective data for the subjective ERM requires diverse and more systematic approaches. Out of the six papers presented in the special issue, the one on ERM should be made more region-specific with regard to China, Korea and Taiwan; more content specific in terms of technological, policy, and behavioral aspects; and more methodology specific in terms of system dynamics, structural equation modeling, and multiple-objective programming. In the short book review, Olson and Wu pointed out that volcanic eruptions are representative of events that have a significant impact on enterprises, but their low rates of occurrence prevent them from being forecast (Olson and Wu [2013b](#)). Therefore, an organization's value increases if it is in a position to adapt to whatever uncertainties occur, and has contingency plans to tackle these uncertainties.

Operational efficiency is a crucial component in the ERM, especially for firms contemplating the consolidation of both internal and external business units. Wu and his coauthors explore potential improvement of the operational efficiency under a game theory framework. Wu et al. ([2014a, b, c](#)) develop a leader-follower game model to assess such potential gains from the merger of different organizations with constrained resources. In the paper, they employ profit-sharing strategy and algorithm to solve the model while maintaining incentive compatibility within each unit's decision-making process. Their results show that a supply chain with an upstream leader and downstream followers is efficient if and only if both the leader and the followers are individually efficient. They also provide a case study of a banking operations merger to show how incentive compatible merger of operations can produce overall efficiency improvement.

Cash flow management is a critical element of many firms' operational strategies, therefore, cash flow risk is highly relevant for the ERM. Focusing on multi-period cash flow risk which is measured by the SD in dual-channel supply chain, Zhao and Dash ([2014](#)) analyze cash inflows, outflows, and netflows of each member in dual-channel supply chain and examine different influencing factors on the preference of cash flows in dual-channel supply chain. Their results provide important implications for cash flow risk management in the ERM.

Financial contagion specifically deals with the domino effect of one banking institution failing, which, as a result of interrelationships with other banks, leads to further failures, it also undermines confidence in similar institutions. It therefore becomes a great concern for the ERM. Wu and Olson ([2014](#)) examine whether the role of accounts receivable payments is affected by the financial contagion, in other words, by social interaction of those holding loans from a lending institution. They employ system dynamics modelling to demonstrate the impact of word-of-mouth social contacts on accounts receivable, and the ensuing increase in financial risk. They show that accounts receivable involves financial risk contagion, which was recognized as critically important after scandals and market disruptions centering around 2000, and has become even more critical since 2008, and accurate management of risk enables firms to profit, even in turbulent markets.

Work safety, which concerns the safety of the working environment within an enterprise, is commonly considered as a very special area of the ERM. Wei et al. ([2015](#)) demonstrate that the grey theory is a powerful and accurate method to evaluate and forecast in the short term the work safety situations in Mainland China, which could help improve the work and social environment. To summarize this section, we aim to generalize Wu and Olson's ERM Work and Methodology which we term as "W-O ERM Model". Based on many further advice from Wu² and analysis of Wu and Olson's ERM Work, we present in Fig. [6](#) the W-O ERM Model and Methodology.

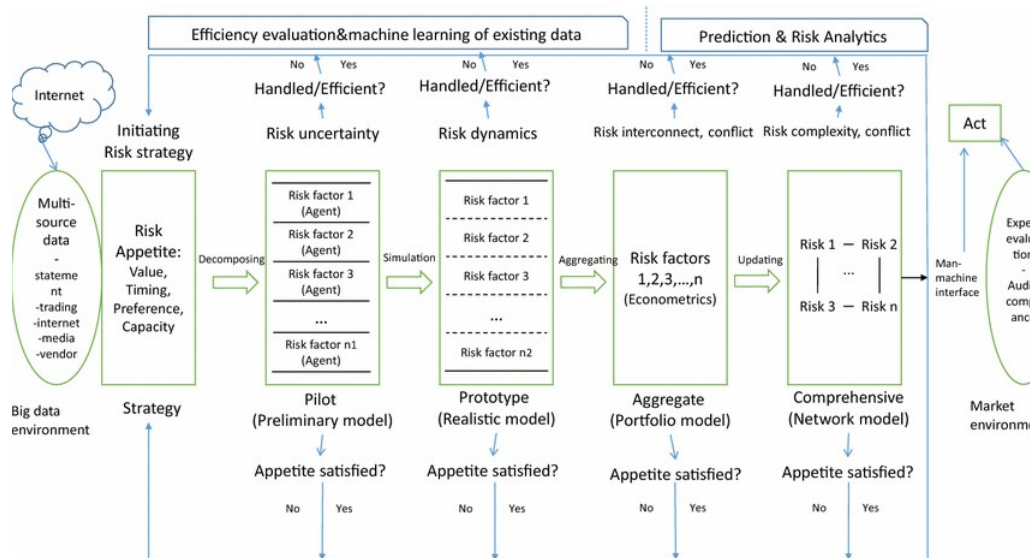


Fig. 6

W-O ERM model and methodology

6 Conclusion

Based on diverse research by Wu and Olson, ERM should be dealt with very a unique optimization process for every individual procedural decision of a company depending on its business decision content, the methodological modeling, and the surrounding environment coming from time and special factors. Nonetheless, he showed it is feasible not only to quantify risks, but to uniquely customize ERM more systematically. Even if the elements of risks are complicated and diverse, it is preferable for individual companies to integrate several methods for similar contents of risks and compare these with several other alternative methods. Even if there is no generalized version of ERM, it is feasible for professional experts to search, measure, monitor, and manage all the contents and methodology-specific risks by a systematic integration of the diverse approaches and by comparing the possible outcomes with the alternative approaches.

After the prolonged global economic crisis, many countries and global enterprises are hoping for a ray of hope. However, ever increasing risks from global markets demand a more systematic strategy for a contingency plan. Therefore, research on ERM could be and should be the core competitiveness for the first mover of this rapidly changing frontier for the future. Wu and Olson showed that diverse risks can be tackled by the customization and optimization of all the issues related to ERM.

Footnotes

¹

Dr. Wu advises adding both big data and market environment, and risk conflict property besides the other four he generalized in Wu and Olson (2013) and Wu et al. (2014a). The W-O ERM Model is a summary of Wu and Olson theories and methodologies in ERM.

Acknowledgments

This work is partially supported by NFSC grant (Grant # 71471055), the 100-Talents plan Program at Chinese Academy of Sciences and 1000-Talents plan Program for the Young Scientists.

References

- Arena, M., Arnaboldi, M., & Azzone, G. (2010). The organizational dynamics of enterprise risk management. *Accounting Organizations and Society*, 35(7), 659–675. [CrossRef \(http://dx.doi.org/10.1016/j.aos.2010.07.003\)](http://dx.doi.org/10.1016/j.aos.2010.07.003).
- Arena, M., Arnaboldi, M., & Azzone, G. (2011). Is enterprise risk management real? *Journal of Risk Research*, 14(7), 779–797. [CrossRef \(http://dx.doi.org/10.1080/13669877.2011.571775\)](http://dx.doi.org/10.1080/13669877.2011.571775).
- Arnold, V., Benford, T., Canada, J., & Sutton, S. G. (2011). The role of strategic enterprise risk management and organizational flexibility in easing new regulatory compliance. *International Journal of Accounting Information Systems*, 12(3), 171–188. [CrossRef \(http://dx.doi.org/10.1016/j.accinf.2011.02.002\)](http://dx.doi.org/10.1016/j.accinf.2011.02.002).
- Baranoff, E. G. (2004). Risk management: A focus on a more holistic approach three years after September 11. *Journal of Insurance Regulation*, 22(4), 71–82.
- Beasley, M. S., Clune, R., & Hermanson, D. R. (2005). Enterprise risk management: An empirical analysis of factors associated with the extent of implementation. *Journal of Accounting and Public Policy*, 24(6), 521–531. [CrossRef \(http://dx.doi.org/10.1016/j.jaccpubpol.2005.10.001\)](http://dx.doi.org/10.1016/j.jaccpubpol.2005.10.001).
- Beasley, M., Pagach, D., & Warr, R. (2008). Information conveyed in hiring announcements of senior executives overseeing enterprise-wide risk management processes. *Journal of Accounting, Auditing & Finance*, 23(3), 311–332.
- Bell, L. W., & Moore, A. D. (2012). Integrated crop-livestock systems in Australian agriculture: Trends, drivers and implications. *Agricultural Systems*, 111, 1–12. doi:10.1016/j.agsu.2012.04.003 <http://dx.doi.org/10.1016/j.agsu.2012.04.003> ; [CrossRef \(http://dx.doi.org/10.1016/j.agsu.2012.04.003\)](http://dx.doi.org/10.1016/j.agsu.2012.04.003).
- Blome, C., & Schoenherr, T. (2011). Supply chain risk management in financial crises—A multiple case-study approach. *International Journal of Production Economics*, 134(1), 43–57. [CrossRef \(http://dx.doi.org/10.1016/j.ijpe.2011.01.002\)](http://dx.doi.org/10.1016/j.ijpe.2011.01.002).
- Chen, X., Wang, X., & Wu, D. D. (2010). Credit risk measurement and early warning of SMEs: An empirical study of listed SMEs in China. *Decision Support Systems*, 49(3), 301–310. [CrossRef \(http://dx.doi.org/10.1016/j.dss.2010.03.005\)](http://dx.doi.org/10.1016/j.dss.2010.03.005).

- Choi, Y., & Lee, E. Y. (2009). Optimizing risk management for the sustainable performance of the regional innovation system in Korea through metamediation. *Human and Ecological Risk Assessment*, 15(2), 270–280.
[CrossRef \(http://dx.doi.org/10.1080/10807030902761189\)](http://dx.doi.org/10.1080/10807030902761189)
- COSO. I. (2004). Enterprise risk management-integrated framework. Committee of Sponsoring Organizations of the Treadway Commission.
- Dickinson, G. (2001). Enterprise risk management: Its origins and conceptual foundation. *Geneva Papers on Risk and Insurance-Issues and Practice*, 26(3), 360–366.
[CrossRef \(http://dx.doi.org/10.1111/1468-0440.00121\)](http://dx.doi.org/10.1111/1468-0440.00121)
- Diers, D. (2011). Management strategies in multi-year enterprise risk management. *The Geneva Papers on Risk and Insurance-Issues and Practice*, 36(1), 107–125.
[CrossRef \(http://dx.doi.org/10.1057/gpp.2010.39\)](http://dx.doi.org/10.1057/gpp.2010.39)
- Gatzert, N., Schmeiser, H., & Schuckmann, S. (2008). Enterprise risk management in financial groups: Analysis of risk concentration and default risk. *Financial Markets and Portfolio Management*, 22(3), 241–258.
[CrossRef \(http://dx.doi.org/10.1007/s11408-008-0081-u\)](http://dx.doi.org/10.1007/s11408-008-0081-u)
- Gatzert, N., & Schmeiser, H. (2011). On the risk situation of financial conglomerates: Does diversification matter? *Financial Markets and Portfolio Management*, 25(1), 3–26.
[CrossRef \(http://dx.doi.org/10.1007/s11408-010-0149-3\)](http://dx.doi.org/10.1007/s11408-010-0149-3)
- Gordon, L. A., Loeb, M. P., & Tseng, C. Y. (2009). Enterprise risk management and firm performance: A contingency perspective. *Journal of Accounting and Public Policy*, 28(4), 301–327.
[CrossRef \(http://dx.doi.org/10.1016/j.jaccpubpol.2009.06.006\)](http://dx.doi.org/10.1016/j.jaccpubpol.2009.06.006)
- Ho, C. T. B., Wu, D. D., Chou, C., & Olson, D. L. (2009). A risk scoring model and application to measuring Internet stock performance. *International Journal of Information Technology & Decision Making*, 8(1), 133–149.
[CrossRef \(http://dx.doi.org/10.1142/S0219622009003302\)](http://dx.doi.org/10.1142/S0219622009003302)
- Hoyt, R. E., & Liebenberg, A. P. (2011). The value of enterprise risk management. *Journal of Risk and Insurance*, 78(4), 795–822.
[CrossRef \(http://dx.doi.org/10.1111/j.1539-6975.2011.01413.x\)](http://dx.doi.org/10.1111/j.1539-6975.2011.01413.x)
- Huang, S. M., Hung, W. H., Yen, D. C., Chang, I. C., & Jiang, D. N. (2011). Building the evaluation model of the IT general control for CPAs under enterprise risk management. *Decision Support Systems*, 50(4), 692–701.
[CrossRef \(http://dx.doi.org/10.1016/j.dss.2010.08.015\)](http://dx.doi.org/10.1016/j.dss.2010.08.015)
- Koutoupis, A. G., & Tsamis, A. (2009). Risk based internal auditing within Greek banks: A case study approach. *Journal of Management & Governance*, 13(1–2), 101–130.
[CrossRef \(http://dx.doi.org/10.1007/s10997-008-9072-7\)](http://dx.doi.org/10.1007/s10997-008-9072-7)
- Kretzschmar, G., McNeil, A. J., & Kirchner, A. (2010). Integrated models of capital adequacy—Why banks are undercapitalised. *Journal of Banking & Finance*, 34(12), 2838–2850.
[CrossRef \(http://dx.doi.org/10.1016/j.jbankfin.2010.02.028\)](http://dx.doi.org/10.1016/j.jbankfin.2010.02.028)
- Kuhn, J. R., Jr., & Sutton, S. G. (2010). Continuous auditing in ERP system environments: The current state and future directions. *Journal of Information Systems*, 24(1), 91–112.
[CrossRef \(http://dx.doi.org/10.2308/jis.2010.24.1.91\)](http://dx.doi.org/10.2308/jis.2010.24.1.91)
- Liu, J. Y., Low, S. P., & He, X. (2011). Current practices and challenges of implementing enterprise risk management (ERM) in Chinese construction enterprises. *International Journal of Construction Management*, 11(4), 49–63.
[CrossRef \(http://dx.doi.org/10.1080/15623599.2011.10773178\)](http://dx.doi.org/10.1080/15623599.2011.10773178)
- Markowitz, H. (1952). Portfolio selection*. *The Journal of Finance*, 7(1), 77–91.
- McShane, M. K., Nair, A., & Rustambekov, E. (2011). Does enterprise risk management increase firm value? *Journal of Accounting, Auditing & Finance*, 26(4), 641–658.
[CrossRef \(http://dx.doi.org/10.1177/0148558X11409160\)](http://dx.doi.org/10.1177/0148558X11409160)
- Mikes, A. (2009). Risk management and calculative cultures. *Management Accounting Research*, 20(1), 18–40.
[CrossRef \(http://dx.doi.org/10.1016/j.mar.2008.10.005\)](http://dx.doi.org/10.1016/j.mar.2008.10.005)
- Mills, E. (2009). A global review of insurance industry responses to climate change. *The Geneva Papers on Risk and Insurance-Issues and Practice*, 34(3), 323–359.
[CrossRef \(http://dx.doi.org/10.1057/gpp.2009.14\)](http://dx.doi.org/10.1057/gpp.2009.14)
- Moore, A. D., Bell, L. W., & Revell, D. K. (2009). Feed gaps in mixed-farming systems: Insights from the Grain & Graze program. *Animal Production Science*, 49(10), 736–748.
doi:10.1071/AN09010 <http://dx.doi.org/10.1071/AN09010>
- Nakata, A., Ikeda, T., Takahashi, M., Haratani, T., Fujioka, Y., Fukui, S., et al. (2005). Sleep-related risk of occupational injuries in Japanese small and medium-scale enterprises. *Industrial Health*, 43(1), 89–97. doi:10.2486/indhealth.43.89 <http://dx.doi.org/10.2486/indhealth.43.89>
[CrossRef \(http://dx.doi.org/10.2486/indhealth.43.89\)](http://dx.doi.org/10.2486/indhealth.43.89)
- Nakata, A., Ikeda, T., Takahashi, M., Haratani, T., Hojou, M., Fujioka, Y., et al. (2006). Impact of psychosocial job stress on non-fatal occupational injuries in small and medium-sized manufacturing enterprises. *American Journal of Industrial Medicine*, 49(8), 658–669.
[CrossRef \(http://dx.doi.org/10.1002/ajim.20338\)](http://dx.doi.org/10.1002/ajim.20338)
- O'Donnell, E. (2005). Enterprise risk management: A systems-thinking framework for the event identification phase. *International Journal of Accounting Information Systems*, 6(3), 177–195.
[CrossRef \(http://dx.doi.org/10.1016/j.jaccinf.2005.05.002\)](http://dx.doi.org/10.1016/j.jaccinf.2005.05.002)
- Olson, D. L., & Wu, D. D. (2008). *Enterprise risk management* (Vol. 1). Singapore: World Scientific.
- Olson, D. L., & Wu, D. (2011a). The impact of distribution on value-at-risk measures. *Mathematical and Computer Modelling*, 58(9), 1670–1676.
- Olson, D. L., & Wu, D. (2011b). Multiple criteria analysis for evaluation of information system risk. *Asia-Pacific Journal of Operational Research*, 28(01), 25–39.
- Olson, D. L., & Wu, D. (2011c). Risk management models for supply chain: A scenario analysis of outsourcing to China. *Supply Chain Management—An International Journal*, 16(6), 401–408.
- Olson, D. L., & Wu, D. (2013). Extreme-event risk management: A review of “Lee, B., Preston, F. 2012. Preparing for High-impact, Low-probability Events: Lessons from Eyjafjallajökull. London: Chatham House”. *Journal of Cleaner Production*, 53, 67–68.
- Paape, L., & Speklé, R. F. (2012). The adoption and design of enterprise risk management practices: An empirical study. *European Accounting Review*, 21(3), 533–564.
- Pagach, D., & Warr, R. (2011). The characteristics of firms that hire chief risk officers. *Journal of Risk and Insurance*, 78(1), 185–211.
[CrossRef \(http://dx.doi.org/10.1111/j.1539-6975.2010.01378.x\)](http://dx.doi.org/10.1111/j.1539-6975.2010.01378.x)
- Raiborn, C. A., Butler, J. B., & Massoud, M. F. (2009). Outsourcing support functions: Identifying and managing the good, the bad, and the ugly. *Business Horizons*, 52(4), 347–356.
[CrossRef \(http://dx.doi.org/10.1016/j.bushor.2009.02.005\)](http://dx.doi.org/10.1016/j.bushor.2009.02.005)
- Robertson, M. J., Lawes, R. A., Bathgate, A., Byrne, F., White, P., & Sands, R. (2010). Determinants of the proportion of break crops on Western Australian broadacre farms. *Crop and Pasture Science*, 61(3), 203–213.
[CrossRef \(http://dx.doi.org/10.1071/CP09207\)](http://dx.doi.org/10.1071/CP09207)
- Serrat, O. (2009). Social network analysis. Knowledge Solutions No 28, Asian Development Bank, Manila.
- She, S. X., Ma, C. Q., & Wu, D. D. (2010). General probability-time tradeoff and intertemporal risk-value model. *Risk Analysis*, 30(3), 421–431.
[CrossRef \(http://dx.doi.org/10.1111/j.1539-6924.2009.01344.x\)](http://dx.doi.org/10.1111/j.1539-6924.2009.01344.x)
- Sutton, S. G. (2006). Extended-enterprise systems' impact on enterprise risk management. *Journal of Enterprise Information Management*, 19(1), 97–114. doi:10.1108/17410390610636904 <http://dx.doi.org/10.1108/17410390610636904>
[CrossRef \(http://dx.doi.org/10.1108/17410390610636904\)](http://dx.doi.org/10.1108/17410390610636904)
- Walker, R. (2013). *Winning with risk management*. Singapore: World Scientific.
[CrossRef \(http://dx.doi.org/10.1142/8377\)](http://dx.doi.org/10.1142/8377)
- Wei, J., Zhou, L., Wang, F., & Wu, D. (2015). Work safety evaluation in Mainland China using grey theory. *Applied Mathematical Modelling*, 39(2), 924–933.
[CrossRef \(http://dx.doi.org/10.1016/j.apm.2014.06.012\)](http://dx.doi.org/10.1016/j.apm.2014.06.012)
- Wu, D. D. (2011). Introduction to the special SERRA issue on risks, uncertainties and the environment. *Stochastic Environmental Research and Risk Assessment*, 25(3), 301–304.
[CrossRef \(http://dx.doi.org/10.1007/s00477-010-0368-1\)](http://dx.doi.org/10.1007/s00477-010-0368-1)
- Wu, D. D., & Birge, J. R. (2012). Serial chain merger evaluation model and application to mortgage banking. *Decision Sciences*, 43(1), 5–36.
[CrossRef \(http://dx.doi.org/10.1111/j.1540-5915.2011.00340.x\)](http://dx.doi.org/10.1111/j.1540-5915.2011.00340.x)
- Wu, D. D., Chen, S. H., & Olson, D. L. (2014a). Business intelligence in risk management: Some recent progresses. *Information Sciences*, 256, 1–7.

[CrossRef \(http://dx.doi.org/10.1016/j.ins.2013.10.008\)](http://dx.doi.org/10.1016/j.ins.2013.10.008)

Wu, D. D., Luo, C., Wang, H., & Birge, J. R. (2014b). Bi-level programing merger evaluation and application to banking operations. *Production and Operations Management*.

Wu, D., & Olson, D. L. (2008). Supply chain risk, simulation, and vendor selection. *International Journal of Production Economics*, 114(2), 646–655.

[CrossRef \(http://dx.doi.org/10.1016/j.ijpe.2008.02.013\)](http://dx.doi.org/10.1016/j.ijpe.2008.02.013)

Wu, D. D., & Olson, D. L. (2009a). Enterprise risk management: Small business scorecard analysis. *Production Planning & Control*, 20(4), 362–369.

[CrossRef \(http://dx.doi.org/10.1080/09537280902843706\)](http://dx.doi.org/10.1080/09537280902843706)

Wu, D. D., & Olson, D. L. (2009b). Introduction to the special section on “Optimizing risk management: Methods and tools”. *Human and Ecological Risk Assessment: An International Journal*, 15(2), 220–226. doi:[10.1080/10807030902760967](https://doi.org/10.1080/10807030902760967) (<http://dx.doi.org/10.1080/10807030902760967>);

[CrossRef \(http://dx.doi.org/10.1080/10807030902760967\)](http://dx.doi.org/10.1080/10807030902760967)

Wu, D., & Olson, D. L. (2010a). Enterprise risk management: Coping with model risk in a large bank. *Journal of the Operational Research Society*, 61(2), 179–190.

[CrossRef \(http://dx.doi.org/10.1057/jors.2008.144\)](http://dx.doi.org/10.1057/jors.2008.144)

Wu, D. D., & Olson, D. (2010b). Enterprise risk management: A DEA VaR approach in vendor selection. *International Journal of Production Research*, 48(16), 4919–4932.

[CrossRef \(http://dx.doi.org/10.1080/00207540903051684\)](http://dx.doi.org/10.1080/00207540903051684)

Wu, D. D., & Olson, D. L. (2010c). Introduction to special section on “Risk and technology”. *Technological Forecasting and Social Change*, 77(6), 837–839.

[CrossRef \(http://dx.doi.org/10.1016/j.techfore.2010.01.014\)](http://dx.doi.org/10.1016/j.techfore.2010.01.014)

Wu, D. S. D., & Olson, D. L. (2013). Computational simulation and risk analysis: An introduction of state of the art research. *Mathematical and Computer Modelling*, 58(9–10), 1581–1587.

[CrossRef \(http://dx.doi.org/10.1016/j.mcm.2013.07.004\)](http://dx.doi.org/10.1016/j.mcm.2013.07.004)

Wu, D. D., & Olson, D. L. (2014). A system dynamics modelling of contagion effects in accounts risk management. *Systems Research and Behavioral Science*, 31(4), 502–511.

[CrossRef \(http://dx.doi.org/10.1002/sres.2291\)](http://dx.doi.org/10.1002/sres.2291)

Wu, D., Wu, D. D., Zhang, Y., & Olson, D. L. (2013). Supply chain outsourcing risk using an integrated stochastic-fuzzy optimization approach. *Information Sciences*, 235, 242–258.

[CrossRef \(http://dx.doi.org/10.1016/j.ins.2013.02.002\)](http://dx.doi.org/10.1016/j.ins.2013.02.002)

Wu, D. D., Xie, K., Chen, G., & Gui, P. (2010a). A risk analysis model in concurrent engineering product development. *Risk Analysis*, 30(9), 1440–1453.

[CrossRef \(http://dx.doi.org/10.1111/j.1539-6924.2010.01432.x\)](http://dx.doi.org/10.1111/j.1539-6924.2010.01432.x)

Wu, D. D., Xie, K. F., Hua, L., Shi, Z., & Olson, D. L. (2010b). Modeling technological innovation risks of an entrepreneurial team using system dynamics: An agent-based perspective. *Technological Forecasting and Social Change*, 77(6), 857–869.

[CrossRef \(http://dx.doi.org/10.1016/j.techfore.2010.01.015\)](http://dx.doi.org/10.1016/j.techfore.2010.01.015)

Wu, D. D., Zhang, Y. D., Wu, D. X., & Olson, D. L. (2010c). Fuzzy multi-objective programming for supplier selection and risk modeling: A possibility approach. *European Journal of Operational Research*, 200(3), 774–787.

[CrossRef \(http://dx.doi.org/10.1016/j.ejor.2009.01.026\)](http://dx.doi.org/10.1016/j.ejor.2009.01.026)

Wu, D. D., Zheng, L., & Olson, D. L. (2014c). A decision support approach for online stock forum sentiment analysis. *IEEE Transactions on Systems Man and Cybernetics*, 44(8), 1077–1087.

[CrossRef \(http://dx.doi.org/10.1109/TSMC.2013.2295353\)](http://dx.doi.org/10.1109/TSMC.2013.2295353)

Wunder, H. F. (2009). Tax risk management and the multinational enterprise. *Journal of International Accounting, Auditing and Taxation*, 18(1), 14–28.

[CrossRef \(http://dx.doi.org/10.1016/j.intaccaudtax.2008.12.003\)](http://dx.doi.org/10.1016/j.intaccaudtax.2008.12.003)

Xu, K. Q., Liao, S. S., Li, J. X., & Song, Y. X. (2011). Mining comparative opinions from customer reviews for competitive intelligence. *Decision Support Systems*, 50(4), 743–754.

[CrossRef \(http://dx.doi.org/10.1016/j.dss.2010.08.021\)](http://dx.doi.org/10.1016/j.dss.2010.08.021)

Yow, S., & Sherris, M. (2008). Enterprise risk management, insurer value maximisation, and market frictions. *Astin Bulletin*, 38(1), 293.

[CrossRef \(http://dx.doi.org/10.2143/AST.38.1.2030415\)](http://dx.doi.org/10.2143/AST.38.1.2030415)

Zhao, F., Dash, Wu, D., Liang, L., & Dolgui, A., (2014). Cash flow risk in dual-channel supply chain. *International Journal of Production Research*, 1–14, doi:[10.1080/00207543.2014.986302](https://doi.org/10.1080/00207543.2014.986302) (<http://dx.doi.org/10.1080/00207543.2014.986302>);

Zhao, X., Hwang, B.-G., & Low, S. P. (2013). Developing fuzzy enterprise risk management maturity model for construction firms. *Journal of Construction Engineering and Management*, 139(9), 1179–1189.

[CrossRef \(http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000712\)](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000712)

Copyright information

© Springer Science+Business Media New York 2015

Support