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Toward a Unified Framework for RFID Adoption in Healthcare Sector

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ABSTRACT

Healthcare organisations are attempting to aggressively use internet of things (IoT) technologies in order to improve the quality of services provided to patients and to the workforce. Radio frequency identification (RFID) is considered a promising IoT technology that offers many benefits to the healthcare industry. When management decides to adopt RFID, this decision has strategic importance for the healthcare organisation, as it affects the whole organisation and leads to significant changes through the potential to improve operational processes by enabling real-time traceability, monitoring and identification. In this paper, an extensive, comprehensive study of the factors and attributes that contribute to the decision to adopt RFID is conducted. The study presents a proposed framework for RFID use that considers three theories: the technology–organisation–environment framework, diffusion of innovation, and the human, organisation and technology fit.

Key words: IoT, RFID, framework, healthcare

1. INTRODUCTION

The healthcare sector is one of the biggest industries currently facing the challenge of transforming digitally and reducing operational costs to achieve efficiency and effectiveness. Management plays a prominent role in making decisions about digital transformation and leading this innovation, which is based on emerging technologies in healthcare that are intended to improve the services provided to staff and the care given to patients. In recent years, healthcare leaders have begun adopting internet of things (IoT) technologies as a primary agent in their future strategies. According to Grand View Research Inc., the global IoT healthcare industry is expected to reach a value of approximately $534.3 billion by 2025. This rise in the adoption of IoT solutions reflects the advantages of using these effective technologies in the healthcare sector. The main benefits of applying IoT in the healthcare industry include the ability to use patient telemonitoring [1, 2], reduce medical errors [3, 4], and implement medical asset tracking [5].

Proposed in late 1990, the IoT concept refers to the interconnection of physical devices via wireless or wired communication technologies, such as Wi-Fi, ZigBee, Bluetooth Example of a figure caption and radio frequency identification (RFID), to name a few [6–8]. These technologies, when connected to the internet, establish an extended network for information collection and processing using devices. RFID, in particular, is considered one of the key sensing technologies in IoT and has received considerable attention in recent years for the advantages it offers within the healthcare context. Invented in 1948 during World War II, RFID is defined as “a wireless automatic identification and data capture (AIDC) technology” [9]. It has continued to grow and develop through theoretical exploration and research, and by 2000, the use and implementation of RFID had grown substantially. The technology has garnered significant interest in the fields of education and commerce. As shown in Fig. 1, RFID has three major components: an RFID tag, an RFID reader and a central server to process the information collected from the tags [10, 11]. The RFID tags are attached to the object and contain memory that stores a unique number, whereas the RFID reader exchanges the information with the RFID tag via radio waves [12]. Generally, the operation process of RFID is similar to that of a barcode, as it has the ability to store a unique number for identifying objects on a microchip [13]. However, RFID differs from barcodes in that it offers the ability to track objects and store more data [14]. RFID has three functions: monitoring, supervising and tracking. The monitoring function observes the specific conditions of the system, and usually, a warning is sent when abnormal actions are detected. The supervising function observes the activities of any type of object without knowledge of whether that object is a human, an application or a device. The tracking function gathers sequence data on the location of the object whilst moving [15]. These functions contribute to expanding the use

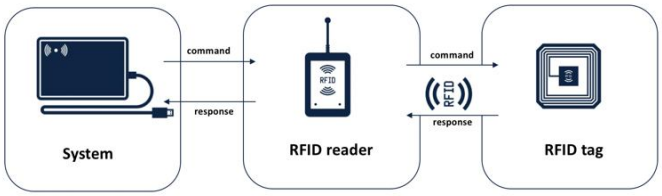

Figure 1. RFID main components

Within the healthcare sector, RFID is considered a useful information tool that offers potential benefits for healthcare services, such as improving the safety of patients' medication, facilitating contact between patients and medical staff [16], tracking medical equipment stock and supervising the workforce [17]. Despite the benefits of using RFID in the healthcare sector and the advancements in RFID technology in terms of having reliable tags, a lower price and high performance, the adoption of RFID in healthcare organisations remains slow for the following reasons:

- Limited empirical research that demonstrates the benefits of RFID in the healthcare sector [18, 19]
- The hype related to the adoption of new technology, which might slow the adoption process [20] because of related concerns, such as cost and technological issues
- Technical complexity related to technology implementation [21, 22]
- Security and privacy challenges associated with adopting the technology [23, 24]
- Scarcity of publications on RFID adoption in the healthcare sector [25]
- Unavailability of valid constructs that allow for the study of RFID adoption [26]

An extensive review of studies that addressed the factors affecting RFID adoption revealed that most of these studies concentrated on respondents' perceptions of RFID implementation [27, 28]. Others focused on specific factors or issues, such as staff management [29], organisational factors [30, 31], privacy issues [23] and improvement of the reliability of RFID [32]. Some used existing frameworks, such as the technology–organisation–environment (TOE) framework [22] and the unified theory of acceptance and use of technology [25]. There is a need to incorporate all these factors into a single framework [33]. However, all these factors and their attributes need to be identified first in order to gain a better understanding of how the adoption of RFID technology can be encouraged in healthcare.

In this paper, we aim to address the adoption of RFID in the healthcare sector in a comprehensive manner and offer the following contributions:

- An explanation of the applications and benefits of RFID in healthcare
- A framework for the adoption of RFID in healthcare
- An exposition of detailed attributes that affect the adoption of RFID.

We assume that by providing a complete picture of the elements required to successfully implement the technology, we can encourage medical organisations to adopt RFID.

The remainder of this paper is structured as follows. Section 2 reviews the use of RFID in healthcare and addresses its applications and benefits therein. Section 3 uses relevant available theories in conjunction with recent studies to select suitable attributes for designing the framework. and Section 4 compares this framework with others. Section 5 explains the proposed framework and its evaluation, and Section 6 summarises the results of the study.

2. RFID IN HEALTHCARE SECTOR

In this section, we provide an overview of RFID in healthcare, including the uses and benefits of the technology in this industry.

2.1 Use of RFID in Healthcare

RFID is increasingly being used for the following applications in healthcare:

- Tracking

One of the main functions of RFID is tracking, which improves healthcare provision and management, as the technology can be used to monitor the work done by doctors, nurses and other hospital staff; the administration or use of medical equipment, drugs and medication; the storage conditions of blood bags; and the availability of inventory. In one of the successful case studies presented in [34], an RFID system was developed for the day hospital at the University Hospital of A Coruña to track the use cycle of medication from preparation to transportation to the eventual administration to patients. The tracking system uses ultra high frequency passive RFID tag and additional pertinent information, such as the date and time when medicines are prepared, data related to medications (name, dosage) and patients (name, previous medicine) and data related to prescriptions (schedule, conditions of conservation). The results of the study showed that using RFID ensures safety and strengthens the process of medication administration to patients because all the information required by any of the medical staff is available on the system; a total of 2,525 prescriptions from 285 patients have been tracked and saved on the system. Another successful usage of RFID can be seen in the Bon Secours Health System of Richmond in Virginia, where the technology is also used to track patients and assets using UHF and NFC frequency passive tags. A study on this usage found that the proposed RFID-based equipment management system improves asset utilisation and cost efficiency, as it was able to save more than $1.5 million from supply rentals as a result of tracking these supplies using RFID [35].

- Monitoring

Monitoring patients in hospitals is another important function of RFID. This helps doctors enhance patient safety, reduce medical errors and prevent medical negligence. Almasri and Hamdi [36] proposed a mobile monitoring system called

RFIDTrack, which uses active RFID tags connected to a patient registration system. RFIDTrack enables real-time surveillance and observation of patients' vital signs, such as their heartbeat and glucose level, and the transmission of emergency alerts to doctors in case of urgent signs and/or changes in the normal status of a patient. Almasri and Hamdi carried out a test run of the system in the Paediatric Surgery Department of the CDH Hospital in Kuwait. The experimental results show promise during a one-month testing of the system; the accuracy of RFIDTrack was clear, and the system dealt with 99.5% of all precursors of adverse events on time without any difficulties.

- Identification

Identifying patients, staff and newborns is the most crucial task in hospitals because it helps prevent adverse events. The importance of RFID in this respect was demonstrated by Inglesby [35], who examined the case of the Jacobi Medical Centre in the Bronx, New York, in which a system developed to use RFID technology for identifying patients and drugs was tested. The system was implemented in two companies, Siemens Business Services and Precision Dynamics Corporation. The author reported improvements to the level of care provided to patients, to productivity and to cost efficiency. Previous studies have discussed other benefits that RFID technology brings to hospitals, including the identification of infants for the prevention of newborn abduction and misidentification [37-38].

- Management

RFID can be used to manage hospital processes and workflows. A successful case study in the Naval Medical Centre of San Diego, California involved the use of the MASCAL system, which applies RFID in managing the resources of the hospital during emergency events. The system helps hospital management enhance the institution's emergency response, as it features a visual dashboard that managers and local area managers can operate. An example of MASCAL-based resource management is the adoption of high frequency RFID (13.56 MHz) to identify each casualty in the case of a disaster, which thereby aids receiving personnel in identifying each patient and linking their information to that in the MASCAL database [39]. Generally, the value of the system lies in its functioning as a successful reference framework that uses RFID technology in managing hospital resources.

2.2 Benefits of RFID in Healthcare

As described in the previous sections, RFID has been successfully used in the healthcare context, with recent studies describing the various advantages that this innovation offers the industry, including improving safety and efficiency levels, enhancing management processes, increasing quality and reducing workload, medical errors and operational costs [23, 25, 40-42]. Table I organises these benefits in relation to recently conducted studies on RFID technology adoption in healthcare.

3. Relevant Theories and Suitable Attributes

According to the literature, a wide range of factors affect the adoption of RFID technology. This section elaborates on the most important determinants of adoption in the healthcare context.

Table 1. Benefits of RFID

Benefit	Reference
Improves safety	[31][43][44][45][5][46][23]
Saves time	[46][47][48]
Reduces medical errors	[18][46] [47][49][50]
Reduces workload	[47][48][49][50]
Enhances security	[43][48] [51][52][53]
Improves efficiency	[44][54][55]
Enhances management processes and workflows	[18][23][43][44][56][57][46] [52][53]
Increases quality	[41] [58]
Reduces operational cost	[23][54][44][45][5][56][57][46][48][52][53]
Improves productivity	[28] [48][59][49][50]

3.1 Organisational Factor

The nature of an organisation is considered one of the most important factors affecting the adoption of a new technology. This encompasses descriptive organisational measures, including capacity of the organisation, decision making and structure [22]. Theories, such as the TOE framework proposed by Tornatzky and Fleischer [60], support the idea that organisational factors have a significant influence on the decision to adopt technology. The diffusion of innovation (DOI) theory addresses the internal structural attributes and external features of organisations as factors of technology adoption [61]. The human, organisation and technology fit (HOT-fit) theory, developed by Yusof et al. [62], highlights the organisational attributes that influence successful technology usage, such as structure and environment. A review of the most recent studies focusing on RFID adoption also uncovered various organisational attributes that bear on the acceptance of this innovation. For instance, Dabo [63] explored the impact of technological and organisational dimensions on the three stages (pre-implementation, implementation and post-implementation) of RFID technology using two research approaches: a questionnaire and case studies. The results indicate that three organisational attributes, namely, organisational size, strength of culture and the application of re-engineering, are positively associated with the decision to adopt RFID and the advantages gained thereafter. Park and Rim [64] identified RFID cost and upper-level management support as attributes in the organisational

context. Aboelmaged and Hashem [22] examined the main enablers of and impediments to the implementation of RFID on the basis of TOE theory and identified five contributing organisational attributes: communication skills, decision making, structure, organisational size and resistance. Others [65, 66] have argued that IT expertise should be regarded as an organisational factor, as this may minimise the efforts, planning time and cost involved in the process of integrating RFID into a specific system. Other organisational determinants of new technology implementation in the medical context include the availability of needed resources [67] as well as strategy, autonomy and planning and control systems, which are part of a proposed framework for health information systems based on HOT-fit theory [62].

3.2 Technological Factor

Technological determinants refer to technological attributes, amongst which the most frequently addressed on the basis of the TOE framework are the availability of the technology and its internal and external characteristics [60]. Many studies on the adoption of RFID have found that the attributes identified in TOE theory significantly influence the technology adoption process [64, 68]. According to DOI theory, technological factors include compatibility, relative advantage, complexity, observability and trialability [69]. Other studies have added performance [70], complexity, compatibility [71] and infrastructure [40] as technological variables in the adoption of RFID. The authors of [22] addressed technological characteristics, such as availability of a global standard, tag frequency, reader range, operating system and architecture whilst explaining the complexity of RFID. Mishra and Roy [72] conducted a comparative analysis of three RFID innovations that can be used in healthcare, namely, Raspberry Pi, Android and Bluetooth, investigating five features of each of the studied technologies: cost, safety, accuracy, scalability and speed. The authors of [73] conducted an empirical study to determine the most influential factors for RFID adoption and implementation and found that perceived benefits and standardisation affect the extent to which RFID is used. The authors in [26] identified four benefits of implementing RFID: improved asset management, communication, customer service and productivity. In another recent study [74], the authors introduced a framework to be used in the application of RFID and sensors in healthcare settings and summarised some RFID attributes that affect design-related decisions, including those on data storage and power source. An equally important point mentioned by the authors is that various architectural implementation decisions determine the mobility of RFID tags and readers. Mobility, which refers to the energetic spatial relationship between the tag and the reader, affects decisions on appropriate health applications.

3.3 Environmental Factor

Environment-related issues should be considered before making the decision to adopt RFID; these factors bear on the setting in which the innovation is to be implemented. According to several studies, environmental factors are instrumental to decision making on the adoption of RFID in a specific organisation [75] because these provide insights into the environmental pressure imposed on the adoption process [76]. Based on TOE theory [60], industry characteristics, the supported infrastructure and the government are the core environmental factors. In the medical context, the authors of [77] conducted an experimental study to determine the most effective placement of RFID tags in the clinical environment and to examine the environmental factors that affect the performance of RFID based on the selected tags and their location. They concluded that environmental factors influence the performance of the used RFID. Other studies in the same setting identified RFID reader location as a variable that affects RFID performance [59]. Baker [78] determined the high-level skills of staff and the availability of consultants and technology service providers as additional elements that support the adoption of new technologies however, from our perspective these elements can be categorised as human attributes. Finally, the existence of governance frameworks and mechanisms for RFID adoption encourages organisations to implement the technology [79], thus rendering these components suitable environmental determinants of RFID adoption.

3.4 Human Factor

Human determinants pertain to the effects of humans on the adoption of new technology. In this respect, the HOT-fit theory considers two human dimensions: user satisfaction and system use [62]. Khalifa [80] discussed some human contextual factors in healthcare, including the lack of specialists in the health informatics domain and the lack of technology expertise. The authors of [81] put forward a framework for a hospital information system that includes employee knowledge and perceived technical competence as human contextual factors for technology adoption. The authors of [82] investigated the RFID usage behaviours of healthcare professionals on the basis of data collected from 178 medical employees and found that satisfaction, attitudes, RFID continuance intention and perceived ease of use play a critical role in the attitudes of medical professionals towards using RFID. All these attributes must be considered when deciding to adopt RFID in the medical context.

The preceding sections, which included a comprehensive study of available theories related to the adoption of new technologies and an analysis of associated empirical studies on RFID adoption in the healthcare sector, examined the four factors specified by current research on the basis of TOE, DOI and HOT-fit theories. To the best of our knowledge, no study has investigated the adoption of RFID in healthcare via the integration of these three theories. As indicated in the reviewed literature, attributes that affect technology adoption can differ even within the same context and with the same innovation. Nevertheless, Baker [83] contended that it is normal for different elements to arise in accordance with variances in adopted technologies and adopting industries. Using this argument and the differences in elements that encourage RFID adoption in various domains as guidance, we

were motivated to carry out our work in determining clear and unified attributes that support the escalating usage of RFID. Table II shows the 44 attributes that were selected for inclusion in the design of a framework that covers organisational, technological, environmental and human factors and that is based on TOE, DOI and HOT-fit theories, along with other related studies.

Table 2. Selected attributes

Factor	Attribute	Ref.
Organizational context	Organisation capacity	[22]
	Decision making	[22]
	Structure	[22]
	Strength of culture	[63]
	Re-engineering	[63]
	Cost	[64]
	Upper-level management	[64]
	Communication skills	[22]
	Resistance	[22]
	Availability of needed	[67]
	Strategy	[62]
	Autonomy	[62]
	Planning and control	[62]
Technological	Compatibility	[69]
	Complexity	[69]
	Observability	[69]
	Trialability	[69]
	Performance	[70]
	Availability of global	[22]
	Tag frequency	[22]
	Reader range	[22]
	Operating system	[22]
	Cost	[72]
	Safety	[72]
	Accuracy	[72]
	Scalability	[72]
	Speed	[72]
	Data storage	[74]
	Power source	[74]
	Mobility	[74]
environmental	Industry characteristics	[60]
	Government	[60]
	Infrastructure	[40]
	Tag's location	[77]
	Governance frameworks and mechanisms	[79]
Human	Satisfaction	[62]
	High-level skills of staff	[78]
	Availability of consultants	[78]
	Technology service	[78]
	Employee knowledge	[81]
	Perceived technical	[81]
	Attitudes	[82]
	Continuance intention	[82]
	Perceived ease of use	[82]

4. COMPARISON WITH OTHER FRAMEWORKS

As discussed previously, the 44 attributes were selected based on the relevant theories and empirical studies confirming that they significantly affect the adoption of RFID. In this section, we review the efforts to date to propose a framework for the adoption of RFID in the healthcare industry. Some research has predominately focused on the implementation processes for RFID. The authors of [84] developed a framework based on phases to evaluate the performance of RFID in the medical setting; each phase described specific steps to test the environmental factors that influence the quality of RFID. The developed framework does not refer to any of the theories of adoption of new technology; rather, it used reviewed literature and the authors' experience with RFID testing. In [47], the authors proposed a generic framework for implementing RFID that consists of the following six steps: project scoping, analysis of existing systems, system design, system testing, implementation and continuous improvement. However, these steps relate more to the feasibility of adopting the technology than to the features of the technology itself. The authors of [26] identified the major dimensions of RFID adoption in the supply chain. These dimensions include management leadership, drivers, barriers and benefits. Generally, the study added value by investigating in depth the benefits of RFID in the supply chain in the healthcare sector. The authors of [22] used the TOE framework to identify the main enablers of and impediments to implementing RFID in healthcare. The results indicate that technical advantages and organisational capacity significantly influence the adoption of RFID; however, any human factors are not included in the authors selection.

5. THE PROPOSED FRAMEWORK AND EVALUATION

The proposed framework presented in Fig. 2 suggests integrating the four factors (organisational, technological, environmental and human) based on TOE, DOI and HOT-fit theories. The attributes of each factor were selected based on these theories and the reviewed empirical studies. To construct the attributes, we first grouped them under themes. For example, for the technological factor, we grouped tag frequency, reader range, data storage, speed, power source and mobility, categorising them as RFID properties because they all provide details about the selected RFID. For the organisational factor, we grouped structure, re-engineering and strategy under leadership, and for the human factor, we grouped high-level staff skills and employee knowledge under staff background. We also removed two attributes from the technological factor: (1) cost, as it was included within the organisational factor and (2) infrastructure, as it was included within the environmental factor and is more associated with the environmental state.

To evaluate the designed framework, we chose an expert walkthrough method, selecting a panel of six experts to rate the framework using a 5-point Likert scale (ranging from 1-strongly disagree to 5-strongly agree) that addressed the following areas:

- Framework comprehensibility
- Interdependency among factors and attributes
- Clarity of framework terminology
- Applicability of the factors/attributes to RFID technology adoption in healthcare
- Importance of factors/attributes
- Conflict among factors/attributes

In addition, we gathered qualitative data from these experts to obtain their opinions about potentially missing attributes and more detailed framework evaluation explanations. The selected experts were a mix of academics and hospital leaders, with broad understanding of new technology adoption in the healthcare field. The average expert evaluation duration was 40 minutes. Table 3 shows the mean scores of the assessment criteria used during the expert walkthrough evaluations. All mean scores were above 4, indicating evaluator agreement with each statement. However, the experts made several recommendations that will be considered to improve the proposed framework:

- For organizational attributes, the attributes 'decision-making','upper-level management' support and 'communication skills' could be grouped under management style.
- The operating system could be omitted, as it does not affect RFID implementation.
- The element 'staff background' could be omitted, as the element 'availability of consultants' is a suitable measurement of the organisation's ability to adopt the technology.

Table 3. Mean scores for the evaluation criteria by selected experts

Variable	*Mean*	*Std. Deviation*
The framework factors/attributes are easy to understand.	5	0.00
The framework factors/attributes are interdependent.	4.33	0.8
The terminology used in the framework is understandable.	4.5	0.83
The framework factors/ attributes are applicable to adopting RFID in healthcare.	4.33	0.51
The framework factors/attributes are important.	4.33	0.51
There are no conflicts among the framework factors/attributes.	4.83	0.41

6. CONCLUSION

The purpose of this paper was to identify the factors and attributes that influence the adoption of RFID technology in healthcare through a comprehensive study of the existing relevant theories and empirical studies. The resulting framework integrates three theories: TOE, DOI and HOT-fit. It also incorporates all the attributes we determined can influence the implementation of RFID technology in the healthcare context. The evaluation of the proposed framework indicates its applicability to RFID adoption in the healthcare sector, and the participating experts confirmed the importance of its factors and attributes.

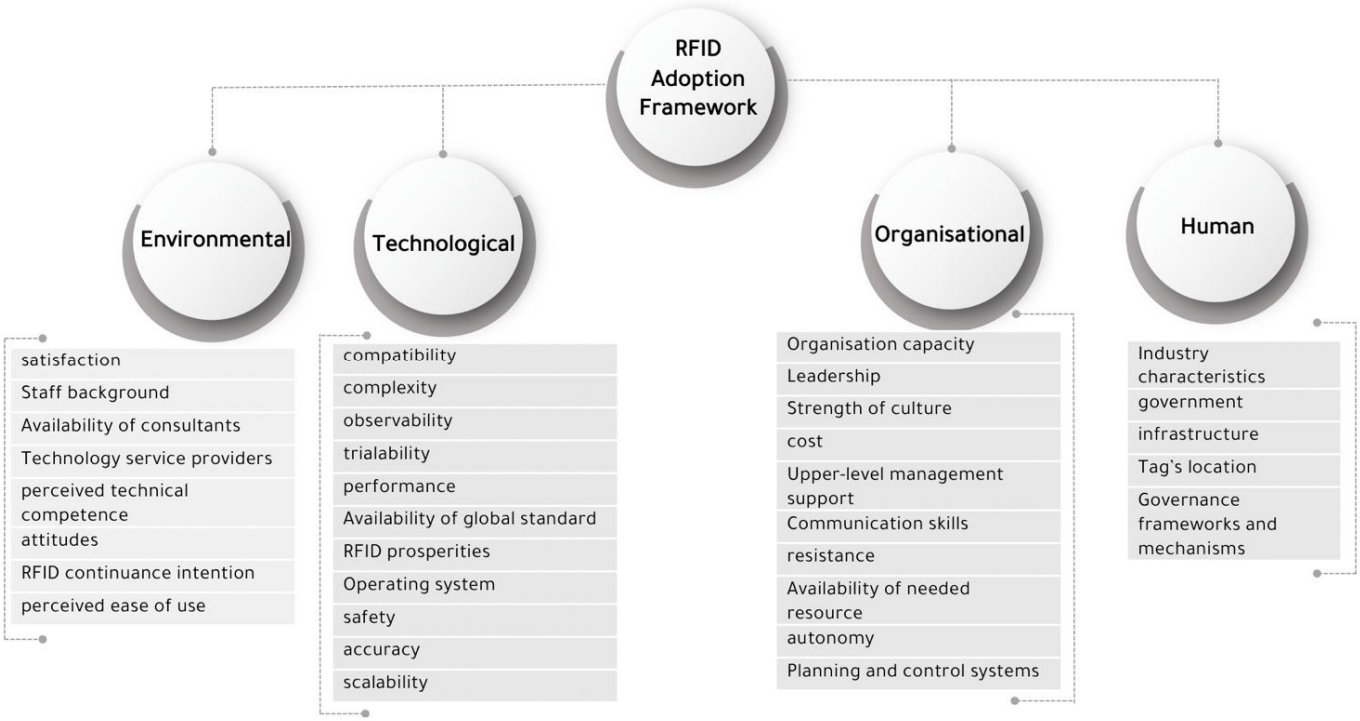

Figure 2. Proposed framework.

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