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Reaping Benefits and Overcoming Challenges in Pneumatic Tube System Adoption for Hospital Logistics: Learnings from a Decade of Utilization

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Abstract. This study investigates user perceptions and maintenance practices related to the decade-long utilization of pneumatic tube systems (PTSs) for internal transport logistics at a Moroccan university hospital center (UHC). A survey of 64 hospital staff reveals unanimous agreement regarding the system's benefits in improving sample transportation speed, security, reliability and quality. However, challenges persist around carrier availability, technology malfunctions and human errors highlighting the needs for better change management and upgrades. Regular preventative and corrective maintenance procedures have contained but not eliminated recurrent technical and ergonomic issues. By providing granular insights on satisfaction factors, persistent pain points, and maintenance limitations in a complex, multi-site installation, implications are offered to guide strategic investments and process improvements.

Keywords: Pneumatic Transport system; internal transport logistics; University Hospital Center; maintenance; reflective study, healthcare

1. Introduction

In recent years, the utilization of pneumatic tube systems (PTSs) has become increasingly prevalent in various industries, including healthcare (Feibert and Jacobsen, 2019). Several factors have contributed to their growing adoption. For example, PTSs make internal transport logistics faster and more efficient, streamlining operations and improving productivity (Benzidia *et al.*, 2019). They also enhance security by protecting items during transport, minimizing the risk of theft or damage, and ensure reliable and accurate delivery, reducing the potential for human errors (Fernandes *et al.*, 2006). Previously, larger hospitals started implementing more extensive networks of PTSs to facilitate the movement of items across different departments and buildings within their campuses (Sodi *et al.*, 2004). PTSs played a crucial role in improving the efficiency of internal logistics, reducing manual handling, and ensuring prompt delivery of critical items (Dr. Arun. Mavaji, 2013). However, in recent years, the evolution of PTSs in hospital logistics has been driven by advancements in digital connectivity and integration with other healthcare systems. For instance, PTSs are nowadays integrated with electronic medical record (EMR) systems, laboratory information systems (LIS), and pharmacy systems, allowing for seamless and efficient exchange of information and data. This integration has further streamlined workflows, improved patient safety, and enhanced overall operational efficiency in hospitals.

However, academic researchers have highlighted the importance of effective hospital logistics for improving patient outcomes, reducing costs, and enhancing operational efficiency (Chen *et al.*, 2013; Nyaga *et al.*, 2015). Hospital logistics is divided to external and internal supply chain, external from suppliers such as medical drugs suppliers to hospitals, and internal from central pharmacy or storage place to different departments .(Božić *et al.*, 2022) The internal transportations, logistics and supply chain operations are influenced by the hospital building architecture and layout. Hospital buildings are complex structures that present unique challenges for internal logistics and supply chain management. They may have multiple floors, specialized departments, and a wide range of equipment and supplies that need to be managed efficiently (Cubukcuoglu *et al.*, 2021).

Various forms of internal transport have been used in hospitals. First, manual transport involves the use of manual labor, such as orderlies or porters, to move equipment, supplies, and patients around the hospital. This method is typically employed for short distances or for large, bulky items that cannot be moved with automated equipment (Makkar and Madaan, 2016; Morillo *et al.*, 2018). Elevators are another crucial means of vertical transportation within hospitals. They enable the movement of patients, staff, and equipment between different floors of the hospital. Automated guided vehicles (AGVs) are unmanned vehicles that rely on a computerized system to transport equipment and supplies throughout the hospital(Ozkil *et al.*, 2009). AGVs are particularly beneficial for transporting heavy or bulky items over longer distances. Conveyor belts are frequently employed to transport linen, laundry, and waste within the hospital. These belts can be automated and programmed to move items between different locations. Wheelchairs and stretchers are used for transporting patients who are unable to walk or require assistance with mobility(Liu *et al.*, 2022). Robotic vehicles have also been introduced for the transportation of patients, meals, and small-sized cargo (Ozkil *et al.*, 2009). Pneumatic tube systems (PTSs) are networks of pneumatic tubes used for transporting small items, such as blood samples and medication, throughout the hospital. These items are placed in capsules and sent through the tube system to their desired destinations (Garg and Dewan, 2022).

This paper has focused on PTSs adoption in the hospital logistics within the context of a university hospital center (UHC) in Morocco. Generally, the healthcare sector in Morocco, including UHC, is facing challenges related to a shortage of human resources. Particularly, there is insufficient staff available for the transportation of blood samples and other products to laboratories, as well as the supply of drugs to various services. This issue becomes more pronounced in multi-site UHCs like the IBN SINA University Hospital in Rabat, Morocco. In addition to the scarcity of human resources, the transport of samples by drivers or couriers generates several problems, such as delays in deliveries, errors in destinations, loss and damage of samples, lack of traceability, fatigue of personnel and increase of energy consumption. To fill this gap, the proposed paper will explore the PTSs adoption for internal transport logistics at a Moroccan UHC. This research concentrates on the following research questions to address:

RQ.1 What are the benefits of PTS in hospitals?

RQ.2 What is the level of satisfaction among the staff users regarding the PTS?

RQ.3 What are the challenges faced by both users and maintenance operators?

Furthermore, the primary research objectives of this study are highlighted as follows:

(1) To provide a comprehensive analysis of user satisfaction regarding the advantages offered by PTSs, as well as a detailed account of the primary challenges faced during the nearly ten-year operation period at UHC IBN SINA.

(2) To propose the actions carried out or in progress by the UHC to remedy these problems.

(3) To describe the preventive and corrective maintenance actions carried out to maintain the system and prevent problems.

To the best of our knowledge, this is the first study that explore the implementation PTSs for internal transport logistics at university hospital centers in Morocco.

The remainder of this paper is organized as follows. Section 2 presents the literature background associated with the proposed study. section 3 explains the research methodology employed for the study. Findings and discussions are explained in section 4. Finally, section 5 shows the conclusions, limitations and future work.

2. Literature Background

2.1. Definition of a pneumatic transport system

The fundamental structure of a pneumatic transport system consists of interconnected receiving and arrival stations, linked by PVC tubes. Propelled by pneumatic energy generated by turbines or blowers, cylindrical containers known as carriers are utilized. One of the advantages of using carriers is that they effectively isolate transported blood products from the tube, ensuring their protection and minimizing the risk of any changes during transportation. The typical speeds within the system range from 3 to 8 m/s, allowing for the coverage of a distance of approximately 500m in just about 1 minute (Bardiaux *et al.*, 2012; Slavík *et al.*, 2020a). Figure 1 represents the structure of a PTS.

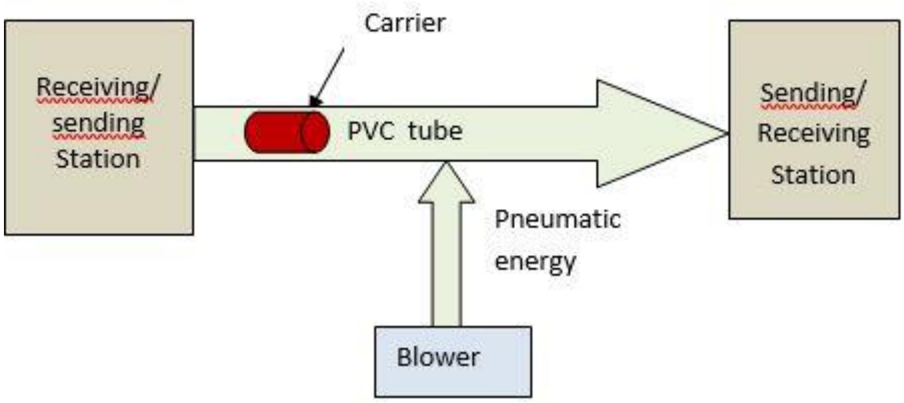

Fig. 1: Representation of a Pneumatic Transport System (Gallab *et al.*, 2024)

2.2. Pneumatic transport systems in UHC IBN SINA of RABAT

In 2013, UHC IBN SINA of Rabat successfully installed a pneumatic transport system. The installation was based on a thorough preliminary study that took into account the architectural limitations of the buildings. Since its installation, the system has been fully operational and has effectively connected multiple hospitals within the UHC. This includes Souissi Maternity Hospital, IBN SINA Hospital, Pediatric Hematology and Oncology Center, Children's Hospital, and Specialties Hospital, which are seamlessly connected through an inter-hospital pneumatic network. Additionally, an intra-hospital pneumatic network was implemented to facilitate the efficient and reliable transportation of items between different services across various floors of the buildings. The system was designed to meet strict requirements for transfusion safety and prioritized robustness, ease of use, and compliance with specific constraints related to the transportation of blood products. By considering various requirements during the design process, the system was optimized to achieve excellent performance and ensure the highest standards of efficiency and reliability in transporting critical items within the hospital facilities (Maasz, 2000). The number of items sent and received through the system has been increasing each year, as shown in Figure 2. In 2019, there were 68,040 items sent and 76,168 items received. However, due to the impact of the Covid-19 situation, these numbers have decreased, affecting the overall activity of the UHC.

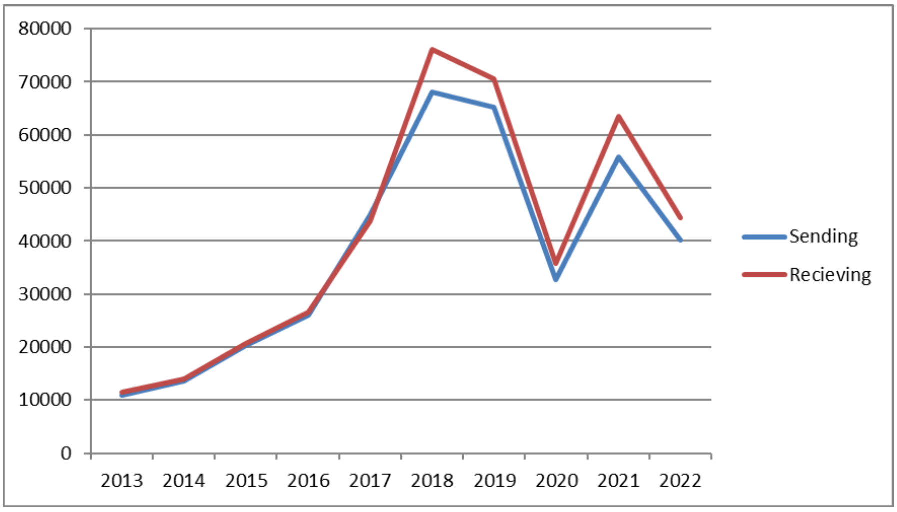

Fig. 2: Evolution of the number of sending and receiving carriers in UHC IBN SINA of Rabat

Furthermore, The PTS in UHC IBN SINA includes the following technical installations:
• Networks of PVC tubes with a diameter of 160 mm divided into 10 lines (8 kilometers in total)
• 35 sending and receiving stations
• 02 multi-sending type stations
• 251 carriers working with Radio Frequency Identification (RFID) technology
• 01 disinfection carrier
• 01 set of referral system
• 04 sets of transfer systems
• 01 Propulsion System Assembly
• 01 set of control and supervision system
• 01 main technical room located at the Children's Hospital
• 01 secondary technical room located at the IBN SINA Hospital
• Monitoring software
• 8 inverters (three with 1 KVA, five with 850 VA)

2.3. Related works

Different authors define hospital logistics either as support activities or as a flow management technique. The specific activities of logistics in a hospital can vary from one hospital to another and from one country to another (Jawab, 2018). In the existing literature, most of the research on pneumatic transport focuses on its impact on the stability of blood samples (Martin *et al.*, 2012). However, according to (Nybo *et al.*, 2018), a literature review study found inconclusive results due to the heterogeneity of the collected studies. This study could not provide evidence for the safety of using pneumatic systems for transporting blood samples. As a result, laboratories should measure and document the actual acceleration forces in their pneumatic transport systems and establish quality thresholds. Other studies have shown that despite changes in certain blood parameters (such as hemolysis, platelets, coagulation, hematology, blood gas, etc.), these changes are not clinically significant (Farnsworth *et al.*, 2019; Kobayashi *et al.*, 2019; Oyaert *et al.*, 2020; Pupek *et al.*, 2017; Slavík *et al.*, 2020; Subbarayan *et al.*, 2018; Yurt *et al.*, 2022). No studies were found that demonstrate the benefits of pneumatic transport systems in hospital logistics or specifically address the technical aspects of installation and maintenance. Additionally, there is a lack of research investigating user satisfaction or the challenges faced, despite the numerous advantages of the PTS and its crucial role in the internal logistics of hospitals (Garg and Dewan, 2022). It is worth noting that this installation is particularly remarkable for its ability to handle the transportation and distribution of various medical and non-medical items, as defined in previous studies (Kriegel *et al.*, 2013).

3. Research methodology

The proposed study is a descriptive and analytical investigation conducted at UHC in Rabat during the final quarter of 2022. It is based on a structured survey addressed to the direct users of PTS. The methodology associated with the paper can be visualized in Figure 3, which illustrates four key steps that were followed.

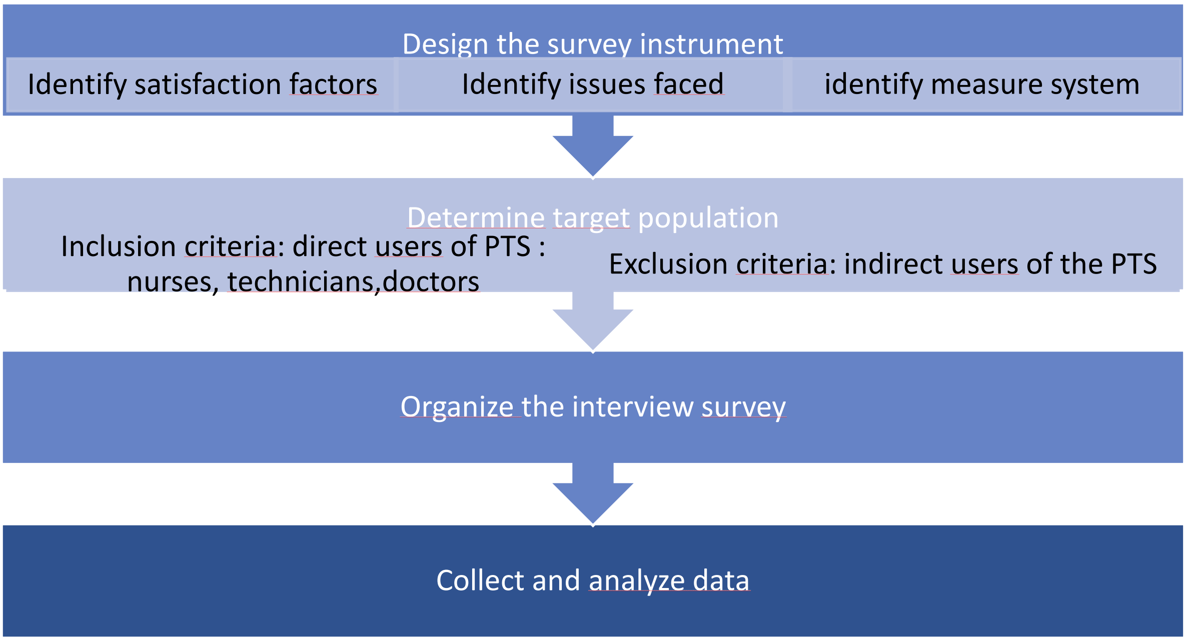

Fig.3: Methodology followed in the study

3.1. Questionnaire design

3.1.1 Satisfaction factors and challenges faced identification

The first step focused on designing the questionnaire survey, which was a critical aspect in ensuring user response and collecting pertinent information. In this regard, a systematic approach has been employed, beginning with a thorough review of existing literature to identify relevant constructs and items for inclusion in the questionnaire. Due to the complete lack of literature on this specific topic, despite its significance, our questionnaire development relied exclusively on the authors' expertise and the data available from documents collected over the past decade since the system's inception.

To identify satisfaction factors, we relied on the authors' extensive practical experience in the field, as well as an analysis of reports, work orders, and previous user complaints. Satisfaction was described in terms of the benefits that users actually experienced. Conversely, barriers were identified through a thorough examination of maintenance reports and historical files pertaining to the various components of the PTS.

3.1.2 Pilot study and validation

Prior to the main data collection phase, we conducted a pilot study to test the questionnaire for clarity, comprehensibility, and relevance. This pilot study involved a small sample of respondents (10 users) who were representative of the target population. We chose two users from each hospital to ensure the representativeness of our target group. Feedback from the pilot study participants was used to refine the questionnaire, including revising unclear or ambiguous items and adjusting response options as needed. Validity testing was another crucial step in ensuring the quality of our measurement procedures. We employed both content validity, by ensuring that the questionnaire items adequately covered the intended constructs, and construct validity, by examining the relationships between different questionnaire items and external criteria. This validation process involved consultations with experts in logistics, maintenance and statistics (inside and outside the UHC). The questionnaire comprised a combination of closed-ended and open-ended questions, aiming to gather both quantitative and qualitative data.

3.1.3 Measure data

In our study, we adopted a binary (yes or no) response format for the satisfaction factor questionnaire. This approach was chosen to simplify the response process for participants and to focus on capturing clear and concise feedback regarding satisfaction and challenges with the Pneumatic Transport System (PTS) among users at University Hospital Center (UHC) in Rabat. These types of questions (Dolnicar *et al.*, 2011)were chosen for their efficiency, as participants tended to answer them more quickly compared to questions with multiple response options. Additionally, participants perceived binary questions as less difficult to answer, which may have contributed to higher response rates and reduced respondent burden.

3.2. Identify target group

By including all direct users of the PTS in UHC, we ensure that our study represents the entire population of interest without the need for sampling. This maximizes the representativeness of our findings and enhances the generalizability of our results to the entire direct user population which essentially constitutes a census of this specific group for our research on the use of the PTS.

Involving all direct users allows us to obtain a comprehensive understanding of the experiences, perceptions, and satisfaction levels regarding the PTS across the entire user population. This approach ensures that no subgroup is excluded, providing a complete picture of the situation.

Given that the UHC is the focus of our study and we have access to all direct users, conducting a census rather than sampling is practically feasible. It eliminates the need for sampling procedures, reduces potential sampling bias, and streamlines data collection efforts.

The pneumatic tube system consists of a total of 32 functioning stations. To ensure reliable and robust results, we aimed to gather responses from a minimum of two users per station. Therefore, our study includes a total of 64 direct users (n=64) who actively utilize the system. The participants primarily consist of nurses and laboratory technicians working in departments that make use of this installation. These departments are distributed across the five main hospitals of the University Hospital Center mentioned earlier. Table 1 provides an overview of the distribution of departments or services within these five establishments. It is worth noting that pharmacies were excluded from the study as they were not operational during the survey period.

Table.1: Departments utilizing the Pneumatic Transport System in UHC IBN SINA

HOSPITAL	DEPARTMENTS
Children Hospital	Pharmacy
	Medical Emergencies
	Surgical Emergencies
	Neonatology
	hospitalization Pediatrics I
	hospitalization Pediatrics II
	hospitalization Pediatrics III
	hospitalization Pediatrics IV
	Surgery A
	Surgery B
	Surgery C
	Resuscitation A
	Dialysis
Pediatric Hematology and Oncology Center	Hospitalization
	Day hospital
	Transfusion
Souissi Maternity Hospital	Pharmacy
	Emergency operating room
	Delivery room
	Gynecological emergencies
	Expectants room
	Operating room Floor
	Resuscitation
	Endoscopy 1
	Endoscopy 4
	Endocrinology
	Cancer
	Pediatric Cardiology B
	Adult Cardiology B
Specialties Hospital	Pharmacy
	Virology laboratory
IBN SINA Hospital	Emergency
	Biochemistry laboratory
	Hematoparasite Laboratory
	Bacterio laboratory

3.3. Organize the interview

In our case, we took advantage of the scheduled preventive maintenance visits conducted for each station to administer the questionnaire to users. During these visits, we had the opportunity to interact with users directly, allowing us to gain insights into their perceptions and address any ambiguities they may have regarding the PTS. By integrating the questionnaire administration into the routine maintenance process, we ensured minimal disruption to users' workflow while maximizing the efficiency of data collection. This approach also provided a structured environment for users to provide feedback and allowed for immediate clarification of any concerns or questions they had regarding the PTS. Overall, leveraging the scheduled maintenance visits proved to be a convenient and effective method for survey administration, enabling us to gather valuable user insights while maintaining operational continuity within the UHC.

3.4. Collect and analyze data

3.4.1 Coding and theming

Our research employs deductive coding, drawing upon our extensive experience and a decade-long historical analysis of maintenance records, as well as insights gathered from expert consultations, to develop our coding framework. The pre-coded binary questions in our questionnaire are an approach, for confirming predefined attributes of satisfaction related to the use of PTS and also for the different encountered issues.

We incorporate open-ended questions during interviews with users to complement the structured approach of binary questions. Open-ended questions allow respondents to provide detailed, nuanced responses, which can help us uncover additional insights and perspectives that may not be captured by predefined categories or options. We can mitigate potential biases associated with binary questions and ensure that we capture a comprehensive range of perspectives related to satisfaction and problems. This approach enhances the richness and depth of our qualitative data.

The survey was conducted using a questionnaire consisting of two parts. Satisfaction was assessed based on the benefits experienced, including:

Satisfaction Factors:

- Speed of time-saving: Faster diagnosis and treatment due to reduced time between sampling and analysis results.
- Reliability of analysis results: The faster process enhances the reliability of the results, minimizing the impact of delays.
- Quality: Samples remain unmanipulated and protected, ensuring better sample quality.
- Traceability: Real-time and accurate recording of all carrier movements improves traceability.
- Security: Safe transportation of samples, reducing the risk of loss, theft, and infection.

The theming of problems can be categorized into organizational, human, and technical issues:

Organizational Issues:

- Destination error: Composing the station code incorrectly due to user omission or lack of knowledge.
- Loss of a carrier: Failure to receive a carrier at the intended location.
- Damage: Specimens or drugs arriving in a damaged state.
- Ergonomics: Discomfort caused by noise at certain stations, affecting staff.
- Unavailability of carrier: Failure to return empty carriers to the sending service.
- Technical Problems:
- Key pad crash: Freezing of the send/receive station's keypad, obstructing carrier sending.

Human Issues:

- Problem of use: Congestion of carriers in the arrival basket, hindering carrier reception at the same station., or sending of samples without a carrier.

The statistical analysis was conducted utilizing SPSS version 24.0 software. Satisfaction factors and issues were treated as qualitative variables and represented statistically through numerical values and percentages.

4. Results and discussion

4.1. Employee Satisfaction

In this section, we present the results of our comprehensive survey aimed at gauging employee satisfaction within the University Hospital Center (UHC) in Morocco, focusing on the Pneumatic Tube System (PTS). Remarkably, the findings indicate an unprecedented level of satisfaction among the staff, with a unanimous 100% satisfaction rate across all evaluated factors, including speed, security, reliability, traceability, and quality (refer to Table 2). These results not only underscore the efficiency and effectiveness of the PTS in the hospital setting but also highlight the positive impact such systems have on the operational workflow and employee morale.

The survey achieved a 100% response rate over a period of approximately three months, ensuring participation from at least two users per station. In cases where direct meetings were not possible, phone interviews were conducted.

Table. 2: Results of the satisfaction factors (first part of the questionnaire)

Variables (Satisfaction factors)	Result
Speed	Oui 100% (n=100)
Security	Oui 100% (n=100)
Reliability	Oui 100% (n=100)
Traceability	Oui 100% (n=100)
Quality	Oui 100% (n=100)

Following the unequivocal results indicating complete satisfaction with the PTS, we have delved into the specific factors that have led to such positive feedback. During the interviews, employees consistently highlighted several key aspects of the PTS that contributed to their satisfaction. These aspects include the system’s speed, which ensures timely delivery of materials, and its traceability, which provides a sense of security and accountability in the transport process. In the forthcoming paragraphs, we will explore each factor in detail, elucidating the reasons behind the employees’ satisfaction and how these align with the overarching goals of efficiency and effectiveness in hospital operations.

PTS plays a crucial role in expediting the processing of blood samples, leading to faster initiation of diagnostic or treatment processes and enhancing the reliability of the results. This, in turn, positively impacts patient care. The implementation of the PTS has significantly reduced destination errors. In the event of a misdirected reception, the receiving service promptly returns the carrier to its original sender through an automated process facilitated by RFID technology. The robust carrier used by the system ensures that the samples or specimens remain intact during transportation, resulting in better quality upon arrival and eliminating the risk of damage. Moreover, the PTS has improved security measures by minimizing carrier losses through real-time monitoring and recording of all shipments using RFID technology. As a result, the system enhances safety by reducing the need for manual routing, thereby mitigating the risk of staff, visitors, or patients being exposed to infections.

The incorporation of RFID technology in PTS has revolutionized traceability, offering a multitude of benefits. By utilizing RFID, the system enables precise tracking of products, effectively identifying their routing and preventing any potential incidents along the logistics circuits. This type of traceability is set to advance further, providing comprehensive monitoring of each sample and blood product, and offering detailed information about the entire logistic journey. Notably, it provides crucial insights into the healthcare professionals responsible for the collection, handling, and transportation of blood samples. The RFID tags allow real-time monitoring of the carrier's exact location as it moves from the service area to the laboratory, facilitating seamless supervision. The automation software, with its user-friendly computer interface, simplifies the control and documentation of each shipment, enabling the generation of reports and statistical analysis. Furthermore, the system's flexibility allows for easy configuration of new sending and receiving stations, ensuring adaptability to evolving needs. Considering these compelling arguments, the 100% satisfaction rate is well-justified, as the PTS offers numerous advantages for staff, the healthcare establishment, and patients alike.

4.2. Challenges faced

While the PTS has garnered high satisfaction rates in several areas, our study also sheds light on the challenges encountered by users. Over half of the participants reported experiencing significant issues that impact the system's efficiency. These challenges, detailed in Table 3, include carrier unavailability, frequent keypad malfunctions, and general usability concerns. The following section provides an in-depth analysis of these challenges, reflecting on their implications for system performance and user experience within the hospital's operational framework.

Table.3: results of the issues encountered (second part of the questionnaire)

The problem type	Variables (problems)	Result
Organizational	Error destination	Oui 15,6% (n=10) Non 84,4 (n=54)
	Damage	Oui 100% (n=68) Non 0% (n=0)
	Loss	Oui 3,1% (n=2) Non 96,9% (n=62)
	Ergonomics(noise)	Oui 3,1% (n=2) Non 96,9% (n=62)
	Carrier unavailability	Oui 44,4% (n=54) Non 15,6% (n=10)
Technical	Blocking numeric key Pad of the station	Oui 68,8% (n=44) Non 31,3% (n=20)
Human	Problem of use	Oui 68,8% (n=44) Non 31,3% (n=20)

The recurring issue of key pad crashing at the stations stems from electrical and electrostatic problems associated with the power supply. To address this challenge, UHC IBN SINA has implemented inverters to safeguard the electronic cards against potential electrical hazards, including micro cuts, under voltage, voltage peaks, and more.

The problem of use arises when users fail to adhere to the work instructions prominently displayed near each station. Instances of non-compliance include errors in shipping instructions, mistakes on address labels, congestion of carriers in the arrival basket, and sending samples without carriers. To tackle this issue, the team responsible for managing the automatic pneumatic system consistently conducts awareness-raising initiatives to encourage users to follow the prescribed instructions. They maintain an open line of communication with users, actively seeking feedback and modification requests to enhance the pneumatic network.

Regarding the issue of carrier unavailability, two primary reasons can be identified. Firstly, the receiving service may have failed to return empty carriers to the sending service, which is crucial since each service has a designated number of carriers. Secondly, the limited availability of carriers is attributed to damage. To tackle this, UHC has implemented repairs and procured a new stock of carriers to ensure an adequate supply.

One user raised concerns regarding the ergonomics of a station located in a staff rest area, specifically regarding the noise generated. This issue arose due to a reorganization that occurred subsequent to the installation of the system. However, the complaint has been duly acknowledged, and the possibility of relocating the stations is being considered to address this matter.

Indeed, the prioritization of issues in a hospital depends on the assessment of criticality, which takes into account several key factors: severity, frequency and detectability. Combining these three dimensions allows hospital managers to categorize issues and determine which ones require immediate attention to minimize risks and improve patient care quality. This systematic approach is essential, especially in complex hospital environments where each service has its own specificities and requirements. Criticality helps guide maintenance efforts and allocate resources effectively.

The results of our study must be understood within the unique context of the Moroccan hospital system. The challenges and successes of the Pneumatic Tube System (PTS) implementation in Morocco offer valuable insights into its potential application in comparable healthcare settings. Our analysis reveals that while the PTS has significantly improved operational efficiency and employee satisfaction, it has also faced challenges unique to the local context, such as carrier unavailability and keypad malfunctions. These findings provide a nuanced understanding of the PTS's role in a developing country's healthcare infrastructure, where resource constraints and system demands differ markedly from those in more developed nations. Furthermore, PTS in University Hospital Centers in Morocco are very rare. To date, there are three UHCs that have a PTS network: the UHC of Fes with an average of 50 stations in total, and the UHC of Oujda are the hospitals that have had a functional PTS for a long period.

The significance of the PTS in hospital logistics is evident. To ensure its smooth operation and performance, it is crucial to proactively identify and prevent potential problems. In line with this, the UHC has opted to outsource the maintenance and supervision of the system, recognizing the importance of professional expertise in ensuring its efficient functioning and minimizing disruptions. By entrusting this responsibility to specialized personnel, the UHC aims to maintain the system's performance and mitigate any operational challenges that may arise.

4.3. How does the UHC maintain the Pneumatic Transport System?

The UHC places significant emphasis on two crucial aspects: maintenance and supervision of the PTS. The supervision entails continuous monitoring and control of the automatic system, which is facilitated in a dedicated room equipped with specialized software interface (Figure. 4). Technicians are stationed on-site to ensure real-time oversight and promptly address any system shutdowns, either through the software interface or by swift physical intervention.

The scope of supervision encompasses various actions, including:

- Programming and configuring the system in case of any modifications, such as adding or removing stations.
- Activating or deactivating lines or stations as required.
- Processing and analyzing the data stored in the control PC.
- Identifying and rectifying system alarms that may occur.
- Manually routing carriers in the event of a system shutdown.
- Providing user information and assistance during system disruptions.
- Offering training and support to users as needed.
- Performing necessary updates to the PC and supervision software.

Through efficient supervision, the UHC ensures the smooth operation and optimal performance of the PTS, facilitating seamless logistics within the hospital environment.

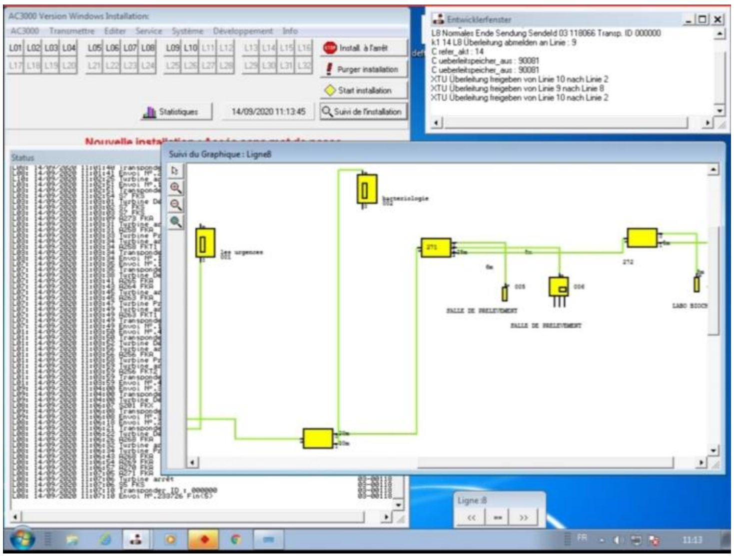

Fig.4: supervision screen Maintenance

Regarding maintenance, it is essential to adhere to a checklist of maintenance actions provided by the manufacturer. While each manufacturer may have specific requirements, we will outline some general maintenance actions that should be performed:

- Conduct comprehensive verifications of the pneumatic transport installations, including mechanical, electrical, pneumatic, and computer network verifications.
- Perform air tightness tests on the pneumatic network to ensure its proper functioning.
- Maintain the technical rooms of the pneumatic transport system, including regular dust removal actions to maintain cleanliness and efficiency.
- Monitor and maintain the inverters responsible for protecting electronic cards against electrical hazards, replacing them if necessary.
- Repair any damaged carriers, ensuring they are in proper working condition.
- Address any issues with the keypads of the various stations, either through repair or replacement.
- Repair or replace any malfunctioning sensors within the installation, such as presence sensors or contact passage optics.
- Maintain or replace arrival baskets as needed to ensure smooth operations.

By diligently performing these maintenance actions, the UHC can uphold the functionality, reliability, and longevity of the pneumatic transport system, contributing to efficient and effective operations within the hospital.

Preventive maintenance

The pneumatic system undergoes scheduled preventive actions on a quarterly basis, adhering to the manufacturer's guidelines. These preventive measures encompass the entirety of the pneumatic system, ensuring that all components and subsystems are thoroughly inspected and maintained. By following this regular preventive maintenance schedule, potential issues or deteriorations can be identified and addressed promptly, contributing to the system's optimal performance, reliability, and longevity.

Table.4: Some preventive maintenance actions recommended by the manufacturer

Component	Maintenance preventive action
Diverters verification .	**Checking and Correcting Alignment**
	Checking the masses (grounding)
	Verification of connections
	Checking the belts (change if necessary), checking the tension
	Checking and changing passage contacts and others
	Diverters cleaning
Stations verification	**Verification of the alignment of the arm with respect to the passage**
	Checking the masses
	Verification of connections
	Verification and change of passage contacts (change if necessary),
	Verification of the arm contacts (change if necessary)
	Checking the valve contacts (change if necessary)
	Lubrication of the arm guides
	Cleaning the interior of the station
	Central-Station dialogue tests
	Checking the cables
	Voltage check
Blowers' verification	**Checking and adjusting the three-way valve**
	(change if necessary)
	Bypass cleaning **Verification of the tightness of the lugs**
	Verification of contactors and protection **(change if necessary)**
Verification of the supervisory post	**Verification of PC and supervision software**
	Checking PC operation
	Disk cleaning, data backup
	Analysis of statistics
Inverters verifications	**Input and output voltage**
	Checking cooling fans and filters
	Battery input and output voltage
	Cleaning

Corrective maintenance (palliative and curative)

Curative maintenance

Curative maintenance refers to the corrective actions taken to restore the functionality of a component or system after a failure has occurred, enabling it to perform its intended function. While the following list is not exhaustive, it has been compiled based on past failures observed in our system. These curative maintenance activities aim to address specific issues and rectify any malfunctions, ensuring the smooth operation and reliability of the pneumatic transport system.

Table.5: Some corrective maintenance actions done by the UHC IBN SINA

Component	Possible corrective maintenance action
Station	**Changing the numeric keypad** **Change of optical sensor.** **Change of the gasket.** **Replacement of the electronic control board.** **Replacement of the positioning sensor**
Diverters (Three port)	**Change of sensors.** **Change of the gasket.** **Replacement of the electronic control board.**
Carrier store	**Change of sensors.** **Replacement of the electronic control board.**
Piping PVC 160 mm	**Change of the pipe or PVC pipe fitting**

Palliative maintenance

The automatic pneumatic system plays a crucial role in the internal logistics of the entire UHC, and any unavailability of the system can have negative consequences for various hospital services. To ensure uninterrupted usage of the system, the UHC must be prepared to implement palliative actions as temporary solutions while awaiting definitive curative maintenance. In order to effectively manage palliative troubleshooting maintenance, the supervising and maintenance company should:

- Maintain round-the-clock monitoring and control of the entire installation, including both hardware and software components.
- Implement preventive maintenance strategies to prevent and minimize plant downtime using systematic and condition-based approaches.
- Optimize repair times during breakdowns to minimize service disruptions.
- Address repetitive breakdowns by conducting thorough diagnostics to identify root causes and implementing effective maintenance actions.
- Ensure that all facilities and their networks, from sources to terminals, are in good working order and maintain performance levels comparable to the initial specifications.

Continuous improvement is essential for each system, and this is achieved by analyzing maintenance and supervision reports. Problems should be thoroughly examined to identify root causes and plan appropriate actions for their elimination or reduction. A yearly report based on the PDCA methodology (Plan, Do, Check, Act) should be produced in collaboration with user departments and the maintenance department, incorporating their valuable input.

5. Conclusion

The proposed study has demonstrated the numerous advantages of the PTS over manual sample transport. Findings have shown that PTS optimizes hospital logistics significantly, resulting in reduced lead times, improved quality, reliability, safety, and traceability, which have been positively received and acknowledged by the staff. However, like any automated system, pneumatic transport faces organizational, technical, and human challenges as outlined above. To ensure the system's effectiveness and expected benefits, maintenance holds significant importance. Regular performance monitoring is necessary to identify areas for improvement or modification, aiming to enhance security, performance, and internal customer satisfaction among professional users.

However, the proposed study has certain drawbacks that open up opportunities for future research directions. First, it is important to acknowledge the necessity for a larger sample size in order to ensure he reliability of the obtained results. Additionally, future studies could explore the usage of the PTS in other hospitals to provide a more comprehensive understanding of its effectiveness and potential areas for improvement. There are additional areas to explore regarding PTS, such as the examination of predictive maintenance strategies. By leveraging sensor data and historical maintenance records, researchers can develop predictive models that anticipate potential system failures. These models enable proactive maintenance actions, resulting in reduced downtime and enhanced system reliability. Furthermore, the utilization of Industry 4.0 technologies can enhance the supervision and maintenance of PTSs. Augmented Reality (AR) and Virtual Reality (VR) applications can greatly improve troubleshooting and maintenance activities through interactive guides and virtual simulations. These immersive technologies provide visual aids and step-by-step instructions, facilitating efficient and effective maintenance procedures. Additionally, the integration of Blockchain technology can enhance security and traceability within PTS operations. By ensuring item integrity and regulatory compliance, blockchain technology adds an extra layer of trust and transparency to the system. It enables secure and tamper-proof record-keeping, facilitating regulatory audits and ensuring the reliability of transported items. Moreover, the implementation of Internet of Things (IoT) technologies allows for real-time monitoring and control of PTSs. Through the use of sensors and analytics, IoT enables continuous data collection, analysis, and automated maintenance actions (Oubrahim and Sefiani, 2023). This real-time monitoring and control system can proactively detect anomalies, optimize system performance, and minimize the risk of failures or disruptions. The maintenance of the Pneumatic Transport System (PTS) should also be regarded as a support process, seamlessly integrating with the hospital's existing systems related to quality, health, safety, and the environment. Especially in cases where systems are pre-aligned with established integration framework (Ahidar et al., 2019), the process of incorporating the PTS becomes more streamlined and efficient. By exploring these research areas, future studies can contribute to the development of intelligent and efficient pneumatic transport systems within the context of Smart Hospitals and Logistics 4.0. This, in turn, will lead to improved patient care, enhanced operational efficiency, and better resource utilization in healthcare logistics.

References

Ahidar, I., Sarsri, D. and Sefiani, N. (2019), "Approach to integrating management systems: Path to excellence application for the automotive sector using SYSML language", *The TQM Journal*, Vol. 31 No. 2, pp. 183–204, doi: 10.1108/TQM-02-2018-0025.

Benzidia, S., Ageron, B., Bentahar, O. and Husson, J. (2019), "Investigating automation and AGV in healthcare logistics: a case study based approach", *International Journal of Logistics Research and Applications*, Vol. 22 No. 3, pp. 273–293, doi: 10.1080/13675567.2018.1518414.

Božić, D., Šego, D., Stanković, R. and Šafran, M. (2022), "Logistics in healthcare: a selected review of literature from 2010 to 2022", *Transportation Research Procedia*, Vol. 64, pp. 288–298, doi: 10.1016/j.trpro.2022.09.033.

Chen, D.Q., Preston, D.S. and Xia, W. (2013), "Enhancing hospital supply chain performance: A relational view and empirical test", *Journal of Operations Management*, Vol. 31 No. 6, pp. 391–408, doi: 10.1016/j.jom.2013.07.012.

Cubukcuoglu, C., Nourian, P., Tasgetiren, M.F., Sariyildiz, I.S. and Azadi, S. (2021), "Hospital layout design renovation as a Quadratic Assignment Problem with geodesic distances", *Journal of Building Engineering*, Vol. 44, p. 102952, doi: 10.1016/j.jobe.2021.102952.

Dolnicar, S., Grün, B. and Leisch, F. (2011), "Quick, Simple and Reliable: Forced Binary Survey Questions", *International Journal of Market Research*, Vol. 53 No. 2, pp. 231–252, doi: 10.2501/IJMR-53-2-231-252.

Dr. Arun. Mavaji, Dr.Arun.M. (2013), "Innovative Methods To Improve Hospital Efficiency- Study Of Pneumatic Transport Systems (Pts) In Healthcare.", *IOSR Journal of Business and Management*, Vol. 9 No. 6, pp. 10–15, doi: 10.9790/487X-0961015.

Farnsworth, C.W., Webber, D.M., Krekeler, J.A., Budelier, M.M., Bartlett, N.L. and Gronowski, A.M. (2019), "Parameters for Validating a Hospital Pneumatic Tube System", *Clinical Chemistry*, Vol. 65 No. 5, pp. 694–702, doi: 10.1373/clinchem.2018.301408.

Feibert, D.C. and Jacobsen, P. (2019), "Factors impacting technology adoption in hospital bed logistics", *The International Journal of Logistics Management*, Vol. 30 No. 1, pp. 195–230, doi: 10.1108/IJLM-02-2017-0043.

Fernandes, C.M.B., Worster, A., Eva, K., Hill, S. and McCallum, C. (2006), "Pneumatic Tube Delivery System for Blood Samples Reduces Turnaround Times Without Affecting Sample Quality", *Journal of Emergency Nursing*, Vol. 32 No. 2, pp. 139–143, doi: 10.1016/j.jen.2005.11.013.

Gallab, M., Ahidar, I., Zrira, N. and Ngote, N. (2024), "Towards a Digital Predictive Maintenance (DPM): Healthcare Case Study", *Procedia Computer Science*, Vol. 232, pp. 3183–3194, doi: 10.1016/j.procs.2024.02.134.

Garg, A. and Dewan, A. (2022), "Pneumatic Tube Systems (PTS)", *Manual of Hospital Planning and Designing*, Springer Nature Singapore, Singapore, pp. 463–465, doi: 10.1007/978-981-16-8456-2_44.

Jawab, F. (2018), "Hospital Logistics Activities", p. 10.

Kobayashi, K., Ebihara, Y., Asami, I., Kinoshita, H., Tanazawa, T., Taji, Y., Ishida, A., *et al.* (2019), "Quality of red blood cell and platelet concentrates after transportation by a pneumatic tube system", *ISBT Science Series*, Vol. 14 No. 4, pp. 379–386, doi: 10.1111/voxs.12510.

Kriegel, J., Jehle, F., Dieck, M. and Mallory, P. (2013), "Advanced services in hospital logistics in the German health service sector", *Logistics Research*, Vol. 6 No. 2–3, pp. 47–56, doi: 10.1007/s12159-013-0100-x.

Liu, X., Wang, W. and Han, X. (2022), "Medical Intelligent Wheelchair System Design", *2022 IEEE 10th Joint International Information Technology and Artificial Intelligence Conference (ITAIC)*, presented at the 2022 IEEE 10th Joint International Information Technology and Artificial Intelligence Conference (ITAIC), IEEE, Chongqing, China, pp. 2576–2579, doi: 10.1109/ITAIC54216.2022.9836750.

Maasz, S. (2000), "Specimen Transport Systems- Design Issues in Creating Efficient Pneumatic Tube Transport Networks", *JALA: Journal of the Association for Laboratory Automation*, Vol. 5 No. 1, pp. 68–71, doi: 10.1016/S1535-5535-04-00054-1.

Makkar, N. and Madaan, N. (2016), "Study of compliance of crash carts to standards in the emergency of a tertiary care teaching hospital", *International Journal of Research in Medical Sciences*, pp. 3968–3976, doi: 10.18203/2320-6012.ijrms20162917.

Martin, J., Schuster, T., Moessmer, G., Kochs, E.F. and Wagner, K.J. (2012), "Alterations in rotation thromboelastometry (ROTEM ®) parameters: point-of-care testing vs analysis after pneumatic tube system transport", *British Journal of Anaesthesia*, Vol. 109 No. 4, pp. 540–545, doi: 10.1093/bja/aes213.

Morillo, P., Orduña, J.M., Fernández, M. and García-Pereira, I. (2018), "Comparison of WSN and IoT approaches for a real-time monitoring system of meal distribution trolleys: A case study", *Future Generation Computer Systems*, Vol. 87, pp. 242–250, doi: 10.1016/j.future.2018.01.032.

Nyaga, G.N., Young, G.J. and Zepeda, E.D. (2015), "An Analysis of the Effects of Intra- and Interorganizational Arrangements on Hospital Supply Chain Efficiency", *Journal of Business Logistics*, Vol. 36 No. 4, pp. 340–354, doi: 10.1111/jbl.12109.

Nybo, M., Lund, M.E., Titlestad, K. and Maegaard, C.U. (2018), "Blood Sample Transportation by Pneumatic Transportation Systems: A Systematic Literature Review", *Clinical Chemistry*, Vol. 64 No. 5, pp. 782–790, doi: 10.1373/clinchem.2017.280479.

Oubrahim, I. and Sefiani, N. (2023), "Exploring the drivers and barriers to digital transformation adoption for sustainable supply chains: a comprehensive overview", *Acta Logistica*, Vol. 10 No. 2, pp. 305–317, doi: 10.22306/al.v10i2.396.

Oyaert, M., Heireman, L. and Delanghe, J. (2020), "Potentially Confounding Variables in the Validation of Hospital Pneumatic Tube Systems", *The Journal of Applied Laboratory Medicine*, Vol. 5 No. 2, pp. 422–423, doi: 10.1093/jalm/jfz009.

Ozkil, A.G., Fan, Z., Dawids, S., Aanes, H., Kristensen, J.K. and Christensen, K.H. (2009), "Service robots for hospitals: A case study of transportation tasks in a hospital", *2009 IEEE International Conference on Automation and Logistics*, presented at the 2009 IEEE International Conference on Automation and Logistics (ICAL), IEEE, Shenyang, China, pp. 289–294, doi: 10.1109/ICAL.2009.5262912.

Pupek, A., Matthewson, B., Whitman, E., Fullarton, R. and Chen, Y. (2017), "Comparison of pneumatic tube system with manual transport for routine chemistry, hematology, coagulation and blood gas tests", *Clinical Chemistry and Laboratory Medicine (CCLM)*, Vol. 55 No. 10, doi: 10.1515/cclm-2016-1157.

Slavík, L., Úlehlová, J., Bradáčová, P., Chasáková, K., Hluší, A., Palová, M. and Entrová, A. (2020), "The Modern Pneumatic Tube System Transports with Reduced Speed Does Not Affect Special Coagulation Tests", *Journal of Medical Systems*, Vol. 44 No. 9, doi: 10.1007/s10916-020-01614-6.

Sodi, R., Darn, S.M. and Stott, A. (2004), "Pneumatic tube system induced haemolysis: assessing sample type susceptibility to haemolysis", *Annals of Clinical Biochemistry: International Journal of Laboratory Medicine*, Vol. 41 No. 3, pp. 237–240, doi: 10.1258/000456304323019631.

Subbarayan, D., Choccalingam, C. and Lakshmi, C.K.A. (2018), "The Effects of Sample Transport by Pneumatic Tube System on Routine Hematology and Coagulation Tests", *Advances in Hematology*, Vol. 2018, pp. 1–4, doi: 10.1155/2018/6940152.

Yurt, E.F., Akbiyik, F. and Bicer, C. (2022), "Investigation of the effects of pneumatic tube transport system on routine biochemistry, hematology, and coagulation tests in Ankara City Hospital", *Clinical Chemistry and Laboratory Medicine (CCLM)*, Vol. 60 No. 5, pp. 707–713, doi: 10.1515/cclm-2021-1235.