Exploring Industry 4.0 technologies to improve manufacturing enterprise safety management: A TOPSIS-based decision support system and real case study

Author Antonio Forcina, Parthenope University, Italy

Seminar on Technology Management
Professor Lee, Chen-Wen
Student Tse-Wen Hong 洪哲文
October 08, 2004

Paper PDF

Table&Figure

Abstract

This article discusses how Industry 4.0 is transforming manufacturing through digitalization, focusing on safety management. Key points include:

1. *A systematic review identified the most impactful Industry 4.0 technologies for safety management.*
2. *A Decision Support System (DSS) was created, using a flowchart and TOPSIS tool to select optimal technologies.*
3. *Cloud technology was found to be the most impactful for safety, followed by IoT.*
4. *The methodology was validated in a real-world food company case study.*

1. Introduction

Industry 4.0 transforms factories into hyperconnected ecosystems through technologies like AI, IoT, cloud computing, and augmented reality. These disruptive technologies bring new opportunities for improving efficiency and safety but also pose risks such as chemical hazards and information overload. Safety management must adapt to these changes, integrating organizational structures and policies to prevent accidents.

- *Industry 4.0 technologies enhance safety through real-time communication, IoT sensors, and data analytics.*
- *Augmented reality and robots improve operator safety and reduce risks.*
- *Safety management must incorporate both traditional methods and new technologies to create a safer environment.*
- *A systematic review identifies critical technologies, supported by a decision support system for optimizing safety management, validated through a real case study.*

2. Method

Outlines a method for identifying the most suitable Industry 4.0 technologies for safety management using a Systematic Literature Review (SLR) and a Decision Support System (DSS). Key steps include:

1. ***SLR:*** *The SLR was conducted using Scopus database, focusing on Industry 4.0 technologies like IoT, cloud computing, and augmented reality. The SLR process involved identifying key themes and technologies relevant to safety management.*
2. ***DSS Design:*** *The DSS combines a flowchart for decision-making and a TOPSIS-based tool to rank and quantify the effectiveness of different technologies. The DSS helps simplify the decision-making process by guiding users through a structured pathway.*
3. ***Expert Validation:*** *Semi-structured interviews with 12 industry experts were used to validate the SLR findings and refine the DSS design.*
4. ***OPSIS Tool:*** *TOPSIS was used to evaluate and rank technologies by calculating the ideal and least ideal solutions for a given safety scenario.*

Key findings include the value of combining both SLR and DSS approaches to effectively integrate Industry 4.0 technologies into safety management.

3.1. SLR results

The SLR analyzed 447 documents, narrowing them to 65 relevant studies (29 articles, 36 conference papers).

Table 1
Systematic Literature Review (SLR) procedure.

Step 1 *Formulation of the research question*	**Research Question** Which are the most suitable Industry 4.0 technologies for safety management?
Step 2 and **Step 3** *Locating, selecting, and evaluating articles*	**Electronic databases**- Scopus (scopus.com) **Inclusion Criteria** - Papers that developed or investigated safety management tasks in Industry 4.0 context - Peer reviewed journal, reviews, and international conferences - Paper title **Search Strings** - "industry 4.0" AND "safety" - "safety" AND "…" *(each industry 4.0 technology)* **Exclusion Criteria** - Papers in languages that differ from "*English*" - First selection after reading the paper title- Second selection after reading the paper abstract (and full text)
Step 4 *Assessment of findings*	**Analysis phase** - Iterative compilation of the database
Step 5 *Reporting of findings*	**Synthesis phase** - Emerged aspects and results are extraction from database and discussion

3.1. SLR results

The most applied technologies for safety management were IoT, Cloud Computing, and Augmented Reality, present in over 85% of the studies.

Table 2
Relative number of papers for considered research strings and research phase.

Research strings	After reading paper's title n	After reading paper's Abstract n	After reading full paper n
"Industry 4.0" AND "Safety"	34	19	5
"Internet of Things" AND "Safety"	143	36	25
"Big Data" AND "Safety"	17	4	2
"Cloud" AND "Safety"	159	35	15
"Horizontal integration" AND "Vertical integration" AND "Safety"	0	0	0
"Advanced Manufacturing" AND "Safety"	2	2	0
"Additive Manufacturing" AND "Safety"	7	3	1
"Augmented Reality" AND "Safety"	55	22	15
"Autonomous robots" AND "Safety"	3	1	1
"Simulation" AND "Safety"	4	1	1
"Cyber Security" AND "Safety"	32	14	2
Total	449	135	67
Total (without duplicates)	**447**	**133**	**65**

3.1. SLR results

Research interest has grown since 2018, with China contributing the most papers (22), followed by the USA (13).

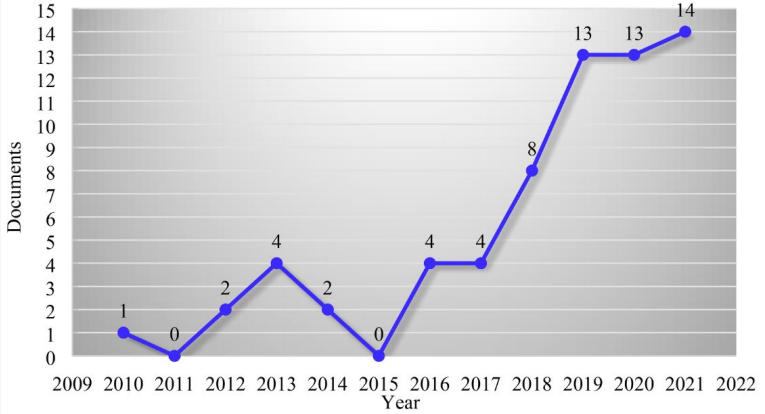

Fig. 2. Temporal distribution of documents.

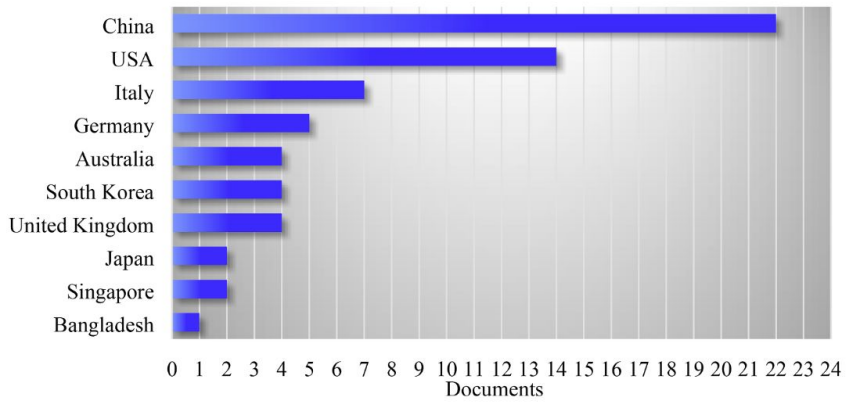

Fig. 3. Countries of origin of the first author of the selected papers.

S04.4- 3.1. SLR results

Case studies made up 52.2% of the selected documents, primarily validating theoretical models through empirical applications. The most frequent publications were in "Advances in Intelligent Systems and Computing" and "Automation in Construction."

Table 3
Sources of selected documents.

Journal	n	%
Advances In Intelligent Systems And Computing	4	6.15%
Automation In Construction	4	6.15%
Safety Science	2	3.08%
Sensors Switzerland	2	3.08%
OTHERS	53	81.54%

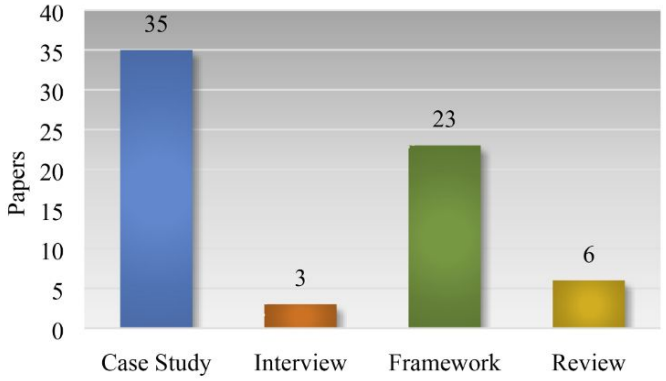

Fig. 4. Distribution based on research typology.

3.1.2. Content analysis

The article identifies four key Industry 4.0 technologies in safety management: IoT for monitoring in underground construction, Cloud for real-time remote accessibility, Big Data for decision-making and accident prevention, and Augmented Reality for situational awareness and operator performance in hazardous environments.

Table 4
Relative number of papers for considered research strings and research phase.

Technology	Devices	Areas of application
Internet of Things	Sensors for hazard detection	Underground construction site, mine
	Monitoring sensors	Construction site
	Wearable sensors	Manufacturing industry
	Vehicle sensors	Electric infrastructure
		Transport vehicle, highway
		Port, maritime sector
Cloud	Monitoring systems	Underground construction site, mine
	Safety Management systems	Construction site
	Data transmission systems	Manufacturing industry
		Electric infrastructure
		Port, maritime sector
Augmented Reality	Wearable displays	Manufacturing industry
	Wearable sensors	Transport vehicles, highways
	Communication systems	Port, maritime sector
Big Data analytics	Safety Management systems	Underground construction site, mine
	Data analysis systems	Manufacturing industry
		Electric infrastructure

3.2. DSS results

*The **DSS design** evaluated **four key Industry 4.0 technologies** for safety management: IoT, Cloud, Augmented Reality (AR), and Big Data.*
***Five criteria were used to assess these technologies:** multi-sector applicability, ease of installation, need for specialized personnel, scope of action, and tangible results.*

Table 5
TOPSIS-based matrix of the alternatives.

		Alternatives			
		A_1	A_2	A_3	A_4
Criteria		Internet of Things	Cloud	Augmented Reality	Big Data analytics
C_1	*Multi-sector applicability*	–	–	–	–
C_2	*Ease of installation*	–	–	–	–
C_3	*Need for specialized personnel*	–	–	–	–
C_4	*Scope of action*	–	–	–	–
C_5	*Tangible results*	–	–	–	–

3.2. DSS results

A team of xperts reviewed and validated the framework for content and applicability. Table 6 details the employers involved. Over the last five years, the company has gradually adopted Industry 4.0 technologies across various areas, including intelligent manufacturing, food safety, quality control, traceability systems, training, marketing, and customized orders in production activities.

Table 6

Study participants and experience.

Role	Company experience (years)
Director	*11*
Site engineer	*5*
Project manager	*6*
Consultant	*5*
Site engineer	*8*
Site engineer	*7*
Safety engineer	*9*
Safety team leader	*9*
Safety engineer	*5*
Technical engineer	*6*
Head of Engineering	*6*
Safety engineer	*7*

3.2. DSS results

The TOPSIS model was applied to rank these technologies based on their scores across these criteria.
IoT, Cloud, AR, and Big Data were identified as the most impactful technologies for safety management.

The flowchart in the DSS highlights barriers and enablers for implementing these technologies in companies.

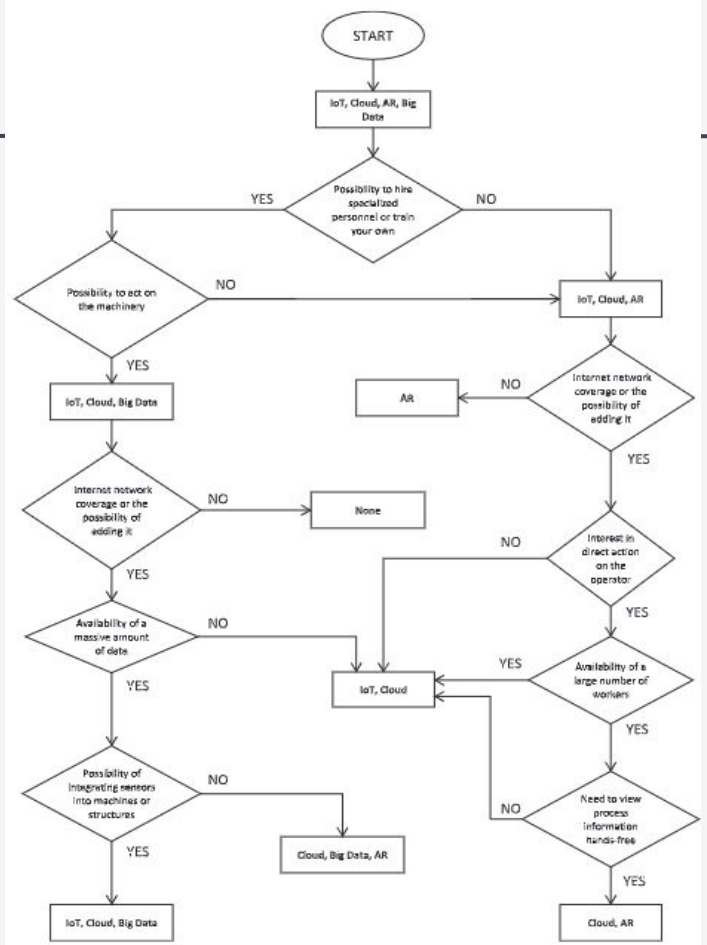

Fig. 5. The flowchart step of the designed DSS, representing the logical architecture of the decision-making pathway.

3.3. DSS application: Case study

This case study focuses on the application of a Decision Support System (DSS) to enhance safety management in a large food processing company in Italy.
The company has implemented Industry 4.0 technologies such as Big Data, IoT, and Cloud computing to improve food processing, distribution, and worker safety.
These technologies enable real-time monitoring, predictive analysis, and remote access to data.
The DSS flowchart and TOPSIS model were used to assess technologies based on criteria like multi-sector applicability, ease of installation, and tangible results.

Table 7
Case study decision matrix.

		Alternatives															
		A1				A2				A3				A4			
Criteria		Internet of Things				Cloud				Augmented Reality				Big Data analytics			
		Mean	Mode	Sigma	Rank	Mean	Mode	Sigma	Rank	Mean	Mode	Sigma	Rank	Mean	Mode	Sigma	Rank
C1	Multi-sector applicability	4.67	5.00	0.89	**5**	4.67	5.00	0.89	**5**	4.25	4.00	0.87	**4**	3.33	4.00	0.78	**3**
C2	Ease of installation	3.01	3.08	0.95	**3**	3.52	4.00	0.69	**4**	3.82	4.00	0.83	**4**	3.55	3.29	0.89	**4**
C3	Need for specialized personnel	3.35	3.00	0.98	**3**	3.37	3.21	0.88	**3**	2.44	2.13	0.99	**2**	4.17	4.04	0.94	**4**
C4	Scope of action	3.51	3.04	1.08	**3**	3.43	3.00	0.66	**3**	3.63	3.79	0.64	**4**	1.76	2.00	0.76	**2**
C5	Tangible results	4.64	5.00	0.48	**5**	4.54	4.75	0.50	**5**	4.54	5.00	0.89	**5**	4.06	4.00	0.53	**4**

3.3. DSS application: Case study

Cloud was identified as the most impactful technology for safety management, followed by IoT, Augmented Reality, and Big Data.

While Cloud and IoT were already implemented, Augmented Reality was suggested for future consideration to further enhance safety.

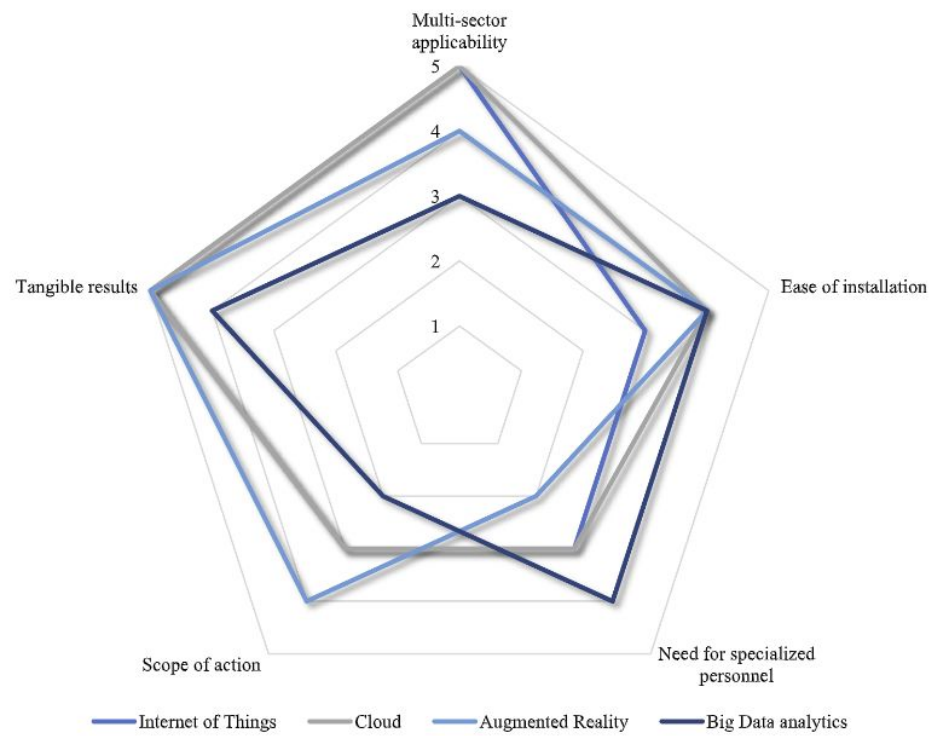

Fig. 7. Technologies evaluation in a 5-point scores scale.

3.3. DSS application: Case study

- *The company uses IoT, Big Data, and Cloud for safety monitoring and predictive analysis.*
- *DSS ranked Cloud as the most effective technology for safety, followed by IoT, AR, and Big Data.*
- *The DSS helps prioritize technologies when simultaneous implementation isn't feasible.*
- *The integration of AR was proposed for future use to complement existing IoT and Cloud technologies.*

Table 8
Calculation of the separation measures from the positive ideal solution and the negative ideal solution.

	d_w	d_b
A1	0.074722684	0.090710951
A2	0.073972614	0.091323646
A3	0.107825752	0.108464111
A4	0.117048811	0.105144791

Table 9
The ranking of the A_i alternatives.

	s_w
A1	0.548322298
A2	0.552484648
A3	0.501475701
A4	0.473212505

Table 10
The final ranking of the Industry 4.0 technologies.

Technology	Ranking
Cloud	1
Internet of Things	2
Augmented Reality	3
Big Data analytics	4

4. Discussion

- *The research confirms that only some Industry 4.0 technologies, like IoT, Big Data, AR, and Cloud, bring real benefits to safety management, often as a secondary advantage to improving production.*

- *However, their application can be limited by the specific production system's constraints. Effective implementation requires collaboration between experts and technicians with relevant skills.*

- *Decision Support Systems (DSS) help navigate the complex decision-making process by considering various constraints, making the DSS applicable across different industries.*

5. Conclusion

- *The study examined Industry 4.0 technologies and their potential impact on safety management.*
- *A systematic review of 65 papers (2010-2021) identified key technologies, including Cloud, IoT, Augmented Reality, and Big Data.*
- *A Decision Support System (DSS) was developed to select the best safety technology for specific enterprises and tested in a food company.*
- *The DSS determined Cloud as the most impactful technology for safety management, followed by IoT, AR, and Big Data.*
- *Future development will focus on integrating AI to enhance the DSS's usability without expert intervention.*

Thank **you!**

| Paper [PDF] [HTML] | [Table & Figure] |