De Felice, Fabio (Ed.); Petrillo, Antonella (Ed.)

Book

Theory and application on cognitive factors and risk management : new trends and procedures

Provided in Cooperation with:
IntechOpen, London

Reference: (2017). Theory and application on cognitive factors and risk management : new trends and procedures. Rijeka, Croatia : InTech.
doi:10.5772/65180.

Chapter 1

A Cognitive Model for Emergency Management in Hospitals: Proposal of a Triage Severity Index

Marco Frascio, Francesca Mandolfino, Federico Zomparelli and Antonella Petrillo

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68144

Abstract

Hospitals play a critical role in providing communities with essential medical care during all types of disasters. Any accident that damages systems or people often requires a *multi-functional* response and recovery effort. Without an appropriate emergency planning, it is impossible to provide good care during a critical event. In fact, during a disaster condition, the same "critical" severity could occur for patients. Thus, it is essential to *categorize* and to *prioritize* patients with the aim to provide the best care to as many patients as possible with the available resources. Triage assesses the severity of patients to give an order of medical visit. The purpose of the present research is to develop a *hybrid algorithm*, called triage algorithm for emergency management (TAEM). The goal is twofold: First, to assess the priority of treatment; second, to assess in which hospital it is preferable to conduct patients. The triage models proposed in the literature are qualitative. The proposed algorithm aims to cover this gap. The model presented exceeds the limits of literature by developing a quantitative algorithm, which performs a numerical index. The hybrid model is implemented in a real scenario concerning the accident management in a petrochemical plant.

Keywords: emergency management, triage, hospital location, petrochemical plant, safety

1. Introduction

The continuous evolution of production processes has resulted in increased effectiveness and process efficiency. On the other hand, however, the systems are much more complex and difficult to manage [1, 2]. For this reason, to handle any emergencies that are created, it is necessary to develop a proper plan to respond to emergencies. The emergency can be

caused: by a fault of a system, by a human error, or by natural factors [3]. The National Governor's Association designed four phases of disaster: (1) *mitigation*, (2) *preparedness*, (3) *response*, and (4) *recovery*. Each phase has particular needs, requires distinct tools, strategies, and resources and faces different challenges [4]. One of the most important phases is the *response phase* that addresses immediate threats presented by the disaster, including saving lives, meeting humanitarian needs, and starting of resource distribution. In this phase, a particular process involves the *triage efforts* that aim to assess and deal with the most pressing emergency issues. This period is often marked by some level of chaos, a period of time that cannot be defined a priori, since it depends on the nature of the disaster and the extent of damage [5]. It is obvious that it is necessary to assess the conditions of the patients during the response phase and to reduce waiting time for medical services and transport [6]. A timely and quickly identification of patients with urgent, life-threatening conditions is needed [7]. Accurate triage is the "key" to the efficient operation of an emergency department (ED) to determine the severity of illness or injury for each patient who enters the ED [8]. The term triage comes from the French verb trier, meaning to separate, sift, or select. A system for the classification of patients was first used by Baron Dominique Jean Larry, a chief surgeon in Napoleon's army [9]. Originally, the concepts of triage were primarily focused on mass casualty situations. Many of the original concepts of triage remain valid today in mass casualty and warfare situations. Triage is a dynamic and complex decision-making process [10]. In general, patients should have a triage assessment within 10 min of arrival in the ED in order to ensure their proper medical management. However, it is not always possible to achieve this purpose. Some weaknesses characterize the classic triage models. It is worthy to underline that several methods of triage exist for evaluating the condition of a patient and treat him/her accordingly. The triage methods most commonly used are *Australasian Triage* scale (ATS), the *Canadian Triage and Acuity Scale (CTAS), Manchester Triage System (MTS)*, and *Emergency Severity Index* (ESI) [11]. As highlighted by Lerner *et al*. [12], each protocol may be very different from another in terms of methods of care, treatments, and strategies. Furthermore, the medical staff has to analyze several factors to decide in which hospital the patient has to be admitted but qualitatively [13]. The *effective triage* is based on the knowledge, skills, and attitudes of the triage staff. However, despite this knowledge, it is evident that the use of one triage algorithm is limited [14]. Thus, the definition of an integrated triage system is an important research priority. This study aims to cover this research gap. The aim of the research is twofold. First, the model provides a hybrid algorithm to define the priority of treatment. Second, a multi-criteria model is developed to evaluate the most suitable hospital where patients can be admitted. The hybrid algorithm exceeds the literature limits, developing a numerical model for the evaluation of triage hospital. The study helps to expand the knowledge on emergency management and also develops a standard algorithm that can be used in emergency situations, to evaluate the patient's condition, and choose the most suitable hospital. The model can be used in different conditions, both for major emergencies and in emergency conditions, medium-low. In the present work, the model is applied during an emergency simulation in a petrochemical company.

The chapter is organized as follows. Section 2 presents an overview of the four triage models most used in the world. Section 3 describes the proposed hybrid algorithm. Section 4 presents a real case study. Finally, Section 5 summarizes conclusions and future developments.

2. The four principal triage models

2.1. The Australasian Triage scale (ATS)

The Australasian Triage scale (ATS) was developed in the 1994 in an Australasian emergency department [15, 16]. All patients presenting to an emergency department should be assessed by a nurse or a doctor. The triage assessment generally goes on no more than 2–5 min. Patients who are waiting are processed again, to see if their condition deteriorated. The nurse or the doctor may also initiate the assessment or initial management, according to organizational guidelines. **Table 1** shows the Australasian Triage scale. Each category is rated with a number between 1 and 5 and a color scale. The second column represents the maximum time within which it is necessary to cure the patient. The third column describes the reference category, and finally the fourth column describes the patient's symptoms.

Table 2 incorporates the classification of **Table 1** and shows the performance indicator threshold. The indicator threshold represents the percentage of patients assigned ATS categories, who commence assessment and treatment within the relevant waiting time from their time of arrival.

2.2. The Canadian Triage and Acuity Scale (CTAS)

The Canadian Triage and Acuity Scale (CTAS) is based on the ATS and was developed in the 1990s in Canada [10]. In the CTAS, a list of clinical symptoms is used to determine the triage level. CTAS defines a five-level scale with level 1, representing the worst case and level 5, representing the patient with less risk. The CTAS establishes a relationship between patient's presenting symptoms and the potential causes. Other factors called modifiers refine the classification [17–19] as follows:

1. *Resuscitation*. Conditions expecting the risk of death. These are patients that have their heart arrested, or are heart pre-arrest, or heart post-arrest. Their treatment is often started in the pre-hospital setting and further aggressive or resuscitative efforts are required immediately upon arrival at the emergency department;

Category	Response	Category description	Clinical descriptors
1	Immediate simultaneous assessment and treatment	Immediately life-threatening	Cardiac arrest, respiratory arrest, immediate risk to airway
2	Assessment and treatment within 10 min	Imminently life-threatening	Airway risk, severe respiratory distress, circulatory compromise
3	Assessment and treatment within 30 min	Potentially life-threatening	Severe hypertension, moderate severe blood loss, vomiting
4	Assessment and treatment within 60 min	Potentially serious or urgency situation	Mild hemorrhage, vomiting, eye inflammation, minor limb trauma
5	Assessment and treatment within 120 min	Less urgent	Minimal pain, low risk, minor symptoms, minor wounds

Table 1. Australasian Triage scale.

ATS scale	Treatment acuity (maximum waiting time for medical assessment and treatment)	Performance indicator threshold
1	Immediate	100%
2	10 min	80%
3	30 min	75%
4	60 min	70%
5	120 min	70%

Table 2. ATS performance indicator threshold.

2. *Emergent*. The patient risks his/her life because of serious injuries and requires quick cures. The doctor must act to stabilize the vital conditions;
3. *Urgent*. The patient is not life-threatening, but his/her condition could worsen. The vital signs are normal, but it is necessary to act soon to avoid being impaired;
4. *Less urgent*. The patient has no serious injuries. His condition depended on the strain, age, and little pain. The medical examination is not required;
5. *Non-urgent*. The patient's condition is not pejorative. They may be due to a chronic problem. Then, the patient can go home if the hospital resources do not allow the visit.

The CTAS is developed in several steps (**Figure 1**):

- **Quick look:** The first step of the CTAS analysis. When the symptom is obvious it is simple to evaluate the level;
- **Presenting complaint:** The second step is to analyze the symptoms. As with the "Quick Look," the symptom should only be used to evaluate if the patient is into CTAS Level 1;
- **First-/second-order modifier**: In many cases, the "Quick Look" is not sufficient to analyze the complaint. To refine the assessment, modifiers are analyzed. This makes it possible to better assess the patient.

Figure 1 describes the CTAS analysis step to assess the patient's condition.

2.3. The Manchester Triage System (MTS)

The Manchester Triage System (MTS) is used in emergency departments in Great Britain [20, 21]. The MTS model has a scale with five levels (**Table 3**). The time is relative to a maximum time to response. **Table 3** shows the Manchester Triage scale. Each category is rated with a number between 1 and 5 and a color scale. The second column describes the name of the assessment. The third column represents the maximum time within which it is necessary to cure the patient. The fourth column describes the patient's symptoms.

The MTS uses 52 diagrams which represent symptoms, with which to evaluate the patients. When a patient reports symptoms, the nurse examines his/her situation and he/she determines

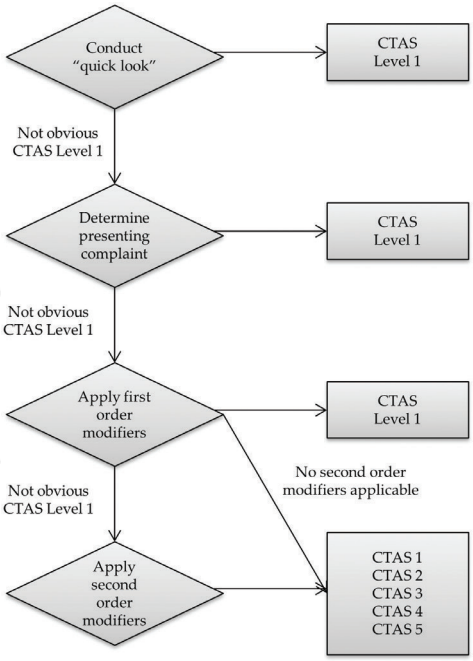

Figure 1. CTAS approach.

the treatment priority according to the triage scale. It utilizes a series of flow charts that lead the triage nurse to a logical choice of triage category also using a five-point scale [22]. The MTS model is a powerful tool to evaluate patients. Its discriminatory power is not equal for medical and surgical specialties, which may be linked to the nature of inbuilt discriminators [23].

2.4. The Emergency Severity Index (ESI)

The Emergency Severity Index (ESI) is a triage algorithm that was developed in the USA in the late 1990s [24]. The priority depends on the patient's severity and the necessary resources. Initially, the nurse analyzes the vital signs. If the patient is not in critical conditions (level 1 or 2), the decision maker has to evaluate the expected resource necessary to determine a triage level (level 3, 4, or 5). Algorithms are frequently used in emergency care. The ESI model is based on a four-point decision. **Figure 2** shows the four decision points reduced to four key questions [25]:

A. Does this patient require immediate lifesaving intervention?

B. Is this a patient who shouldn't wait?

C. How many resources will this patient need?

D. What are the patient's vital signs?

Category	Name	Time (min)	Symptoms
1	Immediate	0	Airway compromise Inadequate breathing Shock
2	Very urgent	10	Severe pain Cardiac pain Abnormal pulse
3	Urgent	60	Pleuritic pain Persistent vomiting Significant cardiac history
4	Standard	120	Vomiting Recent mild pain Recent problem
5	Non-urgent	240	Vomiting Recent mild pain Recent problem

Table 3. Manchester Triage scale.

Figure 2 represents the structure of the ESI model. The decision responds to certain questions and based on the answers you associate a different assessment.

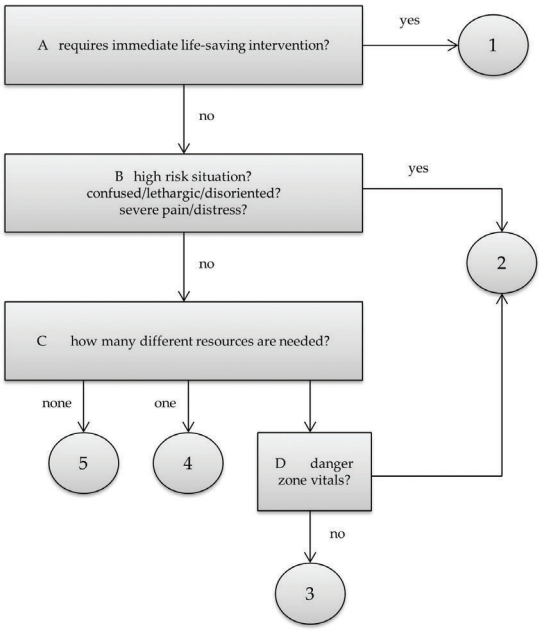

Figure 2. ESI approach.

Table 4 describes the action considered lifesaving and those that are not, for the purposes of ESI assessment level 1 [26]. Classifications are present in the first column, the second column describes the interventions that save lives, while in the last column, there are interventions that do not save lives.

	Lifesaving	Not lifesaving
Airway/breathing	BVM ventilation	
	Intubation	Oxygen administration
	Surgical airway	Nasal cannula
	Emergent CPAP	Non-rebreather
	Emergent BiPAP	
Electrical therapy	Debrifillation	
	Emergent cardioversion	Cardiac monitor
	External pacing	
Procedures	Chest-needle decompression	ECG
	Pericardiocentesis	Laboratory tests
	Open thoracotomy	Ultrasound
	Intraoseous access	FAST
Hemodynamics	Significant fluid resuscitation	Access
	Blood administration	Saline lock
	Control of major bleeding	
Medications	Naxolone	ASA
	D50	Antibiotics
	Dopamine	Nitroglycerin
	Atropine	Heparin
	Adenocard	Pain medications

Table 4. Lifesaving interventions.

In the first point (A), the decision maker assesses whether the patient needs immediate care. In this case, the patient is valued as level 1; otherwise, it goes to decision point B. The triage nurse verifies if the patient is at high risk. The patient's age and the past medical history influence the triage nurse's determination of risk. This patient has a potential condition of a threat to his/her life. The nurse recognizes a patient at high risk, when he/she realizes that the vital signs may get worse. The triage nurse assesses this patient as level 2 because the symptoms are dangerous. The decision maker should ask, "*How many different resources do you think this patient is going to consume in order for the physician to reach a disposition decision*?" The patient can be discharged, leaving the hospital or transferred to another hospital. Nurses assess the need for resources for each patient, comparing it to the capacity of the hospital. The nurse again examines the patient's symptoms. If the symptoms have worsened, then the patient is evaluated for level 2, or level 3. If the patient needs few resources, he/she is estimated level 4; otherwise it is evaluated level 5. This is decision point D. The limit of the literature about the hospital triage is the qualitative approach used.

3. The rationale: TAEM algorithm

Studies of the reliability and validity of triage models underline that existing models are very qualitative [27–29]. However, it is important to standardize a model and to measure the degree with which the measured acuity level reflects the patient's true acuity at the time of triage. Thus, the proposed model developed in our research aims to be "quantitative." It uses numerical indicators to measure the patient's acuity level. The hybrid model evaluates the condition of patients (triage) and the hospital to conduct the patients; it mixes qualitative aspects (defined in the literature) with quantitative/numerical elements. Emergency management is divided into three phases:

1. Phase#1: Emergency start;
2. Phase#2: Triage algorithm for emergency management (TAEM);
3. Phase#3: Rating hospitals.

Figure 3 represents a scheme of the new hybrid model that we have developed, starting from the four previous models analyzed. Classical approach requires that the decision maker assesses different questions before to achieve at an evaluation of the patient. Our model allows a quantitative numerical evaluation of the patient's condition and better hospital choice. TAEM algorithm is proposed to be used by medical staff during an emergency management situation. The model can be used in different and more or less serious emergency conditions.

The subsequent text provides detailed description of the TAEM algorithm.

3.1. Phase#1: emergency start

The present phase aims to measure emergency preparedness in order to predict the likely performance of emergency response systems. This is a critical phase to define actions to be implemented. When an accident occurs, an emergency condition is manifested. Depending on the type of emergency, the internal emergency plan is triggered. The internal emergency plan provides implementing all the preventive and protective systems to prevent the emergency situation from becoming worse. If the emergency is serious, the external aid has to be alarmed (medical personnel, policeman, and firemen). Thus, it is essential to define the number of relief efforts and the type.

3.2. Phase#2: triage algorithm for emergency management (TAEM)

The TAEM model identifies five levels of emergency. The basic structure is acquired by ESI model. However, different from ESI model, the TAEM algorithm associates a score to each element, obtaining a total coefficient (numerical approach). The colors are taken from the Manchester methodology and the operation times are taken by the Australasian methodology. **Figure 4** shows the methodological flowchart for the TAEM algorithm. It is a part of the complete pattern shown in **Figure 3**. In particular, the model that we developed involves the use of an algorithm to identify the patient's classification.

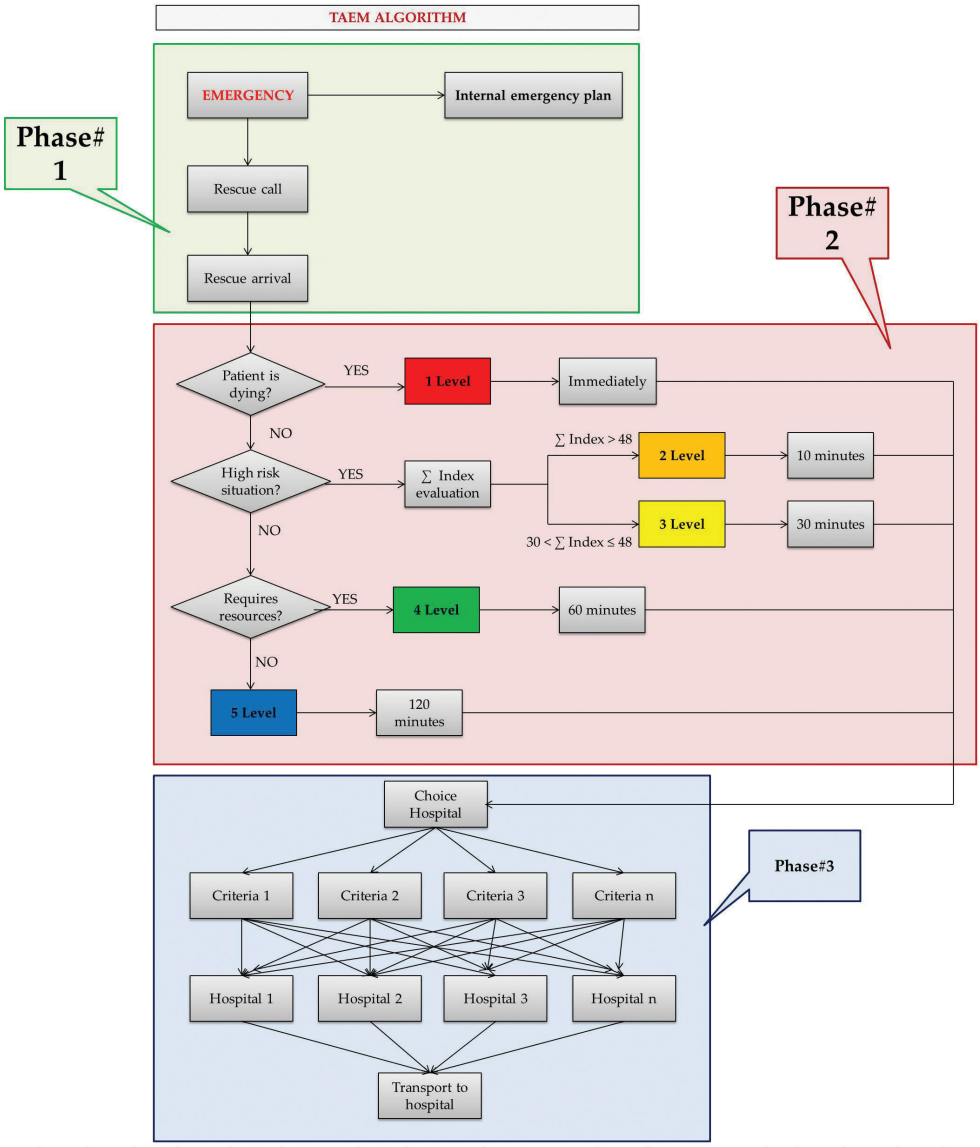

Figure 3. Emergency management research flowchart.

Patient assessment is carried out by the nurse through three different steps (**Figure 5**), which are described below. The model that we have developed considers the structure of the ESI model, the MTS model colors, the response times described by the ATS method, and the inclusion of a quantitative numerical approach

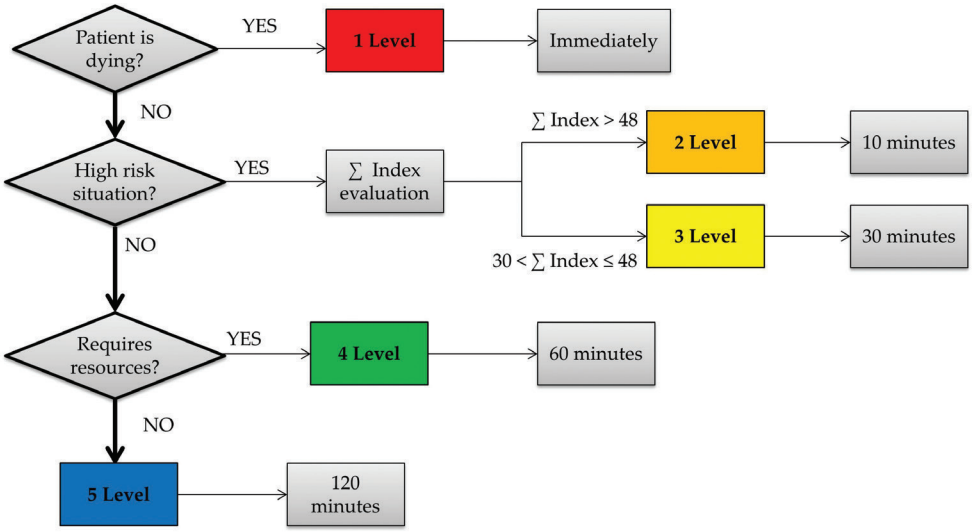

Figure 4. TAEM approach.

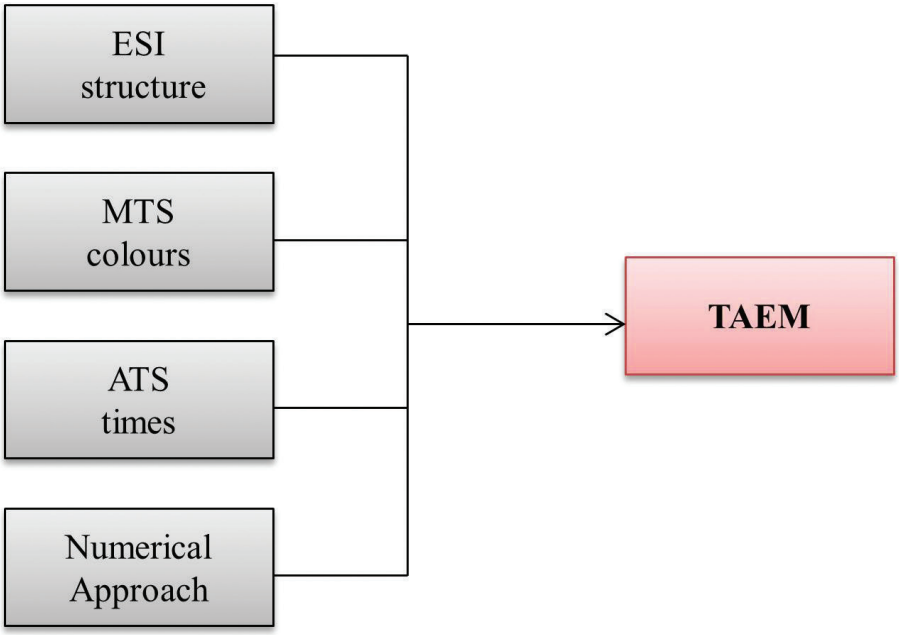

Figure 5. TAEM algorithm flowchart.

In addition to the development of TAEM structure, we have developed a new standardization to identify the classification of patients. **Table 5** summarizes the triage scale of the TAEM algorithm. Each category is rated with a number between 1 and 5 and a color scale. The second column describes the name of the assessment. The third column represents the maximum time within which it is necessary to cure the patient. The fourth column describes the patient's symptoms.

If one of the main vital functions is not active, then the patient is assessed level 1. **Table 6** shows the vital functions analyzed in the death-danger analysis, to assess the patient level 1. The symptoms of a patient in critical condition are as follows:

- Cardiac arrest;
- Respiratory arrest;
- Severe respiratory distress;
- Child who is unresponsive to pain;
- Hypoglycemic with a change in mental status;
- Severe bradycardia;
- Critically injured, patient unresponsive.

If the patient has none of these symptoms, it is not evaluated for level 1. The nurse must decide whether the patient is level 2. We have developed a numerical algorithm that allows evaluating an index for the patient severity. The algorithm has been represented in **Table 6**.

For the assessment, it considers various factors, and it associates with each of these factors increasing a value according to severity. Each factor has a predetermined weight, depending on the importance of the factor. The values shown in the table have been proposed by analyzing the literature on triage procedures.

For each factor, the index (Eq. (1)) is calculated. Then, add up the indexes (Eq. (2))

Category	Name	Time (min)	Symptoms
1	Immediate	0	Airway compromise Inadequate breathing Shock
2	Very urgent	10	Severe pain Cardiac pain Abnormal pulse
3	Urgent	30	Pleuritic pain Persistent vomiting Significant cardiac history
4	Standard	60	Vomiting Recent mild pain Recent problem
5	Non-urgent	120	Vomiting Recent mild pain Recent problem

Table 5. TAEM scale.

Factors	Severity			Weight			Index
	1	2	3	0.5	1.5	5	
Level of consciousness					x		
Heart beat						x	
Breathing						x	
Pain				x			
Panic				x			
Injury						x	
Age					x		
Pressure level					x		
Past medicals				x			
							∑ index

Table 6. Index triage.

$$Index = Severity \times Weight \tag{1}$$

$$\sum Index = \sum(Severity \times Weight) \tag{2}$$

The minimum value of ∑ Index is 21, then the maximum value of ∑ Index is 63. In detail,

- If ∑ Index > 48, the patient is evaluated level 2.
- If 30 < ∑ Index ≤ 48, the patient is evaluated level 3.
- If the patient is not level 2 or 3 and is not an urgent situation, then the nurse should assess the resources available to define the triage level.

The triage nurse should ask, "*How many different resources do you think this patient is going to consume in order for the physician to reach a disposition decision*?" The nurse to answer these questions must take into account the routine practice in the particular emergency department. The resources that are considered by the nurse are as follows:

- Blood laboratories;
- Urine laboratories;
- Electrocardiogram (ECG);
- X-rays;
- Computed tomography-magnetic resonance imaging (CT-MRI) ultrasound angiography;
- Fluids hydration;
- Specialty consultation;
- Sedation.

If the patient requires different resources, it is catalogued level 4, otherwise level 5.

3.3. Phase#3: rating hospitals

The present phase aims to determine the best choice of the hospital, according to predetermined criteria. For the hospital evaluation, it has adopted a multi-criteria algorithm, which takes into account the criteria listed in **Table 7**. For each criterion, a weight (*W*) is associated, and for every hospital, an evaluation (*E*) is associated. The product $W \times E$ greater determines the optimal solution (**Table 7**). The sum of the weight values is 100. The evaluation value is between 0 and 90.

		Evaluation (*E*)				*W* × *E*			
Criteria	**Weight criteria (*W*)**	**Hospital 1**	**Hospital 2**	**Hospital 3**	**Hospital n**	**Hospital 1**	**Hospital 2**	**Hospital 3**	**Hospital n**
Departments									
Distance (km)									
Secondary road									
Beds									
Transport									
Tot									

Table 7. Quantitative model.

4. The experimental scenario

The case study is related to a management of emergency, after an accident, which occurred in a petrochemical company plant. The emergency is related to the explosion of a hydrogen sulfide tank. **Figure 6** shows the petrochemical plant layout and the hydrogen sulfide tank under study. Immediately after the explosion, the foreman activates the emergency management practices. During the explosion, one operator was located near the tank and he was affected by the fire. The manager called health aid.

The medical staff checked the vital functions to see if the two operators were dying. The evaluation was negative. So, the medical staff verified the other functions (**Table 8**) to assess the patient's condition. The severity index was 32; this means that the patient was level 3 and must be taken care of within 30 min. It is important to note that the values reported in **Table 8** are related to a real simulation of an incident occurred in the petrochemical company.

In 30 min it would be possible to reach four different hospitals. Thus, it was necessary to evaluate the best hospital in which to carry the injured. **Table 9** shows the criteria adopted

Figure 6. Chemical plant and hydrogen sulfide tank.

Factors	Severity			Weight			Index
	1	**2**	**3**	**0.5**	**1.5**	**5**	
Level of consciousness		x			x		3
Heart beat	x					x	5
Breathing	x					x	5
Pain	x			x			0.5
Panic		x		x			1
Injury		x				x	10
Age		x			x		3
Pressure level		x			x		3
Past medicals	x			x			1.5
						∑ index	**32**

Table 8. Triage index.

	Hospital 1	Hospital 2	Hospital 3	Hospital 4
Departments	Resuscitation surgery orthopedics emergency room dermatology	Resuscitation surgery emergency room dermatology	Resuscitation orthopedics emergency room dermatology	Resuscitation orthopedics emergency room dermatology
Distance (km)	3.4	4.5	6	6.8
Secondary road	2	3	4	4
Beds	370	165	221	234
Transport	3	1	2	3

Table 9. Criteria values.

for the choice of the hospital. Each criterion is given a weight (*W*) and each criterion on the hospital is given one vote (**Table 10**). The numbers shown in **Table 9** are real values, relative to the nearest hospital's petrochemical plant.

		Evaluation (*E*)				*W* × *E*			
Criteria	**Weight (*W*)**	**Hospital 1**	**Hospital 2**	**Hospital 3**	**Hospital 4**	**H 1**	**H2**	**H3**	**H4**
Departments	24	90	72	72	72	2160	1728	1728	1728
Distance (km)	24	90	80	75	70	2160	1920	1800	1680
Secondary road	19	45	68	90	90	855	1292	1710	1710
Beds	19	90	40	54	57	1710	760	1026	1083
Transport	14	90	30	60	90	1260	420	840	1260
Total						**8145**	**6120**	**7104**	**7461**

Table 10. Hospital choice.

Table 10 calculates through the multi-criteria approach to the importance of each hospital according to different criteria presented in **Table 9**. **Table 10** shows that the best result is hospital 1, where the patient is cured.

5. Conclusion

Emergency management plays an increasingly important role, in order to safeguard the human life. The present research proposed a hybrid model for the emergency management. The model is completely innovative and exceeds the limits of the literature. Starting from triage models known in literature, we have developed a hybrid algorithm (TAEM algorithm) for the evaluation of the patients. TAEM algorithm aims to evaluate both qualitative and quantitative factors that may influence the final decision in the rescue of patients. Thus, a quantitative index is defined to achieve this goal. In particular, the algorithm allows defining a patient's subjective assessment analyzing the subjective aspects that are translated into numbers. In this way, it is possible to define an index that represents the patient assessment. Furthermore, it is possible to define the severity of the patient and treat him/her accordingly. In addition, the TAEM algorithm aims to complete the emergency management through a multi-criteria approach in order to define in which hospital it is proper to conduct the injured. Different criteria in different hospitals, associating a numerical value, have been evaluated. The hospital that has a higher rating is the best choice. This model allows avoiding long lines and long waits in emergency rooms in case of serious emergency situations in which there are many injured. The validity of the model is demonstrated applying it in a real case study. The model presented assumes an important role in research because it exceeds the qualitative limits of existing triage models; it is also useful for practical purposes, during emergency situations.

The future developments of the work aim to develop a software tool to implement the TAEM algorithm. The final result will be an application that can support various types of emergency triage at the point of care using mobile devices. The system will be designed for use in the emergency department of a hospital and to aid physicians in disposition decisions. The system will facilitate patient-centered service and timely, high-quality patient management.

Acknowledgements

This research represents a result of research activity carried out with the financial support of MiuR, namely PRIN 2012 "DIEM-SSP, Disasters and Emergencies Management for Safety and Security in industrial Plants."

Author details

Marco Frascio[1], Francesca Mandolfino[1], Federico Zomparelli[2] and Antonella Petrillo[3]*

*Address all correspondence to: petrilloantonella@gmail.com

1 Università degli Studi di Genova (GE), Genova, Italy

2 Università degli Studi di Cassino e del Lazio Meridionale (FR), Cassino, Italy

3 Università degli Studi di Napoli "Parthenope," Napoli (NA), Italy

References

[1] Waugh WL, Streib G. Collaboration and leadership for effective emergency management. Public Administration Review. 2006;66(s1):131-140.

[2] De Felice F, Falcone D, Petrillo A, Bruzzone A, Longo F. A simulation model of human decision making in emergency conditions. 28th European Modeling and Simulation Symposium, EMSS 2016, 26-28 September, Larnaca (Cyprus), pp. 148-154.

[3] Meshkati N. Human factors in process plants and facility design. In: Zimmerman R, editors. Cost-Effective Risk Assessment for Process Design. McGraw Hill; New York. 1995. p. 6.

[4] Fereiduni M, Shahanaghi K. A robust optimization model for distribution and evacuation in the disaster response phase. Journal of Industrial Engineering International. 2017;13(1):117-141.

[5] Caunhye AM, Nie X, Pokharel S. Optimization models in emergency logistics: A literature review. Socio-Economic Planning Sciences. 2012;46(1):4-13.

[6] Hamm C, Goldmann BU, Heeschen C, Kreymann G, Berger J, Meinertz T. Emergency room triage of patients with acute chest pain by means of rapid testing for cardiac troponin T or troponin I. New England Journal of Medicine. 1997; 337(23):1648-1653.

[7] Buckle P. Re-defining community and vulnerability in the context of emergency management. Australian Journal of Emergency Management. 1999;13(4):21.

[8] Christ M, Grossman F, Winter D, Bingisser R, Platz E. Modern triage in the emergency department. Deutsches Arzteblatt. 2010;107(50):892-898.

[9] Burris DG, Welling DR, Rich NM. Dominique Jean Larrey and the principles of humanity in warfare. Journal of the American College of Surgeons. 2004;198(5):831-835. doi: 10.1016/j.jamcollsurg.2003.12.025.

[10] Bullard MJ, Unger B, Spence J, Grafstein E. Revisions to the Canadian Emergency Department Triage and Acuity Scale (CTAS) adult guidelines. Canadian Journal of Emergency Medicine. 2008;10:136-51.

[11] Sauer LM, McCarthy ML, Knebel A, Brewster P. Major influences on hospital emergency management and disaster preparedness. Disaster Medicine and Public Health Preparedness. 2009;3(S1):68-73.

[12] Lerner EB, Schwartz RB, Coule PL, Weinstein ES, Cone DC, Hunt RC, et al. Mass casualty triage: an evaluation of the data and development of a proposed national guideline. Disaster Medicine and Public Health Preparedness. 2008;2 Suppl 1:S25-34.

[13] Andersson AK, Omberg M, Svedlund M. Triage in the emergency department—a qualitative study of the factors which nurses consider when making decision. Nursing in Critical Care. 2006;11(3):136-145.

[14] Twomey M, Wallis LA, Myers JE, Limitations in validating emergency department triage scales. Emergency Medicine Journal. 2007 Jul;24(7):477-479.

[15] Australasian college for emergency medicine. Guidelines on the implementation of the Australasian Triage scale in emergency departments [Internet]. Available from: www.acem.org.au

[16] Considine J, Le Vasseur SA, Villanueva E. The Australasian Triage scale: examining emergency department nurses' performance using computer and paper scenarios. Annals of Emergency Medicine. 2004;44(5):516-523.

[17] Canadian Ministry of Health and Long-Term Care. Prehospital Canadian triage & acuity scale. [Internet]. Available from: http://www.lhsc.on.ca/

[18] Warren DW, Jarvis A, Le Blanc L, Gravel J. Revisions to the Canadian triage and acuity scale paediatric guidelines. Canadian Journal of Emergency Medicine. 2008;10(3):224-233.

[19] Schellein O, Ludwig-Pistor F, Bremerich DH. Revisions to the Canadian emergency department triage and acuity scale (CTAS). Adult guidelines. Canadian Journal of Emergency Medicine. 2008;10:136-151.

[20] Windle J. Manchester triage system. A global solution. [Internet]. Available from: http://www.triage.it/congresso/images/edocs/abstract/1sess/slide/2-J.%20Windle.pdf

[21] Grouse AI, Bishop RO, Bannon AM. The Manchester triage system provides good reliability in an Australian emergency department. Emergency Medical Journal. 2009;26(7):484-486.

[22] Martins HMG, Curia LDCD, Freitas P. Is Manchester (MTS) more than a triage system? A study of its association with mortality and admission to a large Portuguese hospital. Emergency Medicine Journal. 2009;26(3):183-186.

[23] Shelton R. The emergency severity index 5-level triage system. Adult guidelines. Dimensions of Critical Care Nursing. 2009;28(1):9-12.

[24] Gilboy N, Tanabe P, Travers D, Rosenau AM. Emergency severity index (ESI). A triage tool for emergency department care. [Internet]. Available from: www.ahrq.gov

[25] Wuerz RC, Milne LW, Eitel DR, Travers D, Gilboy N. Reliability and validity of a new five-level triage instrument. Academic Emergency Medicine. 2000;7(3):236-242.

[26] Platts-Mills TF, Travers D, Biese K, McCall B, LaMantia M, Cairns CB. Accuracy of the emergency severity index triage instrument for identifying elder emergency department patients receiving an immediate life-saving intervention. Academic Emergency Medicine. 2010;17(3):238-243.

[27] Robertson-Steel I. Evolution of triage systems. Emergency Medicine Journal. 2006 Feb;23(2): 154-155.

[28] Robertson-Steel I, Edwards SN. Integrated triage: the time has come. Pre-Hospital Immediate Care 20004173-175.175

[29] European Emergency Data Project EMS Data-based Health Surveillance System. European Commission, 2004. http://www.eed-project.de [Accessed: 2005-12-09]

Chapter 2

Human Error Analysis in Software Engineering

Fuqun Huang

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68392

Abstract

As the primary cause of software defects, human error is the key to understanding, detecting and preventing software defects. This chapter first reviews the state of art of an emerging area: software fault defense based on human error mechanisms. Then, an approach for human error analysis (HEA) is proposed. HEA consists of two important components: human error modes (HEM) and an undated version of causal mechanism graphs (CMGs). Human error modes are the general erroneous patterns that humans tend to behave in a variety of activities. Causal mechanism graph provides a way to extract the error-prone contexts in software development, and link the contexts to general human error modes. HEA can be used at various phases of software development, for both defect detection and prevention purposes. An application case is provided to demonstrate how to use HEA.

Keywords: human error analysis, software defect prevention, fault detection, causal mechanism graph, software quality assurance

1. Introduction

Software has become a major determinant of how reliable, safe and secure computer systems can be in various safety-critical domains, such as aerospace and energy areas. Despite the fact that software reliability engineering has remained an active research subject over 40 years, software is still often orders of magnitude less reliable than hardware. There are over 200 software reliability models, but each of which can apply to only a few cases. Based on scientific intuition, if there were a model that had captured the essence of an entity of interest, it should be able to describe the entity in a variety of contexts. It is necessary to reflect what have been overlook in the current research and practices in software (reliability) engineering.

Software, as a pure cognitive product [1, 2], does not fail in the same way as how hardware fails. Software does not have material or manufacturing problems, for example, corrosion or aging problems. How a software system performed in the last second could tell nothing about whether the system will fail or not in the next second; and people can hardly anticipate the consequences of a software failure until it happens. Drawing upon the notion of the cognitive nature of software faults, there is a need to build software dependability theories on the foundation of cognitive science.

As the primary cause of software defects, human error is the key to understanding and preventing software defects. Software defects are by nature the manifestations of cognitive errors of individual software practitioners or/and of miscommunication between software practitioners. Though the cognitive nature of software has been realized early in 1970s [3], significant progress has only been made in recent years on how we can use human error theory to defend against software defects [4].

This chapter reviews the new interdisciplinary area: Software Fault Defense based on Human Error mechanisms (SFDHE) and proposes an approach for human error analysis (HEA). HEA is at the core of various methods used to defend against software faults in the SFDHE area.

The chapter is organized as follows: Section 2 reviews the emerging area SFDHE; Section 3 proposes the method for human error analysis (HEA); Section 4 presents an application example; Section 5 makes conclusion.

2. The new interdiscipline: *S*oftware *F*ault *D*efense based on *H*uman *E*rror mechanisms (SFDHE)

2.1. History

Human cognition plays a central role in software development even if in the modern large projects [4–7]. A previous analysis on a large set of industrial data shows that eighty seven percent of the severe residual defects are caused by individual cognitive failures independent of process consistency [8]. Approaches for defending against cognitive errors are necessary to improve software dependability.

Software Fault Defense based on human error mechanisms [5], firstly proposed in 2011 by Huang [4], is an area aiming to systematically predict, prevent, tolerate and detect software faults through a deep understanding of the causal mechanisms underlying software faults—the cognitive errors of software practitioners. This is an interdisciplinary area built on integrative theories in software engineering, systems engineering, software reliability engineering, software psychology and cognitive science.

2.2. State of art

2.2.1. Human error mechanisms underlying software faults

The first phase of SFDHE is to identify the factors that influence software fault introduction, as well as how various factors interact with each other to form a software defect. The factors related to programming performance are traditionally studied in software psychology, with a thorough review in [9]. However, there is few study focusing on identifying factors that influence human errors in programming. One of Huang's recent experimental studies was devoted to comparing the effects of various human factors on fault introduction rate [7]. Results show that a few dimensions of programmers' cognitive styles and personality traits are related to fault introduction rate [7] as significantly as the conventional program metrics [10].

In order to study human errors in software engineering, there is a need to integrate general human error theories with the cognitive nature of software development. Huang [2] developed an integrated cognitive model of software design. Based on the cognitive model, a human error taxonomy was proposed for software fault prevention [2]. Another human error taxonomy was recently developed by Anu and Walia et al. [11] for with an emphasis on software requirement review. These human error taxonomies vary in details in order to achieve different purposes, however, they both place Reason's human error theory [12] as a fundamental theory.

A recent experiment [13] examined how an erroneous pattern called "postcompletion error" [14] manifests itself in software development. Postcompletion error is a specific type of human errors that one tends to omit a subtask that is carried out at the end of a task but is not a necessary condition for the achievement of the main subtask [14]. Postcompletion errors have been observed in a variety of tasks by psychologists, but there is a lack of empirical studies in software engineering. The author's experiment shows that 41.82% of programmers committed the postcompletion error in the same way. As the first attempt to link general human error modes (HEM) to programming contexts, the study has set a significant paradigm for investigating the human error mechanisms underlying software defects.

2.2.2. Software fault prevention based on human error mechanisms

A key activity of the traditional defect prevention process is to identify root causes. Root causes are generally classified into four categories: method, people, tool, and requirement; detailed causes are analyzed by brainstorming with cause-effect diagrams [15]. Such taxonomies are too abstract to be helpful for those organizations with little experience. Huang's human error taxonomy [2] has been used to advance the process of traditional software defect prevention [16, 17].

Huang [18] also developed an approach called defect prevention based on human error theories (DPeHE) to proactively prevent software defects by promoting software developers' cognitive ability of human error prevention. Compared to the conventional defect prevention that

focuses on organizational software process improvement, DPeHE focuses more on software developers' metacognitive ability to prevent cognitive errors. DPeHE promotes software developers' error prevention ability through two stages. In the first stage, DPeHE provides developers with explicit knowledge of human error mechanisms and prevention strategies. In the second stage, software developers use the provided strategies and devices to practice error regulation during their real programming practices. Through this training program, software developers gain better awareness of error-prone situations and better ability to prevent errors. This method has received very positive feedbacks from a variety of industrial users [18].

2.2.3. Software fault tolerance based on human error mechanisms

Independent development (i.e., development by isolated teams) is used to promote the fault tolerance capability in N-version programming. However, empirical evidence shows that coincident faults are introduced even if the redundant versions are truly built independently [19, 20]. Programmers are prone to make the same errors under certain circumstances, thus introducing the same faults at certain places. Huang [4] has been devoted to first understanding why, how and under what circumstances programmers tend to introduce the same faults, and then to seeking a scientific way to achieve fault diversity and enhance software systems' fault tolerant capability [4]. Huang's theory [7] relates the likelihood of identical faults to the "performance level" of the activity required from the programmers. Remarkably, the most frequent coincident fault does not occur at difficult task points that involve knowledge-based performance, but rather at an easy task point that involves rule-based performance [7].

2.2.4. Software fault detection based on human error mechanisms

Since the idea of using human error theories to promote software fault detections at various stages of software development lifecycle was presented in 2011 [4], significant progress has been made recently [11, 21]. Anu and Walia et al. [11] developed a human error taxonomy for requirement review, and positive effects on subjects' fault detection effectiveness were observed. Li, Lee and Huang et al. [21, 22] introduced human error theories to prioritize test strategies at coding and evolution phases.

3. Human error analysis

Human error analysis (HEA) is at the core process of various methods for defending against software faults in SFDHE. HEA can be employed at different phases during software development, for both defect detection and prevention purposes, shown in **Figure 1**. For instance, HEA can be used to promote requirement review, design review and code inspection. At requirement and design phases, HEA can also help one identify contexts prone to trigger software developers' cognitive errors at the next phase, so one can take strategies to prevent the errors.

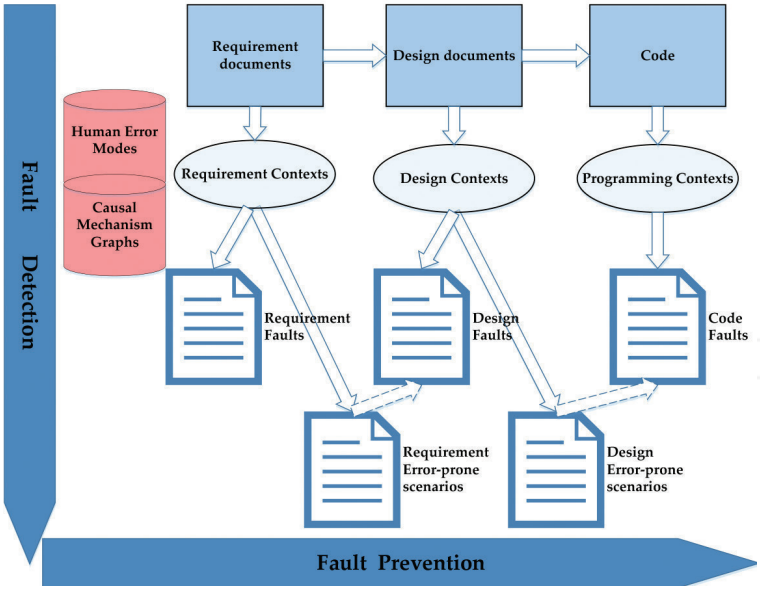

Figure 1. The framework of HEA in software engineering.

HEA consists of two components: human error modes (HEM) and causal mechanism graph (CMG). Human error modes are the erroneous patterns that psychologists that have observed to recur across diverse activities [12, 14]. CMG provides a way to extract a specific set of contexts of the artifact (e.g., requirement, design and code) under analysis to the general conditions that associates with a human error mode.

3.1. Human error modes

Though human errors appear in different "guises" in different contexts, they take a limited number of underlying modes [12]. A human ***error mode*** is a particular pattern of human erroneous behavior that recurs across different activities, due to the cognitive weakness that shared by all humans, for example, applying "strong-but-now-wrong" rules [12].

Understanding such recurring error modes is essential to identifying software defects and the contexts prone to trigger a human error. A sample of the error modes are describes in **Table 1**. These error modes were observed to manifest themselves in software development contexts in the author's previous experimental studies [5, 7, 13] or industrial historical data [8]. More software defects examples associated with these human error modes can be found in [18].

3.2. Causal mechanism graphs

The author recommends a graphic tool called causal mechanism graph (CMG) for causal mechanism modeling. CMG is a notation system firstly used to represent and model the

Error mode name	Explanation and scenarios
Lack of knowledge [2]	Software defects are introduced when one omits related knowledge, or even does not realize related knowledge is required. This error mode is prone to appear especially when the problem is an interdisciplinary problem.
Postcompletion error [13, 14]	The pattern of "post completion error" is that if the ultimate goal is decomposed into several subgoals, a subgoal is likely to be omitted under such conditions: the subgoal is not a necessary condition for the achievement of its corresponding superordinate goal; the subgoal is to be carried out at the end of the task.
Problem representation error	Misunderstand task representation material and simulate wrong situation model of the problem, due to the ambiguity of the material.
Apply "strong but now wrong" rules	People tend to behave the same way in a context that is similar to past circumstances, neglecting the countersigns of the exceptional or novel circumstances. In software development, this means that when solving problems, developers tend to prefer rules that have been successful in the past. The more frequent and successful the rule has been used before, the more likely it is recalled.
Schema encoding deficiencies	Features of a particular situation are either not encoded at all or misrepresented in the conditional component of the rule.
Selectivity	Psychologically salient, rather than logically important task information is attended to. In software development, "selectivity" means that when a developer solving problems, if attention is given to the wrong features or not given to the right features, mistakes will occur, resulting in wrong problem presentation, or selecting wrong rules or schemata to construct solutions.
Confirmation bias	People tend to seek for evidence that could verify their hypotheses rather than refuting them, whether in searching for evidence, interpreting it, or recalling it from memory. Others restrict the term to selective collection of evidence.
Problems with complexity	As problem complexity arises, error symptoms tend to occur such as delayed feedback, insufficient consideration of processes in time, difficulties with exponential developments, thinking in causal series not causal nets, thematic vagabonding, and encysting (topics are lingered over and small details attended to lovingly).
Biased review	People tend to believe that all possible courses of action have been considered, when in fact very few have been considered.
Inattention	Fail to attend to a routine action at a critical time causes forgotten actions, forgotten goals, or inappropriate actions. "Automatic processing" in software developing happens when no problem solving activities are involved, such as typing. Slips might happen without proper monitoring and error detection.

Table 1. Sample of human error modes (adopted from Ref. [18]).

complex causal mechanisms that determine software dependability, which encompasses different attributes, such as reliability, safety, security, maintainability and availability [23, 24].

A causal mechanism graph is capable of capturing logic, time and scenario features, which are essential to the description of interactions between various factors to produce an effect. The notations in CMG allow researchers to model causal mechanisms more accurately: logic

symbols allow for various logical combinations between causes or effects; the scenario symbol enables the identification of situations in which a relation is likely to exist; and time flow allows a number of cause-effect units to develop into a cause-effective chain. Moreover, notations are designed to capture the recurrent patterns of comprehensive causal mechanisms (e.g., activate and conflict).

CMG is especially suitable to represent one's cognitive knowledge, as it allows one to model the dynamic causal mechanisms in a robust way. This feature, combined with excellent reliability and validity [23], positions CMG as a powerful method to extract and model the

Symbol	Name	Description
a_1 a_2 b	AND	Entity a_1 AND entity a_2 form entity b.
a_1 a_2 b	OR	Entity a_1 OR entity a_2 form entity b.
$a_1 \overset{\subseteq}{\longrightarrow} a_2$	Subset	A set a_1 is a subset of a set a_2, that is, all elements of a_1 are also elements of a_2. "•" denotes the place where the connection ends, i.e., a_2 around the "•" is the set, while a_1 is the subset
$a_1 \overset{\in}{\longrightarrow} S$	Element	An element a_1 is a singleton of the distinct objects that make up that set, S. "•" denotes the place where the connection ends.
$a_1 \overset{E}{\longrightarrow} S$	Property	A property a_1 is special quality or characteristic of an entity, S. "•" denotes the place where the connection ends.
$a_1 \longrightarrow a_2$	Cause	Influence describes the causal relations between two entities. a_1 causes a_2.
$a_1 \dashrightarrow a_2$	Imply	Directed implication. When one variable implies another variable, it means dependency exists between the two variables (say a_1 implies a_2). Such dependency allows one to make inference about one variable according to another variable.
a_1 a_2 $\otimes \rightarrow$ b	Conflict	Effect b is present when a_1 is in conflict with a_2. The effect b is present only when these two factors (a_1 and a_2) are coupled, and where these two factors have different types of influences (e.g., positive versus negative).
a_1 a_2 $\odot \rightarrow$ b	Trigger	Effect b is caused by "event a_2 Triggering event a_1."
	Human error mode	A general psychological error pattern.
	Context	The conditions contained in a software artifact that tend to trigger a human error mode.
	Top event (software defect)	The ultimate result (i.e., software defect) produced by the interactions between various contexts and human error modes.

Table 2. Sample notation for causal mechanism graph (Version E for human error analysis).

human error mechanisms underlying software faults. A sample of the CMG notation adapted for human error analysis is shown in **Table 2**.

3.3. An application example

An example of using CMG to perform human error analysis is shown in **Figure 2**. The proposed approach is applied on a software requirement called "Jiong" problem provided in Ref. [13].

A requirement segment is extracted, shown in **Figure 2**. To complete the "Jiong" problem, a programmer first needed to calculate the structure of a "Jiong" using a recursion or iteration algorithms (A.1 in **Figure 2**), and then print a blank line after the word (A.2 in **Figure 2**).

Using HEA, we see that this requirement segment contains three conditions: (1) A.1 is the main requirement; (2) A.2 is not a necessary condition to A.1; (3) A.2 is the last step of A. These three conditions consist a scenario that tends to trigger "postcompletion error." Postcompletion error is an error pattern whereby one tends to omit a subtask that should be carried out at the end of a task but is not a necessary condition for the achievement of the main goal [14].

This requirement was presented to student programmers in a programming contest in the previous study [13]. Results show that 23 out of 55 (41.8%) programmers committed the error of "forgetting to print a blank line after each word," in the same way as observed by psychologies in other tasks.

It is notable that "printing a blank line" is a very simple requirement and have been explicitly specified; this requirement is correct and clear. According to the current requirement quality criteria such as correctness, completeness, unambiguity and consistency, this requirement

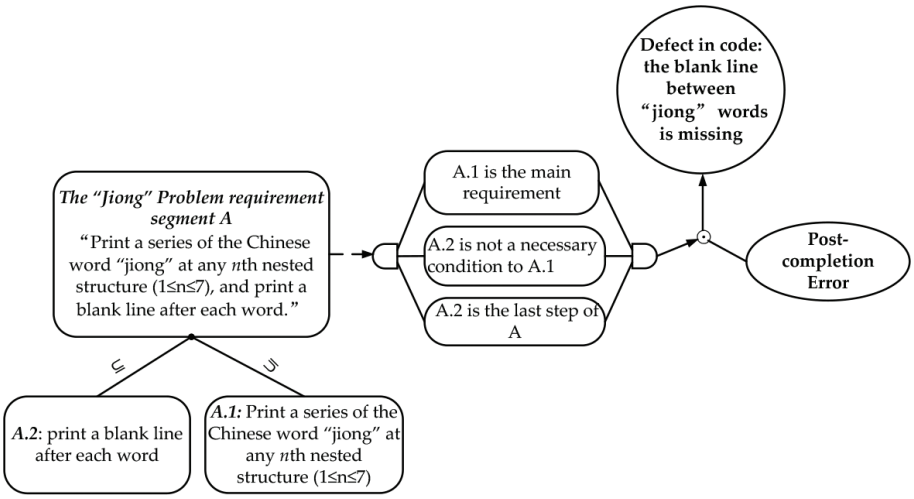

Figure 2. An example of human error analysis.

contains no features prone to trigger a software development error. In fact, this requirement triggered significantly more programmers to commit the error than any of other locations, and amazingly in the same way [13].

Once the error-prone representation is identified, one can use strategies to prevent it from triggering development errors. For instance, the requirement writer may highlight (e.g., using bright colors and/or bold font) the places of postcompletion tasks in the requirement documents ("printing a blank line after each word" in the "Jiong" case), since visual cues are an effective way to reduce postcompletion errors [25]. Though using styles to facilitate readers' cognitive process is not new in software requirement engineering, the contribution here is to tell the writer the exact location that should be highlighted, in order to reduce a developer's error-proneness.

4. Conclusion

This chapter emphasizes the necessity of understanding the cognitive nature of software and software faults, and reviews the emerging area of defending against software defects based on human error theories (SFDHE). An approach of human error analysis (HEA) is proposed to detect and/or prevent software defects at various stages of the software development life cycle. The application on a requirement review shows that HEA is able to identify an error-prone scenario that can never been captured by any existing criteria for requirement quality. HEA offers a promising perspective to advance the current practices of software fault detection and prevention.

Author details

Fuqun Huang

Address all correspondence to: huangfuqun@gmail.com

Institute of Interdisciplinary Scientists, Seattle, Washington State, USA

References

[1] Détienne F. Software Design–Cognitive Aspects. New York, NY: Springer-Verlag New York, Inc.;2002

[2] Huang F, Liu B, Huang B. A Taxonomy System to Identify Human Error Causes for Software Defects. In: The 18th International Conference on Reliability and Quality In Design, Boston, USA; 2012. pp. 44-49

[3] Weinberg GM. The Psychology of Computer Programming. VNR Nostrand Reinhold Company; New York: 1971

[4] Huang F, Liu B. Systematically Improving Software Reliability: Considering Human Errors of Software Practitioners. In: 23rd Psychology of Programming Interest Group Annual Conference (PPIG 2011), York, UK; 2011

[5] Huang F. Software Fault Defense based on Human Errors. Ph.D., Beijing: School of Reliability and Systems Engineering, Beihang University; 2013

[6] Visser W. Dynamic Aspects of Design Cognition: Elements for a Cognitive Model of Design. France: INRIA; Research Report 2004

[7] Huang F, Liu B, Song Y, Keyal S. The links between human error diversity and software diversity: Implications for fault diversity seeking. Science of Computer Programming. 2014;**89**, Part C:350-373

[8] Huang F, Liu B, Wang S, Li Q. The impact of software process consistency on residual defects. Journal of Software: Evolution and Process. 2015;**27**:625-646

[9] Huang F, Liu B, Wang Y. Review of Software Psychology (in Chinese). Computer Science. 2013;**40**:1-7

[10] Huang F, Liu B. Study on the correlations between program metrics and defect rate by a controlled experiment. Journal of Software Engineering. 2013;**7**:114-120

[11] Anu V, Walia G, Hu W, Carver JC, Bradshaw G. Using a Cognitive Psychology Perspective on Errors to Improve Requirements Quality: An Empirical Investigation. In:Software Reliability Engineering (ISSRE), 2016 IEEE 27th International Symposium on; 2016, pp. 65-76

[12] Reason J. Human Error. Cambridge, UK: Cambridge University Press; 1990

[13] Huang F. Post-completion Error in Software Development. In The 9th International Workshop on Cooperative and Human Aspects of Software Engineering, ICSE 2016Austin, TX, USA; 2016, pp. 108-113

[14] Byrne MD, Bovair S. A working memory model of a common procedural error. Cognitive Science. 1997;**21**:31-61

[15] Card DN. Myths and Strategies of Defect Causal Analysis. In: Proceedings of the Twenty-Fourth Annual Pacific Northwest Software Quality Conference; 2006, pp. 469-474

[16] Mohammadnazar H. Improving Fault Prevention with Proactive Root Cause Analysis (PRORCA method). 2016

[17] Huang B, Ma Z, Li J. Overcoming obstacles to software defect prevention. International Journal of Industrial and Systems Engineering. 2016;**24**:529-542

[18] Huang F, Liu B. Software defect prevention based on human error theories. Chinese Journal of Aeronautics. 2017. In Press

[19] Knight JC, Leveson NG. An experimental evaluation of the assumption of independence in multi-version programming. IEEE Transactions on Software Engineering. 1986; **12**:96-109

[20] Avzenis A, Lyu MR, Schutz W. In search of effective diversity: A six-language study of fault-tolerant flight control software. In: Proceedings of the 18th International Symposium on Fault-Tolerant Computing, Tokyo, Japan; 1988, pp. 15-22

[21] Li Y, Li D, Huang F, Lee SY, Ai J. An Exploratory Analysis on Software Developers' Bug-introducing Tendency Over Time. In: The Annual Conference on Software Analysis, Testing and Evolution, Kunming, Yunnan; 2016

[22] Lee SY, Li Y. DRS: A Developer Risk Metric for Better Predicting Software Fault-Proneness. In: Trustworthy Systems and Their Applications (TSA), 2015 Second Inter national Conference on; 2015, pp. 120-127

[23] Huang F, Smidts C. Causal mechanism graph — A new notation for capturing cause-effect knowledge in software dependability. Reliability Engineering & System Safety. 2017;**158**:196-212

[24] Huang F, Li B, Pietrykowski M, Smidts C. Using Causal Mechanism Graphs to Elicit Software Safety Measures. In: 39th Enlarged Halden Programme Group Meeting (EHPG meeting at Sandefjord 2016); 2016

[25] Chung PH, Byrne MD. Cue effectiveness in mitigating postcompletion errors in a routine procedural task. International Journal of Human-Computer Studies. 2008;**66**:217-232

INTECH

INTECH

Chapter 3

Production and Marketing Risks Management System in Grazed Systems: Destocking and Marketing Algorithm

Mathew Gitau Gicheha, Grant Edwrads,
Bell Stephen and Bywater Anthony

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68394

Abstract

This study was carried out to explore potential approaches to managing production and market risks associated with climatic variability in dryland grazed systems. The methodology is novel in that it considers farmers' ability to make sequential adjustments to their production activities when information on uncertain events becomes available. Traditional approaches to evaluation of farmers' response to risk assume perfect knowledge of production resources and that risk emanates from uncertainty in yield returns. Strategic approaches are mostly considered in evaluating farmer's risk attitude implying that managing the variability (risk) assumes that different production activities resource requirements are known (non-embedded risk). In real farming systems, the producers make sequential decisions and adjust the timing and methods of their activities as a season progresses and more information on uncertainty becomes available (embedded risk). This chapter describes a platform adopted in making destocking and marketing decisions by simulating the impact of implementing alternative tactical adjustments. The algorithm was successfully tested in a research that investigated the physical and economic impact of incorporating tactical responses in risk management strategies in dryland sheep production systems in New Zealand. The algorithm can be integrated into existing grazing models and can also be used as a standalone system.

Keywords: embedded risk, climatic variability, tactical adjustments, dryland grazing systems, algorithm, risk management strategies

1. Introduction

1.1. Background information

The overall objective of grazed systems is the maintenance of high animal and pasture performance as it results in optimization of enterprise production and profitability. In dryland systems, this is complicated by the need to balance the fluctuating animal feed demand as well as pasture quality and quantity [1]. Setting stocking rate (SR) is the principal managerial decision in these systems [2] but a variety of other short- or medium-term management options (tactical responses) are available [3]. The most commonly used strategy in managing the effects of climatic variability in dryland grazed systems is understocking [4]. This results in lost opportunity of increased profitability in better than average seasons (when feed supply exceeds demand). Conversely, high stocking rate increases risk in such a variable environment especially so in worse than average seasons (when there is feed deficit). In order to mitigate the challenge of fluctuating feed demand and supply, there is a need for the inclusion of a series of options which provide the flexibility to alter feed demand, and to a lesser extent supply, in response to changes in climatic conditions during the season.

The study [5] from which this chapter was extracted from indicated that incorporating a framework to implement such options would result in physical (in terms of pasture utilization) and economical (enterprise profitability) benefits. The findings from the study by Gicheha etal. [5] indicated that all strategies incorporating tactical responses were economically superior to those which did not. In some instances, the difference in GM between corresponding strategies with and without including tactical adjustment to climatic variability was as high as 39.65%. In all cases, corresponding risk management strategies incorporating tactical responses to climatic variability resulted in higher gross margin (GM) ($P < 0.05$) and lower risk ($P < 0.05$). The extra income derived from including tactical responses can be viewed as the cost to the farmer of basing choice regarding a management strategy on analysis that neglects the tactical advantages afforded by such a strategy. This chapter describes a destocking and marketing algorithm integrated into a grazed system model (LincFarm; [4, 6]) to implement tactical adjustments to climatic variability in a dryland grazed system in Canterbury Plains in New Zealand. The algorithm is implementable in any grazed system as an in an integral part of the model or a standalone subsystem.

1.2. Risk analysis

Risk from the dictionary perspective is the possibility of incurring misfortune or loss.[1] According to Ref. [7], the risk is defined as the possibility of adversity or loss, and referred to risk as "uncertainty that matters". A study by Kay and Edward [8] further defined risk as a situation in which more than one possible outcome exists, some of which may be unfavorable. However, it was [9] who provided the three common interpretations of risk as a chance of a bad outcome, a variability of outcome and uncertainty of outcomes. Considering risk as a chance of a bad outcome implies the

[1] Collins Concise Dictionary, 3rd edition, 1995.

probability of some undefined unsatisfactory outcome occurring. For example, assuming there is a single measure of outcome denoted X much of which is always preferable to less. The chance of bad outcome definition could be represented by the following probability:

$$P^* = p(X \leq X^*) \tag{1}$$

where P is probability, X is the uncertain outcome, and X* is some cut-off or minimally acceptable outcome level below which outcomes are regarded as 'bad' and P* denotes the probability of X* occurring. In some cases, the value X* might reflect some disaster level such as 'insolvency;' however, more often this may be a less clear-cut notion, with application of this measure of risk favoring specification of the two parameters P* and X*.

The interpretation of risk as variability can be measured statistic of dispersion of the distribution of outcomes, such as the variance (V) or standard deviation (SD) of the uncertain outcome [9]:

$$V = V[X] \tag{2}$$

or:

$$SD = \sqrt{V} \tag{3}$$

However, neither V nor SD provides information on the location of the distribution of outcomes on the X axis necessitating use of the dispersion statistics to link V or SD with the mean or expected value (E) as follows:

$$E = E[X] \tag{4}$$

Variance may then be described as the risk around the specified mean. The study by Newberry and Stiglitz [10] extended the notion to reflect risk using the coefficient of variation (CV) of X:

$$CV = \frac{SD}{E} \tag{5}$$

In order to define risk as the distribution of outcomes the whole distribution of X needs to be specified with a complete specification requiring the probability density function, f(X), or equivalent and often more conveniently, the cumulative distribution function F(X). However, in practice, summary statistics including moments are commonly used to describe the probability distribution. This means that there is some similarity with the measurements based on the definition of risk as dispersion. In such cases as the normal, the distribution of outcomes is completely defined by only the mean and variance. Few other distributions might be approximated in terms of mean and variance, though higher order moments may be needed to clearly describe the shape of the distribution.

The limitation of defining risk as a chance of a bad outcome or variability of outcome [3] and their associated measures is that neither gives the whole picture especially when a choice has to be made among many risky alternatives. In regard to risk as a chance of a bad outcome, it is

evident from observing behavior that not all risks with bad outcomes are rejected. For example, many people travel by car to sightseeing with the knowledge that there is increased probability of death or serious injury in case of a road accident. Apparently, choices with chances of very bad outcomes such as death or serious injury are at times accepted, assumingly because the benefits of the up-side consequences such as seeing interesting sights are sufficiently attractive to offset the relatively low chances of the bad outcome. Subsequently, to evaluate or asses a risk, there is need to consider the whole range of possible outcomes, good and bad, and their respective probabilities. Thus, as suggested by Hardaker [9], expressing risk in terms of only the probability in the lower limit of the distribution of outcomes does not provide full information for proper risk assessment and may thus be seriously misleading.

Different studies have considered risk and uncertainty with varied reactions and have defined them differently [10]. For instance, Knight [11] suggested an existence of three states or 'categories' of knowledge in decision-making situations: perfect knowledge, risk, and uncertainty. The suggestion was that risk is variability of an outcome with known probabilities, while uncertainty is variability of an outcome with unknown probabilities. Other authors such as Anderson et al. [12] recognized little difference between risk and uncertainty by Arguing that all probabilities in decision-making are subjective, and thus, the difference between risk and uncertainty becomes insignificant. In this chapter and the study from which it was extracted from, risk and uncertainty are treated as the same; risk and/or uncertainty are considered in general as the variability of outcomes, that is, the converse of stability and are referred to as either risk or variability. This has a significant impact on what constitute good climatic variability management strategies to be considered and good risk management in general.

1.3. Sources and responses to risk

Various potential sources of risk in agriculture have been identified. Risk was summarized into production, price or market, currency, institutional, financial, legal, and personal by MAFF [13] while Waterman [14] classified sources of risk into five categories as production, marketing, financial, legal or human resource. Production risk comes from the unpredictable nature of weather and uncertainty about the performance of crops and/or livestock, while marketing risk refers to the uncertainty of prices of farm inputs and outputs. Farmers are increasingly being exposed to unpredictable competitive markets for inputs and outputs [13]. Currency risk as noted in Ref. [13] relates to the revaluation or devaluation of the national currency which affects export and imports demand and domestic prices for competitively traded inputs and outputs. In countries where agriculture is export, oriented currency risk is considered an important aspect when designing a farm model.

There are a number of basic responses to risks in agriculture that have been identified. A decision-maker can respond by accepting the risk, transferring the risk via insurance or contracts, or by eradicating or managing the risk by putting in place risk reduction strategies. The work by Waterman [14] suggested five responses to risk as retain, shift, reduce, self-insure and avoid, while the study by Barry [15] had summarized risk responses into four basic categories as either being production, marketing, financial or integrated. Examples of production risk responses include development of a decision support system for predicting seasonal rainfall

variation [16] and a decision support system on the impact of planting drought resistant pasture [17] in management of climatic variability. Similarly, various marketing risk response options exist, and examples include forward contracting with the buyer of the crop or livestock, spreading sales throughout the season, or hedging [18]. A financial response could be to carry a large cash reserve to protect the business from a failed crop or a poor season. An integrated response would be a combination of any or all of the listed responses. In managing climatic variability in high-performance dryland sheep systems, a range of alternative risk management options was explored.

All risk responses, however, come at a cost [19]. For instance, a decision to forward contract the sale of animals could mean that if the price of the increases, the farmer would be losing out on potential extra income. The decision to carry a large cash reserve or to limit the level of borrowings may limit the potential rate of growth of the business. It is this complexity in decision-making that emphasizes the need for simulation models to evaluate and identify optimal strategies. For a farm model to be relevant, it should account for such tactical responses to risk to optimize productivity and profitability. This is the main focus of this chapter.

1.4. Resilience

Resilience was defined as the ability of a system such as the ecosystems, societies, corporations, nations and socio-ecological systems to undergo a disturbance and maintain its functions and control by Gunderson and Holling [20]. They considered resilience as a measure of the magnitude of disturbance a system can tolerate and still persist. This is different to the concept previously advanced by Pimm [21] as a system's ability to resist disturbance and the rate at which it returns to equilibrium following disturbance. The study by Holling [24] observed that the distinction between the two definitions of resilience has been useful in encouraging the managers of naturally variable systems such as the dryland pastoral systems to move away from concentrating on management aimed at the unachievable goal of stability. However, it is important to simultaneously consider resistance which is a complementary aspect of resilience and is defined as the amount of external pressure needed to bring about a given amount of disturbance in the system by Carpenter et al. [22].

According to climate change research by Crawford et al. [23], farmers will continue to encounter increasing climatic extremes, and it is important therefore to design farming systems that will cope with the increased climatic extremes and variability. Resilient farming systems would take advantage of the three properties conceived by Holling [24], that is the amount of change the system can undergo and still retain the same functions and control, the degree to which the system is capable of self-reorganization, and the degree to which the system can build the capacity to learn and adapt (such as use of available information and tools in implementing flexibilities in dryland pastoral systems). These three properties have been explored further by Rusito et al. [25] who identified buffer capacity, adaptive capacity, and transformability as three elements that allow the manager to respond to different degrees of change in the production environment. Buffer capacity is defined as the constancy of system productivity when subjected to small disturbances as a result of fluctuations and cycles in the production

environment in Ref. [26]. Adaptive capacity was defined by Brooks [27] as the capacity of a system to respond to a change or shift in the environment to cope better with existing or anticipated external shocks [22], however, do not distinguish between resilience and adaptive capacity and have used these terms interchangeably. Transformability was defined by Darnhofer et al. [28] as the ability of a manager to find new ways of organizing resources when the disturbance in the production environment is extreme enough to compromise the current system.

The work by Rusito et al. [25] recognized that resistance, described by Carpenter et al. [22] as the amount of external pressure needed to bring about a given amount of disturbance in the system, measured as efficiency, the degree to which the system is capable of self-reorganization [24] measured as liquidity, and vulnerability which was defined as the potential for loss by Luers et al. [29] and measured as solvency in Ref. [23] are useful indicators of buffer capacity. Highly efficient systems are characterized by higher resistance, and that farms with good liquidity have more ability to reorganize themselves (return to the original state) following a shock as noted by Rusito et al. [25]. In a study of the resilience of New Zealand dairy farm business from 2006 to 2009, a period characterized by wide fluctuation in milk price [16], observed that farmers who took best advantage of upside price risk did not cope well with downside price risk. This implies that the portfolio of risk management strategies used by farmers to respond to upside price risk did not align well with downside price risk management. Their study underlines the importance of risk management portfolios whose strategies take advantage of the upside risk while at the same time minimizing downside risk.

The research whose findings are presented in this chapter was set to take advantage of both upside risk (stock for better than average growing conditions) and downside risk (retreat by sale of animals as and when conditions dry out) resulting from climatic variability. Alternative risk management portfolios are identified (in the form of risk-efficient strategies) from which farmers with different production objectives and preferences can choose. The portfolios differ in pasture types and combinations, flexible stock class combinations (saleable animals maintained in the system), and soil moisture levels to trigger stock sale decisions.

1.5. Risk management

Risk management as defined by Landcare Research [30] is the culture, processes, and structures that are directed toward the effective management of potential opportunities and adverse effects. In an agricultural setting, risk can be defined as choosing among alternatives that reduce the financial effects of the uncertainties of weather, yields, prices, government policies, global markets, and other factors which can cause variations in farm income [13].

It was suggested [31] that as all actions that might be taken by a farmer are subject to risk, there is no distinction between farm management and what is historically called risk management. In many ways, all decisions made in agricultural systems are made with imperfect knowledge about the outcomes. A crop is selected, sown, managed and harvested in weather conditions that are uncertain at sowing. A yield of unknown quality is harvested and after which, the product is then sold at what may be an unknown price. These unknowns make efficient resource allocation decisions difficult. Since agricultural production occurs in a risky environment, there is

a need to make decisions on how to manage the risk. Until mid1990s, priority with respect to analyzing risky decisions has been placed mostly on choice of farming strategy and on accounting for the effects of attitude to risk [32, 33].

A decision tree obtained from Ref. [9] is presented to describe the effects of attitude to risk on choice of strategy. The decision tree (**Figure 1**) represents three stocking options, to buy 300, 400 or 500 steers. The next step in the decision tree relates to factors outside the farmer's control, the weather in this case for which it is assumed there are just three scenarios resulting in good, average, or poor growth. The probability of good growth is 0.2, of average growth 0.5 and of poor growth 0.3. For each of the three stocking options and the three possible weather circumstances at their probabilities, there is a net return. The net return range from $34,000 where 500 steers are purchased and favorable weathers follow to a loss of $10,000 where 500 steers are purchased and the weather condition is not favorable.

The possibilities of each weather condition multiplied by its corresponding net return give the expected value of that strategy. In the case presented here, the strategy with the highest expected value is that of purchasing 400 steers. Although it would be seen as the best in terms of expected value, it does not account for risk attitudes or some other influential factors which can have a direction in decisions made. For example, with this strategy, there is a 0.3 probability of earning $0, which may cause harm to the business. The option of buying just 300 steers always results in a positive return, but the corresponding returns are smaller compared to the positive returns probable from the other two options. The optimal choice for a given individual may not necessarily be the strategy with the highest expected value, relative to the individual's attitude to the possible outcomes, such as making a significant loss.

1.6. Farmer risk attitudes and preferences

Risk attitudes are typically divided into just three categories, risk-neutral, averse and risk-loving. A risk-neutral person would be expected to choose the strategy with the highest expected value regardless of the variations of possible returns, that is, choose the option of purchasing 400 steers from the decision tree presented in **Figure 1**. Conversely, risk-averse individuals exhibit a willingness to accept a lower expected return so as to avoid the opportunity of unfavorable outcomes. As presented in **Figure 1**, the chance of earning $0 or making a $10,000 loss may be unacceptable and the option of purchasing 300 steers although resulting in a lower expected return may be preferable [8]. However, risk-aversion does not necessarily mean that individuals are not willing to take risks. Rather it means that individuals must be compensated for taking the risk and that the required compensation must increase as the risk and/or the levels of risk-aversion increase.

To be more useful, agricultural models should account for risk and the risk attitudes of farmers. The work by Pannell and Nordblom [34] recognized the need for models to account for risk and the risk attitudes of farmers to be considered useful. In their report on the effect of risk aversion on whole farm management in Syria, they found significant effects in terms of farming policies related to risk attitudes. Different approaches [35, 36] have been used in describing risk in agriculture: the expected value and utility approaches and models (e.g. [37, 38]), heuristic safety-first approaches (e.g. [12, 37]), farmers' risk aversion [38, 39], and the

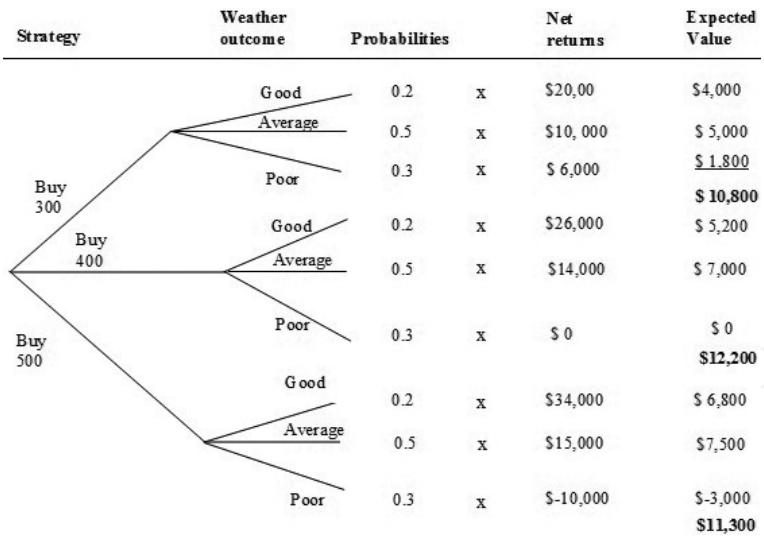

Figure 1. Decision tree (Source: Kay and Edward [8]).

effect of risk on farmers' resources [40]. Traditionally, farming systems were modeled with regard to risk attitude, thus assuming decision-makers to be either averse or neutral, or generally just assuming risk aversion, using some measure of preference such as subjective expected utility (SEU) [41]. The SEU hypothesis involves breaking down risky decision problems into separate assessments of the decision-makers beliefs about uncertainty, captured via subjective probabilities, and the decision-makers preferences for consequences, obtained via a utility function, the two parts are then recombined to select as optimal the decision which yields the highest expected utility or certainty equivalent (CE). Generally, the SEU hypothesis provides the best operational basis for structuring risky choices.

1.6.1. Utility and expected value

To explain utility and expected value, assuming there are just two possible choices, one with a greater expected value than the other, that choice with the greater expected value is the best. However, if the option with the greater expected value has two possible outcomes, one of great profit as well as one of great loss, and the second possible choice has a lower expected value, with neither of the two potential outcomes resulting in a significant loss, the second possible choice may be preferable to some people which introduces the concept of risk attitudes and utility [36].

A sample demonstration decision problem was used by Hardaker et al. [36] in which there was a once-only choice to be made between options a1 and a2, with consequences depending on two equally likely uncertain events s1 and s2 to explain the economic concept of utility. This is presented in **Table 1** below.

S_i	$P(S_i)$	a_1	a_2
s_1	0.5	1000	500
s_2	0.5	0	500
EMV[1]		500	500

[1]See text for description.

Table 1. Economic concept of utility example.

A risk averse individual will prefer a2 to a1, whereas a risk preferrer will chose a1 to a2. Ordinarily, any person indifferent to risk would base their choice on the expected monetary value (EMV) therefore portraying indifference between the two options. Assuming that there is a progressive reduction of the $500 payoffs represented by choice a2, there would come a point where the risk adverse decision maker is indifferent between options a1 and a2. Presume that the certainty equivalent (CE) for some individual is $450 in the example above. It can be said that the utility of the risky prospect a1 is equal to the utility of the $450 CE for this person. Based on arguments presented above, it can be shown that utility function, U, exists and exhibits the properties that:

$$U_{(a1)} \succ U_{(a2)} \tag{6}$$

From Eq. (1), utility function U exists only if a1 is preferred ($\succ$) to a2 and that the utility of a risky prospect is its expected value (E):

$$U_{(a1)} = E\left[U_{(a2)}\right] \tag{7}$$

The second property suggests that the utility of the risky prospect aj is equal to its expected utility, computed as the probability weighted average of the utilities of the individual consequences, while the first property implies that this utility value is equal to the utility of the CE such that:

$$U_{(a1)} = 0.5U(1000) + 0.5U(0) = U\left(U_{(a2)}\right) = U(450) \tag{8}$$

1.6.2. Assessing risky alternatives

According to the subjective expected utility (SEU) hypothesis [12, 42], the decision-makers utility function for outcomes is necessary in order to assess risky prospects. The SEU hypothesis states that the utility or index of relative preference, of a risky prospect is the decision-makers expected utility for that prospect, that is, the weighted average of the utilities of outcomes. The index is calculated using the decision-makers utility function to encode preferences for outcomes. Given a choice among alternative risky prospects, the hypothesis implies the prospect with the highest expected utility which is preferred.

The expected utility of any risky prospect can be converted through the inverse utility function into a CE. Ordering prospects by CE is the same as ordering them by expected utility, that is, in the order preferred by the decision-maker. Besides, the difference between the CE and the

expected value of a risky prospect, referred to as the risk premium (RP), is a measure of the cost of the risk:

$$RP = E - CE \tag{9}$$

In the case of a risk-averse decision makers, RP will be positive and its magnitude will depend on the distribution of outcomes as well as the decision makers attitude to risk.

As shown, thus SEU hypothesis demonstrates how to integrate the two components of utility (preference) and probability (degree of belief) to afford a means of ranking risky prospects, thus enabling risky choices to be rationalized. The utility a person gains from a decision and not just the expected financial return obtained from it are as important in making risk management decision.

A study by Kingwell [43] using a model called Model of Uncertain Dryland Agricultural System (MUDAS) looked at the effect of risk attitudes on responses to risk in dryland farming systems. Under the two price scenarios considered, increased risk aversion shifted resources away from cropping toward the livestock enterprise and changed the tactical management of the farming system. In particular, increased risk aversion reduced the area of crop in favorable weather-years and enabled pasture to be produced, thereby supporting more sheep at higher stocking rates. A study by Kingwell et al. [32] explored the importance of considering tactical response in addition to the traditional risk attitude in modeling agricultural systems. They concluded that stochastic models which do not include activities for tactical adjustments miss the benefits of flexibility due to knowledge about uncertain prices and costs (read profit). Inclusion of tactical response options has previously received little attention compared to farmers' risk attitude [44].

The benefits of including tactical response options in a farm model are often greater than the benefits of including risk aversion were hypothesized by Pannell et al. [33]. The importance for strategic choice of accounting for the opportunities to tactically respond to outcomes of risk provided by each strategy has attracted attention [43]. Regardless of whether farmers are averse to risk, prefer it or are ambivalent about it, they tactically adjust their farming strategies as the outcomes of risk relating to seasonal conditions, prices and other sources of risk become known [45]. This is what constitutes embedded risk [35].

1.7. Embedded risk

Evaluation of farmers' risk attitude mostly addresses non-embedded risk where activities are assumed to have known resource requirements but to yield uncertain returns, as a result of physical yield or output price uncertainty [46]. In many situations, however, farmers face "embedded risk" [35], where they have the opportunity to make sequential decisions and adjust the timing and methods of their activities as a season progresses and more information on uncertain events or occurrences becomes available. Embedded risk allows for adjustments to be made to farming operations tactically to suit the conditions as they develop, that is, to make management changes within a season. **Figure 2** below was obtained from Ref. [35] to simply illustrate a decision tree notion of options or choices within a season.

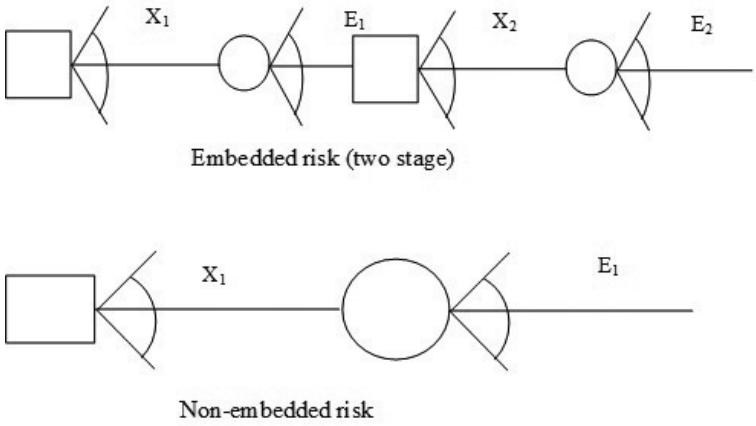

Figure 2. Embedded and non-embedded risk decision tree [35].

An argument was made by Hardaker et al. [35] that modeling farming system considering non-embedded risk is inadequate since it assumes that it is realistic to model a system as if all decisions (e.g., X1) are made initially and then the uncertainty unfolds subsequently in terms of risky consequences (e.g., E1) of the choice taken. In an embedded risk scenario, decisions are segregated into those taken initially (e.g., X1) and those taken at a later stage (e.g., X2) when some information on uncertain events (e.g. E1) has unfolded. Most real decisions about farming systems have the characteristics of the second case where farmers respond tactically as information on uncertain events becomes available. Despite this reality, many mathematical programming models (MP) addressing decision-making in agricultural systems have either ignored risk or have treated it as non-embedded [35] pointed to the complexity of modeling embedded risk as the main cause of this omission. The importance of embedded risk is to complex, diverse, and risk prone agriculture was examined by Dorward and Parton [47]. They discussed risk such as uncertain climatic behavior, pests and diseases as well as output price risk in agriculture. They then described how a farmer could respond to the uncertainty as the season progressed and more information became available as shown in **Figure 3**.

The work by Pannell et al. [33] hypothesized that the benefits of including tactical response options in a farm model are often greater than the benefits of including risk aversion. This is in line with studies by Kingwell et al. [32] and Marshall et al. [44], Kingwell et al. [32] found that modeling tactical adjustments resulted in the identification of an optimal farming strategy expected to be 20.0% more profitable on average than the strategy that would have been identified considering a non-tactical approach. Modeling risk aversion was found to result in the identification of an optimal strategy that had only 2.0–6.0% higher CE than the strategy that could otherwise have been identified [43]. The study by Marshall et al. [44] in supporting the hypothesis by Pannell et al. [33] noted that, failing to account for risk aversion would not affect the strategy chosen; however, failing to account for tactical adjustments would lead to the choice of a sub-optimal strategy. Their research investigated the optimal reticulation strategy in relation to the storage of irrigation water. Alternative strategies were modeled assuming

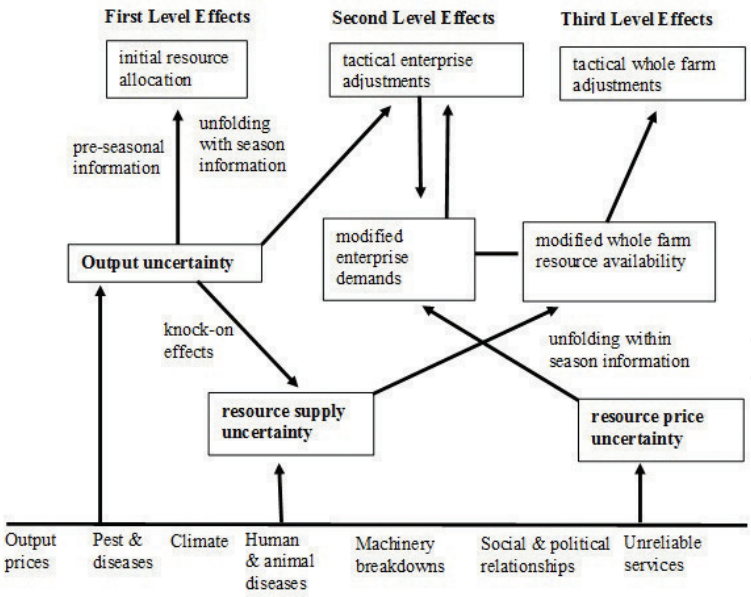

Figure 3. Tactical responses to uncertainty [47].

farmers to be either risk-neutral or averse (within bounds). The strategy determined to be optimal under the assumptions above was then compared against the optimal solution when the model allowed for tactical adjustments. They showed that failing to account for tactical responses would lead to the choice of a sub-optimal strategy, costing the farmer about $3,100 Australian dollars in present value terms. In contrast, failing to account for risk aversion would not affect the strategy chosen. This confirms the observation made by Hardaker et al. [35] that there are potential dangers in ignoring the benefits and costs of tactical choices allowed by the strategies being evaluated. To confirm the importance of including tactical response options in farm models [46] emphasized the need to undertake further studies. The research from this chapter findings was extracted contributed to the critically needed information on the importance of including tactical response options in farm models.

The findings by Antle [45] demonstrated that seasonal variation affects both risk-averse and risk-neutral farmers' decision-making. Risk-averse farmers adopt long-term farming strategies which show preference for lower but stable income. The study by Kingwell et al. [32] established that most farmers are risk-averse. Both risk-averse and risk-neutral farmers make tactical adjustments to their farming strategies in response to short-term seasonal conditions. There are potentially two facets to the value of climatic information used to make these adjustments. Firstly, they allow for improvement in expected income for all farmers, and secondly, they can reduce the cost of risk for farmers who are risk-averse [32].

Agricultural economists have invested more resources in studies of the longer-term implications of seasonal variation for risk-averse farmers with much less emphasis going into short-term

(within season) tactical decisions [32]. The work by Mjelde et al. [48] demonstrated that even where models allow for seasonal variation and risk-aversion, the common practice has been to ignore the potential for tactical adjustments to the farming strategy according to short-term conditions. The result is an underestimation of the profitability of some strategies [34] and inconsistent production function parameter estimates [45].

2. Risk sources and management strategies in dryland pastoral systems in New Zealand

The researches by Martin [49, 50] identified a range of risk sources and corresponding management strategies in a wide variety of farming systems in New Zealand, including both irrigated and dryland pastoral production systems. Results from Ref. [49] survey-based study of pastoral farmers ranked change in products prices as being the most important risk source. Changes in world economic and political situations, changes in New Zealand economic situation, changes in input costs, rainfall variability, pests and diseases (for deer farmers), changes in producer board policies (for dairy and deer farmers), changes in government laws and policies (for deer farmers) and risks associated with accidents or health problems were the other risk sources identified by farmers in the pastoral sector as being important. A previous survey-based study involving dryland sheep farmers on the Canterbury Plains by Boggess et al. [53] identified the three most important risk sources as rainfall, livestock/product prices, and the world economic and political situation.

All the three groups of pastoral farmers surveyed by Martin [49] noted that routine spraying and drenching and maintaining feed reserves were the most important risk management responses. Low debt level was considered important in risk management as was managing capital spending and maintaining short and long-term flexibility in farming operations. Additionally, sheep, beef cattle and deer farmers utilized market information, spreading sales and investing in more than one enterprise as important risk management strategies. The work by Harris et al. [51] singled out use of animal feed reserve to be the most important risk management strategy, followed by production flexibility, market information and pacing of investments and expansion.

It is Gray et al. [52], who classified risk management strategies into three broad categories; those targeted to feed supply, feed demand and marketing decisions. They went further to suggest farmers need to design their systems to cope with these production and market risks. In coping with production risk, farmers have to increase feed supply over the summer and autumn, and target to transfer feed from the spring to the summer-autumn and winter periods, significantly reduce feed demand over the summer-autumn period, protect capital stock live weights and ensure adequate pasture cover levels at lambing.

To eradicate and/or reduce the negative impact of market risk [52], suggested that farmers should: aim for the sale of stock in periods when most other farmers are not selling, target to finish the bulk of stock rather than sell stores, target to purchase stock at times when other farmers are not buying, and generate adequate feed reserves that can be used to delay stock

sales in drought until such a time as the markets improves. They identified four main tactical adjustments to cope with variation in feed supply within years. These were a need for a sophisticated monitoring system that quickly identifies problems or opportunities, a plan with clear targets that monitored data can be compared against, a historical database of climatic and farm performance data, and a broad set of contingency plans and associated decision rules to determine the best option to implement for the existing conditions.

Other risk management strategies have been suggested by different authors such as geographical dispersion by Boggess et al. [53] where farmers buy land in areas where summer production circumstances are good. This strategy would be expected to reduce market risk but it may come with increased financial risk [52]. The study by Finlayson et al. [4] identified destocking as the most used strategy in drought with farmers preferring to dispose of stock instead of incurring the cost of supplementing animals or grazing them off. Other options used in response to dry conditions have been summarized by MAFPolicy [54] as rotational grazing, maintenance of buffer stock, wintering dry ewes and reducing replacement numbers to match feed supply.

Research by Bywater et al. [55] identified the possibility of rainfall decreasing during late spring and early summer to a point where grass growth ceases as a major source of risk in dryland pasture systems and suggested that important variables in managing this risk are fast lamb growth rate and the flexibility to change feed demand (by destocking) or feed supply (by feeding supplements) rapidly when conditions dry out. Lamb growth rate is important because the risk of dry conditions and reduced feed supply increases as the season progresses and faster growing lambs have a higher chance of being drafted before conditions change.

A key variable in lamb growth rate is feed quality. Use of alternative pasture species has been identified as having potential to improve the profitability of hill country farms by Korte and Rhodes [17] so long as the improved pasture production and quality can be captured by livestock in a profitable way. The study by Fraser et al. [56] also investigated improved pasture species under dryland conditions and showed an increase in lamb growth rate and rate of drafting compared with conventional pastures but noted a lower persistence of the improved pasture species. Other studies that placed emphasis on high-quality feed particularly during the pre-weaning period were those by Kinnell [57] and Gray et al. [52]. However, unlike the research from which the information presented in this chapter was obtained from they did not consider use of alternative pasture species to achieve high-quality pasture during lactation. The research by Grigg et al. [58] showed that managing subterranean clover to maximize yields increased subterranean clover content to 40–60% of sward dry matter content over spring. This resulted in increased lamb growth rates from 258 to 350 g head-1 day-1, lamb weaning weights from 29.6 to 40.0 kg and lambing percentage from 108 to 140% through improved ewe weaning weights. The benefits were as a result of more than 7 years use of a range of strategies including application of fertilizer and lime, property sub-division and subsequent improvement, building up a subterranean clover seed bank, controlled grazing of seedlings in autumn, spelling for 2 months pre-set stocking, and managing spring seed head development.

Research by Avery et al. [59] proposed use of lucerne in dryland systems allowing farmers to grow and finish stock faster over late spring, summer and autumn compared to traditional

pastures. The advantage they noted was that lucerne produced higher quality feed as well as a greater quantity over drier months and is more persistent in dryland environments. By extension the downside in use of alternative pasture is the limited feed supply (reduced production) over winter which [59] addressed through the use of Omaka forage barley and annual ryegrass. Financial benefits of the change from a conventional feed supply system reported by these authors have been dramatic.

The field trial carried out by Bywater et al. [60] to investigate and demonstrate key aspects of high performance sheep systems in dryland environments had an emphasis on high pasture quality and utilization, use of breeding ewes selected for low bodyweight and high fecundity (high efficiency ewes [61], and inclusion of flexible management strategies to allow rapid destocking as soon as conditions became dry. The trial considered most of the risk management strategies and flexibilities discussed above.

The information contained in this chapter extended the trial of Bywater et al. [60] to further evaluate risk management strategies and flexibilities by varying stocking rate, pasture combinations, flexibility options and soil moisture levels used to initiate destocking/sale response. Risk management strategies considered include:

- Early lambing of older ewes to allow early weaning and sale
- Use of 2-yr-old cattle to assist in maintaining low residuals in sheep pastures and as a readily sellable stock class
- '2 yr' ewes instead of cattle with majority lambed early
- A paddock of lucerne in grass dominated systems to extend feed supply in dry conditions
- All stock sold before the end of the year
- Use of supplements and grains when absolutely necessary

2.1. Integrating a framework for implementation of tactical decisions in grazing systems models

As noted previously this chapter was extracted from a research that was carried out in dryland farming system and therefore constituted a good case study to demonstrate the efficiency of integrating tactical responses in agricultural systems. Dry land farming on the east coast of New Zealand is subject to significant climatic variability. In the location of this study on the Canterbury plains, winters are normally cool and wet and summers warm and dry, although not always so. Spring and autumn can either be wet or dry, warm or cool. The typical pattern of pasture growth is one of very low growth during winter because soil temperatures are too low even though there may be sufficient moisture, accelerating growth from mid August as soil temperatures start to increase, reaching a peak around October/November followed by an abrupt drop in growth as soils dry out because of a lack of rainfall in summer (anytime from October onwards), a resurgence of growth with the autumn rains in April/May and a return to low growth again as temperatures drop from June onwards. However, spring growth may be delayed because of cooler or dryer conditions than are typical; spring/summer growth may

cease early if there is little rainfall after September or it may continue throughout the season if there is a wet summer; there may or may not be autumn rain. Dryer, cooler conditions early in the season (September/October) may be followed by wetter, milder conditions later (November/December) so that growth patterns can be almost reversed. There have been some years, such as the 1988–1989 drought when there was no rain for 18 months.

From a pastoral livestock perspective, there is generally adequate grass growth in most years to support production from August through to anytime after October when soils dry out and grass growth stops. This provides a 3–5 month 'window of opportunity' for production and most farmers aim to lamb in August/September and have the majority of their lambs finished before Christmas. There is the very strong possibility that lambs remaining on the farm after December will not grow well because of inadequate feed quantity or quality, and with typically falling prices from November onwards, it is often better to sell lambs as store stock early than keep them in the hope of finishing them for the works, only to be forced to sell them as stores later.

From a production and profitability perspective then, perhaps the most difficult period of uncertainty and risk is the time at which conditions dry out in spring/summer and grass growth ceases. Most commentators note that farmers generally wait too long to respond to drying conditions in the hope that there will be some rain, grass growth will recover, and they will be able to put more weight on their lambs before sale. The second most difficult period is autumn in terms of providing adequate feed quantity and quality to flush ewes to ensure high lambing percentages in the following season. This can be exacerbated if lambs are retained, grow slowly over summer, are held too long and start to compete with ewes for the best available feed during flushing.

Decisions on the stock type and number of animals of each type to retain on the farm introduce a complexity in managing the grazing system to achieve optimal productivity and profitability due to this seasonality and annual variability of forage production. Timely decision-making and subsequent actions are crucial to the survival and profitable running of high-performance dryland grazing sheep systems in these climatic conditions.

In order to evaluate different tactical responses to climatic conditions in this situation, an algorithm was developed to carry out destocking and marketing decisions where productivity and profitability are highly influenced by climatic variability. The algorithm is designed to be actioned when soil moisture level reaches a predetermined trigger value indicating the (temporary) cessation of pasture growth and to respond to an assessment of current feed availability on the farm and the prospect of rainfall which will stimulate utilizable pasture growth in time to feed the animals on hand.

2.2. Design, development and implementation of the destocking algorithm

A generic destocking and marketing algorithm were designed and implemented to assist in making tactical destocking and marketing decisions. The aim was to evaluate the effects on productivity and profitability of alternative management responses to different scenarios with respect to feed availability and current and prospective climate conditions, and different trigger values defined as different levels of soil moisture.

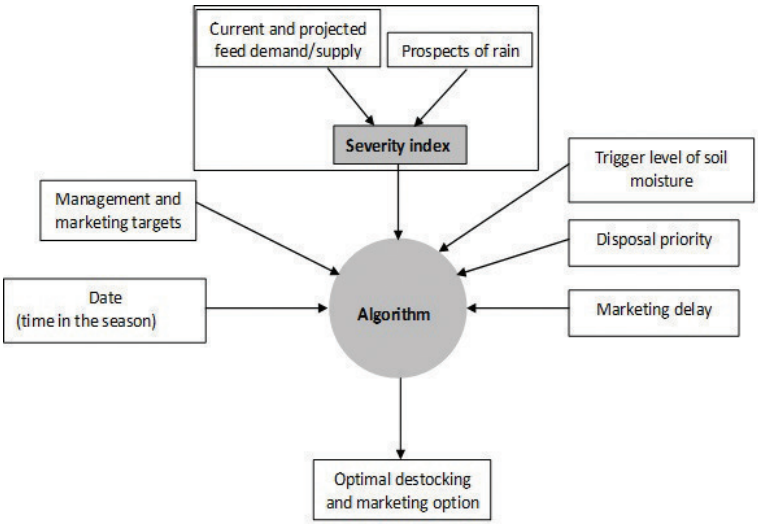

Figure 4. The destocking and marketing algorithm.

Figure 4 shows diagrammatic representation of the algorithm. Based on the time of the season, the target trigger level for soil moisture, current and projected feed demand/supply, prospects of rain, severity index and producer defined stock disposal priority, the algorithm calculates the optimal destocking and marketing option. Tests run from left to right of the diagram. The algorithm loops back to the beginning (time in the season) whenever a condition is not met (e.g., a value below the desired date when destocking and/or marketing action(s) should be activated). The algorithm repeats the process after a defined period (e.g., 7 days from the last test date).

The illustration below shows the pseudo code implementation of the destocking algorithm.

Definitions:

T_i: series of decision times

M_i: soil moisture at time T_i

TM: targetmoisture

$TM_{Levels\ 1-3}$ are 10, 12.5 and 15% of the top 25 cm soil respectively
S_{ji}: stock class j on the farm at time T_i

where j = 1,…,5 represents capital ewe, lambs, cull ewes, 1st cycle ewes, and cattle stock classes respectively

N_{ji}: number of animals in stock class j at time T_i

F_i: farm feed supply at time T_i

R_{ji}: corresponding stock class feed requirement at time T_i

$\mathbf{D_{ji}}$: total animal feed demand at time T_i

$$D_{ji} = \sum_{j=1}^{5} R_{ji} \times N_{ji}$$

PR_i: the probability of substantial rain falling at time T_i

where PR_i is one of high, medium or low defined as follows:
High: High chance that a rain event occurs and that the amount is enough to cause pasture growth that can sustain animals on a farm

Medium: Moderate chance that a rain event occurs and that the amount is enough to cause pasture growth that can sustain animals on hand

Low: Low chance that a rain event occurs and that the amount is enough to cause pasture growth that can sustain animals on hand

SI_i: severity index at time T_i

where SI_i is one of high, medium or low defined as follows:
High: feed days available limited and chance of substantial rain falling low

Medium: feed days available limited and chance of substantial rain falling moderate

Or
feed days available unlimited and chance of substantial rain falling low

Low: feed days available unlimited and chance of substantial rain falling high

P_{ki}: stock class corresponding to feeding priority k at time T_i
where $k = P_{k1-5}$ is S_{j1}, S_{j2} S_{j3} S_{j4} and S_{j5} and S_{j1}, S_{j2} S_{j5} S_{j4} and S_{j3} for pre- and post weaning respectively

A_{di}: destocking action d at time T_i

where d = 1,…,3 represents destock heavily, low to moderate destocking and do not destock now respectively

Algorithm

Function destock()

For times T_i, =0,…, end in steps of 7 days

If soil moisture (M_i) < target (TM_i) then

Calculate F_i

Calculate D_{ji} for each stock class j from T_i to T_{i+1}

Calculate total animal feed demand $\left(\sum D_{ji}\right)$

```
    Evaluate feed situation (compare total animal feed demand with Fi)
    Get the probability of substantial rain falling (PRi)
    Calculate the severity index (SIi)
    If SIi is equal to highthen
    Destock heavily (Ad1)
    Else if SIi is equal to mediumthen
    Apply low to moderate destocking (Ad2)
    Else if SIi is equal to low then
    Do not destock now (Ad3)
  Else do nothing
Return output
```

2.2.1. The destocking algorithm

Running the destocking and marketing algorithm under four potential feed scenarios on a given farm resulted in **Figure 5**. **Figure 5A** represents a scenario where feed available is more than enough to feed all stock types on the farm, **Figure 5B** shows a feed situation where the farmer can feed the capital stock sufficiently and remain with some feed which can be utilized by a proportion of non-capital stock. Under the scenario depicted by **Figure 5C**, the producer would only be able to retain the capital stock on the farm as the feed available is just enough to meet the requirements of those stock. The situation represented by **Figure 5D** means the farmer has either to buy supplementary feed for the breeding stock (capital stock) if a decision is made to retain part or all of the capital stock on the farm, sell a certain proportion of the stock or acceptably underfeed the capital stock. There is also a possibility of combining any two or more of the response noted above to reduce capital stock feed demand on the farm.

Scenarios A, C and D are easier to deal with than scenario B. For instance, in case A, non-capital stock would be sold according to the desired target drafting weight and any extra feed could be sold or conserved for future use. Feed circumstances described by scenario C dictates that the producer can only feed the capital stock and so any other stock on the farm has to be disposed if the cost of buying feed to maintain them is greater than the benefits (i.e., loss avoidance). Under scenario D, feed has to be bought into the farm to feed the capital stock. The other alternative would be to sell a part of the capital stock to release feed required to take the remaining number of animals on the farm to the end of the season.

The feed profile for scenario B can be considered to fall between scenarios A and C, allowing it to be defined within maximum and minimum constraints. **Figure 6** shows the minimum (requirements for capital stock) and maximum (reference profile) constraints. The area between the two constraints represents the feed needed to supply nutrients required for non-capital stock to the end of the season. The minimum constraint is more important since it is the

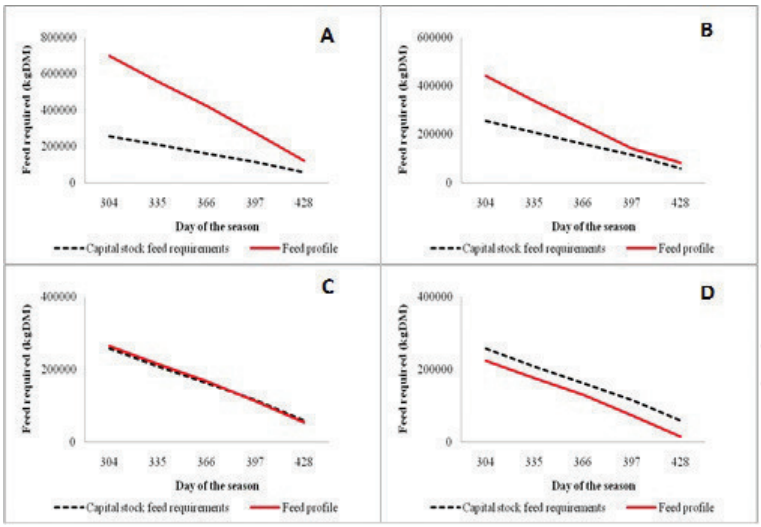

Figure 5. The four potential animal feed demand and supply scenarios (A–D) under a grazing system.

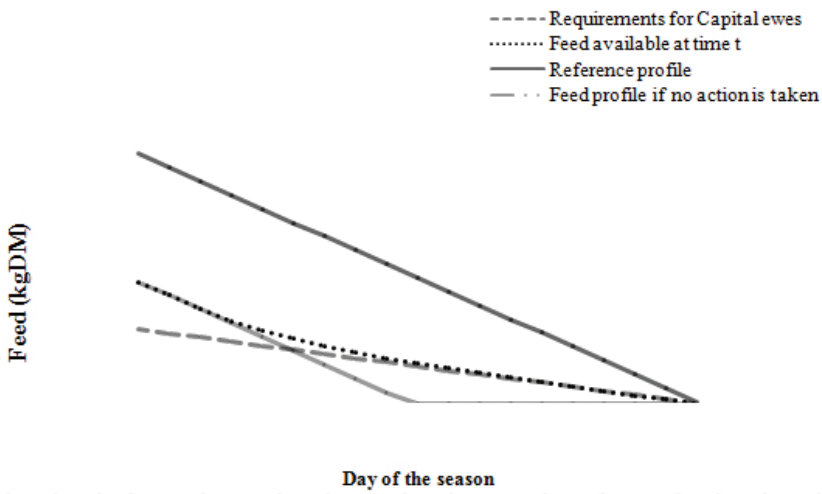

Figure 6. Results from the destocking and marketing algorithm feed profiles.

minimum feed required to supply the capital stock to ensure acceptable levels of (re)production in the following season.

The curves presented in **Figure 6** were obtained from implementing the destocking and marketing algorithm. There are two options available to a farmer faced with feed scarcity as shown in **Figure 6**. At any given point in time when conditions dry out, depending on the current feed demand and supply and the prospects of receiving sufficient rainfall to generate

enough pasture growth to supply the anticipated feed deficit, the farmer could retain the stock on hand and follow a predetermined marketing policy to the end of the season or until conditions dry out again. However, if there is little prospect of rain falling and the feed available cannot carry the stock on hand to the end of the season, the producer may opt to destock to match the feed demand and supply. For the example presented here, the farmer would only be able to retain stock on hand for 61 days (between day 304 and 365) if no action is taken to destock the farm and there is no rain. If on the other hand the farmer's decision is to destock the farm, the algorithm should ensure that the feed available is utilized optimally, that is, no feed remains on the farm at the end of the season following destocking. Optimal solutions should map the feed profile curve as close to the minimum constraint as possible following destocking. The current algorithm was able to satisfy this requirement as no feed remained on the farm at the end of the season (the February 28; in the context of this study) as shown in **Figure 6** (feed available at time t).

2.2.2. The 'severity index'

The combined effect of current feed demand and supply and the probability of sufficient rain falling to stimulate pasture growth were incorporated in the algorithm by developing a severity index (SI) as a guide to how aggressive the farmer should be in responding to any given situation.

Soil moisture level is a balance between the addition of water (through rainfall or irrigation) and loss through evapotranspiration. If there is no rain falling or irrigation being applied to replace the lost water, the soil moisture falls to the extent that plants reduce growth and ultimately wilt and die [53]. A survey presented by MAFPolicy [54] indicates that at least 65.0% of farmers take current crop condition and forecasted weather into consideration with respect to the state of the soil moisture on their farms for the purposes of feed planning. The survey concluded that the majority of farmers considered the state of the soil and the crops, and how the two might change given the weather forecast in their management decision-making. This approach was used to develop the SI. In addition to the soil and pasture conditions and weather forecast, a feed budget to the end of the season is calculated. This ensures that the index is not just responsive to the current feed situation but rather to the combined effect of the current and prospective feed supply/demand situation and the possibility of receiving rainfall.

The algorithm is designed to scan rainfall forecasts for a user defined number of days ahead of the test day. With the rain forecast obtained, an approximation of the quantity of additional feed resulting from the rainfall is made. An analysis is then done to determine whether the feed at hand is enough to carry the animals at hand to a time when the projected feed resulting from the rainfall event(s) is available, and this modifies the SI. It is important to note, however, that the prospect of rainfall does not change the amount of feed available at the test day, rather it results in an approximation of feed available at and after the time the rainfall event(s) occurs. Weather forecast data are readily available in New Zealand from the National Institute of Water and Atmospheric Research Ltd of New Zealand (NIWA). Where the algorithm is used as a standalone decision aid, forecasts of the prospect of receiving rainfall in a future period are assumed to be obtained from NIWA. In the context of the simulation, a 28 days rainfall forecast

was utilized, but due to the fact that the study was based on historical weather data for the 19 years of analysis, it was assumed that rainfall records for 28 days after the test day were indicative of such a forecast. The 'forecast' was thus read from climate data input files. Note that the severity index has no bearing on the calculation of current feed demand or supply, it simply alters the aggressiveness or otherwise of the response to the current feed situation.

Three levels of severity are defined in the index as low, medium or high. For independent use by farmers, a severity ranking can be assigned by the user according to their production circumstances and experience. But generally, if the farm feed situation and/or the prospect of rain falling is good, severity is considered low. The reverse holds for high severity. Given an evaluation of the severity, the algorithm responds differently in terms of destocking. For instance, if the severity is low, even if the feed available cannot carry the stock on hand to the end of the season, animal disposal can be delayed which may result in feed available falling below the minimum constraint trajectory.

Figure 7 shows a feed profile curve resulting from a sequential evaluation of the algorithm behavior in the light of encountering the three potential levels of severity. The assumption is that in areas with high climatic variability, it would be possible to experience two or three SI circumstances within a season. The shape of the resultant curve shows that the algorithm is able to respond dynamically to varying severity index levels within a season. At the point marked high on the curve, the algorithm ranks the pasture availability and rainfall probability situation as highly severe, resulting in a heavy destocking (sharp rise noted on the feed profile curve at the decision point) to correct the situation. Under a situation of medium severity, it would be expected that only a certain proportion of the non-capital stock would be retained on the farm since the index is assigned relative to feed demand and supply. This means that the anticipated rainfall and/or current feed situation would still be limiting but to a lesser degree

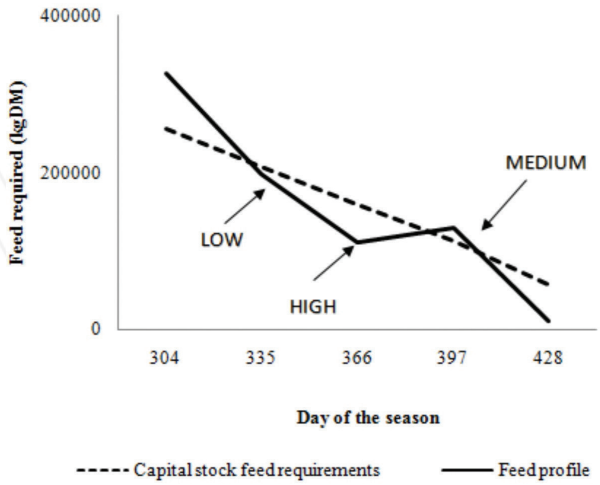

Figure 7. Feed profile for a farm situation where the three severity circumstances are encountered as indicated on the graph.

compared to the high severity scenario. Under low severity, it would be possible to retain all non-capital stock and follow the target marketing strategy, assuming the low severity status is maintained through the season.

2.2.3. Testing the destocking and marketing algorithm

A hypothetical farm was defined and different feed scenarios tested using the destocking and marketing algorithm. The farm's overall objective was to maximize productivity and profitability through finishing as many lambs as possible. The farm had a total of 1099 ewes divided into a main ewe mob and a first cycle ewe mob tupped to lamb 3 weeks earlier. The total number of ewes in the first cycle ewe mob (older ewes) was set at 241 or approximately 22.0% of the entire ewe flock. It was also assumed that culling occurred at 16.0% of the total ewes on the farm which totals to approximately 176 ewes. The first cycle ewes were either selected from the cull ewes considered to be in good condition or sourced from outside the farm through purchase. The combined lambing percentage for both ewe mobs was taken to be 155.0% which translates to approximately 1700 finishing lamb assuming no lambs losses occur pre- or post-parturition. In addition to the sheep flock, a total of 120 head of cattle were bought onto the farm in autumn (during May). The cattle and old ewes were considered to provide flexibility options for risk management and could be sold off at any time depending on the feed situation on the farm.

The key options available to a farmer for balancing feed supply and demand in a grazing system in the face of climatic variability partly relate to animal categories on the farm and the economic efficiency of retaining a particular stock type for a longer period on the farm. The first consideration is normally to supply the capital stock (breeding ewes) with sufficient feed to maintain acceptable levels of future (re)production performances before considering retaining any other stock type. **Figure 8** shows stock-type retention priorities for the hypothetical farm as the season progresses.

These stock disposal priorities are based on the policies adopted by the Silverwood farmer reference group for operation of the Silverwood innovative sheep systems trial [51]. Further details of the philosophies and operating policies for the farm units included in this trial are presented in Ref. [55].

It was considered more economically efficient to keep un-weaned cull ewes and their lambs for longer than growing cattle when faced with a feed deficit prior to weaning as shown in **Figure 8** due to the benefits obtained through higher growth rates from suckling lambs. However, once the main mob is weaned, it is more profitable to sell off the cull ewes compared to selling the growing cattle which have the potential to continue gaining weight. In a scenario where cull ewes have been sold and a producer faces a feed deficit and the only potential stock types available for disposal includes growing cattle and lambs, it would be more economically efficient to sell the growing cattle. In extreme cases, such as is in a developing drought situation, the producer's choices are limited after sale of all disposable stock types (that is—cull ewes, cattle and lambs) and the only options would be to (i) buy feed to supplement breeding stock (capital stock) if a decision is made to retain all or part of the capital stock on the farm, (ii) sell all or part of the stock or (iii) acceptably underfeed the capital stock which can be also considered as the wait and see strategy (A.C. Bywater, pers com).

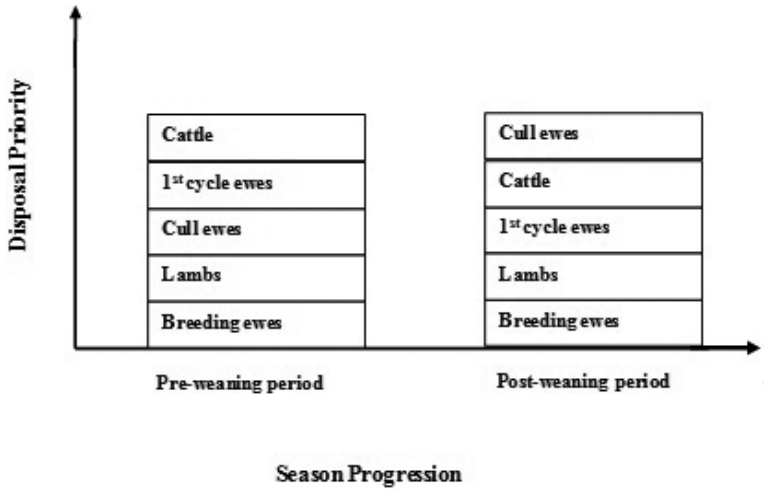

Figure 8. Stock-type disposal priority for the hypothetical farm with the progression of the season.

Table 2 shows sample potential decision rules for the hypothetical farm based on different feed and moisture level circumstances. The table is divided into four sections. Items in the top two sections represent a list of conditions to be tested and the respective condition values. Items in the bottom two sections show the list of potential actions and the actions taken in response to results from the tested conditions. The sample lists a total of 17 distinct decision rules each represented by a column. Each decision rule (column) is a unique combination of a set of conditions-value(s) and the action(s) to be taken correspondingly. For instance, the first decision rule tests whether tailing has occurred. If tailing has not been carried out, the algorithm loops back to test tailing after a period of 1 week. However, if tailing has occurred, it proceeds to test whether the current date is less than 31st October. If current date is less than 31st October, a soil moisture test is carried out and compared to target trigger values of 10.0, 12.5 and 15.0% by volume in the top 25 cm of soil. A value below any of the target trigger values causes the algorithm to do a feed profiling analysis giving dates when destocking should be done to make it to the end of the season. A moisture level above the target trigger values causes the algorithm to divert from the feed profiling analysis to a test aimed at establishing the proportion of lambs whose weight is greater than the target drafting weight (DW) for drafting.

In scenarios where moisture level is above the corresponding target trigger levels of 10.0, 12.5 and 15.0%, tests for feed available for animals on hand are not implemented; rather the proportion of the lambs weighing greater than target weaning weight (WW) and the average lamb LW (ALW) are tested irrespective of the results of the current date test. If more than 10.0% of lambs are heavier than the target DW and the ALW is lower than the target WW, lambs are drafted. Where less than 10.0% of lambs are heavier than the target DW and the ALW of the lamb crop is higher than the target WW, lambs are weaned.

A delay occurs between the time a producer opts to sell stock and the actual killing space allocation. An average of between 7 and 10 days delay has been suggested as the time between

Destocking responses	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tailing has occurred?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Current date < 31st October?	-	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Soil moisture below target level?	-	N	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-
Enough feed for capital stock to a target time in the season?	-	-	Y	Y	N	-	-	-	-	-	-	-	-	-	-	-	-
Enough feed for non-capital stock to a target time in the season?	-	-	Y	N	-	-	-	-	-	-	-	-	-	-	-	-	-
10% of the lambs > Target DW?	-	-	-	-	-	N	Y	N	Y	N	Y	N	Y	-	-	-	-
Lamb avg wt > Target WW?	-	-	-	-	-	N	N	Y	Y	N	N	Y	Y	-	-	-	-
Current date < 15th December?	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
Current date > 15th December?	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y
Soil moisture below target level?	-	-	-	-	-	N	N	N	N	Y	Y	Y	Y	-	-	-	-
Enough feed for capital stock to a target time in the season?	-	-	-	-	-	-	-	-	-	Y	Y	N	N	Y	N	Y	N
Enough feed for non capital stock to a target time in the season?	-	-	-	-	-	-	-	-	-	Y	N	-	-	Y	-	Y	-
Current date < 28th February?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N	-
Buy feed or sell part of the capital stock	-	-	-	-	X	-	-	-	-	-	-	X	X	-	X	-	X
Sell a proportion or all animals in non-capital stock type with no feed allocation	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-
Draft mobs	-	-	-	-	-	-	X	-	X	-	X	-	X	-	-	-	-
Wean mobs	-	-	-	-	-	-	-	X	X	-	-	X	X	-	-	-	-
Wean all mobs	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Set draft fortnightly for all mobs	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-
Sell all non-capital stock	-	-	-	-	X	-	-	-	-	-	-	X	X	-	X	X	X
Reset and start again	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Where N = no, Y = yes, and X the corresponding marketing and/or destocking response.

Table 2. Destocking and marketing policies decision rules table for the hypothetical farm.

killing space booking and allocation in late spring through summer for the Canterbury region of New Zealand (A.C. Bywater, pers com). However, the delay is dynamic ranging between 7 and 12 days.

3. Results

Figure 9 presents results for the algorithm test for the hypothetical farm described above. When feed available was enough to feed the non-capital stock to the end of the season, all

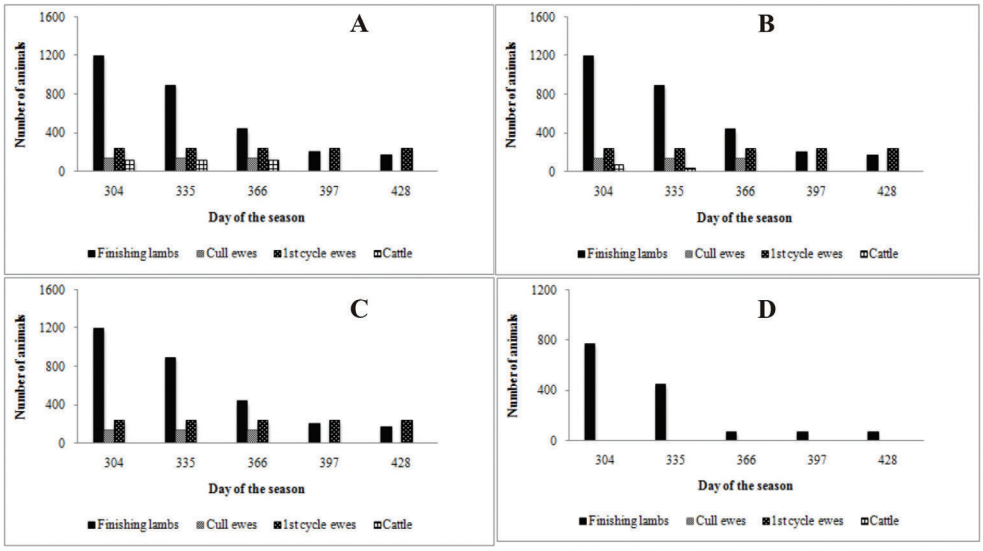

Figure 9. Animal number retained on farm when 100% (A), 75% (B), 50% (C), and 25% (D) of required feed is available for the non-capital stock.

stock classes were retained on the farm, and disposal was only as a result of sale following attainment of target drafting weight as shown in **Figure 9A**. This scenario simulates a farm situation where feed available is not limiting which means the destocking and marketing algorithm is able to respond to the planned marketing regime. For instance, all cattle were sold off at the end of the year which was the target marketing policy for the hypothetical farm.

In all cases, cull ewes are sold off the farm after weaning as shown in **Figures 9A–C**, while the 1st cycle ewes were retained on the farm in anticipation of a better than average pasture growth in the following season. In essence, culling could be carried out on the 1st cycle ewe mob with replacements being sourced from cull ewes deemed to be in better (re)production condition than animals in the 1st cycle ewe mob.

Figure 9D represents a situation where the farm cannot support all the lambs to finishing. It is notable that the height of the column representing the number of animals is shorter compared to the other three cases (**Figure 9A–C**).

Figure 10 shows the feed requirements corresponding to the number of animals presented in **Figure 9**. Generally, feed requirements follow the same pattern as the number of animals. The high number of lambs is reflected by high feed requirements especially toward the start of the season but as the season progresses and as more lambs are sold off, their requirements reduce and are overtaken by the cattle and 1st cycle ewes' requirements.

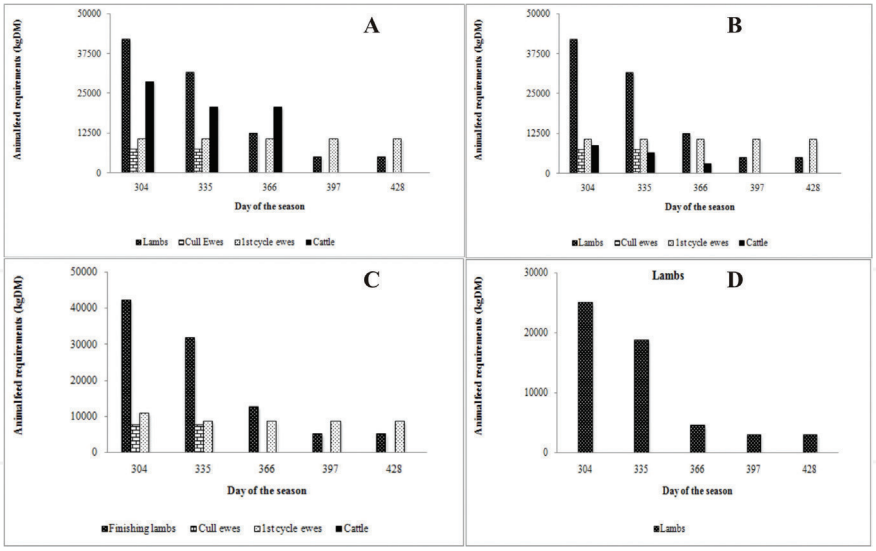

Figure 10. Total feed consumed by each stock category retained on farm when 100% (A), 75% (B), 50% (C), and 25% (D) of required feed is available for the non-capital stock.

Unlike lambs and cattle, cull and first cycle ewe mobs were sold 'all or none' depending on the feed availability. For example, if a mob had a total of 100 ewes and the feed available is enough to maintain 80 ewes, the mob was sold off entirely. Assuming that lamb feed requirements have been satisfied, such a production circumstance led the algorithm to retain a certain number of cattle that can be fed using the feed saved from selling the entire ewe mob (i.e., feed for the 80 ewes). This algorithm capability ensures that no feed is unutilized irrespective of stock type prioritization.

4. Conclusions

Based on the destocking and marketing policies of the hypothetical farm, the algorithm reproduced well the projected and desired results. In general, the algorithm reported here can be used in any grazing system. In order to be used as a stand-alone decision aid, the farmer would be required to provide a stock type prioritization list, an estimate of the feed available at the time, and his or her estimate of the prospects of rainfall, presumably based on official current forecasts (from NIWA in the case of New Zealand). The algorithm has been incorporated into the LincFarm grazing system model [4, 6] model and an evaluation of the extended model carried out for all the new extensions before use in evaluating alternative risk management strategies.

Author details

Mathew Gitau Gicheha[1]*, Grant Edwrads[2], Bell Stephen[2] and Bywater Anthony[2]

*Address all correspondence to: gicheham@jkuat.ac.ke

1 Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

2 Lincoln University, Christchurch, New Zealand

References

[1] Ramirez-Restrepo CA, Barry TN, López-Villalobos N. Organic matter digestibility of condensed tannin-containing lotus corniculatus and its prediction in vitro using celulase/hemicellulase enzymes. Animal Feed Science Technology. 2006;**125**:61–71

[2] Díaz-Solís HM, Kothmann M, Grant WE, de Luna-Villarreal R. Application of a simple ecological sustainability simulator (SESS) as a management tool in the semi-arid rangelands of northeastern Mexico. Agricultural System. 2006;**88**:514–527

[3] Webby RW, Bywater AC. Principles of feed planning and management. In Rattray PV, Brookes IM, and Nicol AM, editors. Pasture and Supplements for Grazing Animals. Hamilton, New Zealand: New Zealand Society of Animal Production; 2007. pp. 189–220

[4] Finlayson JD, Cacho OJ, Bywater AC. A simulation model of grazing sheep. I: Animal growth and intake. Agricultural System. 1995;**48**:1–25

[5] Gicheha MG, Edwards GR, Bell ST, Bywater AC. Embedded risk management in dryland sheep systems I. Field results and development of a destocking algorithm. Agricultural Systems. 2014;**124**:12–20

[6] Cacho OJ, Finlayson JD, Bywater AC. A simulation model of grazing sheep: II. Whole farm model. Agricultural Systems. 1995;**48**:27–50

[7] Harwood J, Heifner R, Coble K, Perry J, Somwaru A. Managing risk in farming: Concepts, research and analysis. Market and economics division and resource economics division, economic research service, U.S. Department of Agriculture. Agricultural Economic Report No. 774. Washington, DC 20036-5831. March 1999

[8] Kay RD, Edward WM. Farm Management. 4th ed. Iowa: McGraw-Hill Companies, Inc.; 1999

[9] Hardaker JB. Some Issues in Dealing with Risk in Agriculture. Working paper series in agricultural and resource economics No. 2000-3 March 2000. Available from: http://www.une.edu.au/febl/GSARE/AREwpOO-3.pdf [Accessed July 15, 2009]

[10] Newberry DM, Stiglitz JE. The Theory of Commodity Price Stabilization. Great Britain: Oxford University Press; 1981

[11] Knight FH. Risk, Uncertainty and Profit, 1st ed. 1921. Boston: Hart, Schaffner and Marx; Cambridge: Houghton Mifflin Company, The Riverside Press; 1921. Available from: http://www.econlib.org/library/knight/knRUP.html

[12] Anderson JR, Dillon JL, Hardaker JB. Agricultural Decision Analysis. Ames, Iowa: The Iowa State University Press; 1977. p. 355

[13] MAFF, 2001. Risk management in agriculture. A discussion document prepared by the Economic and Statistics Group of the Ministry of Agriculture, Fisheries and Food January 2001. Available from: http://www.defra.gov.uk/farm/agendtwo/strategy/riskman/mainrpt.pdf

[14] Waterman L. Building a Comprehensive Risk Management Plan. 2002. Available from: http://www.vermontagriculture.com/Risk%20Management/article1.html

[15] Barry PJ. Risk Management in Agriculture. Ames, Iowa: Iowa State University Press; 1984

[16] Hutchison GK. A decision support system for predicting seasonal rainfall variations in sub-humid and semi-arid high country areas. Proceedings of the New Zealand Grassland Association. 1996;**58:**87–91

[17] Korte CJ, Rhodes AP. Economics of drought-tolerant pastures for cattle finishing on Hawkes Bay and Wairarapa hill country farms. Proceedings of the New Zealand Grassland Association. 1993;**55**:45–49

[18] Battles RW, Thompson RC. Fundamentals of Agribusiness Finance. Ames, Iowa: Iowa State University Press; 2000

[19] Patrick GF. Managing Risk in Agriculture. West Lafette: Purdue University; 1992. Available from: http://www.agcom.purdue.edu/AgCom/Pubs/NCR/NCR-406.html

[20] Gunderson L, Holling CS. Panarchy: Understanding Transformations in Human and Natural Systems. Washington, DC: Island Press; 2001

[21] Pimm SL. The complexity and stability of ecosystems. Nature. 1984; **307:**321–326

[22] Carpenter S, Walker B, Anderies J, Abel N. From metaphor to measurement: resilience of what? Ecosystems. 2001;**4**:765–781

[23] Crawford A, McCall D, Mason W, Paine M. Industry adaptation—challenges when building resilient farming systems. In: Chapman DF, Clark DA, Macmillan KL, Nation DP, editors. Meeting the Challenges for Pasture-Based Dairying. Proceedings of the 3rd Dairy Science Symposium. Melbourne, Australia. 2007. pp. 508–519

[24] Holling C.S. Engineering resilience versus ecological resilience. In: Schulze P, editor. Engineering within Ecological Constraints. Washington DC: National Academy Press; 1996. pp. 31–44

[25] Rusito B, Shadbolt NM, Gray DI, Olubode-Awasola F. Resilience of New Zealand dairy farms in a turbulent environment: Definition and measurement. In: Proceedings of the International Food and Agribusiness Management Association 21st Annual World Symposium. Frankfurt, Germany: IFAMA; 20–21 June 2011. pp. 1–25

[26] Conway GR. Sustainable agriculture: The trade-offs with productivity, stability and equitability. in: Barbier EB, editor. Economics and Ecology: New Frontiers and Sustainable Development. London: Chapman and Hall; 1993

[27] Brooks N. Vulnerability, risk and adaptation: A conceptual framework. Working paper, Tyndall Centre for Climate Change. 2003

[28] Darnhofer I, Fairweather J, Moller H. Assessing a farm's sustainability: Insights form resilience thinking. International Journal of Agricultural Sustainability. 2010;**3**:186–198

[29] Luers A, Lobell D, Sklar L, Addams L, Matson P. A method for quantifying vulnerability, applied to the agricultural system of Yaqui Valley, Mexico. Global Environmental Change. 2003;**13**:255–267

[30] Landcare Research 2003. What is Risk Management? Available from http://contamsites.landcareresearch.co.nz/whatisriskman.htm [Accessed July 15, 2009]

[31] Jolly RW. Risk management in agricultural production. American Journal of Agricultural Economics. 1983;**65**:1107–1113

[32] Kingwell RS, Pannell DJ, Robinson SD. The tactical responses to seasonal conditions in whole-farm planning in Western Australia. Agricultural Economics. 1993;8:211–226

[33] Pannell DJ, Malcom B, Kingwell RS. Are we risking too much? Perspectives on risk in farm modelling and farm management. In: Proceedings of the Annual Conference of the Australian Agricultural Economics Society. Perth: University of Western Australia; 14–16 February 1995

[34] Pannell DJ, Nordblom TL. Impact of risk aversion on whole-farm management in Syria. Australian Journal of Agricultural and Resource Economics. 1998;**42**(3):227–247. DOI: 10.1111/1467-8489.00048

[35] Hardaker JB, Pandey S, Patten LH. Farm planning under uncertainty: A review of alternative programming models. Review of Marketing and Agricultural Economics. 1991; **59**:9–22

[36] Hardaker JB, Huirne RB, Anderson JR. Coping with Risk in Agriculture. Wallingford: CAB International; 1997

[37] Roumasset JA. Rice and Risk: Decision Making Among Low Income Farmers. Amsterdam: North Holland Publishing Co; 1976

[38] Hazell BR. Instability in Indian Food grain Production, Research Report No. 30, Washington, DC, USA: International Food Policy Research Institute; 1982

[39] Binswanger H. Attitudes toward Risk: Experimental Measurement in Rural India, American Journal of Agricultural Economics. 1980;**62**:395–407

[40] Herath G, Hardaker JB, Anderson JR. Choice of varieties by Sri Lanka rice farmers: Comparing alternative decision models. American Journal of Agricultural Economics. 1982;**64**:87–93

[41] Hardaker JB, Lein G. Stochastic Efficiency Analysis with Risk Aversion Bounds: A Simplified Approach. Oslo: Norwegian Agricultural Economics Research Institute; 2003

[42] Savage LJ. The Foundation of Statistics. New York: Wiley; 1954

[43] Kingwell RS. Risk attitude and dryland farm management. Agricultural Systems. 1994; **45**:191–203

[44] Marshall RM, Randall EJ, Lisa MW. Tactical opportunities, risk attitude and choice of farming strategy: An application of the distribution method. The Australian Journal of Agricultural and Resource Economics. 1997;**41**:499–519

[45] Antle JM. Sequential decision-making in production models. American Journal of Agricultural Economics. 1983**;65**:282–290

[46] Dorward A. Modelling embedded risk in peasant agriculture: Methodological insights from northern Malawi. Agricultural Economics. 1999;**21**:191–203

[47] Dorward A, Parton K. Quantitative whole farm models and embedded risk in complex, diverse and risk prone agriculture. Quarterly Journal of International Agriculture. 1997; **36**:317–330

[48] Mjelde JW, Sonka ST, Peel DS. The Socioeconomic Value of Climate and Weather Forecasting: A Review (Research Report No. 89-01). Champagne, IL: Midwestern Climate Center, Climate and Meteorology Section, Illinois State Water Survey; 1989

[49] Martin SK. Risk perceptions and management responses to risk in pastoral farming in New Zealand. Proceedings of the New Zealand Society of Animal Production. 1994;**54**: 363–368

[50] Martin SK. Risk management strategies in New Zealand agriculture and horticulture. Review of Marketing and Agricultural Economics. 1996**;64**:31–44

[51] Harris SR, Martin SK, Lamb CG. Farmer risk perceptions and management responses to risk in a New Zealand dryland farming system: An exploratory study. In: Proceedings of the Australian Agricultural Economics Society Sixteenth Annual Conference, Lincoln University, New Zealand. 1991; p. 8

[52] Gray DI, Kemp PD, Kenyon PR, Morris ST, Brookes IM, Matthew C, Osborne M. Strategies used to manage climatic risk: Lessons from farmers with expertise in dryland farming. Proceedings of the New Zealand Grassland Association. 2008;**70**:59–68

[53] Boggess WG, Anaman KA, Hanson GD. Importance, causes and management responses to farm risk: Evidence from Florida and Alabama. Southern Journal of Agricultural Economics. 1985;**17**:105–116

[54] MAFPolicy 1992. Dryland farm survey: A survey of financial performance and drought management strategies used by South Island East Coast farmers. MAFPolicy Technical Paper 90/8. MAFPolicy, Wellington.

[55] Bywater AC, Logan CM, Edwards GR. Flexibility and climate risk management in high stocking rate dryland sheep farming systems. Proceedings of the New Zealand Society of Animal Production. 2011;**71**:96–102

[56] Fraser T, Moss R, Daly M, Knight T. The effect of pasture species on lamb performance in dryland systems. Proceedings New Zealand Grassland Association. 1999;**61**:23–29

[57] Kinnell D. Managing for risk on summer dry hill country. Proceedings of the New Zealand Grassland Association. 1993;**55**:51–52

[58] Grigg DW, Grigg JM, Lucas RJ. Maximising subterranean clover in Marlborough's hill country is key to weaning 80% of sale lambs prime. Proceedings of the New Zealand Grassland Association. 2008;**70**:25–29

[59] Avery D, Avery F, Ogle GI, Wills BJ, Moot DJ. Adapting farm systems to a drier future. Proceedings of the New Zealand Grassland Association. 2008;**70**:13–23

[60] Bywater AC, Logan CM, Edwards GR. Innovative management systems to increase flock productivity in a variable dryland environment. Final report to the sustainable farming fund, Project SFF 06/120. Available from: http://www.lincoln.ac.nz/Documents/Silverwood-Farm/2011-Innovative-Sheep-Systems-Trials-Final-Report.pdf [Accessed May 16, 2011]

[61] Rutherford L, Nicol AM, Logan CM. Recognising the limits to live weight-reproduction relationships in ewes, Proceedings of New Zealand Society of Animal Production. 2003;**63**:140–143

Chapter 4

Cognitive Factors and Risk Management of Concurrent Product Realisation

Lidija Rihar, Tomaž Berlec and Janez Kušar

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68398

Abstract

In projects of development and industrialization of new products or to improvement of the existing ones not only quality and costs but also the time of product entering the market and delivery time to the client are important. This can be achieved by efficient project management, where classic methods of project management need to be upgraded by elements of concurrent engineering. In this chapter, a method for risk management in cyclically recurrent projects is demonstrated, in which conventional models of risk management based on an assessment of probability of risk event occurrence and an assessment of their consequences are supplemented by a third parameter—assessment of frequency of recurrence of risk events. An important advantage of the suggested solution lies in that a project manager and team members take into account cognitive factors, when managing recurrence of risk events which are usually due to poorly organized business processes of a company. A template was created in the Microsoft Project environment, by means of which the project team tested the suggested methodology on an example of concurrent realization of a pedal assembly of a car.

Keywords: cognitive factors, risk management, project risk, activity risk, critical success factors

1. Introduction

Nowadays, the companies involved in development and industrialization of new products or in the improvement of existing ones mostly deal with orders for a known client. The client not only expects a product of high quality at acceptable prices but also delivery in a term agreed upon [1, 2]. This means that the companies predominantly face project manufacturing processes instead of conventional continuous processes (**Figure 1**).

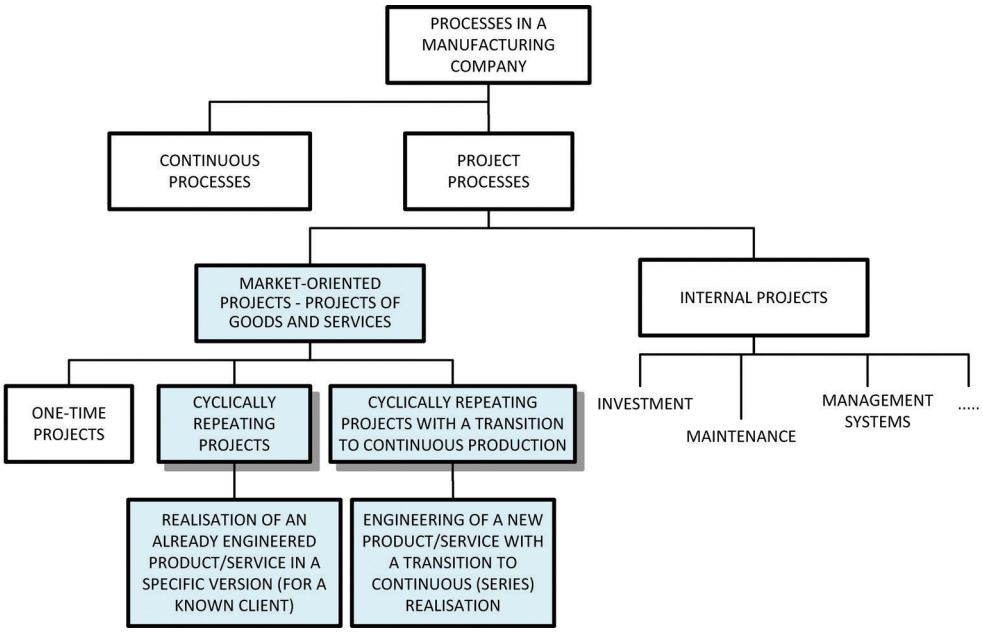

Figure 1. Processes in a manufacturing company.

Continuous processes run for an "indefinite time." Based on demands of the market, they are used to define the necessary quantities of products, for which a process for their development and industrialization had been carried out before.

Project processes are carried out once or in regular intervals and are market oriented to reach a precisely defined goal, for a known client, usually with a higher added value. They have a limited expiration date.

A problem of risk management is relatively low in continuous processes, while it has a very important impact on the achievement of desired results/project goals in project processes.

The chapter only deals with cyclically recurring realization projects of an engineered product in a specific version and with projects that end with a transition to continuous production (e.g., engineering of a car component).

To reach a reduced time needed for product development and industrialization, strategies of concurrent engineering need to be included in processes of project management (parallelism, standardization, and integration), and a track-and-loop principle should be used to carry out activities [3]. Such projects will hereinafter be called concurrent product realization (CPR) projects.

Even though the strategies of parallelism, process integration, and the track-and-loop principle of implementation of project activities considerably shorten the time, reduce the costs, and achieve higher product qualities of the project [3], they may simultaneously be an important cause of risk events that might jeopardize the success of a project.

The importance of managing risks of CRP projects is very high although recurrent project processes are in question. These are the projects that are very precisely specified as to the time, the cost, and the quality, and any deviation from the project plan may result in a business and competitive loss for the company. The client and the company usually assume a joint risk for a successful realization of a project and product placement on the market at the very beginning of the project.

The companies often fear that a risk analysis might cause the projects to get paralyzed or that by identifying the risks we would get frightened and will therefore not carry out the project. In fact, risk management has the following benefits for the company [4]:

- Organizational benefits relating to an increase in efficiency of project implementation—less errors, corrections, and delays due to efficient cooperation and direct communication among project participants.
- Market benefits relating to success of projects—the more precisely the necessary times and costs for the implementation of a project are assessed, the more efficiently risks are managed, and the higher the earning in the implementation of a project and higher clients' confidence.
- Strategic benefits of risk management on projects are logical if market benefits of a larger number of successfully completed projects are correlated and if long-term benefits for the company are assessed.

Planned risk management of CPR projects makes the company more trustworthy and more respected. Progressive project management with an established culture of risk adoption allows the company to operate much more efficiently and successfully in the time of constant changes.

2. Methods of risk management of a project of concurrent product realization

Risks of an entire project or its activities [5] are potential events or situations that may jeopardize a planned implementation of a project. The most important in managing risk events of a project is use of various tools for analysis, evaluation, planning, and carrying out of measures to prevent or at least reduce the influence of risk events.

Several models and methods are available for managing risks of an entire project and of individual project activities [5–10]. The suggested risk management methods are similar to each other, a difference lies in a detail of subdivision of the entire risk management process to subprocesses. **Table 1** illustrates a comparison of four various concepts [5–8], which were a basis for designing a model for risk management in the case of CPR projects.

The first three models are a general approach to project risk management and include methods and techniques that are generally applicable on any project. Colin's model proved to be the most appropriate basis for a development of a risk management model in CPR projects since individual phases of a risk analysis are very precisely defined.

A critical analysis of the discussed models and methods of project risk management supported by experiences in implementing projects in an industrial environment, particularly in car

PMBOK 2013	PRINCE2	DOD Risk management	COLIN
Plan risk management	Identify risk	Identify risk	Risk content
Identify risks			Preliminary risk identification
			Detailed risk identification
Perform quantitative risk analysis	Assess risk	Risk analysis	Detailed risk analysis
Perform qualitative risk analysis		Risk mitigation planning	Detailed risk evaluation
Plan risk responses	Risk plan	Risk mitigation plan implementation	Risk treatment planning
			Prepare risk management plan
Monitor and control risks	Implement and communicate	Risk tracking	Risk monitoring and control
			Review

Table 1. Overview of several models for project risk management.

industry, led the authors to design a method for activity risk management of a project that is shown in **Figure 2**.

In the suggested method, the analysis of project risks and their activities is carried out in seven consecutive steps:

Step 1. Preliminary analysis of project risk management.

Step 2. Project risk identification/assessment.

Step 3. Activity risk identification/assessment.

Step 4. Qualitative and quantitative analysis of activity risks.

Step 5. Planning risk management measures.

Step 6. Monitoring, recording, control, and taking measures.

Step 7. Analysis, evaluation, and archiving.

Compared to the reference models of project risk management [5–8], the suggested methods differ in the following items:

- A phase of project risk analysis is separated from the project activity risk analysis.
- Assessment of risk parameters and a method for the assessment of project activity risks are logically linked to each other.
- A two-dimensional (for one-time projects) and a three-dimensional (in cyclically recurrent projects) level of activity risk can be calculated.

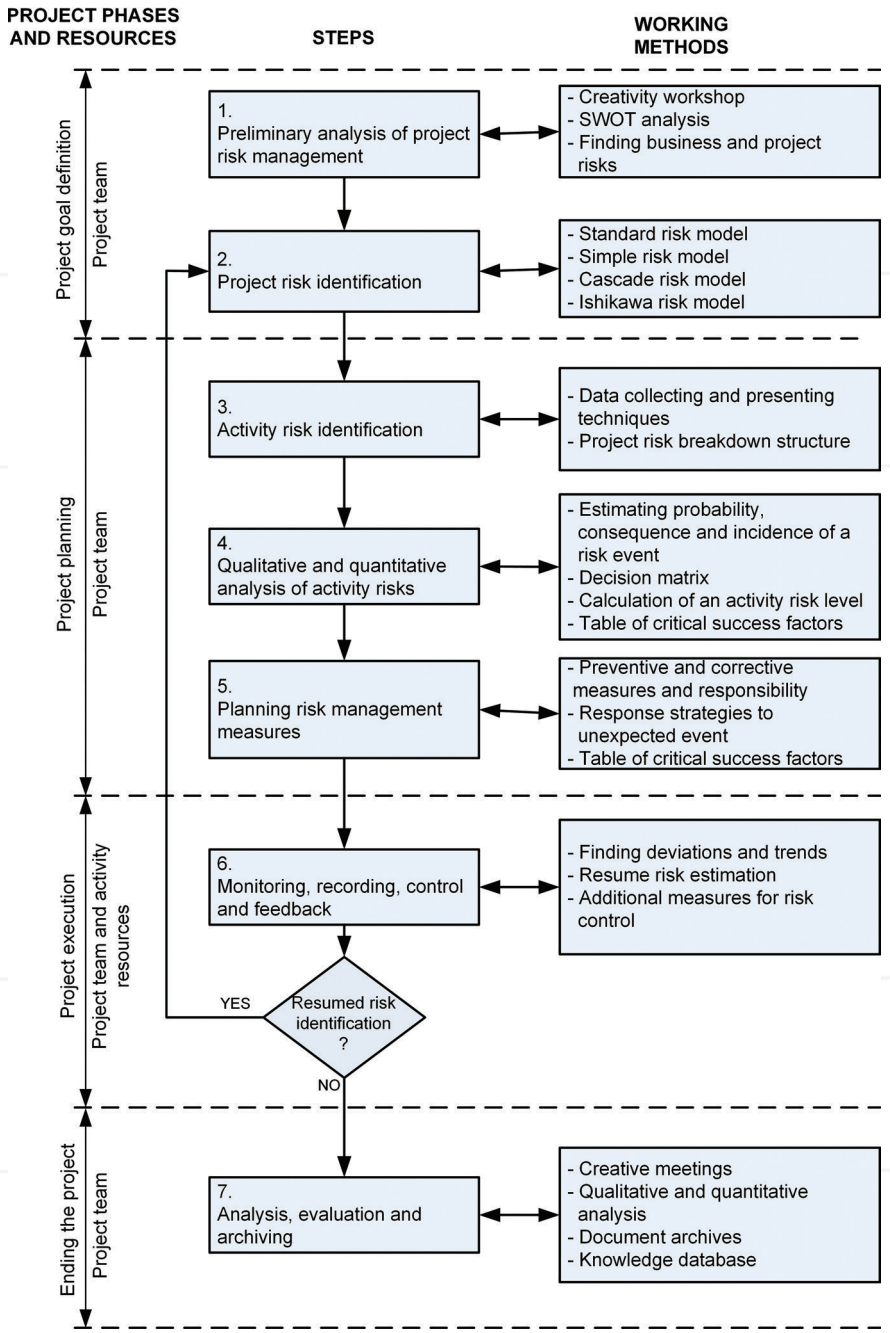

Figure 2. Risk management method of CPR projects.

- The use of a table of critical success factors is suggested for a qualitative and a quantitative analysis and for planning and monitoring preventive and corrective measures.
- Evaluation of project activity risk management and formation of new knowledge based on experience obtained from a completed project are emphasized.

When designing the suggested risk management model of CPR projects, we predominantly relied on the Colin's concept [8], therefore, **Table 2** shows the main differences between them.

Apart from the steps of performing a project risk analysis and a project activity analysis, the suggested method includes the most often applied work methods that a project manager and a project team can use in the implementation of an individual step of the risk analysis.

In literature, different processes and methods for risk management of project activities were proposed, but we did not notice any solution where cognitive factors and risk management of

Steps of the Colin's model	Steps of the suggested model	Differences
1. Establishing a context	1. Preliminary analysis of project risk management	– Steps 1 and 2 of the reference models are combined in one step in the suggested model – Preliminary analysis of the suggested model refers to the entire project
2. Preliminary risk analysis		
3. Detailed risk identification	2. Project risk identification	– Step 3 of the reference model is logically divided into a risk analysis of the entire project and then to a detailed analysis of risk activities
	3. Activity risk identification	
4. Detailed risk analysis	4. Qualitative and quantitative analysis of activity risks	– Assessment of risk parameters and risk evaluation are logically connected
5. Detailed risk evaluation		
6. Risk treatment (planning)	5. Planning risk management measures	– Planning measures are carried out based on risk evaluation, so two steps are not necessary
7. Prepare risk management plan		
8. Risk monitoring and control	6. Monitoring, recording, control and feedback	
9. Review	7. Analysis, evaluation, and archiving	– In the suggested model, emphasis is placed on evaluation and formation of knowledge based on experience obtained from the completed project

Table 2. Overview of differences between the discussed risk analysis models.

concurrent product realization were connected. Most of the methods are based on two-dimensional risk analysis, therefore, we suggest a use of third factor—assessment of frequency of recurrence of risk events.

To the basic Microsoft Project software, a Monte Carlo method can be added, but this solution is insufficient for integration of cognitive factors with risk analyses.

Based on these facts and the experiences from real industrial environment (especially automotive industry), new individual steps of the suggested method for managing cyclically recurrent project activity risks with respect to cognitive factors are described with an emphasis on a detailed description of solutions suggested by the authors for the implementations of Steps 4 and 5.

2.1. Preliminary analysis of project risks

A project team conducts a creativity workshop to establish possible project risks with respect to strategic, organizational, and project goals. The team also analyses the stakeholders' impact on risks.

The risks are divided into business-related and project-related risks. Business-related risks especially have influence on a decision, whether a project is feasible or reasonable, whereas project-related risks have influence on decisions how to carry out a project in the most successful way with respect to the goals and given circumstances.

In implementing this step, the project team uses a SWOT analysis, in which advantages, disadvantages, opportunities, and dangers related to project implementation and consequently its risks are defined.

Based on the findings of the SWOT analysis, the project team and the client who ordered the project conclude whether the risk is acceptable and the project will be carried out or that there is too much risk involved and the project will not be carried out.

2.2. CPR project risk identification

For identifying/assessing project risks, the project team can use one of the following models [9]:

- Standard model, in which the risk is defined by two parameters: a risk event and its impact on the course of the project.
- Simple model, in which the risk is defined by one parameter referring to the risk event and its impact.
- Cascade model, in which the risk is defined by the risk event, consequences, and impact on the course of the project.
- Ishikawa model, in which causes and respective risk events are determined for project-related risks. The project team uses this model to identify those risk causes and risk events that have the greatest impact on the implementation of the project in question.

An analysis of application of said models in real life has shown that the most adequate model for identifying project-related risks of development and industrialization of products/services is the Ishikawa model (**Figure 3**) which has the following advantages:

- The companies are already acquainted with the Ishikawa model as one of efficient tools for total quality management (TQM).
- The model clearly illustrates why project risks occur.
- Separate risk events allow prevention.
- The model supports the cause-effect concept.

A disadvantage of the Ishikawa model is its complexity in case of a larger project and its inability to show interactions between influences of the same risk event in different risk causes [9].

The Ishikawa model for identifying project risks may be used both for identifying risks of the entire project or individual project activities.

When identifying CPR project risks, apart from the risks that are usual for development and industrialization of a product, there is a strong presence of risks that may be caused by process complexity due to performance of concurrent engineering loops.

The risks which may be due to the performance of concurrent engineering loops may be caused by the following:

- Poorly defined concurrent engineering loop and the activities performed within the loop.
- Lack of knowledge and willingness to participate by various individuals who make up working teams who simultaneously perform activities within the loop.
- Poor communication among individuals who perform activities that are carried out in parallel.
- Inadequately selected communication tools.

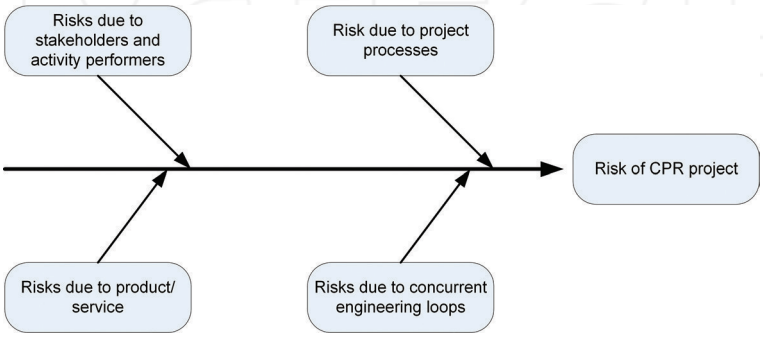

Figure 3. Ishikawa model for identifying CPR project risks.

2.3. CPR project activity risk identification

For the purpose of a quantitative analysis of project activity risks, a project team may use techniques of collecting and presenting the data, e. g., recurrence frequency of risk event, wherein the findings from previously completed similar projects are taken into consideration, or a method of an itemized structure of project activity risks [10]. Apart from that, the methods indicated in Section 2.2 may be used, especially the Ishikawa model.

The method of the itemized structure of project risks is the most adequate method for practical use. In this structure, the standard WBS project structure [5, 10] is expanded by risks identified for each individual activity. If a risk is not identifiable at a certain activity, the risk is left out. An itemized structure of project activity risks is shown in **Figure 4**.

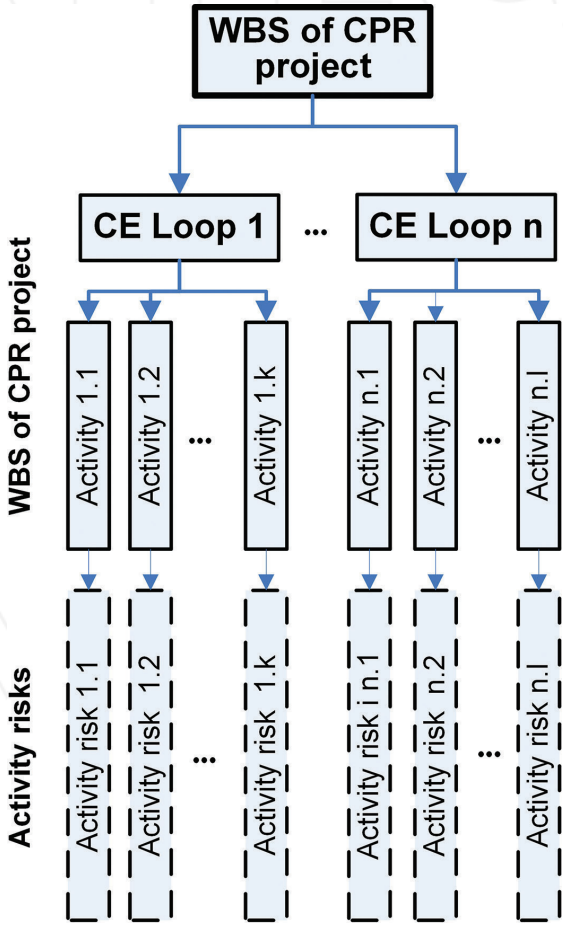

Figure 4. Itemized structure of CPR project activity risks.

In the concurrent product realization, the same activity may be present in two or more loops, wherein identical or different risks may appear in all loops.

2.4. Qualitative and quantitative analysis of project activity risks

The qualitative and quantitative analysis of project activity risks is performed by assessing [5, 7]:

- Probability of occurrence of a problem/risk event.
- Consequences of the problem/risk event.
- Determining a risk level.

To assess the probability of occurrence of a risk event, either an interval assessment scale with rates from 1 to 5 or a scale with descriptive probability rates [5] can be used. For simplicity reasons, a scale with rates from 1 to 5 is usually applied in practice.

The values given in **Table 3** are used to assess the probability of occurrence of a problem/risk event.

The values given in **Table 4** are used to assess consequences of occurrence of a problem/risk event.

The project team may perform a qualitative risk assessment by means of a probability and impact matrix [7] or can calculate a rate of project activity risk [4] based on the assessment of probability of occurrence of a risk event and the assessment of consequences of risk occurrence. The rate of activity risk in the two-dimensional analysis is

Estimate	Probability of event occurrence—*EP*
1	Very little (~10%)
2	Little (~30%)
3	Medium (~50%)

Table 3. Probability of occurrence of a risk event.

Estimate	Assessment of consequences of event occurrence—*EC*
1	Very small
2	Small
3	Medium
4	Big
5	Very big

Table 4. Assessment of consequences of risk event occurrence.

$$RL_2 = EP \times EC \tag{1}$$

where RL_2 is the rate of activity risk in the two-dimensional analysis of a project activity risk; EP is the probability of occurrence of an activity risk event; and EC is the assessment of consequences of occurrence of an activity risk event.

The data on the quantitative and qualitative risk analyses of a certain project activity are entered into the table of critical success factors as shown in **Table 5**.

Instead of calculating the risk rate, the project team may use the probability and impact matrix [7].

As this chapter discusses the risks in cyclically recurrent projects, the experience obtained from previously performed similar projects can be used for the assessment of the frequency of recurrence of risk event occurrence [4].

Example: in its product realization, a company plans activities such as client's confirming documentation and samples. The time needed for the implementation of these activities is planned, however, a client frequently, yet not always, exceeds the planned time. Hence, this is a recurrent risk event.

To assess the frequency of recurrence of risk events, the authors suggest the values indicated in **Table 6**.

No.	WBS code/activity/problem	Event probability—*EP*	Assessment of consequences—*EC*	Risk rate—RL_2
1.	Activity 1/problem A	3	2	6
2.	Activity 2/problem B	2	4	8
:	:	:	:	:
j.	Activity j/problem N	4	5	20
:	:	:	:	:
n	Activity n/problem X	4	5	20

Table 5. Table of critical success factors—two-dimensional analysis.

Estimate	Assessment of event recurrence frequency—*ER*
1	Never
2	Very rarely
3	Rarely
4	Often
5	Very often

Table 6. Assessment of recurrence frequency of a risk event.

The level of project activity risk in the three-dimensional analysis is

$$RL_3 = EP \times EC \times ER \tag{2}$$

where RL_3 is the level of activity risk in the three-dimensional analysis of activity risk; EP is the probability of occurrence of an activity risk event; EC is the assessment of consequences of occurrence of an activity risk event; and ER is the assessment of frequency of recurrence of a risk event.

Table 7 shows an example of calculation of critical success factors for the three-dimensional risk analysis.

2.5. Planning measures and risk management

Once the two-dimensional risk analysis is completed, it should be determined—based on the assessment of probability of event occurrence and the assessment of its consequences, based on a decision matrix [5, 7]—whether the activity risk is low, medium, or high.

In the suggested three-dimensional risk analysis, the activity risk is determined based on predefined boundary values of a rate/probability of risk [4]:

- If $RL \leq 24$ (risk probability up to 20%), the risk is low.
- If $25 \leq RL \leq 60$ (risk probability between 20 and 50%), the risk is medium.
- If $RL \geq 61$ (risk probability higher than 50%), the risk is high.

If the risk is low, the project team does not prepare potential measures.

If the risk is medium, the project team prepares preventive measures directed at eliminating causes for the occurrence of risk events. If a risk event occurs anyway, the project team must immediately prepare corrective measures.

In the event of a huge risk, the project team prepares both preventive measures to prevent the occurrence of risk events (risk elimination, lowering of probability of realization, transfer of risks) and corrective measures (active adoption of risks) that can trigger processes for alleviation of consequences of a risk event.

Risk analysis					
No.	**WBS code/activity/ problem**	**Event probability—*EP***	**Assessment of consequences—*EC***	**Assessment of recurrence frequency—*ER***	**Rate of risk—RL_3**
1.	Activity 1/problem A	3	2	4	24
2.	Activity 2/problem B	2	4	4	32
:	:				
j.	Activity j/problem N	4	5	5	100
:	:	:	:	:	
n	Activity n/problem X	4	5	3	60

Table 7. Table of critical success factors—three-dimensional analysis.

We suggest using **Table 8**, which is an amendment of **Table 7**, for entering the measures together with responsible owners.

Table 8 was also the basis for a template in the Microsoft Project software that allows the project manager and the project team to plan, monitor, control, and take measures if a risk event occurs in an activity.

This approach provides more opportunities to the project team and other project stakeholders for identification of potential risk events and searching for possible solutions for elimination or mitigation of risk consequences based on thinking out of the box with the use of cognitive factors. Based on this approach, the solutions for risk management are more sufficient, creative, innovative, and clearly described and collected in one place.

2.6. Monitoring, recording, control, and taking measures

Responsibility for monitoring project activity risks and their implementation lies with: project manager, project team, client, and individuals performing the activities.

Responsibility of a risk owner should be determined for each risk. The risk owner has a task to detect a symptom of an approaching risk as soon as possible and to trigger planned measures accordingly. The sooner a risk is discovered, the less serious the consequences.

The project manager verifies the status of risks at regular control briefings and amends a list of risks if necessary. The team must bear in mind that the level of risk can vary during the entire project—there is a higher possibility of one risk getting realized in a certain phase and of another risk getting realized in another phase. To have a better control, the risks should be specified in the table by size and topicality.

Several approaches are suggested to reduce the level of project risks:

- Active risk assumption.
- Risk elimination.
- Reduction in probability of risk realization.
- Alleviation of consequences by transferring risks to another organization.
- Passive assumption of risks with a reserve in time and money.

Active risk assumption means that a plan of measures is prepared for the event of occurrence of an activity risk event. Usually, reserves in time and money are foreseen to solve the consequences of the occurred risks.

A risk may be completely avoided by eliminating or circumventing a cause for its occurrence. The latter is possible by changing a project plan, wherein a change is applied on the entire project or only an individual phase, activity duration, tactics of activity implementation, supplier, or contractor. A new plan which attempts to circumvent a risk can be defined as an alternative method for achieving key events and can be more expensive.

Another way of risk elimination is elimination of certain requirements by the client that are hardly achievable and represent various risks (time, costs, and quality). This mode of risk

Risk analysis						Risk management		
No.	**WBS code/activity/problem**	**Event probability—*EP***	**Estimate of consequences—*EC***	**Estimate of recurrence frequency—*ER***	**Risk rate—RL_3**	**Measures** **P—preventive** **C—corrective**	**Risk owner**	**Indicator**
1.	Activity 1/problem A	3	2	4	24			
2.	Activity 2/problem B	2	4	4	32	P—prevent. measure 1	Project manager	
:	:	:	:	:	:	:	:	:
j.	Activity j/problem N	4	5	5	100	P—prevent. measure 2 C—Corr. measure 1	Head of develop.	Delay x days
:	:	:	:	:				
n	Activity n/problem x	4	4	3	48	P—measure 3	Project manager	

Table 8. Amended table of critical success factors.

elimination includes negotiations with the client, and when deciding, a size of a risk must be compared with the positive effect of realization of the client's or customer's requirement.

By listing a risk to the risk list, a probability of occurrence of a risk event is automatically reduced due to subsequent systematic control. Planned reduction in probability can be achieved by additional activities and costs; there are also measures such as better and more expensive equipment, better and more expensive technology for the implementation, assistance of external experts, and preliminary simulations.

When a reduction in risk consequences is in question, the best solution is to transfer the risk to another organization. Among participants in a project the risks may be transferred to the client, an external contractor or supplier, wherein the transfer of risks (delays and extra costs) is defined by a contract [11]. As the risk owners tend to avoid extra costs, a probability of occurrence is consequently reduced. Another way of alleviating the consequences is insurance. Insurance is the most adequate when a huge risk is encountered, the probability of occurrence is rather low but may have devastating consequences for the project.

The more project activities on a critical path, the riskier the project since a delay in critical activities has a direct impact on a delay of the entire project. Time reserves in noncritical activities can be an important factor for risk reduction due to a delay in the implementation of activities.

Microsoft Project is a tool often used in information support to project management, therefore the Laboratory for Manufacturing Systems of the Faculty of Mechanical Engineering in Ljubljana has decided in cooperation with partners in companies to integrate the presented expanded methodology of project activity risk management into previously created templates. Although a server version of the Microsoft Project offers a possibility of use of the tool for risk analysis, we estimate that the suggested solution is simpler for a user yet very efficient. This allegation is especially confirmed by use of the expanded risk analysis on several projects from industrial environment [12, 13].

2.7. Analyzing, evaluation, and archiving

Once a project is completed, the project team, apart from performing other analyses, performs a risk management evaluation to establish which anticipated risk events have actually happened, what the consequences were and how efficient the preventive and corrective measures were.

All documents related to risk management are archived and the database of knowledge about risks is adequately amended.

3. Case study

The suggested method for project activity risk management was performed on an example of a project of concurrent development and industrialization of a pedal assembly for a personal vehicle as shown in **Figure 5**.

Figure 5. Pedal assembly for a personal vehicle.

A customer who develops a new car sent an order for development and industrialization of a pedal assembly to his development supplier. Since the terms for obtaining an order were very demanding in terms of time, costs, and quality, the management of the company decided to include as many elements of concurrent engineering in the project management of the pedal assembly as possible and to organize the project by the track-and-loop principle [3, 12, 13]. In fact, the company faced a huge risk because such mode of carrying out a project requires the project participants and the contractors to be well connected in terms of organization and information exchange.

It was for the first time that the company dealt with implementation of a risk analysis of such a project, and the management of the company therefore organized a creativity workshop [14], the goal of which was to identify all types of risks by means of the Ishikawa model, which can occur in the implementation of the CPR projects in their company.

The result of the creativity workshop is the Ishikawa chart (**Figure 6**), which includes four major causes for the occurrence of risk events in the CPR project of the pedal assembly.

Based on the created Ishikawa chart, the project team reviewed the WBS structure of the project of the pedal assembly, which was created by the principle of concurrent engineering loops and identified potential risk events in each activity.

Figure 7 depicts a track-and-loop principle of implementation of the CPR project of the pedal assembly, which is divided in six stages and five concurrent engineering loops (T-3 loops).

The WBS structure of the CPR project consists of five tasks at the first level, the tasks representing concurrent engineering loops. This is shown in **Figure 8**.

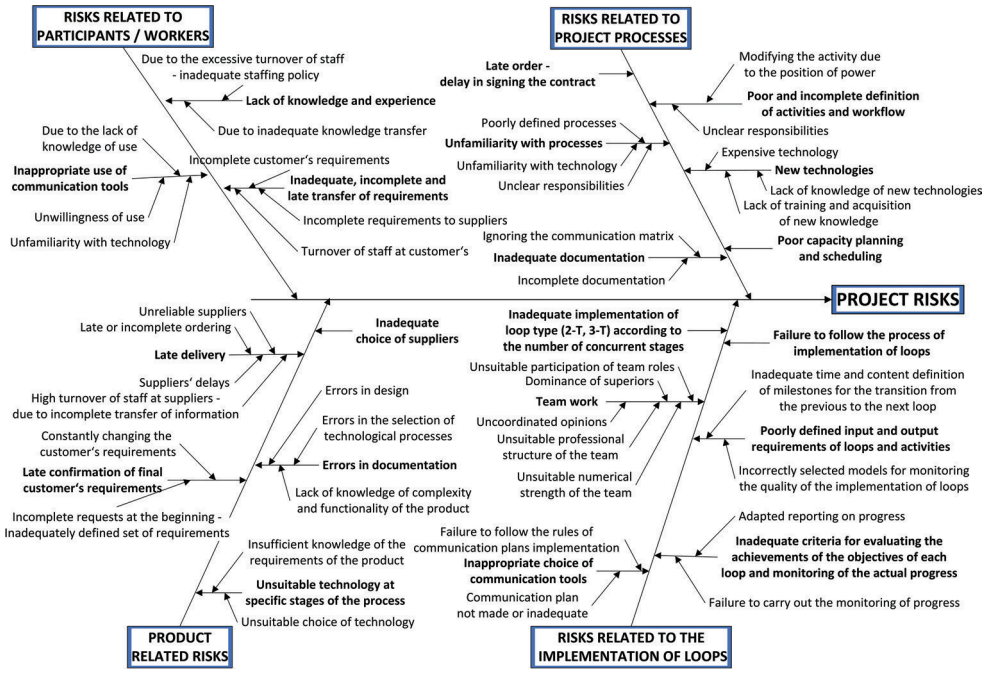

Figure 6. Ishikawa chart of project risks of the CPR project of the pedal assembly.

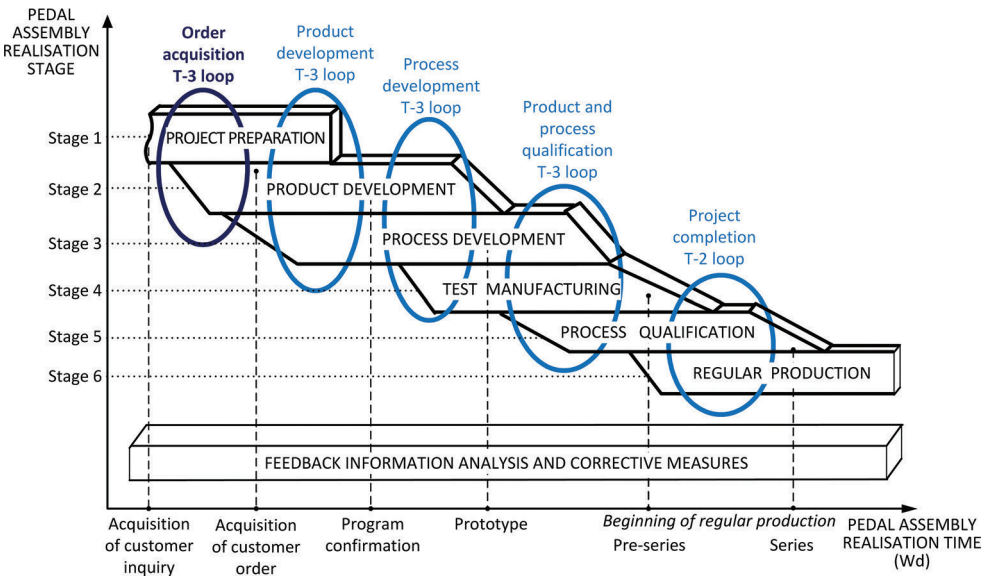

Figure 7. Track-and-loop principle of implementation of the CPR project of the pedal assembly.

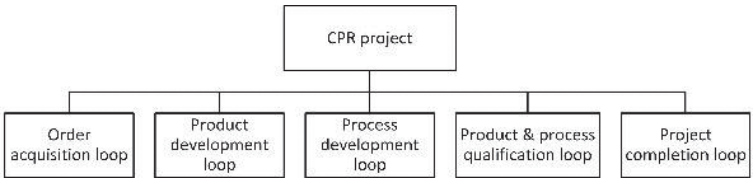

Figure 8. First level of the WBS structure of the CPR project of the pedal assembly.

The project team amended the WBS structure of the project with assessed potential activity risks and transformed the structure into an itemized structure of project risks by adding potential risk events to the activities. **Figure 9** shows a more detailed itemization of loop 2: a loop of product development on the activity and on the last level on potential risk events.

The project team made a table of critical success factors for a qualitative and quantitative analysis of activity risks of the pedal assembly project. The team members have decided to perform a three-dimensional risk analysis, in which it should be determined for each activity and the risk associated therewith—in compliance with the suggested model: probability of occurrence, assessment of consequences, and assessment of recurrence frequency of a risk event, then the level or activity risk should be calculated. For the activities, in which the risk is medium or high, preventive, or corrective measures and status indicators are foreseen.

Figure 10 shows the part of the table of critical success factors for loop 2 of the pedal assembly.

The table of the critical success factors empowered us to identify several potential risks in each activity and to take the maximum value as the level of activity risk.

As the company uses Microsoft Project software for planning and managing projects, we used a standard template for activity risk management of the project (Microsoft Project template).

The project manager inserted the data from **Figure 10** into a prepared template, the result is shown in **Figure 11**.

The advantage of the suggested template for managing activity risks of the project is the fact that the software tool which serves for planning time, resources, and project activity costs can also be used to manage activity risks of the project.

Apart from the advantages, the suggested template also has a limitation. If several potential risks are identified at an activity, only a risk having the maximum level of activity risk is entered in table in **Figure 11**, the remaining risks are noted in a notepad of activities.

The project manager, the project team members, and the individuals performing activities can obtain the following data from the table in **Figure 11**:

- Short risk description.
- Assessment of probability of event occurrence.
- Assessment of consequences of event occurrence.

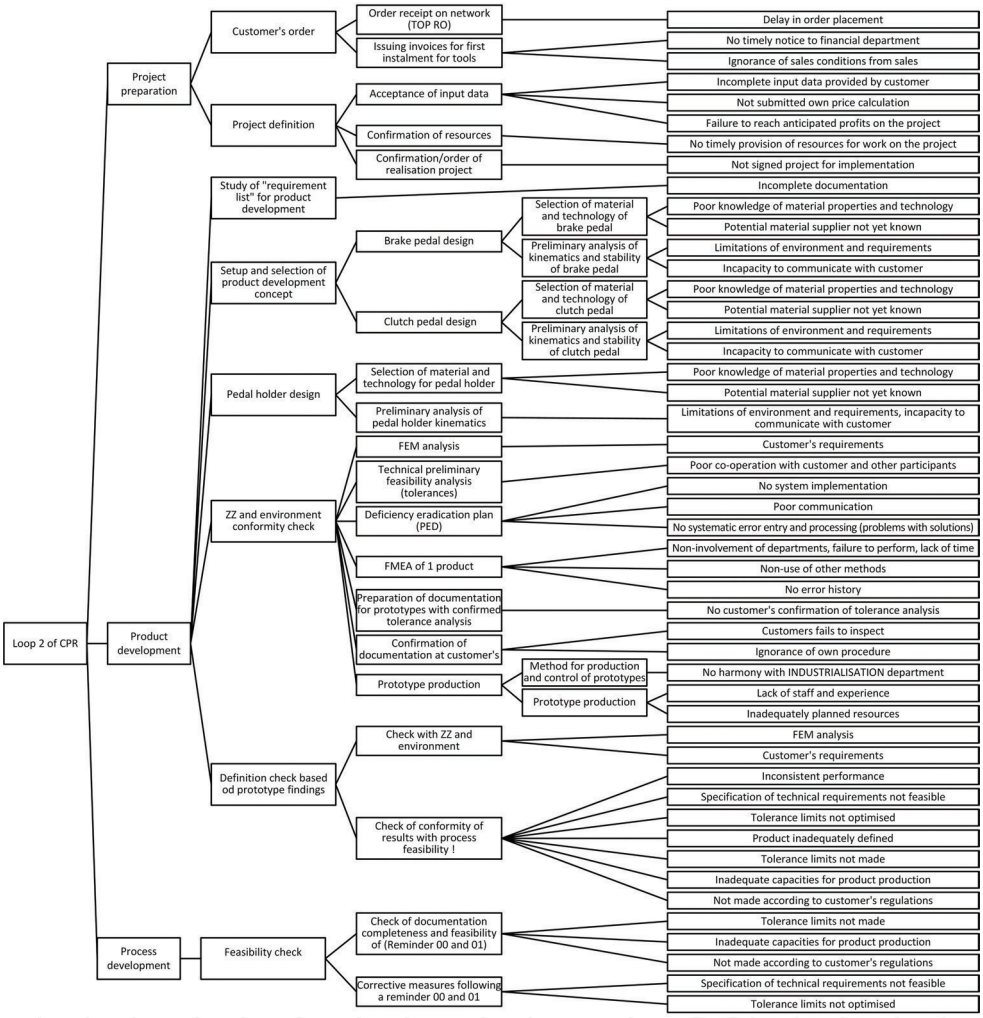

Figure 9. Itemized structure of activities and risks of loop 2 of the CPR project of the pedal assembly.

- Assessment of frequency of event occurrence.
- Level of risk and risk indicator (in colors).
- Responsibility for risk management.
- Link to a document containing a detailed description of risks and measures.

The color of the risk indicator visually draws attention of the project manager and the team members to the level of risk of an individual activity and to foresee preventive and corrective measures.

Risk analysis						Risk management		
ID	***ACTIVITY***	***EP***	***EC***	***ER***	***RL3***	***CAUSE***	***CONSEQUENCE***	***MEASURE***
75	***Order receipt on network (TOP RO)***	**3**	**3**	**4**	**36**	Delay in issuing order – consequence: delay in plan, failure to provide items to customer	Correction of customer's plan	Purchase, Sales
76	Issuing invoices of first instalment for tools	3	3	4	36	No timely notice to financial department, ignorance of sales conditions from sales Consequence: customer's late payment, company's insolvency	Customer's order transferred to customer's portal - (Renault)	Sales logistics, Sales
	Input data takeover	**5**	**3**	**3**	**45**	Incomplete input data provided by customer, no own price calculation. Consequence: problems in actual purchase of equipment, failure to reach anticipated profit on the project	In-person delivery of investment offers	Purchase, Sales
81	***Confirmation of resources***	**3**	**3**	**4**	**36**	No timely provision of resources for work on the project Consequence: delay in beginning of implementation	Managing of allocation of resources of individual organisational managers by departments	Project manager
84	Confirmation/order of realisation project	3	4	2	24	Not signed project for implementation Consequence: delay in implementation	Confirmation of project for implementation within 5 days at the latest	Project office
87	***Study of "requirement list" for product development***	**1**	**3**	**1**	**3**	Incomplete documentation	Search for additional information, too time consuming	Material information should be looked for in real time (Sales) in preliminary phases
91	***Selection of material and technology for brake pedal***	**3**	**4**	**2**	**24**	Poor knowledge of material properties and technology, potential material supplier not yet known	Increased costs, terms becoming overdue, calls for new technology, extension of time	More communication with supplier and other technical departments, material standardisation, process standardisation (research)
92	***Preliminary analysis of brake pedal kinematics and stability***	**3**	**3**	**4**	**36**	Limitations of environment and requirements, incapacity of communicating with customer	Unfeasibility, poor stability, increased costs	Better communication with customer (Development, Purchase, Sales)
95	***Selection of material and technology for clutch pedal***	**3**	**4**	**2**	**24**	Poor knowledge of material properties and technology, potential material supplier not yet known	Increased price, terms overdue, calls for new technology, time extension	More communication with supplier and other technical departments, material standardisation, process standardisation (research)
96	***Preliminary analysis of clutch pedal kinematics and stability***	**3**	**3**	**4**	**36**	Limitations of environment and requirements, incapacity of communicating with customer	Unfeasibility, poor stability, increased costs	Better communication with customer (Development, Purchase, Sales)
99	***Selection of material and technology for pedal holder***	**3**	**4**	**2**	**24**	Poor knowledge of material properties and technology, potential material supplier not yet known	Increased price, terms overdue, calls for new technology, time extension	More communication with supplier and other technical departments, material standardisation, process standardisation (research)
100	***Preliminary analysis of pedal holder kinematics***	**3**	**3**	**4**	**36**	Limitations of environment and requirements, incapacity of communicating with customer	Unfeasibility, poor stability, increased costs	Better communication with customer (Development, Purchase, Sales)

Figure 10. Table of critical success factors of loop 2 of the pedal assembly project (part).

ID	ACTIVITY	EP	EC	ER	RL3	CASUE	CONSEQUENCE	MEASURE
0	**BRAKE PEDAL**							
73	**Project preparation**							
74	**Customer's order**							
75	Order receipt on network (TOP RO)	5	3	3	◆	Delay in issuing order – consequence: delay in plan, failure to provide items to customer	Correction of customer's plan	Sales, Project manager
76	Issuing invoices of first instalment for tools	5	3	3	◆	No timely notice to financial department, ignorance of sales conditions from sales Consequence: customer's late payment, company's insolvency	Customer's order transferred to customer's portal - (Renault)	Sales logistics, Sales
79	**Project definition**							
80	*Input data takeover*	3	3	3	◆	*Incomplete input data provided by customer, no own price calculation. Consequence: problems in actual purchase of equipment, failure to reach anticipated profit on the project*	*In-person delivery of investment offers*	*Purchase, Sales*
81	*Confirmation of resources*	3	3	3	◆	*No timely provision of resources for work on the project Consequence: delay in beginning of implementation*	*Managing of allocation of resources of individual organisational managers by departments*	*Project manager*
84	Confirmation/order of realisation project	2	2	2	●	Not signed project for implementation Consequence: delay in implementation	Confirmation of project for implementation within 5 days at the latest	Project offic

Figure 11. Activity risk analysis of the pedal assembly project of loop 2 in MS Project (part).

A level of risk of the entire project is interesting for a comparison of risk of a project with risks of other projects. We decided based on Ref. [15] that a risk level of activity groups and of the entire project is calculated as an average level of activity risk (the lowest level of a WBS project). Of course, an average risk level of a project can only be a statistical piece of data and can be deceiving if uncritically discussed. It may happen that a project has a low average risk level, but includes activities that have a high-risk level. If a risk event occurs in these activities, the project might be seriously jeopardized in terms of foreseen scope, time, and cost.

Apart from the risk indicator, other indicators that warn us of other project-related dangers can be included in the table in **Figure 11**, for instance delays in time, consumption of time reserve, and excess in actual costs compared to the planned ones.

In the case of the pedal assembly project, an overview of risks by CPR loops (**Figure 12**) was made. It can be determined that most risk events occur in loop 3, i.e., a loop of process development.

Moreover, an overview by risk rate size (**Figure 13**) was made for a more detailed analysis. It shows that most potential risk events belong to a medium-risk category (49 risk events), high risks come second (24 risk events), and low risks with 14 risk events are in the last place.

Both analyses performed show that the project of the concurrent realization of the pedal assembly is very risky and this demands from the project team to pay more attention to risk management of this project.

The proposed method requires comprehensive approach for cognitive solving of the risk management problems of concurrent product realization with the use of three factors and three different views on the same risk, which provides better solutions based on team work. Team work is based on a multidisciplinary team of different members for different organizational

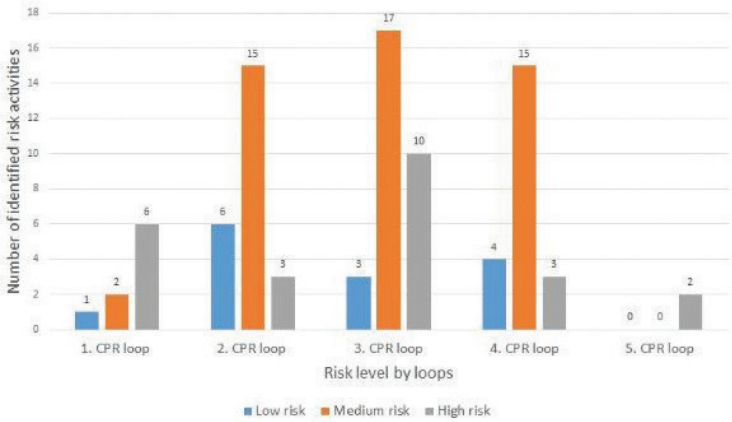

Figure 12. Overview of risks by CPR project loops.

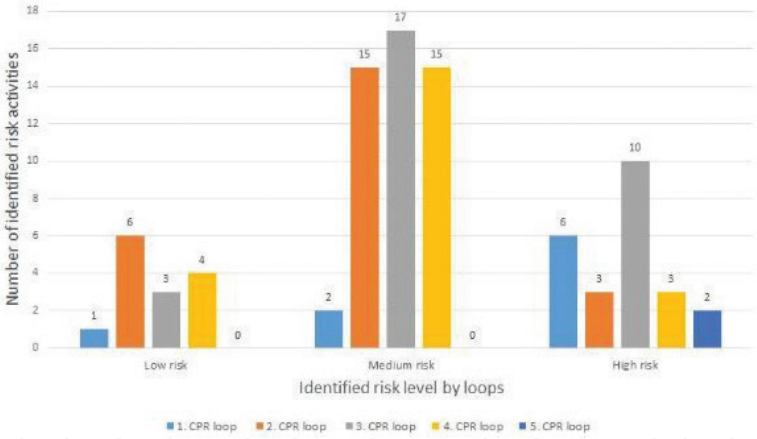

Figure 13. Overview of risks with respect to the level of risk.

units of the company and external stakeholders. This helps a company to detect and solve the main causes of risk based on different point of view taking into account various human and cognitive factors.

This solution is integrated in the proposed model for cognitive risk management and supported with a template in the Microsoft Project software.

4. Conclusion

This paper presented a problem of risk management in CPR projects that are market oriented, i.e., in projects of products and services. It was determined that in such cyclically recurrent projects we frequently run into recurringly similar causes that cause a risk in the implementation of project activities.

In CPR projects, classic methods of project management are upgraded by concurrent engineering elements and a track-and-loop principle of performance of activities is used, hence, we face a huge need for managing risks that may appear in the implementation of the concurrent engineering loops [12, 16]. These risks most often occur because of poor team work, unfamiliarity with the tools of concurrent engineering and lack of cooperation and communication among activity performers (working teams) in concurrent engineering loops. Not only a team responsible for the implementation of the entire project is needed in the implementation of the concurrent engineering loops but also a need for creating working teams for the implementation of the loops [3]. Such team is made up of responsible persons of participants of organizational units who carry out activity loops. Since several activities are carried out in parallel, there is a need for permanent and direct communication between activity performers. Although such projects are cyclically recur-

rent in companies, it was established that the risk events keep occurring each time a project is repeated.

We therefore suggested a method for managing activity risks of a CPR project, in which a third parameter was added to the generally known two-dimensional method of risk analysis—the recurrence frequency of a problem. This piece of data can be evaluated based on the evaluation of previously performed or completed projects. The introduction of this additional parameter has proved to be utterly necessary since it was claimed both by product customers and auditors of a company's project management system.

If the frequency rate of problem recurrence is high and does not have a tendency to reduce in subsequent similar projects, this is a clear indicator that a company does not manage/efficiently eliminate permanently recurring problems. This is an important indicator for the management of a company to urgently adopt adequate measures. A further goal of the suggested method is to gradually reduce the frequency rates of recurrent problems (the goal is rate 1) and to gradually make a transition to a two-dimensional risk analysis.

Since the companies often use the Microsoft Project software to support project management, the Faculty of Mechanical Engineering of Ljubljana in cooperation with partner companies prepared an additional table in support of conventional templates. The table allows a risk analysis in the Microsoft Project environment. The use of such template has proved to be a useful tool since project managers can use the same software to plan and carry out risk management measures.

In the future work, current Microsoft Project templates could be generalized for business use, especially in small companies.

The proposed solution will be extended with the design of threshold area of expected loss, which is an important information for decision-making of risk mitigation or elimination.

Author details

Lidija Rihar, Tomaž Berlec and Janez Kušar*

*Address all correspondence to: janez.kusar@fs.uni-lj.si

Faculty of Mechanical Engineering Ljubljana, Ljubljana, Slovenia

References

[1] Kendall IG, Rollins CS. Advanced Project Portfolio Management and the PMO. J. Ross Publishing, Inc., Boca Raton, USA; 2003.

[2] Fleischer M, Liker KJ. Concurrent Engineering Effectiveness: Integrating Product Development across Organisations. Cincinnati: Hanser Garden Publications; 1997.

[3] Rihar L, Kušar J, Berlec T, Starbek M. Team building for implementation of concurrement engineering loops. In: Constantin Volosencu, editor. New technologies, trends, innovations and research. Intech, Rijeka, Croatia; 2012. pp. 299-326.

[4] Kušar J, Rihar L, Žargi U, Starbek M. Extended risk-analysis model for activities of the project. Springer Plus. 2013;**2**:227.

[5] PMBOK Guide. A guide to the project management body of knowledge. 5th ed. Newtown Square, Pennsylvania, USA: Project Management Institute, Inc.; 2013.

[6] Managing successful projects with PRINCE2. 5th ed. London: TSO, cop.; 2009.

[7] DOD Risk management guide for DOD Acquisition. 6th ed. Department of Defence USA; 2006.

[8] Colin D. A Handbook of Project management. NSW, Australia: Allen Unwin; 2007.

[9] Smith GP, Merritt MG. Proactive Risk Management. New York, USA: Productivity Press; 2002.

[10] Vargas VR. Practical Guide to Project Planning. Boca Raton, New York: Auerbach Publications, Taylor & Francis Group; 2008.

[11] Palčič I, Buchmeister B, Polajnar A. Analysis of innovation concepts in Slovenian manufacturing companies. Journal of Mechanical Engineering. 2010;**56**(12):803-810

[12] Rihar L, Kušar J, Gorenc S, Starbek M. Teamwork in the simultaneous product realisation. Journal of Mechanical Engineering. 2012;**58**(9):534-544. DOI: 10.5545/sv-jme.2012.420

[13] Rihar L, Kušar J, Duhovnik J, Starbek M. Teamwork as a precondition for simultaneous product realization. Concurrent Engineering. 2010;**18**(4):261-273

[14] Scherer J. Kreativitätstechniken. Offenbach: Gabal Verlag GmbH; 2007.

[15] Paul RS. Project Risk management—A Proactive approach. Vienna, VA: Management Concepts; 2002.

[16] Duhovnik J., Tavčar J. Concurrent engineering in machinery. In: Stjepandić Josip, Wognum Nel, Verhagen Wim JC, editors. Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges. Springer international publishing, Switzerland: 2015. pp. 639-670. DOI: 10.1007/978-3-319-13776-6_22

Chapter 5

A Bus Allocation Model for Major Industrial Disasters

Paolo Fadda, Gianfranco Fancello,
Simona Mancini and Claudia Pani

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68808

Abstract

The presented research is part of a broader project DIEM-SSP—Disasters and Emergencies Management for Safety and Security in Industrial Plants –aiming at managing major industrial emergencies by considering both medical and engineering/logistics issues. When a disaster occurs, it is necessary to immediately provide relief plans. Many decisions must be made in very short time, which may have a relevant impact on the consequences of the disaster. For an efficient and smart exploitation of available resources, it is necessary to mitigate damages. From a logistics point of view, one of the major issues in the event of a major industrial disaster (fire, explosion or toxic gas dispersion) is to evacuate the external population that can be affected by the disaster to specific evacuation areas. The purpose of the research is to determine the optimal number and allocation of vehicles (buses) which must be involved in order to evacuate the population located in a defined risk area around the emergency site and the optimal location for evacuation areas. For that reasons, a dynamic version of the bus allocation problem is proposed using a mixed-integer programming model.

Keywords: bus allocation, industrial disasters, mixed-integer programming

1. Introduction

The presented research is part of a broader project (DIEM-SSP—Disasters and Emergencies Management for Safety and Security in Industrial Plants) aiming at managing major industrial emergencies by considering both medical and transport/logistics issues. The study of the scientific literature confirms that the severity of a disaster can be highly influenced by the efficacy of the logistics operations during the disaster response phase [1–3]. Since in these circumstances time is crucial, one of the major issues in emergency conditions is to ensure a quick response of the rescue operations [4].

Several authors have analysed the issue of vehicles' allocation in the emergency situation: Stein et al. [5] have studied the effects of a correct emergency vehicle location plan and the response system design on response time performance in a South Africa Urban Emergency Medical Services (EMSs). The authors have used a discrete-event simulation and the results indicate that more decentralised vehicle location has a greater effect.

Yang et al. [6] have proposed the use of urban rail transit (URT) systems in emergency circumstances, as quick and efficient response for evacuation. Using a genetic algorithm (GA), the authors propose a mathematical programming with an indicator constraint model for designing a responsive bus bridging services under URT line emergency. In detail, the authors have analysed the problem considering the distance between the bus parking spots and the URT station as a starting point of a scheduled line.

Zheng [7] has defined an optimal bus-operating model during an emergency evacuation that minimizes the exposed casualty time rather than the operational cost, as a deterministic mixed-integer program. The solution has been based on a Lagrangian relaxation-based algorithm.

Huang et al. (2006) have studied the problem of allocating limited emergency service vehicles (as ambulances and fire trucks): using a mixed-integer linear programming model, they have analysed the effects of demand at Critical Transportation Infrastructure (CTI) nodes and transportation network performance on the optimal coverage to CTIs: authors have used a case study applied on Singapore.

Oran et al. [8] have defined a new formulation of the facility location problem (using MIP solver) and vehicle routing problem with time windows (a tabu search-based metaheuristic algorithm), analysing a set of possible emergency scenarios with limited emergency resources. Results show that this approach is able to serve higher priority locations better than the much utilized maximal coverage location problems.

Muaafa et al. [9] have studied an integrated approach based on a multi-objective optimization model to manage the emergency medical response strategies; it allows both to specify the locations of temporary emergency units and to assess the emergency vehicles to these temporary emergency units. The objectives of the model are to minimize response time and cost of the response strategy.

Wang et al. [10] have proposed an optimal allocation of bus to coordinate the passengers' evacuation from urban rail transit service caused by the unexpected service interruptions in URT corridors. The results show that as the evacuation time window increases, the total evacuation cost, as well as the number of dispatched feeder-buses, decreases.

Meinzer et al. [11] have studied new strategies for dynamic ambulance allocation in emergency conditions. They propose to adopt a continuous optimization of vehicles distribution over the region and dynamic reassignment of fleets.

This work proposes a mixed-integer programming model for buses allocation able to determine the optimal number and allocation of buses, which must be involved in order to evacuate all the population located in a defined risk area around the emergency site and the optimal location for evacuation areas (EAs).

A company operating on the waste oil regeneration sector, located in Italy, has been considered in order to evaluate the performance of the proposed methodology: it deals with a toxic gas dispersion and involvement of the external population within a radius of 3 km from the company.

With respect to other research studies analysed in the state of the art, the innovative approach proposed by this study considers the following aspects:

- The study uses a mixed-integer programming model, less used for emergency vehicle allocation.
- The emergency condition in the application is an industrial disaster with a toxic gas dispersion.

2. A mixed-integer programming model

Although they are recognized problems from the scientific community, research on transportation problems and emergency vehicle management for disaster response operations is emerging only recently [2, 12, 13].

When a disaster occurs, it is necessary to immediately provide relief plans. Many decisions must be made in very short time, which may have a relevant impact on the consequences of the disaster. For an efficient and smart exploitation of available resources, it is necessary to mitigate damages. Many applications of operations research methods to disaster response optimization may be found in the literature. Barbarosoglu G, Arda Y. [14] proposed a two-stage stochastic programming model for transportation planning in a disaster, while a multi-objective model for quick response to emergencies in logistics distribution has been proposed by Liu and Zhao [15]. In Ref. [16], the authors proposed a mixed-integer programming model for facility location in humanitarian relief. Ozdamar and Yi [17] dealt with vehicle dispatch plan for relief and evacuation. Other papers presented studies related to relief operations in a specific type of disaster, such as in Ref. [18], where a decision support system, specific for emergency response in the case of nuclear accident, has been presented, and in Ref. [19], the authors proposed an optimization model for allocating emergency resources after an earthquake. Similar issues may be found in ambulance allocation dispatching, where a limited fleet of ambulances must be allocated to real-time requests. A complete review on this subject may be found in Ref. [20].

We deal with buses allocation for mass evacuation. In detail, considering a case in which, due to toxic gas dispersion, all the population located in a risk area surrounding the emergency site must be evacuated. This area is sub-divided into zones, for each one of which the number of people to be evacuated is known. We consider a set of depots where buses are located, for each one of which, we suppose to know the number of available vehicles of identical capacity (in terms of the number of people which can be carried), and the delay with which the vehicles will be available at that depot. A delay equal to 0 means that vehicles are always located at the depot and that they are immediately available. We consider a set of potential evacuation areas with different capacities. For operational reasons, people from the same zone must be evacuated in the same evacuation point located within the area [21–23].

The goal is to minimize the averaged evacuation time. In particular, for evacuation time of a zone, we intend the time within which all the people from that zone are evacuated.

Before proceeding with the mathematical formulation, we define the parameters, sets and variables of the model.

Model parameters:

- q_i: number of people to be evacuated from zone i
- c: vehicles' capacity
- p_k: delay with which the vehicles are available at depot k
- t_{ij}: travel time between zone i and evacuation area j
- τ_{ik}: travel time between depot k and zone i
- R_k: number of vehicles available at depot k
- C_j: capacity of evacuation area j

Model sets:

- I: set of zones to be evacuated
- J: set of evacuation areas
- K: set of depots

Involved variables:

- Y_{ik}: binary variable taking value equal to 1 if zone i is evacuated by bus located at depot k and 0 otherwise
- Z_{ij}: binary variable taking value equal to 1 if zone i is evacuated to evacuation area j and 0 otherwise
- Y_{ik}: number of vehicles starting from depot k and used to evacuate zone i
- T_i: evacuation time for zone i
- A_i: time within which all vehicles that have been assigned to zone i reach the zone

The mathematical model for buses allocation for mass evacuation can be formulated as follows:

$$\min \sum_{i\ in\ I} \frac{T_i}{|I|} \tag{1}$$

s.t.

$$\sum_{k\ in\ K} Y_{ik} \geq 1 \qquad \forall i \in I \tag{2}$$

$$\sum_{j\ in\ J} Z_{ij} = 1 \qquad \forall i \in I \tag{3}$$

$$\sum_{i\ in\ I} q_i Z_{ij} \le C_j \forall j \in J \tag{4}$$

$$V_{ik} \le R_k Y_{ik} \forall i \in I\ \forall k \in K \tag{5}$$

$$\sum_{i\ in\ I} V_{ik} \le R_k \forall k \in K \tag{6}$$

$$\sum_{k\ in\ K} c * V_{ik} \ge q_i \forall i \in I \tag{7}$$

$$\left(\sum_{k\ in\ K} V_{ik} - 1\right) * c \le q_i \forall i \in I \tag{8}$$

$$A_i \ge \left(\sum_{k\ in\ K} \tau_{ik} + p_k\right) Y_{ik}\ \forall i \in I \tag{9}$$

$$T_i = \sum_{j\ in\ J} t_{ij}\ Z_{ij} + A_i\ \forall \mathrm{i} \in I \tag{10}$$

$$Y_{ik} \in \{0, 1\} \quad \forall i \in I\ \forall k \in K \tag{11}$$

$$Z_{ij} \in \{0, 1\} \quad \forall i \in I\ \forall j \in J \tag{12}$$

$$V_{ik} \in \mathrm{Z}^+ \quad \forall \mathrm{i} \in \mathrm{I}\ \forall \mathrm{k} \in K \tag{13}$$

The objective function is to minimize the averaged evacuation time, expressed in Eq. (1). Constraint Eq. (2) imposes that each zone must be served by at least one depot, while constraint Eq. (3) ensures that all the population of a zone must be evacuated to the same evacuation point. Evacuation areas' capacity restriction is satisfied by constraint Eq. (4). Constraint Eq. (5) imposes that a zone may be evacuated by vehicles located at a depot only if it is served by that depot. The number of vehicles used, for each depot, must be lower than the number of available vehicles at that depot, as stated in constraint Eq. (6). Constraints Eqs. (7) and (8) ensure that the number of vehicles used to evacuate a zone is the minimum necessary. For each zone, the arrival time of the last bus is computed by constraint Eq. (9), while the evacuation time is computed by constraint Eq. (10). In fact, the evacuation time of a zone, defined as the arrival time of the last bus, evacuating people from that zone, to the evacuation area, can be computed as the sum of the arrival time of the last bus to the zone plus the travel time between the zone and the evacuation area. Finally, constraints Eqs. (11)–(13) specify the domain of the variables.

It is also interesting to analyse how the solution changes if instead of minimizing the averaged evacuation time, we would minimize the largest evacuation time, defined as the time necessary to evacuate all the zones. In this case, the new objective function results:

$$\min \sum_{i\ in\ I} W \tag{14}$$

subject to constraints Eqs. (2)–(13) and the following additional constraints:

$$W \geq T_i \quad \forall i \in I \tag{15}$$

$$W \in Z^+ \tag{16}$$

3. Data description

The company is located in Italy and it is the European leading company in the main sector of waste oils regeneration. More than 150 people work for the company. The working activities take place 365 days a year, 24 hours a day, in the two production plants: one in the North of Italy and the other one near Rome.

3.1. Data providing information on the population to be evacuated

The risk area within a radius of 3 km from the emergency site has been divided in 23 potential evacuation zones. For each one, the following information has been defined:

- The number of people to be evacuated: For each zone, the number of people to be evacuated has been calculated considering the total zone size (km^2) and the population density of the zone (inhabitants/km^2) (**Table 1**).
- Collection points' location: For operational reasons, people from the same zone must be evacuated in a specific collection point, identified by its geographical coordinates.
- Distance: Distances between collection points and depots (D) and between collection points and evacuation areas (EAs) have been computed (**Table 2**).

Zones	Inhabitants	Zones	Inhabitants
Zone 1	725	Zone 13	626
Zone 2	422	Zone 14	447
Zone 3	367	Zone 15	775
Zone 4	367	Zone 16	338
Zone 5	442	Zone 17	318
Zone 6	362	Zone 18	218
Zone 7	467	Zone 19	328
Zone 8	343	Zone 20	288
Zone 9	660	Zone 21	745
Zone 10	943	Zone 22	367
Zone 11	278	Zone 23	357
Zone 12	536		

Table 1. List of zones and number of inhabitants to be evacuated.

Zones	D1	D2	D3	EA1	EA2	EA3	EA4	EA5	EA6	EA7	EA8	EA9
Zone 1	2.2	4.7	5.7	10.4	10.3	10.4	9.6	7.2	6	10.5	7.6	6.1
Zone 2	3.5	3.2	8.9	11.7	10.7	10.8	11	8.6	9.3	11.8	8.9	9.3
Zone 3	5	2.7	8	11.2	11.1	11.2	10.4	8.1	8.4	11.3	8.4	8.4
Zone 4	4.4	3.3	8.7	11.9	11.8	11.9	11.1	8.7	9.1	12	9.1	9.1
Zone 5	4	4.1	8.5	12.6	13.1	13.2	11.9	9.5	8.9	12.7	9.8	9
Zone 6	2.9	5.5	7.4	12.1	11.9	12.1	11.3	8.9	7.7	12.2	9.3	7.8
Zone 7	1.8	7.5	6.9	11.6	10.8	10.9	10.9	7.6	6.4	11.7	8.8	6.5
Zone 8	1.6	5	4.8	9.5	9.5	9.6	8.7	6.3	5.1	9.6	6.7	5.2
Zone 9	6.5	0	9.2	8.8	9.3	9.4	8.1	5.7	8.2	8.9	6	10.5
Zone 10	3.4	3.4	5.3	7.3	7.3	7.4	6.6	4.2	6.7	7.4	4.5	6.8
Zone 11	5.3	1.3	8.9	9.6	7.8	7.9	8.9	6.5	9	9.7	6.8	11.3
Zone 12	1.3	6.9	6.3	11	11.1	11.2	10.2	7	5.8	11.1	8.2	5.9
Zone 13	1.6	7	4.9	8.1	7.5	7.8	9.8	5.7	4.5	8.5	7.5	4.6
Zone 14	1.6	6.8	4.7	7.3	7	7.2	9	5	3.8	7.8	6.7	3.9
Zone 15	2.2	7	5.9	7	6.6	6.9	8.7	4.6	3.4	7.4	6.4	3.5
Zone 16	1	6.5	5.2	8.8	7.7	8	10	6.5	5.3	10.8	8	5.4
Zone 17	2.4	5.6	4.3	9.5	9.5	9.6	8.8	6.4	5.7	9.6	6.7	5.8
Zone 18	3.2	5.8	3.1	9.8	6.7	6.8	9	4.7	5.1	9.8	7	6.4
Zone 19	1.8	6.4	4.3	8.6	8.2	8.5	9.6	6.2	5	10.4	7.5	5.1
Zone 20	1.8	6.4	3.5	8.6	8.2	7.1	9.7	62	5	10.5	8	5.1
Zone 21	2.2	6.4	3	7	6.6	6.7	9.6	4.6	5.4	7.6	6.3	5.5
Zone 22	3.1	6.4	2.5	6.4	6.1	6.1	9.6	4	4.4	7	5.8	6.4
Zone 23	3.2	8.1	4.6	5.6	5.3	5.6	7.3	3.3	2.1	6.1	5	2.2

Table 2. Zones and number of inhabitants to be evacuated.

Area	Capacity
Area 1	5000
Area 2	3000
Area 3	2000
Area 4	1000
Area 5	3000
Area 6	5000
Area 7	4000
Area 8	1000
Area 9	1000

Table 3. List of evacuation areas capacity.

3.2. Data providing information on the evacuation area

A set of nine evacuation areas has been identified for each one of which the following information has been collected:

- Location: The location of each area is provided in terms of geographical coordinates.
- Capacity: For each area, it is specified the maximum capacity intended as the maximum number of persons that the area can accommodate (**Table 3**).

4. The case study

In this scenario, we consider a toxic gas dispersion due to which the population within a radius of 3 km from the company must be evacuated.

We defined 23 zones to be evacuated and for each one we supposed to know the number of people to be evacuated.

We consider a homogeneous fleet of 170 vehicles located in three depots. 20 of them are located at Depot 1 and are supposed to be immediately available while the other buses are supposed to be around the city and 50 of them can be available in 20 minutes at each depot (1, 2 and 3). We have defined nine available evacuation areas, each one of them is known with the maximum capacity.

Each zone can be served by buses coming from different depots but, for operational reasons, all the people from the zone must be evacuated to the same evacuation area. Distances between depots and zones and between zones and evacuation areas have been computed with Google Maps. Travel times have been computed considering a travel time equal to 10 Km/h, compatible with a congested urban traffic. We have carried out four tests. In Tests 1 and 2, we have tried to minimize the average evacuation time, while in Tests 3 and 4, we aimed to minimize the total evacuation time, i.e. the time within which all the population is evacuated. Furthermore, Tests 1 and 3 consider all evacuation areas available, while in Tests 2 and 4, evacuation areas 4 and 9 are not available.

Tests outlines are described in **Table 4**.

Test	Evacuation areas	Minimize
1	All	Avg Time
2	No. 4 and 9	Avg Time
3	All	Max Time
4	No. 4 and 9	Max Time

Table 4. Tests outlines.

In **Tables 5** and **6**, we report, for each zone, the area to which it has been evacuated, the evacuation time (expressed in minutes), other than averaged and maximum evacuation time.

In **Tables 7** and **8**, we report the vehicle dispatching resume. In detail, for each zone, we report the number of buses started from each depot to evacuate that zone. Depot 1* concerns vehicles starting from Depot 1 but available after 20 minutes.

Test 1			**Test 2**		
Zone	**Evacuation area**	**Time**	**Zone**	**Evacuation area**	**Time**
1	6	100	1	6	100
2	5	101	2	5	101
3	5	95	3	5	95
4	5	102	4	5	102
5	5	111	5	6	107
6	6	93	6	6	93
7	6	79	7	6	79
8	6	71	8	6	41
9	8	66	9	5	64
10	4	90	10	8	77
11	8	79	11	5	77
12	9	73	12	6	73
13	6	67	13	6	67
14	9	63	14	6	63
15	6	85	15	2	105
16	6	38	16	6	38
17	6	48	17	5	52
18	5	77	18	5	77
19	6	41	19	6	41
20	6	41	20	3	84
21	5	76	21	3	88
22	5	69	22	5	69
23	6	71	23	6	71
	Avg Time	75		Avg Time	77
	Max Time	111		Max Time	107

Table 5. Evacuations area assignment and evacuation time for Tests 1 and 2.

Test 3			Test 4		
Zone	**Evacuation area**	**Time**	**Zone**	**Evacuation area**	**Time**
1	6	94	1	6	94
2	7	92	2	5	73
3	5	95	3	5	95
4	8	81	4	6	81
5	6	77	5	6	77
6	6	93	6	6	93
7	6	79	7	6	79
8	6	90	8	6	91
9	4	79	9	7	83
10	5	75	10	8	89
11	5	77	11	2	85
12	6	73	12	6	73
13	1	89	13	6	86
14	6	63	14	6	94
15	9	86	15	5	71
16	6	68	16	3	84
17	6	78	17	5	94
18	5	93	18	5	77
19	5	93	19	6	71
20	6	81	20	3	84
21	5	76	21	7	94
22	8	80	22	5	69
23	6	71	23	6	92
	Avg Time	82		Avg Time	84
	Max Time	95		Max Time	95

Table 6. Evacuations area assignment and evacuation time for Tests 1 and 2.

Comparing results obtained in Tests 1 and 2, we can observe that if two evacuation areas are not available anymore (Test 2), the average evacuation time only increases by 2 minutes (from 75 to 77), which shows the robustness of the system. The same behaviour can be noted in Tests 3 and 4. In this case, even if evacuation areas 4 and 9 are not available, the optimal maximum evacuation time is the same as in the case in which all the evacuation areas are available, and the increment of average evacuation time is very little.

		Test 1					Test 2		
Zone	**Depot 1**	**Depot 1***	**Depot 2**	**Depot 3**	**Zone**	**Depot 1**	**Depot 1***	**Depot 2**	**Depot 3**
1	0	0	0	11	1	0	0	0	11
2	0	0	7	0	2	0	0	7	0
3	0	0	6	0	3	0	0	6	0
4	0	0	6	0	4	0	0	6	0
5	0	7	0	0	5	0	7	0	0
6	0	6	0	0	6	0	6	0	0
7	0	7	0	0	7	0	7	0	0
8	0	5	0	0	8	5	0	0	0
9	0	0	10	0	9	0	0	10	0
10	0	0	14	0	10	0	0	14	0
11	0	0	4	0	11	0	0	4	0
12	0	8	0	0	12	0	8	0	0
13	0	9	0	0	13	0	9	0	0
14	0	7	0	0	14	0	7	0	0
15	0	0	0	12	15	0	0	0	12
16	5	0	0	0	16	5	0	0	0
17	5	0	0	0	17	5	0	0	0
18	0	0	0	4	18	0	0	0	4
19	5	0	0	0	19	5	0	0	0
20	5	0	0	0	20	0	5	0	0
21	0	0	0	11	21	0	0	0	11
22	0	0	0	6	22	0	0	0	6
23	0	0	0	6	23	0	0	0	6

Table 7. Vehicles dispatching for Tests 1 and 2.

Comparing Tests 1 and 3, we can observe that, trying to minimize the maximum evacuation time or the average one, we obtain sensibly different solutions but values obtained for both criteria are comparable.

The same behaviour can be noted in Tests 2 and 4.

For what concerns vehicle dispatching, we can observe that in Tests 1 and 2, the optimal vehicle assignment is the same, while in Tests 3 and 4, we obtain a different vehicle assignment. This fact depends on the different objective functions. In fact, when we aim to minimize the maximum evacuation time, there are many feasible vehicle assignment configuration, which may yield to the same objective function value.

		Test 3					Test 4		
Zone	**Depot 1**	**Depot 1***	**Depot 2**	**Depot 3**	**Zone**	**Depot 1**	**Depot 1***	**Depot 2**	**Depot 3**
1	0	0	11	0	1	0	0	11	0
2	7	0	0	0	2	7	0	0	0
3	0	0	6	0	3	0	0	6	0
4	6	0	0	0	4	6	0	0	0
5	7	0	0	0	5	7	0	0	0
6	0	6	0	0	6	0	6	0	0
7	0	7	0	0	7	0	7	0	0
8	0	0	0	5	8	0	0	5	0
9	0	0	10	0	9	0	0	10	0
10	0	0	14	0	10	0	0	0	14
11	0	0	4	0	11	0	0	4	0
12	0	8	0	0	12	0	8	0	0
13	0	9	0	0	13	0	0	0	9
14	0	7	0	0	14	0	0	7	0
15	0	0	0	12	15	0	12	0	0
16	0	5	0	0	16	0	5	0	0
17	0	5	0	0	17	0	0	0	5
18	0	0	4	0	18	0	0	0	4
19	0	0	0	5	19	0	5	0	0
20	0	0	0	5	20	0	5	0	0
21	0	0	0	11	21	0	0	0	11
22	0	0	0	6	22	0	0	0	6
23	0	0	0	6	23	0	0	6	0

Table 8. Vehicles dispatching for Tests 3 and 4.

5. Concluding remarks

The state of the art underlines that in the event of a major disaster there is a strong need for decision support tools that give solutions to the allocation problem in a short time interval. From a transport/logistics point of view, the most important decisions that should be made by emergency vehicle managers during a disaster response phase are related to the location and allocation of the emergency vehicles.

A mixed-integer programming model for buses allocation has been calibrated to determine the optimal number and allocation of buses, which must be involved in order to evacuate all the

population located in a defined risk area around the emergency site and the optimal location for evacuation areas.

Four different scenarios have been calibrated: in two of them, the average total travel time of buses has been minimized, while in the other two the maximum total travel time of buses has been minimized.

Comparing the scenarios with all zones, the obtained results are different but values obtained for both criteria are comparable; the same aspects have been noted comparing the scenarios without areas No. 4 and No. 9.

Regarding further evolution of the research, interesting developments can be followed expanding and integrating the results of bus allocation model with a route choice model and a route assignment model.

Author details

Paolo Fadda[1], Gianfranco Fancello[1]*, Simona Mancini[2] and Claudia Pani[3]

*Address all correspondence to: fancello@unica.it

1 DICAAR, University of Cagliari, Cagliari, Italy

2 Polytechnic of Turin, Corso Duca degli Abruzzi, Turin, Italy

3 CIREM, University of Cagliari, Cagliari, Italy

References

[1] Yi W, Özdamar L. A dynamic logistics coordination model for evacuation and support in disaster response activities. European Journal of Operational Research. 2007;**179**(3):1177–1193

[2] Berkoune D, Renaud J, Rekik M, Ruiz A. Transportation in disaster response operations. Socio-Economic Planning Sciences. 2012;**46**(1):23–32

[3] Holguín-Veras J, Jaller M, Van Wassenhove LN, Pérez N, Wachtendorf T. On the unique features of post-disaster humanitarian logistics. Journal of Operations Management. 2012;**30**(7-8):494–506

[4] Talarico L, Meisel F, Sörensen K. Ambulance routing for disaster response with patient groups. Computers & Operations Research. 2015;**56**:120–133

[5] Stein C, Wallis L, Adetunji O. The effect of the emergency medical services vehicle location and response strategy on response times. South African Journal of Industrial Engineering. 2015;**26**(2):26–40

[6] Yang Y, Zhao H. Responsive bus bridging service planning under Urban Rail Transit Line Emergency. In: 3rd International Conference on Vehicle, Mechanical and Electrical Engineering (ICVMEE 2016). 2016. July 30-31, 2016. Wuhan, China. ISBN: 978-1-60595-370-0

[7] Zheng H. Optimization of bus routing strategies for evacuation. Journal of Advanced Transportation. 2014;**48**:734–749

[8] Oran A, Tan KC, Ooi BH, Sim M, Jaillet P. Location and routing models for emergency response plans with priorities. In: Aschenbruck N, Martini P, Meier M, Tölle J, editors. Future Security. Communications in Computer and Information Science. Vol. 318. Berlin, Heidelberg: Springer; 2012

[9] Muaafa M, Concho AL, Ramirez-Marquez JE. Emergency resource allocation for disaster response: An evolutionary approach. In: Conference Paper – PSAM 2014 "Probabilistic Safety Assessment and Management", Honolulu, Hawaii. Vol. 40. June 2014. http://techno-info.com/

[10] Wang Y, Yan X, Zhou Y, Zhang W. A feeder-bus dispatch planning model for emergency evacuation in urban rail transit corridors. PLoS One. 2016;**11**(9):e0161644. DOI: 10.1371/journal.pone.0161644

[11] Meinzer N, Storandt S. Decision Support in Emergency Medical Systems: New Strategies for Dynamic Ambulance Allocation. Albert-Ludwigs-University; 2014. Association for the Advancement of Artificial Intelligence (www.aaai.org)

[12] De la Torre LE, Dolinskaya IS, Smilowitz KR. Disaster relief routing: Integrating research and practice. Socio-Economic Planning Sciences. 2012;**46**(1):88–97

[13] Pedraza-Martinez AJ, van Wassenhove LN. Transportation and vehicle fleet management in humanitarian logistics: Challenges for future research. EURO Journal on Transportation and Logistics. 2012;**1**(1-2):185–196

[14] Barbarosoglu G, Arda Y. A two-stage stochastic programming framework for transportation planning in disaster response. Journal of the Operational Research Society. 2004;**55**(1):43–53

[15] Liu M, Zhao L. A composite weighted multi-objective optimal approach for emergency logistics distribution. In: IEEE International Conference on Industrial Engineering and Engineering Management; 2-5 December 2007, Singapore. IEEE; 2007. pp. 968–972

[16] Balcik B, Beamon BM. Facility location in humanitarian relief. International Journal of Logistics. 2008;**11**(2):101–121

[17] Ozdamar L, Yi W. Greedy neighborhood search for disaster relief and evacuation logistics. Intelligent Systems. 2008;**23**(1):14–23

[18] French S. Multi-attribute decision support in the event of a nuclear accident. Journal of Multi-Criteria Decision Analysis. 1996;**5**(1):39–57

[19] Fiedrich F, Gehbauer F, Rickers U. Optimized resource allocation for emergency response after earthquake disasters. Safety Science. 2000;**35**(1):41–57

[20] Brotcorne L, Laporte G, Semet F. Ambulance location and relocation models. European Journal of Operational Research. 2003;**147**:451–463

[21] Huang Y, Fan Y, Cheu RL. Optimal allocation of multiple emergency service resources for critical transportation infrastructure protection. Transportation Research Record. 2014;**2022**;p-1-8

[22] NajafiM, Eshghi K, de Leeuw S. A dynamic dispatching and routing model to plan/re-plan logistics activities in response to an earthquake. OR Spectrum. 2014;**36**(2):323–356

[23] Yi P, George SK, Paul JA, Lin L. Hospital capacity planning for disaster emergency management. Socio-Economic Planning Sciences. 2010;**44**(3):151–160

INTECH

INTECH

Chapter 6

An Experimental Study on Developing a Cognitive Model for Human Reliability Analysis

Domenico Falcone, Fabio De Felice,
Antonella Petrillo and Alessandro Silvestri

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69230

Abstract

Serious incidents that occur inside or caused by industrial plants represent a very critical issue. In this context, the human reliability analysis (HRA) is an important tool to assess human factors that influence human behaviour in disasters scenario. In fact, the reliability assessment of interaction between human-machine systems is an important factor that affects the overall performance and safety in industrial plants. However, even though HRA techniques have been available for decades, there is not a universal method/procedure to reduce human errors that affect human performance. This study aims to design a novel approach to investigate the relationship between human reliability and operator performance considering the dependence on the available time to make decisions.

Keywords: disaster management, human reliability analysis, cognitive model, PSFs

1. Introduction

The increasing complexity of industrial systems requires the adoption of adequate approaches to manage emergency situations in case of accidents and disasters. In this context, the analysis of human reliability represents a crucial task [1]. In fact, the human factor is a predominant element in the study of accidents/disasters, not only in probability level, but also in terms of severity of the expected effects [2]. HRA is a set of techniques which describes the conditions of the operator during the work, taking into account errors and unsafe actions [3]. In other words, HRA aims to describe the physical and environmental conditions in which operators shall carry out their tasks, considering errors, skills, experience and ability [4]. The importance of the topic is the reason as we conducted a research on Scopus database, the largest abstract and citation database of peer-reviewed literature. Search string used in the literature survey was

'*human reliability analysis*'. String was defined according to the standards of Scopus database. Only articles in which the string '*human reliability analysis*' was found in key words were analysed. The analysis on Scopus pointed out that from 1964 (first year in which the first article appeared) until February 2017 (period of survey) a set of 40,958 documents have been published divided in 32,865 articles, 3671 conference papers and the remaining part on books, editorials, letters, etc. Result showed that the scientific production on this topic is very wide and covers many scientific areas (engineering, medicine, social science, etc.). Furthermore, it is interesting to note that most of the publications (13,842) have been published in the USA. Of course, since the research was very general, it is evident that the large amount of documents found does not allow to have a specific analysis regarding our specific scientific interest. Thus, considering our specific field of interest, we refined our search applying a preliminary filter. Search string used was '*human reliability analysis AND industrial plant*'. Only articles in which the string '*human reliability analysis AND industrial plant*' was found in key words were analysed. In this case, only 46 documents were found from 1984 to 2017. It means that on average two articles per year have been published. Similarly, we conducted a deeper analysis applying a second filter. Search string used was '*human reliability analysis AND industrial plant AND cognitive model*". Firstly, considering the three criteria: (1) article title, (2) abstract and (3) key words), only six articles were found. While taking into account the criterion 'keywords', only four articles were found.

Among the documents found, we selected some of them. An interesting point of view is analysed by Massaiu [5]. In his paper, a new approach is proposed to address the weaknesses of the HRA method or in other words the lack of empirical support of HRA method. In detail, a test of the ability to identify regularities among environmental conditions (procedures), crew expertise (teamwork) and crew behaviours were investigated. Liu et al. [6] apply the cognitive reliability and error analysis method (CREAM) to calculate the failure probability of human cognitive activities for mine hoisting operation. Cheng and Hwang [7] outline the human error identification (HEI) techniques that currently exist to assess latent human errors on the chemical cylinder change task.

Literature review shows that the human reliability analysis is an issue of growing importance in the scientific world. But, there are some limits. The major limit of HRA is related to the uncertainty which does not allow full use of the reliability analysis [8]. Furthermore, several human reliability models follow a static approach, in which human errors are described as omission/commission errors [9]. Really, in our opinion, it is essential to consider the physical and cognitive environment depending on the time in which human errors develop. This consideration led us to the development of an integrated reliability model which takes into account the dynamic influence of operators. Thus, our study aims to propose a novel approach to investigate the relationship between performance shaping factors (PSFs) and operator performances. In HRA, PSFs encompassed the various factors that affect human performance. PSFs can increase or decrease the probability of human error [10, 11]. Our research aims to develop a multi-dimensional and structural model in order to apply it in different types of activities and in different disaster scenarios to avoid potential operational errors. The model takes into account technical and environmental factors that can influence the decisions and the actions of operators. The model combines the cognitive aspects of operational analysis, the

mathematical approach and the probabilistic quantification of the error. A real case study concerning the adoption of best practices for a petrochemical plant's control room during an emergency situation is presented. The rest of the chapter is organized as follows: in Section 2, experimental design is analysed; in Section 3, a detailed model in a real case study is presented; in this section the main results of the model are discussed and finally, in Section 4, conclusion and future development are summarized.

2. Experimental study: the model framework

The most influential models of operator behaviour [12, 13] assume three levels of behavioural errors: (1) automatic reactions demanding little or no attention; (2) attentive reactions when one knows how to handle in a certain, well-known situation; and (3) creative, analytical reactions when confronted with new, unknown problems without off-the-shelf solutions. The above classification is certainly helpful, but it is not sufficient to take into account the dynamism that characterized human-machine systems reliability. It is necessary to reduce human error and

Step	Procedure	Description	Observations
1	Preliminary analysis	**Preliminary Scenario Analysis**	It analyzes the reference scenario by choosing the activities of the decision maker
2	GTTs assessment	**Generic task assessment**	Each activity can be associated with a generic task that represents its
3	∀ GTT f (Weibull)	**Weibull function definition**	Weibull function parameters calculationfor each GTTs
4	PSFs choiche	**PSFs choiche**	It chooses the PSFS that best influence the decision or actions carried out by the decision maker
5	PSF comp	**Index PSF_{comp} determination**	It defines multipliers than the "SPAR-H method". It calculates the indexe PSF_{comp}
6	HEP cont	**Index HEP_{cont} determination**	Determination of the HEP_{cont} depending from the GTTs and PSFs
7	HEP cont *w/d*	**Index $HEP_{cont\ w/d}$ determination**	Determination of the HEP_{cont} depending from the GTTs and PSFs and considering the relation of the PSFs
8	post 8° hour of work	**HEPnom post 8° hour of work determination**	Determination of the HEP_{cont} depending from the GTTs and PSFs and considering the relation of the PSFs
9	HEP tot	**HEPtot determination** **Results Analysis and discussion**	It is replacing the HEP_{cont} with the HEP_{tot}

Figure 1. Methodological flowchart (author's elaboration).

hence to develop the capability to find (intuitively) solutions to unexpected problems. Our model is based on the above consideration. In detail, the model framework consists in nine different steps (as shown in **Figure 1**): Step 1—Preliminary analysis; Step 2—Generic tasks assessment (GTTs); Step 3—Definition of the Weibull distribution function; Step 4—Choice of performance shaping factors (PSFs); Step 5—Determination PSF_{comp}; Step 6—Determination HEP_{cont}; Step 7—Determination $HEP_{cont\ w/d}$; Step 8—Rating HEP_{nom} after the 8th hour of work and Step 9—Determination HEP_{tot}.

The model is applied in a real case study concerning the emergency management within a petrochemical company. In detail, the model aims to investigate the adoption of best practices for company's control room in order to ensure a consistent response under demanding circumstances.

3. Model development: description of a real case study

In the present section, a detailed analysis of each step is provided.

3.1. Step 1: preliminary analysis

The first step aims to define actions carried out by operators. At each operations is assigned a human error probability (HEP_{nom}), that represents the unreliability of the operator and it represents a critical point to perform a proper human reliability analysis [14]. Obviously, the probability of error is a function of the time. Therefore, increasing the working hours, it means that the likelihood of error increases. Scenario analysed concerns the management of a fire occurred in the petrochemical plant. The key element is about maintaining a state of readiness and having an awareness of the working environment. **Figure 2** shows the industrial plant under the study and the control room.

During a fire emergency, it is important to set common standards and to ensure that personnel are continuously trained, assessed and re-assessed against these summaries of best practice. All fire alarms are to be taken seriously. Evacuation of the facility is mandatory until the signal to re-enter has been given by appropriate personnel and the alarm bells have ceased ringing. **Figure 3** shows procedures that are to be followed any time a fire alarm sounds.

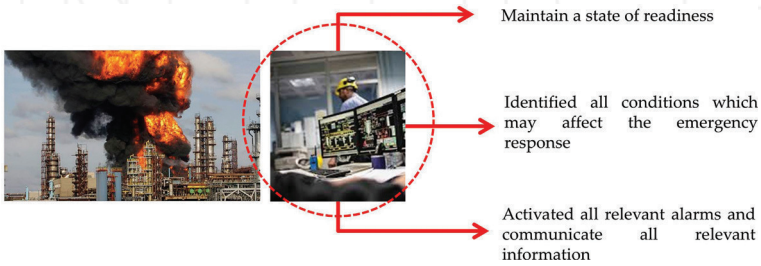

Figure 2. Scenario under study.

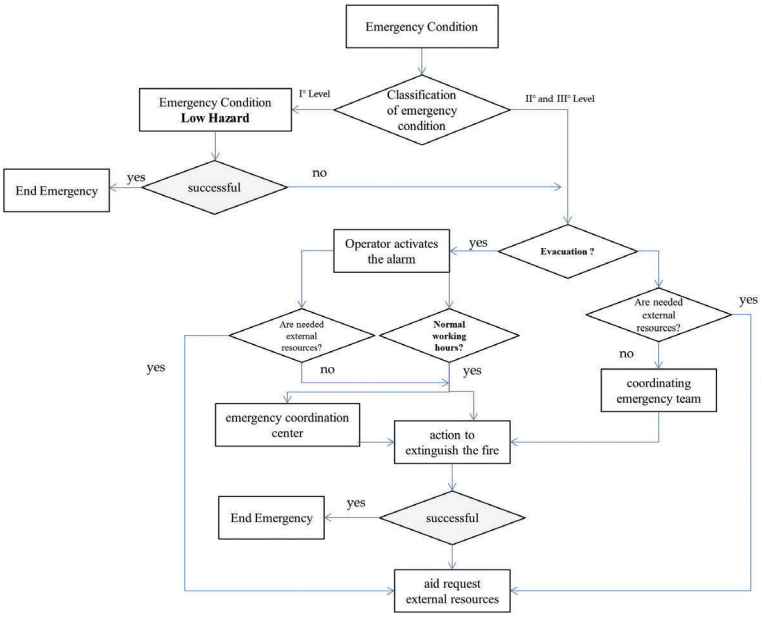

Figure 3. Fire emergency protocol.

In detail, two operators were engaged in the control room, but only one was in charge of handling emergency procedures during the fire. Operator was responsible to activate emergency procedure that includes (1) Total block of the furnaces; (2) Close all turbines; (3) Propane valve closing; (4) Locking the sequence handling propane; (5) Flow control valves closing and (6) Closure of the emergency procedure. The three main emergency conditions that may be occurred are (1) Low hazard occurring despite the emergency the decision maker has been monitoring the situation; (2) Moderate hazard to occur the decision maker emergency can take wrong decisions; and (3) High hazard, the decision maker can make a mistake with a good chance.

3.2. Step 2: generic tasks assessment (GTTs)

The present step aims to define generic tasks (GTTs) or a set of generic error probabilities for different type of tasks. The tasks were defined according the scientific literature [15]. Literature proposes for each task of human unreliability a set of values defined than the 5th percentile (for the first hour of work) and at the 95th percentile (for the eighth hour of work). The reliability is maximum at the first hour of work (t = 1) and minimum at the eighth work time (t = 8), as defined in Eq. (1):

$$k = 1 - HEP_{nom}(t) \forall t \in [1; 8] \tag{1}$$

k parameter represents the value of the operator's reliability.

In our case study, only three significant generic tasks (4, 7 and 8) were considered in order to approximate operator's activities in the control room, as shown in **Table 1**.

3.3. Step 3: definition of the Weibull distribution function

After defining GTTs, the probability of error associated with each GTTs were defined, according to Weibull probability distribution that best describes the probability of error. In detail, the probability of error is described by the index Human Error Probability (HEP), defined according to the Weibull distribution, as follows (Eq. (2)):

$$HEP_{\text{nom}} = 1 - e^{-\alpha t^{\beta}} \tag{2}$$

where the parameters α and β represent respectively the scale and the shape of the curves. The above formula assumes the minimum value of reliability during the first hour of work and a maximum value at the eighth hour of work. Consequently, the probability distribution of error Eq. (2) is adapted as follows (Eq. (3)):

$$\begin{cases} HEP_{\text{nom}}(t) = 1 - k * e^{-\alpha(1\ -t)^{\beta}}\ \forall\ t\ \in [0;\ 1] \\ HEP_{\text{nom}}(t) = 1 - k * e^{-\alpha(t\ -1)^{\beta}}\ \forall\ t\ \in]1;\ \infty[\end{cases} \tag{3}$$

The value of k is calculated according to the value that the curves takes for t = 1, while the parameter β = 1.5 is deducted according to the scientific literature of the human error assessment and reduction technique (HEART) model developed by Williams [16]. The value of α is determined by setting the value of the function for t = 8 for each GTTs. Starting from this function, it is possible to calculates the value of α through the inverse formulas, see Eq. (4):

$$HEP_{\text{nom}}(t) = 1 - k * e^{-\alpha(t-1)^{\beta}}\ \forall\ t\ \in]1; \infty[\tag{4}$$

No.	Generic task	Limitations of unreliability (%)	k (t = 1)	k (t = 8)	α	β
1	Totally unfamiliar	0.35–0.97	0.65	0.03	0.1661	1.5
2	System recovery	0.14–0.42	0.86	0.58	0.0213	1.5
3	Complex task requiring high level of comprehension and skill	0.12–0.28	0.88	0.72	0.0108	1.5
4	Fairly simple task performed rapidly or given scant attention	0.06–0.13	0.94	0.87	0.0042	1.5
5	Routin, highly practised	0.007–0,045	0.993	0.955	0.0021	1.5
6	Restoring a system by following the procedures of controls	0.008–0.007	0.992	0.993	−5.44E−05	1.5
7	Completely familiar, well designed, highly practised, routine task	0.00008–0.009	0.9999	0.991	0.00005	1.5
8	Respond correctly to system command even when there is an augmented or automated supervisory system	0.00000–0.0009	1	0.9991	4.86E−05	1.5

Table 1. Generic tasks.

α coefficient is represented by Eq. (5), as follows:

$$\alpha = \frac{-\ln\left[\frac{k(t=8)}{k(t=1)}\right]}{(t-1)^{\beta}} \tag{5}$$

Figure 4 shows the reliability performance according to Weibull distribution.

Table 2 shows the HEP_{nom} values for the case study, calculated for the three different generic tasks.

3.4. Step 4: choice of performance shaping factors (PSFs)

In the present step, PSFs were defined. PSFs allow to take into account all the environmental and behavioural factors that influence operator's cognitive behaviour. In particular, PSFs simulate different emergency scenarios. Analytically, PSFs increase the value of the error probability introducing external factors that could strain the 'decision maker'. PSFs and their values are deducted by standardized plant analysis risk-human reliability analysis (SPAR-H) method [17, 18]. **Table 3** shows the PSFs considered.

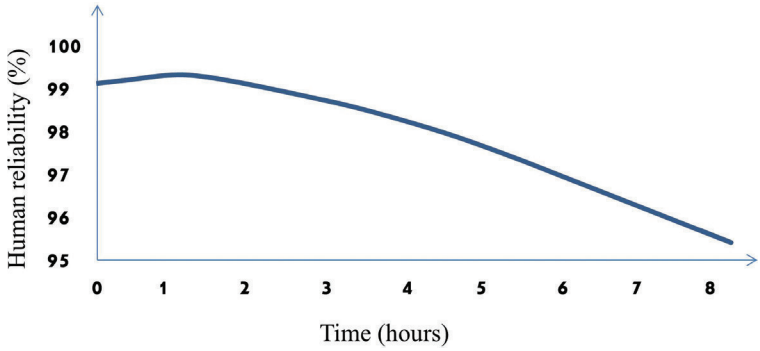

Figure 4. Reliability performance (t = 0–8).

	Generic task 4	Generic task 7	Generic task 8
HEP_{nom} (t = 1)	0.06	0.0001	0
HEP_{nom} (t = 2)	0.0639	0.0006	0.00005
HEP_{nom} (t = 3)	0.0710	0.0014	0.0001
HEP_{nom} (t = 4)	0.0802	0.0026	0.0003
HEP_{nom} (t = 5)	0.0909	0.0039	0.0004
HEP_{nom} (t = 6)	0.1029	0.0055	0.0005
HEP_{nom} (t = 7)	0.1160	0.0072	0.0007
HEP_{nom} (t = 8)	0.1300	0.0090	0.0009

Table 2. HEP_{nom}.

PSFs	PSF level	Multipliers
Available time	Inadequate time	*HEP* = 1
	Time available > 5× time required	0.1
	Time available > 50× time required	0.01
Stress/stressors	Extreme	5
	High	2
	Nominal	1
Complexity	High complex	5
	Moderately complex	2
	Nominal	1
	Good	0.5

Table 3. Performance shaping factors.

PSF	Low hazard	Moderate hazard	High hazard
Available time	0.01	0.1	1
Stress	1	2	5
Complexity	1	2	5

Table 4. PSFs for the three emergency conditions.

While **Table 4** shows PSFs, defined according the three emergency conditions (see Step 1).

3.5. Step 5: determination *PSFcomp*

Defined PSFs and its multipliers, it is important to evaluate the overall PSF index (PSF_{comp}), as follows (Eq. (6)):

$$PSF_{\text{comp}} = \prod_{i=1}^{n} PSFi \tag{6}$$

PSF_{comp} index summarizes the weight of each influencing factor with respect to the actions/decisions operator. **Table 5** describes the values for the PSF_{comp} according to three emergencies levels.

3.6. Step 6: determination HEP_{cont}

The last step consists to contextualize the probability error analysis, defined as follows (Eq. (7)):

	Low hazard	Moderate hazard	High hazard
$\boldsymbol{PSF_{comp} = (PSF_1 \times PSF_2 \times PSF_3)}$	0.01	0.4	25

Table 5. PSF_{comp}.

$$HEP_{\text{cont}} = \frac{HEP_{\text{nom}} * PSF_{\text{comp}}}{HEP_{\text{nom}} * (PSF_{\text{comp}} - 1) + 1} \tag{7}$$

The value of HEP_{cont} provides the level of probability of error of the decision maker, in function of influencing factors. The HEP_{cont} value increases with the increase of time. The HEP_{cont} is closely linked to two parameters. The first one is the time ($1 \leq t \leq 8$). The second one is the value of PSFs. In other words, HEP_{cont} value increases with the time and increases with the increase of the 'danger' of the emergency scenario assumed. **Table 6** shows HEP_{cont} considering generic task 4 and different emergency levels.

From a graphic point of view, **Figure 5** shows the trend of HEP_{cont} the worst case scenario.

Generic task	HEP_{nom} (t)		HEP_{cont}		
			Low hazard	Moderate hazard	High hazard
Fairly simple task performed rapidly or given attention	**t = 1**	0.0600	6.38E−04	2.49E−02	6.15E−01
	t = 2	0.0639	6.82E−04	2.66E−02	6.31E–01
	t = 3	0.0710	7.64E−04	2.97E−02	6.56E–01
	t = 4	0.0802	8.71E−04	3.37E−02	6.86E−01
	t = 5	0.0909	9.99E−04	3.85E−02	7.14E–01
	t = 6	0.1029	1.15E−03	4.39E02	7.41E−01
	t = 7	0.1160	1.31E−03	4.99E−02	7.66E−01
	t = 8	0.1300	1.49E03	5.64E−02	7.89E−01

Table 6. HEP_{cont}.

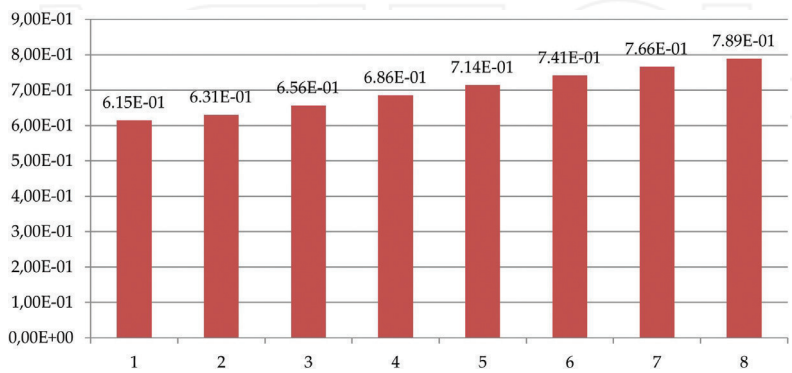

Figure 5. HEP_{cont} (high hazard).

3.7. Step 7: determination $HEP_{contw/d}$

As stated, PSFs have been modelled starting from PSFs proposed by the SPAR-H methodology. It is worthy to note that the values attributable to each PSFs are proportional to the severity of their impact. However, this index does not take into account, any interdependencies among PSFs chosen. To cover this gap, a correlation among PSFs, developed by Boring [19], analysing 82 incidental reports in the US nuclear plants have been taken into account for our case study, as shown in **Table 7**.

Thus, HEP index is given by Eq. (8):

$$HEP_{\text{Task1}}|\{PSF_i; PSF_j\} = HEP_{\text{Task1}}|PSF_i + (1 - k_{ij}) * HEP_{\text{Task1}}|PSF_j \tag{8}$$

where

- PSF_i means the value obtained by the calculation PSF_{comp} (with independent PSFs);
- PSF_j indicates the additional PSF, which is supposed to be dependent on the previous;

For diagnosis	Available time	Stress/ stressors	Complexity	Experience/ training	Procedures	Ergonomics/ HMI	Fitness for duty	Work processes
Available time	1							
Stress/stressors	0.67*	1						
Complexity	−0.02	0.15*	1					
Experience/ training	−0.03	0.06	0.21*	1				
Procedures	−0.07	0.01	0.25*	0.28*	1			
Ergonomics/HMI	0.01	0.06	−0.05	0.20*	0.09	1		
Fitness for duty	−0.03	0.03	−0.03	0.18*	0.09	0.44*	1	
Work processes	−0.06	0	0.24*	0.55*	0.36*	0.15*	0.10	1
For action								
Available time	1							
Stress/stressors	0.50*	1						
Complexity	0.38*	0.35*	1					
Experience/ training	0.31*	0.21*	0.32*	1				
Procedures	0.05	−0.01	0.12*	0.08*	1			
Ergonomics/HMI	0.10*	0.04	0.08*	0.08*	0.29*	1		
Fitness for duty	0.20*	0.29*	0.22*	0.17*	0.12*	0.27*	1	
Work processes	0	0.13*	0.16*	0.20*	0.35*	0.12*	0.15*	1

Asterisk (*) indicated significant correlations with p value <0.05.

Table 7. PSFs correlation developed by Boring.

- k_{ij} is the value of the parameter representative of the inter-dependent between two (or more) PSFs.

To quantify the influence of PSFs, the HEPcont w/d is calculated through Eq. (9):

$$HEP_{\text{cont w/d}} = HEP_{\text{nom}} * [PSF_{\text{i}} + (1 - k_{ij}) * PSF_j] \tag{9}$$

Referring to our case study, HEPcont w/d is given by Eq. (10):

$$HEP_{contw/d}(t = 4) \vee \{PSF_i; PSF_j\} = \frac{0.0802 * [25 + (1 - k_{ij}) * 3]}{0.0802 * [25 + (1 - k_{ij}) * 3 - 1] + 1} \tag{10}$$

The attribution of the k_{ij} value can be assumed, considering the value of the correlation coefficients, or even based on a combination of expert judgment and data extrapolated from previous observations. The correlation between experience/training and the others PSFs is assumed moderate. In particular, a decision tree (**Figure 6**) is defined in order to choose the best value for k_{ij}. The final result is $k_{ij} = 0.6$.

Then, the value of HEPcont w/d is given by Eq. (11):

$$HEP_{cont\frac{w}{d}}(t = 4) \vee \{PSF_i; PSF_j\} = \frac{0.0802 * [25 + (1 - 0.6) * 3]}{0.0802 * [25 + (1 - 0.6) * 3 - 1] + 1} = 0.695 \tag{11}$$

Table 8 shows the new values for PSFs and **Table 9** shows the values of HEPcontw/d for the fourth generic task.

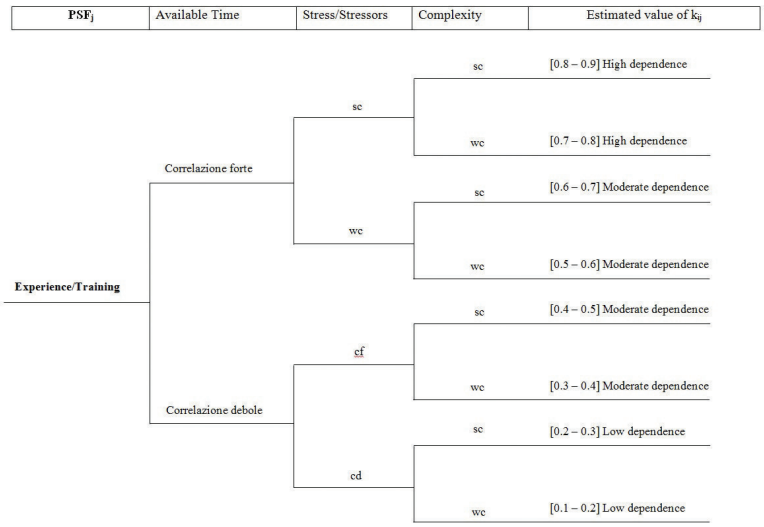

Figure 6. Decision tree.

PSF	Low hazard	Moderate hazard	High hazard
Available time	0.01	0.1	1
Stress	1	2	5
Complexity	1	2	5
Experience/training	0.5	1	3

Table 8. New PSFs value.

Generic task	*HEP*nom (*t*)	*HEP*cont w/d			
		Low hazard		Moderate hazard	High hazard
Fairly simple task performed rapidly or given attention	$t = 1$	0.0600	1.32E−02	4.86E−02	6.26E−01
	$t = 2$	0.0639	1.41E−02	5.18E−02	6.42E−01
	$t = 3$	0.0710	1.58E−02	5.77E−02	6.67E−01
	$t = 4$	0.0802	1.80E−02	6.52E−02	6.95E−01
	$t = 5$	0.0909	2.06E−02	7.41E−02	7.24E−01
	$t = 6$	0.1029	2.35E−02	8.41E−02	7.50E−01
	$t = 7$	0.1160	2.68E−02	9.50E−02	7.75E−01
	$t = 8$	0.1300	3.04E−02	1.07E−01	7.97E−01

Table 9. $HEP_{\text{contw/d}}$.

3.8. Step 8: rating HEP_{nom} after the 8th hour of work

In this step, the analysis was extended over the 8 hours of work. **Figure 7** shows the reliability comprised between 0 and 16 hours of work.

For analysis after 8 hours, the only thing that changes is the k factor. For the analysis after 8 hours, we used the factor k ($t = 8$), while for the first 8 hours, we considered the factor k ($t = 1$). The remaining steps are unchanged. The use of a new factor k (t = 8) defines a raising of operator fatigue. After the 8th hour of work, there is a step on the reliability of the operator. **Table 10** represents the HEP_{cont} values for the first 16 hours of work.

3.9. Step 9: determination HEP_{tot}: discussion and results

During emergency situations, the work shifts may be longer than 8 hours of work, so the operators are subject to high stress loads. For this reason, we considered the variation of PSFs with the passage of time. To calibrate the uncertainty due to the change of time using the success likelihood index method (SLIM) [20], the worse conditions of the work of the operators, through the use of the SLIM methodology, is analysed. The operator fatigue is the first element

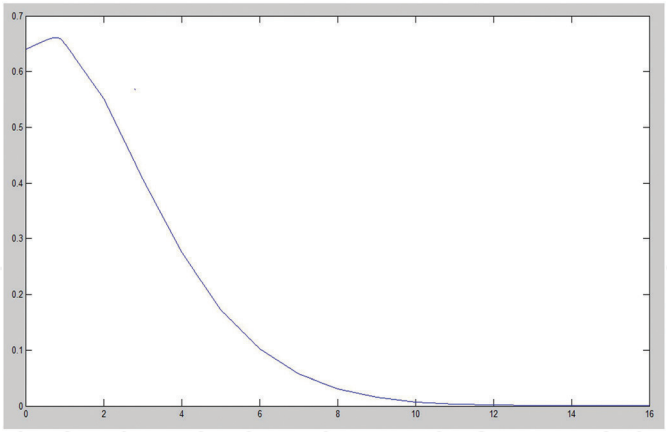

Figure 7. Reliability performance (t = 0–16).

Generic task	HEP_{nom} (t)		HEP_{cont}		
			Low hazard	Moderate hazard	High hazard
Fairly simple task performed rapidly or given attention	t = 1	0.0600	6.38E−04	2.49E−02	6.15E−01
	t = 2	0.0639	6.82E−04	2.66E−02	6.31E−01
	t = 3	0.0710	7.64E−04	2.97E−02	6.56E−01
	t = 4	0.0802	8.71E−04	3.37E−02	6.86E−01
	t = 5	0.0909	9.99E−04	3.85E−02	7.14E−01
	t = 6	0.1029	1.15E−03	4.39E−02	7.41E−01
	t = 7	0.1160	1.31E−03	4.99E−02	7.66E−01
	t = 8	0.1300	1.49E−03	5.64E−02	7.89E−01
	t = 9	0.2085	2.63E−03	9.53E−02	8.68E−01
	t = 10	0.2228	2.86E−03	1.03E−01	8.78E−01
	t = 11	0.2377	3.11E−03	1.11E−01	8.86E−01
	t = 12	0.2530	3.38E−03	1.19E−01	8.94E−01
	t = 13	0.2687	3.66E−03	1.28E−01	9.02E−01
	t = 14	0.2847	3.96E−03	1.37E−01	9.09E−01
	t = 15	0.3010	4.29E−03	1.47E−01	9.15E−01
	t = 16	0.3175	4.63E−03	1.57E−01	9.21E−01

Table 10. HEP_{cont} (t = 1–16).

to consider. Fatigue is quantified using the standard sleepiness scale (SSS) [21]. The scale is represented in **Table 11**. The result is a score related to drowsiness.

The next step is to define the incidence of each PSFs relative to fatigue (W). The values are reported in percentage scale. The sum of the weights must give 100%. At this point, it calculates the modified SLI index using Eq. (12):

$$SLI_{\mathrm{j}} = \sum\nolimits_{\mathrm{i}} R_{\mathrm{ij}} W_{\mathrm{i}} \tag{12}$$

Table 12 shows the SLI index calculation for generic task 4, considering the presented PSFs.

The SLI index must be transformed into *HEP*. It is assumed that between SLI and *HEP* exist the relation as follows (Eq. (13)):

$$\log(P) = aSLI + b \tag{13}$$

where P represents the *HEP* value and a and b are constants. At this point it is necessary to calibrate the value of the constants to obtain the value of *HEP*. To do this, a comparative comparison between the values of SLI is carried out. In the previous step, *HEP* index values for 1 < t < 16 have been obtained. In this step, the extreme values of that range are used, as follows:

- $HEP_{\min}$ = 6,38E−04 ➔ t = 1 (low hazard) SLI = 1
- $HEP_{\max}$ = 9,21E−01 ➔ t = 16 (high hazard) SLI = 7

Degree of sleepiness	Scale rating (*R*)
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7

Table 11. Stanford sleepiness scale.

Weighting (W_k)	PSFs	Rating (R_k)	SLI = W·R
0.2	Available time	4	0.8
0.5	Stress	4	2
0.3	Complexity	4	1.2
Fairly simple task performed rapidly or given attention (t = 10) ∑ 4.			

Table 12. SLI for the GTT 4.

Using the inverse formula, the final equation that calculates the *HEP* index for each task is obtained. The formula is defined according to Eq. (14):

$$log(HEP) = aSLI + b \tag{14}$$

Here is a mathematical formulation that allows to define a and b:

$$\begin{cases} log_{10}(0.000638) = aSLI + b \\ log_{10}(0.921) = aSLI + b \end{cases} \begin{cases} -3.19 = a + b \\ -0.035 = a * 7 + b \end{cases} \begin{cases} b = -3.19 - a \\ 7a = -0.035 - b \end{cases}$$
$$\begin{cases} b = -3.19 - a \\ 7a = -0.035 + 3.19 + a \end{cases} \begin{cases} b = -3.19 - a \\ 6a = -0.035 + 3,19 \end{cases} \begin{cases} a = 0.52 \\ b = -3.71 \end{cases} \tag{15}$$

Having obtained the values a and b, the formulation for the final calculation of the index *HEP* becomes:

$$\begin{aligned} &log(HEP) = 0.52\text{SLI} - 3.71, \ \text{SLI} \ = \ 4 \\ &log(HEP) = -1.63 \rightarrow HEP = 0.023 \end{aligned} \tag{16}$$

It is possible to note that the value of *HEP* is lower compared to the previous *HEP* calculated for t ranging from 1 to 16. In order to obtain a more accurate model a calibration is carried out. **Figure 8** compares the HEP_{nom} curve with the calibrated *HEP* curve.

HEP_{tot} value is calculated by adding up the values HEP_{nom} that the *HEP* values calculated with SLI calibration (ΔHEP). HEP_{tot} value replaces the model EHEA the HEP_{nom} value, as shown in **Table 13**.

Figure 9 shows the graph of the HEP_{tot}. It assumes to model the increase of the HEP_{nom} nominal value, to which are summed the corresponding ΔHEP values, starting from $t = 8$.

The main result of the model shows how the human reliability depends on the time and how it is important to consider operator performance beyond the canonical 8 hours.

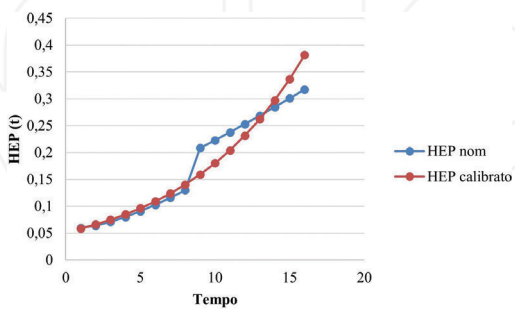

Figure 8. HEP_{nom}—calibrated *HEP* (SLI).

EHEA			SLIM		
*HEP*nom	Log_{10} (*HEP* nom)	*ΔHEP*	Log_{10} (*HEP* nom)	SLI	*HEP*tot
0.060	−1.221	0.0585	−1.232	1	0.118
0.063	−1.194	0.0585	−1.232	1	0.122
0.071	−1.148	0.0585	−1.232	1	0.129
0.080	−1.095	0.0663	−1.178	2	0.146
0.090	−1.041	0.0663	−1.178	2	0.157
0.102	−0.987	0.0663	−1.178	2	0.169
0.116	−0.935	0.0751	−1.124	3	0.191
0.130	−0.886	0.0751	−1.124	3	0.205
0.208	−0.680	0.0751	−1.124	3	0.283
0.222	−0.652	0.0851	−1.069	4	0.307
0.237	−0.623	0.0851	−1.069	4	0.322
0.253	−0.596	0.0964	−1.015	5	0.349
0.268	−0.570	0.0964	−1.015	5	0.365
0.284	−0.545	0.1093	−0.961	6	0.394
0.301	−0.521	0.1093	−0.961	6	0.410
0.317	−0.498	0.1239	−0.906	7	0.441

Table 13. HEP_{tot}.

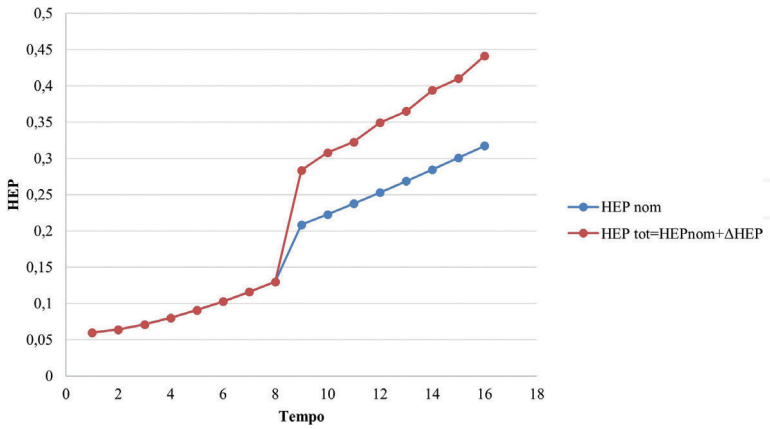

Figure 9. HEP_{nom}—HEP_{tot}.

4. Conclusion

In general, the modelling approaches used in HRA are focused to describe sequential low-level tasks, which are not the main source of systemic errors. On the contrary, we believe that it is important to analyse in deeper human behaviour that causes errors in order to develop managerial practices that could be applied to reduce the failures that occur at the interface of human behaviour and technology. Thus, the aim of this work was to develop an innovative methodology for human reliability analysis in emergency scenarios. A hybrid model that integrates the advantages of the following methodologies: human error assessment and reduction technique (HEART), standardized plant analysis risk-human reliability analysis (SPAR-H) and Success Likelihood Index Method (SLIM) has been proposed. The key point that we have been trying to convey in this research is the analysis of all environmental and behavioural factors that influence human reliability. Results obtained from the analysis of a real case study give an empirical contribution and a theoretical contribution referring to the framework used to detect human error in risk and reliability analysis. Furthermore, the study could be a useful perspective for the entire academic community to make the community fully aware of new assumptions in human reliability analysis.

Acknowledgements

This research represents a result of research activity carried out with the financial support of MiuR, namely PRIN 2012 "DIEM-SSP, Disasters and Emergencies Management for Safety and Security in industrial Plants".

Author details

Domenico Falcone[1], Fabio De Felice[1], Antonella Petrillo[2]* and Alessandro Silvestri[1]

*Address all correspondence to: antonella.petrillo@uniparthenope.it

1 University of Cassino and Southern Lazio Department of Civil and Mechanical Engineering, Cassino (FR), Italy

2 University of Napoli "Parthenope" Centro Direzionale, Napoli (NA), Italy

References

[1] Dhillon BS. Human Reliability, Error, and Human Factors in Power Generation. New York: Springer; 2014

[2] Jung, Won Dea; Kang, Dae Il; Kim, Jae Whan, 2005. Development of A Standard Method for Human Reliability Analysis of Nuclear Power Plants: Report of Korea Atomic Energy Research Institute, code KAERI/TR–2961/2005; (**37**)50. Republic of Korea

[3] Hollnagel E. Cognitive Reliability and Error Analysis Method (CREAM). Amsterdam, Netherlands: Elsevier; 1998

[4] De Felice F, Petrillo A, Zomparelli F. A hybrid model for human error probability analysis. IFAC-PapersOnLine. 2016;**49**(12):1673–1678

[5] Massaiu, S., 2012. A model-based approach for the collection of Human Reliability data. Advances in Safety, Reliability and Risk Management - Proceedings of the European Safety and Reliability Conference, ESREL 2011, Troyes France 18–22 September 2011, pp. 595–603

[6] Liu, Z., Chen, L., Ren, D., 2009. Prediction analysis of human error probability for mine hoisting systems. IE and EM 2009 - Proceedings 2009 IEEE 16th International Conference on Industrial Engineering and Engineering Management, Beijing, China 21 Oct – 23 Oct 2009, pp. 1184–1188.

[7] Cheng C-M, Hwang S-L. Applications of integrated human error identification techniques on the chemical cylinder change task. Applied Ergonomics. 2015;**47**:274–284

[8] De Felice F, Falcone D, Petrillo A, Bruzzone A, Longo F. A simulation model of human decision making in emergency conditions. 28th European Modeling and Simulation Symposium, EMSS 2016; 2016: pp. 148–154

[9] Thiruvengadachari S, Khasawneh MT, Bowling SR, Jiang X. Human-machine systems reliability: In: Current Status and Research Perspective. IIE Annual Conference and Exposition; 2005

[10] Park J, Lee D, Jung W, Kim J. An experimental investigation on relationship between PSFs and operator performances in the digital main control room. Annals of Nuclear Energy. 2017;**101**:58–68

[11] Kim JW, Jung WD. A taxonomy of performance influencing factors for human reliability analysis of emergency tasks. Journal of Loss Prevention in the Process Industries. 2003;**16**(6):479–495

[12] Rasmussen J. Outlines of a hybrid model of the process operator. In: Sheridan TB, Johannsen G, editors. Monitoring Behaviour and Supervisory Control. New York: Plenum Press; 1976

[13] van der Schaaf TW, Kanse L. Biases in incident reporting databases: An empirical study in the chemical process industry. Safety Science. 2004;**42**:57–67

[14] Di Pasquale V, Miranda S, Iannone R, Riemma S. A simulator for human error probability analysis (SHERPA). Reliability Engineering & System Safety. 2015;**139**:17–32

[15] Thommesen J, Andersen Henning B. Human error probabilities (*HEP*s) for generic tasks and performance shaping factors (PSFs) selected for railway operations. DTU Management Engineering Report No. 3. Department of Management Engineering, Technical University of Denmark; Denmark: 2012

[16] Williams, J.C. (1985) HEART – A proposed method for achieving high reliability in process operation by means of human factors engineering technology in Proceedings of a Symposium on the Achievement of Reliability in Operating Plant, Safety and Reliability Society (SaRS). NEC, Birmingham.

[17] Gertman, D., Blackman, H., Marble, J., Byers, J., Smith, C., 2004. The SPAR-H Human Reliability Analysis Method. Washington, DC

[18] U.S. NRC. The Spar-H method. NUREG/CR-6883; 2005

[19] Boring RL. Dynamic human reliability analysis: Benefits and challenges of simulating human performance. Risk, Reliability and Societal Safety. 2007;**2:**1043–1049

[20] Embrey DE, Humphreys PC, Rosa EA, Kirwan B, Rea K. SLIM-MAUD: An approach to assessing human error probabilities using structured expert judgement. NUREG/CR-3518. Washington, DC: U.S. Nuclear Regulatory Commission; 1984

[21] Roelen ALC, Wever R, Hale AR, Goossens LHJ, Cooke RM, Lopuhaa R, Simons M, Valk PJL. Causal modelling of air safety. Demonstration model. NLR-CR-2002-662. Amsterdam: NLR; 2002

INTECH

INTECH