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Innovative Model to Identify and Shunt Patients for Mobile Outpatient Specialist Appointment Registration: A Cloud-based Precise Reservation Path In Shanghai, China

Minjie Chen,[1] Xiaojing Zhao ,[2] Binyuan Zhang,[1] Xuji Zhao,[1] Weijun Shao,[3] Li li,[4,5] Yiling Fan[1*],Tao Zheng,[3*] and Enhong Dong,[6 , 7*]

Author affiliations

[1]Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China

[2]Department of thoracic surgery department, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China

[3]Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China

[4] School of Medicine ,Shanghai Jiao Tong University ,Shanghai ,China

[5] China Hospital Development Institute ,Shanghai Jiao Tong University ,Shanghai , China

[6]School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences, Shanghai, China, 9

[7]Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University, Shanghai, China

Co-Corresponding authors:

Yiling Fan

Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University

No.160 Pujian Road, Pudong new district

Shanghai, 200127
China
Phone:+8613818458771
mail:fanyiling@163.com

Tao Zheng
Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University
No.160 Pujian Road, Pudong new District
Shanghai, 200127
China
Phone:+8618918119818
E-mail: zhengtao@renji.com

Enhong Dong
School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences
No.279 Zhouzhu Road, Pudong new District
Shanghai, 210318
China
Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University
No.1594 Huashan Road, Xuhui District
Shanghai, 200230
China
Phone:+86 13761141620
E-mail: kevin8012@126.com

Abstract

Objective: This study aims to develop a precise reservation path (PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals and to assess its efficacy in timely identification of patients.

Materials and Methods: This study was conducted at a tertiary hospital in China in December 2020. Data of 58271 samples were retrieved from the official WeChat medical service account and HIS at the Hospital. A multivariate logistic regression model and a two-step cluster analysis (TSCA) were performed to identify the main influencing factors and key group characteristics, respectively.

Results: A PRP program was successfully designed and implemented in more than 58000 patients who applied for specialist appointments. Of these, the mean age of all participants was 52.89±15.73 years. Results of this study show that the total patients significantly associated with "Pass" were male, aged 60–74, and aged ≥75 Years. Moreover, female, aged 35–59, and payment by self were significant risk factors influencing “truly failed to pass” , while aged 60–74 years old and aged ≥ 75 years old were protective factors of “truly failed to pass” in group B among which patients failed to pass the review. Additionally, TSCA method produced six clusters of 37981 patients who were rejected in the PRP program.

Conclusions: The PRP program has a key function to efficiently identify and select patients with suspected or confirmed severe illnesses and fulfills a functional role in in identifying patients who may not require specialist care.

Key words: Precise Reservation Path, Tertiary Hospitals, Outpatient, Appointment Registration, Specialist

Strengths and limitations of this study

▸ ▸ The precise reservation path (PRP) was successfully designed and implemented for over 58,000 patients. Its primary function is to identify and select patients with suspected or confirmed severe diseases, ensuring they receive timely and efficient treatment, and optimizing outpatient services procedures in hospitals.

▸▸This study is the first to develop and investigate a cloud-based reservation system specifically designed for patients seeking outpatient specialist medical care in tertiary hospitals in China. It addresses the challenges posed by limited medical resources and offers valuable insights for other developing countries with underdeveloped hierarchical medical and general practitioner systems.

▸▸Further prospective multicenter studies are needed to replicate this study for the generalizability of the findings.

▸ ▸ Additional research is necessary to develop alternative indicators that encompass a broader range of characteristics for patients who are turned away from hospitals when hospital care services are required.

INTRODUCTION

Most people want affordable and dependable high-quality products and services, be it produce, electronics, auto repairs, or a massage. The same is true for the healthcare sector. High-quality healthcare is defined as care that is effective, safe, patient-centered, timely, efficient, equitable, and delivered by professionals who are respectful, communicate clearly, and involve patients in decision-making[1]. To achieve the goals of "Healthy China 2030," in recent years, China has deepened health reform by building high-quality and value-based service delivery, resulting in a series of significant improvements. However, several challenges still exist, including the uneven distribution of healthcare resources and the imbalance between supply and demand[2–3]. To the best of our knowledge, improving the efficiency of hospital care is a fundamental aspect of strengthening the health system. In China, public hospitals are the main body of the medical service system and the primary places for people to seek medical treatment. According to China Health Statistics Yearbook, in 2018, public hospitals provided 92% of outpatient services for all hospitals in China and 82%of inpatient services. According to China's health delivery structure, public hospitals are organized into a three-tier system (designated as primary, secondary, or tertiary institutions). A tertiary hospital is a comprehensive, referral, and general hospital at the city, provincial, or

national level with a bed capacity exceeding 500. Tertiary hospitals are responsible for providing specialist health services, performing a larger role in medical education and scientific research, and serving as medical hubs providing care to multiple regions[4]. As China's healthcare system does not feature a gatekeeping general practitioner system, patients can seek primary care from primary care facilities or hospital outpatient departments[5]. In light of the free choice of healthcare providers, most patients prefer to choose a specialist (who is a medical doctor, often with a senior professional title and an expert in a specific area of medicine) in clinics or private or public hospitals, particularly tertiary public hospitals. However, due to the unequal access to information between doctors and patients, the freedom to choose healthcare providers often leads patients to select doctors without adequate knowledge or understanding, potentially resulting in a significant misallocation of medical resources[6]. This is because patients may lack the necessary information to determine who is the most suitable doctor for their needs. In addition, patients with minor illnesses prefer to visit tertiary hospitals instead of prime care centers. These behaviors lead to a significant squandering of valuable medical resources, creating a dual challenge. Firstly, they impose a heavy economic burden on patients, potentially surpassing the affordability limits of the medical system. Secondly, these behaviors pose obstacles to the high-quality development of tertiary hospitals in China. Moreover, the scarcity of healthcare resources[7] has led to fierce competition among patients. To enable doctors to provide high-quality and timely outpatient services, many hospitals have implemented novel appointment registration systems that assist patients and increase hospital efficiency. With these systems, hospitals can only provide services to patients with limited efficacy. Under the rule of "first registration, first service" in appointment registration systems, some patients with severe diseases requiring specialist treatment may struggle to successfully book appointments with the necessary specialists. This violation of fairness in healthcare resource allocation goes against the principles addressed by China's current medical reform.Thus, optimizing the appointment registration system and improving the

efficiency of medical procedures in Chinese tertiary public hospitals is imperative. Accordingly, hospitals are experimenting with novel appointment registration systems, such as mobile phones, web-based systems, bank-hospital cooperation, and clinical settings. Among these, redesigning the appointment-scheduling system is crucial for making effective use of healthcare resources, increasing operational efficiency, reducing operational costs, and mitigating the imbalance between supply and demand for healthcare services[8].

Over the past decade, China has had the highest number of smartphones per capita among all countries[9]. Equipped with Internet Plus Medical" applications, online appointment systems have become an alternative that optimizes the appointment process, significantly improving the efficiency of hospital services. Hospitals provide various web-based services through mobile platforms, including WeChat and other independently-developed applications. Hospital services include online consultations[10], appointment registration, and online payments. Such mobile health initiatives can overcome geographic boundaries, enhance the equity and accessibility of healthcare resources, and provide effective and equitable access to healthcare services in hospitals[11]. A mobile appointment registration service can provide patients with an important online channel through which all patients with smart devices can access healthcare resources. With the availability of mobile appointment registration services, patients will increasingly turn to online platforms to book appointments, gradually replacing the traditional offline queuing registrations. This shift to online registration is expected to create a higher demand for services on mobile health platforms. In hospitals, the outpatient department plays a critical role in efficiently managing medical resources as it not only directs patients for timely care but also generates numerous benefits, including improved health outcomes and optimized utilization of healthcare resources. As mentioned above, optimizing appointment-registration procedures is the responsibility and commitment of hospital management. Therefore, effective scheduling of on-hand mobile appointment registration

services and providing healthcare services to patients have become key priorities for outpatient departments in tertiary public hospitals in China.

This study aims to develop a precise reservation path (PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals in Shanghai, China. This study first described a specialist-led reservation process whereby the clinical data (history, examination, and past treatment) of a reservation applicant were assessed using relevant ultrasound, laboratory, or radiological records. Subsequently, a decision was made regarding the suitability of the patient for specialist intervention. Second, employing specific statistical analysis methods, our objective was to assess its efficacy in timely identification of patients who require specialist medical services, thereby streamlining their referral to appropriate healthcare settings, such as specialized clinics or primary care institutions. This evaluation aims to strengthen and improve the implementation of the hierarchical diagnosis and treatment system in China.

MATERIALS AND METHODS

Design

Procedure of PRP

This study was conducted at Renji Hospital, School of Medicine, Shanghai Jiao Tong University, a 2,750-bed general tertiary public hospital in Shanghai, China. In an attempt to fully digitize its records, the hospital has put in place a satisfactory information infrastructure in which most medical and health records are stored electronically. The annual number of outpatient and emergency visits to the hospital exceeds 5.820 million, and the annual number of discharged patients is 172,000. Prior to designing the precise reservation path (PRP) system, a literature search, peer-to-peer discussions, panel discussions, and specialist consultations were conducted to determine the structure and design of the system. Staff from the outpatient and emergency management department, as well assurgeons

specializing and IT technicians in thoracic surgery, breast surgery, and urinary surgery, attended the meeting to design the PRP process. The PRP process was designed as follows. Our predefined main objective was to build a cloud-based medical precise reservation path (PRP) connecting all participants (patients and specialists). Based on the PRP framework, patients with suspected severe diseases can send a specialist appointment request and submit their medical records. After a specialist reviews the patient's application and medical records, the specialist may approve or reject the patient's application. A PRP flowchart is shown in Figure 1.

Figure1.The PRP flow chart

Architecture of PRP

The architecture of the PRP model is illustrated in Figure S1. Technical support was provided to make different system modules compatible and establish a cloud-based precise reservation path (PRP) system to connect the new system to Renji Hospital's original hospital information system (HIS). Building on the original HIS, new modules and functions were added to share all specialist outpatient schedules and specialist team accounts, such as WeChat (WeCom). The PRP system was integrated with hospital scheduling systems, enabling automatic identification of appointment statuses, such as whether an appointment had been made, requested, or canceled (and changing the status to require rescheduling). The specialist team user had one-click access to review the patient's application, examine the notes in the submitted medical records, and communicate with the team regarding treatment plans, thereby determining the need for scheduling a further evaluation.

Operation of PRP

The PRP is based on the hospital's official WeChat account platform

WeChat(WeCom) is a free social networking application offering instant messaging services across all platforms. It provides basic text, voice, photos, video sharing, and web-based payments and integration with intelligent hardware. Tencent's financial report shows that the number of combined monthly live WeChat accounts exceeded 1.2 billion by the end of March 2021. Based on the WeChat Framework, we developed a function that can operate on both iOS and Android mobile platforms. Therefore, our design had a minimum learning cost for the participants and ensured the sustainability of users.

PRP is based on an asynchronous form

The exchange of online information between patients and doctors can occur synchronously (when interactions occur in real-time) or asynchronously (when there is a lag between the information being transmitted and the response)[12–13]. We adopted an asynchronous form of PRP because doctors in hospitals are always busy and cannot guarantee that they are online in real-time. In addition, an asynchronous form makes full use of the doctors' fragmented time to process and respond to patient applications.

PRP is also based on cloud computing services

Cloud computing involves the on-demand availability of computer system resources, particularly data storage (cloud storage) and computing power, without direct active management by users. It provides on-demand network access to a shared resource pool and configurable computing resources across the network as a metered on-demand service that efficiently distributes resources. The cloud computing architecture exhibits various characteristics such as cost reduction, device and location independence, easier maintenance of the cloud environment, and on-demand self-service. Similarly, it is well known that one of the essential features of mobile health services is on-demand self-service, where users can

instantly access network storage and server processing time. Therefore, we set the PRP based on cloud-computing services.

PRP Involving users of PRP

The PRP consists of two different types of users: patients and specialists. Mobile Outpatient Specialist Appointment Registration Procedures for patients and specialists were present in Table S1.

Evaluation of the PRP program using two methods

Data resources and measures

Renji Hospital began implementing PRP in December 2020. Data used in the study were retrieved from the official WeChat medical service account and HIS at Renji Hospital from December 1, 2020, to November 30, 2022. In total, 58271 samples were obtained. The specialist's review outcomes were dichotomized into not passed (=0) or passed (=1) as the dependent variable. Independent variables included gender, age, academic level of the specialist, clinical department, insurance status, and type of rejection. The classifications and measures of the variables of interest are present in Table S2. Ethical approval was obtained from the Human Research Ethics Committee of Renji Hospital (LY2023-031-B). All participants gave written informed consent in accordance with the Declaration of Helsinki

Analysis strategy

Traditional statistical method: multivariate logistic regression method

First, all the continuous variables were tested for normality. Means ± standard deviations were used for variables that obeyed a normal distribution. Univariate analysis was then conducted to identify significant contributors to the dependent variable, that is, whether the patient passed the online specialist appointment

registration confirmation. Finally, to identify the main factors influencing the specialist's review outcome, a multivariate logistic regression applying the backward stepwise method was performed.

Two-Step Cluster Analysis (TSCA)

To further understand key demographic characteristics and activities in the "non-pass patients" group, we conducted a two-step cluster analysis (TSCA) approach accordingly. Cluster analysis is an exploratory method that identifies hidden data structures. It identifies homogenous clusters of cases based on the distribution of input variables. More importantly, cluster analysis can be performed even when the actual grouping of cases is unknown.

The TSCA was used in this study because of its ability to handle categorical variables and large sample sizes. Additionally, TSCA presents advantages beyond other methods in that the optimal number of clusters is automatically determined, and no a priori assumptions about the number of clusters are required. TSCA is a hybrid approach that uses a distance measure to separate individuals, similar to Latent Class Analysis(LCA), with the selection of an optimal subgroup model. This approach has been shown to perform better than other traditional hierarchical cluster techniques. The fitness of the models was tested using Schwarz's Bayesian Information Criterion (BIC) with a mean silhouette coefficient.

All statistical analyses were performed using SPSS software (version 23.0; IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to build the study and TSCA models.

RESULTS

Overview and basic characteristics of patients

A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. During this period, 58271 patients applied for specialist appointments through the PRP program. Of these, 20290 (34.8%) patients passed the specialist assessment, and 37981 (65.2%) did not.

Among the 26 specialties, the top 15 specialties that patients applied for were urinary surgery, breast surgery, thoracic surgery, obstetrics and gynecology, gastrointestinal surgery, nephrology, head and neck surgery, biliary and pancreatic surgery, radiotherapy, traumatic orthopedics, vascular surgery, rheumatology, immunology, cardiology, joint surgery, and gynecological oncology (For details to see Table S3).

Of the 58271 patients, the mean age was 52.89 ± 15.73 years. Among them, 22412 (38.5%) were male, and 35859 (61.5%） were female. See Table 1 For more details of patient characteristics.

Results of univariate and multivariate logistic regression analysis in the total population sample (N=58271)

Table 2 presents results of univariate and multivariate logistic regression analysis in the total population sample. Through univariate analyses, the significant factors associated with the specialist review outcome were gender (P < 0.001) and age (P < 0.001), which were included in the multivariate logistic regression model. Then, through a multivariate logistic regression model, it indicates that those who were male and aged 60 years old or above were more likely to pass the specialist's review in the age PRP program, while those aged 35–59 years were less likely to pass the specialist's review in the likely PRP program compared to those who aged 18–34 years old (See Table 1).

Table1.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To The specialist's review outcome

Items	Characteristics		Pass the Review		Univariate Analysis	Multivariate Analysis
	Variable	Frequency (%)	Not Pass (Group	Pass (Group	*Chi square test*	*Logistic Regression*

	s		A)	B)	χ^2	*P*	*OR* (95% *CI*)	*P*
Gender	Male	22412 (38.5)	13819 (61.7)	8593 (38.3)	198.94	<0.001	1.234 (1.190-1.280)	<0.001
	Female	35859 (61.5)	24162 (67.4)	11697 (32.6)			1.000	
Age (years)	18-34	9003 (15.5)	5902 (65.6)	3101 (34.4)	154.93	<0.001	1.000	
	35-59	26590 (45.6)	17939 (67.5)	8651 (32.5)			0.907 (0.863-0.954)	<0.001
	60-74	18405 (31.6)	11577 (62.9)	6828 (37.1)			1.057 (1.002-1.116)	0.04
	Above 75	4273 (7.3)	2563 (60.0)	1710 (40.0)			1.166 (1.080-1.258)	<0.001
If Having Preference to pay with Insurance or not	Yes	42089 (72.2)	27437 (65.2)	14652 (34.8)	0.004	0.95	/	
	No	16182 (27.8)	10544 (65.2)	5638 (34.8)			/	
Whether having	Yes	20290 (34.8)		/	/		/	

Passed the Review	No	37981 (65.2)

Results of univariate and multivariate logistic regression analysis in group B sample (n=37981)

To further investigate the reason why patients did not pass the review by the specialist in the PRP program, we divided the total population involved in the PRP program into two groups: group A("pass" group) and group B ("not-pass" group). Here, we focused on the true reason why B-group patients did not pass the review in the PRP program. We redefined the variable of the reason for rejection as the dependent variable in this study, and it was dichotomized into "not truly fail to pass"(=0) (e.g., rejected for not preparing well, such as having no uploaded past test reports due to inability to use mobile phones or rashly deciding to see a specialist regardless of the severity of diseases) or "truly fail to pass"(=1). Table 2 presents the results of univariate and multivariate logistic regression analysis of factors related to true failure to pass in Group B. By conducting the univariate analyses and multivariate logistic regression analysis (using the backward stepwise method), the findings indicate that those who were female, aged 35–59 years old with self-payment were more likely to be truly rejected than those who were male or aged 18–34 years or paid with medical insurance. Conversely, patients aged 60–74 or 75 years or older were less likely to be fully rejected by the PPR program than those aged 18–34 years old.

Table 2.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To True failure to pass in Group B

Items	Characteristics		Truly failed to pass		Univariate Analysis		Multivariate Analysis	
	Variables	Frequency (%)	No	Yes	*Chi square test*		*Logistic Regression*	
					χ^2	*P*	*OR* (95% *CI*)	*P*
Gender	male	13819 (36.4)	8685 (62.8)	5134 (37.2)	157.65	<0.001	1.000	
	female	24162 (63.6)	13592 (56.3)	10570 (43.7)			1.230 (1.177-1.286)	<.001
Age (years)	18-34	5902 (15.5)	3484 (59.0)	2418 (41.0)	260.60	<0.001	1.000	
	35-59	17939 (47.2)	9831 (54.8)	8108 (45.2)			1.1967 (1.127-1.270)	<0.001
	60-74	11577 (30.5)	7236 (62.5)	4341 (37.5)			0.912 (0.855-0.974)	0.006
	Above 75	2563 (6.7)	1726 (67.3)	837 (32.7)			0.763 (0.691-0.842)	<0.001
Preference to pay					24.42	<0.001		

with insurance or not	yes	27437 (72.2)	16305 (59.4)	11132 (40.6)		1.000	
	not	10544 (27.8)	5972 (56.6)	4572 (43.4)		1.101 (1.051-1.152)	<0.001
Truly failed to pass if rejected	No	22277 (58.7)		/	/	/	
	Yes	15704 (41.3)					

Results of TSCA

Importance and silhouette coefficient

We set the cluster inputs for the categorical variables of gender, age, preference to pay with medical insurance, and the reasons why they were rejected. TSCA produced six clusters of 37981 patients. Gender and payment with or without insurance were the most important predictors of cluster membership (valued 1.00), followed by the reason for rejection (valued 0.66). Age was considered to have little potential to improve the overall goodness of the final model. The silhouette coefficient, or silhouette score, is a metric used to calculate the goodness of a clustering technique. Its value ranges from -1 to 1, with 1 indicating well-separated and distinct clusters, 0 indicating indifference between clusters (i.e., the distance between clusters is insignificant), and -1 indicating incorrect cluster assignment[14]. The silhouette coefficient in this study was 0.86, indicating a good cluster quality.

Specific features of the six clusters

The differences in specific features among the six clusters are present in Figures 2-3, and Table S4

Figure 2. Visualization Cluster Features In The Clusters Of TSCA Results

Figure 3. Different Cluster Distances to Each Other for Six Clusters In TSCA Results

In Figure 3, it can be observed that clusters 1, 2, and 3 were relatively closer to each other, clusters 4, 5, and 6 were relatively closer to each other. The two different types of closer-distance cluster groups were more distant from each other, which was verified by the value of the importance of gender reaching 1(See Figure S2). Moreover, the distances between clusters 1, 2, and 4 were closer to each other, which was also verified by the value of the importance of the preference to pay with insurance or not reaching 1(See Figure S2), indicating that they all belonged to the same groups having a preference to pay with medical insurance.

DISCUSSION

Digital technologies are increasingly being used to support health systems (WHO, 2018) by providing flexible options for interpersonal communication and information exchange[15]. Access, affordability, and equity are three basic goals of a well-functioning health system[16]. The findings of the study of the PRP program indicated that the mobile-health-based PRP program is a practical and innovative approach that can help patients obtain equitable access to medical specialists in hospitals precisely with less doctor-seeking costs and be treated on time and highly efficiently, facilitating the optimization of outpatient procedures in hospital management. In this study, among 58271 patients applying for medical specialists on the PRP-based platform, 20290 patients with severe diseases (suspected or confirmed) passed reviews by specialists, helping them access specialists' medical treatment in hospitals. Moreover, through the PRP program, the remaining 37891 patients who did not pass the specialists' review were identified and advised for appropriate shunts to the hospital's other clinical departments or primary care

centers for treatment by GPs, preventing them from blindly making appointments with specialists, which may waste medical resources in hospitals.

In our study, among the groups aged 60 years or older, the older the patients, the higher the probability of passing the review by a specialist in hospitals. This may be because the elderly, who often suffer a variety of chronic diseases, may have higher medical needs than younger individuals[17]. This is consistent with the evidence that many previous studies have claimed that elderly patients have greater utilization of hospital outpatient or inpatient healthcare services than their younger counterparts because of their unfavorable health status[18]. Conversely, those aged 35–59 years had a lower probability of passing the specialist review and a higher probability of being truly rejected than those aged 18–34 years. This could be explained by the fact that middle-aged patients prefer advanced medical care regardless of their factual medical needs. These patients may see specialists in hospitals for psychological comfort or because they mistrust GPs in primary care settings, although they do not need special medical care. Many previous studies have reported that this phenomenon results from a lack of community gatekeeper systems in China[19–20]. This reflects the urgent need to strengthen primary care and family doctor services that target middle-aged groups in China. Therefore, the Shanghai government and decision-makers in the health sector should make age-specific efforts to facilitate the implementation of hierarchical diagnosis and treatment systems and family doctor services among middle-aged patients. By shunting middle-aged patients toward GPs or secondary hospitals, patient crowding caused by the" siphon effect" can be mitigated, thus improving the efficiency of procedures in tertiary hospitals.

Additionally, female patients were more likely than male patients to be rejected by specialists when they applied for a visit to a specialist using the PRP Apps. Furthermore, they were more likely to be truly rejected. This may be attributed to women's more cautious health beliefs, as well as more health problems, which often occur when they are aging, both of which cause women 'health anxiety' that prompts them to seek medical care more often, particularly medical specialists in

hospitals. According to the gender structure of participants in the study, the number of female applicants exceeded that of male applicants, achieving 61.5% of the total applicants. A similar study conducted in Canada claimed that female patients accounted for 59% of upward referrals from grassroots institutions to hospitals providing specialty care services[21]. This was also consistent with the results of the TSCA method: a cluster (cluster Ⅱ) accounting for one-fifth of the total rejected patients was identified, with some features of being female, having a preference to use medical insurance, having past examination reports uploaded, and truly failing to pass the review. It is crucial to prioritize this specific cluster and urge the government to implement focused interventions. These interventions should aim to educate individuals about the significance of primary healthcare and contracted family doctor services, while also facilitating their smooth transition to general practitioners within community health settings.

Through cluster analysis, we obtained some notable findings regarding the features of the six patient clusters in the study. Among the rejected patients in the six groups, the majority were female. This is because women have greater health anxiety, as interpreted above. Moreover, 70.69% of patient clusters, including Groups 1, 3, 4, and 5, were rejected primarily because they did not prepare well, that is, they did not provide relevant examination reports. This indicates that patients require sufficiently relevant pre-examination proofs when preparing an application for outpatient specialist services. It also reflects a grim situation in which Chinese patients blindly pursue medical experts in hospitals due to a lack of professional medical knowledge or guidance. This may be explained by the fact that hierarchical diagnostic and treatment systems have not been strictly implemented in China, highlighting the crucial role of PRP platforms in patient screening and shunts. Previous literature has posited that due to the suboptimal quality of primary healthcare[22], low recognition of residents, particularly young and healthy people, for contracted family doctor services[23] and their imperfect operating mechanism[24], there exists a phenomenon of 'signed but not contracted' when implementing contracted family doctor services in China. Therefore, the

government and health sectors should optimize mobile outpatient specialist appointment registration, strengthen the guidance for seeking specialists, and prepare patients fully for outpatient services in hospitals. More importantly, the government should also improve budget input into primary health care, educate patients to change the traditional concept of 'only emphasis on treatment over prevention,' optimize the operation mechanism[25] of contracted family doctor services, such as increase of reimbursement for family medicine, amplification of service content, optimization of service process and improvement of quality of service.

This study has some limitations. First, the study was conducted at a single center. Although the dataset contained more than 58,000 cases, further prospective multicenter studies are needed to duplicate this study for the generalizability of the findings. Second, the study relied on a single indicator, that is, the absence of uploaded past test reports, as a measure of failure to pass the specialist review. Additional research is necessary to develop alternative indicators that encompass a broader range of characteristics for patients who are turned away from hospitals due to inadequate preparation for specialist care in the Chinese healthcare context when hospital care services are required.

CONCLUSION

In conclusion, an innovative model, the PRP program, was successfully designed and implemented for more than 58000 patients. The primary function of the function is to identify and select patients with suspected or confirmed severe diseases, ensuring they receive timely and efficient treatment, and optimizing the procedures of outpatient services in hospitals. Moreover, through evaluation analyses using quantitative methods, the PRP program plays a functional role in filtering patients who are not prepared for a specialist and those who should be transferred to primary care institutions, which assists in the implementation of Chinese hierarchical diagnosis and treatment systems. This study is the first to develop and investigate a cloud-based reservation system specifically designed for patients seeking outpatient specialist medical care in tertiary hospitals in China.

The research not only addresses the challenges posed by limited medical resources but also offers valuable insights for other developing countries with underdeveloped hierarchical medical and general practitioner systems.

Abbreviations

BIC: Bayesian Information Criterion

HIS: Hospital information system

PRP: precise reservation path

TSCA:Two- Step Cluster Analysis

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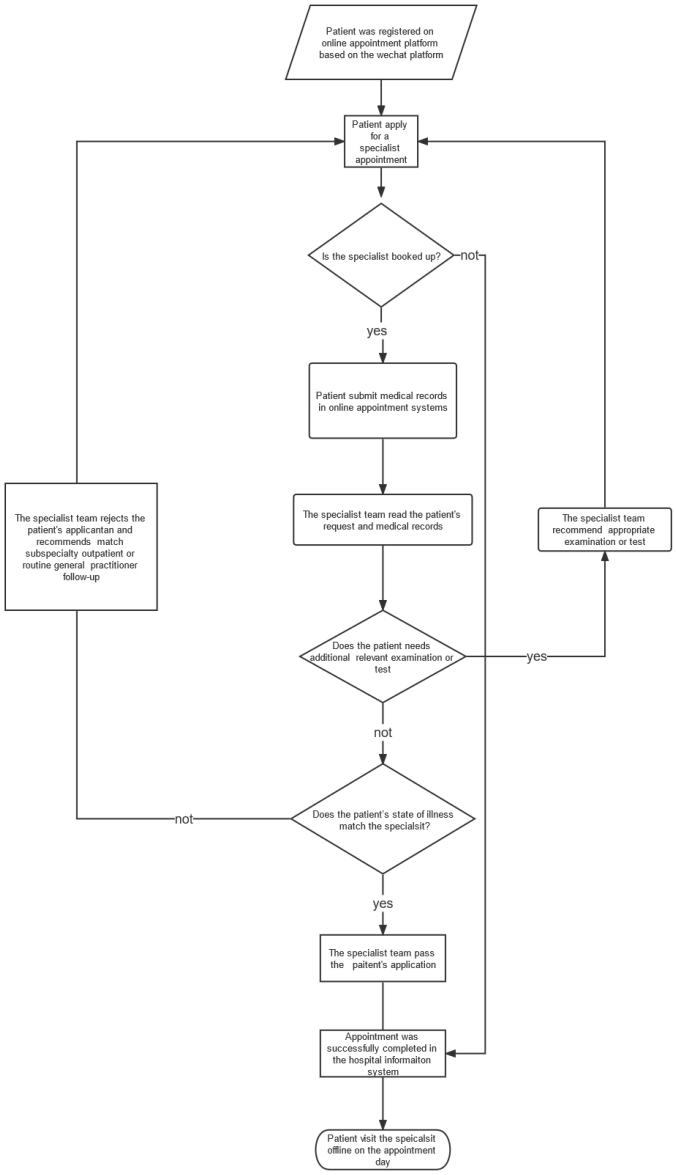

Figure1.The PRP flow chart

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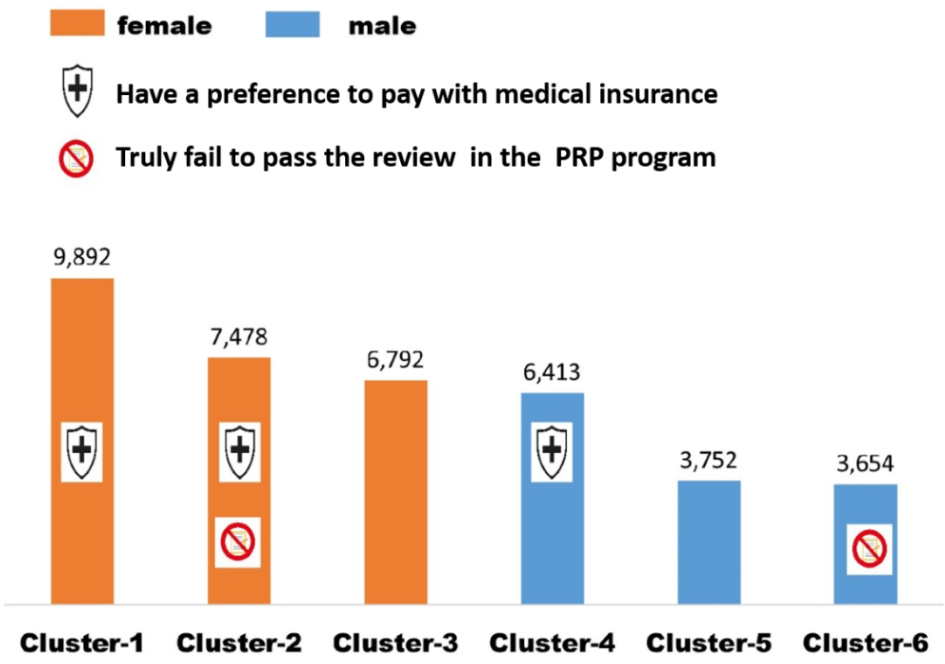

Figure 2. Visualization Cluster Features In The Clusters Of TSCA Results

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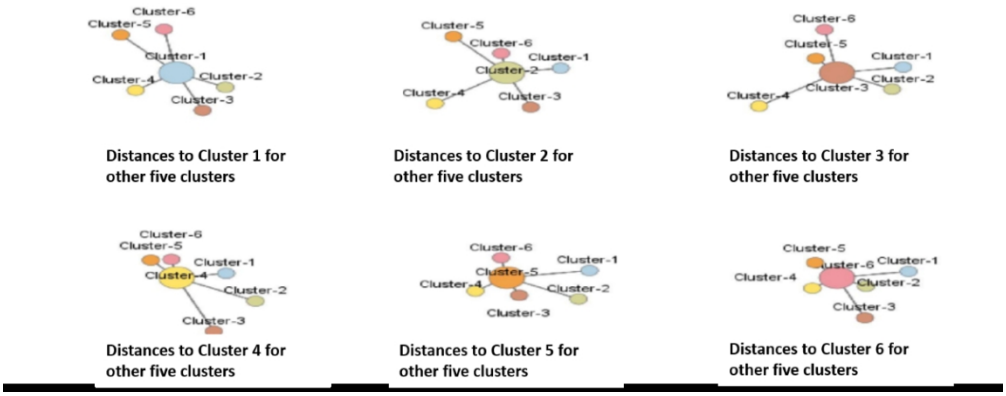

Figure 3. Different Cluster Distances to Each Other for Six Clusters In TSCA Results

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Table S1 Mobile Outpatient Specialist Appointment Registration Procedure for patients and specialists

Steps	Procedure for patients
1	The patient registers on the WeChat official medical service account of Renji Hospital using a mobile phone.
2	The patient reads the online specialist directory of the hospital and the diseases in which the specialist specializes.
3	The patient selects a specific specialist and requests an appointment by accessing the "Precise Reservation Path (PRP)" label.
4	The patient confirms the informed consent of the PRP, protocol, and submission of medical records.
5	According to the requirements of different specialist protocols, the patient also needs to submit relevant past examination reports (no earlier than 3 months), such as blood laboratory tests, ultrasound rays, computed tomography (CT), magnetic resonance imaging (MRI), and pathological reports.
6	If approval is received from the specialist users, the patient is allowed to visit the specialist offline on the appointed day.

Steps	Procedure for specialists
1	The specialist team user registers on the official WeChat accounts of Renji Hospital to build a PRP account using a mobile phone and obtains approval from the PRP system administrator.
2	The specialist team user completes their individual profile, including information about diseases in which they are specialized, past examination reports, and informed consent for patients before obtaining approval from the hospital's information administrator.
3	The specialist team user responds to patients' requests in a timely manner.
4	A specialist team user approves or rejects the patient's application. In the event of rejection, the user provides specific advice, such as recommending a well-matched subspecialty for the patient or suggesting a referral to their general practitioner.

Table S2 The classifications and measures of variables of interest

Variables	How to measure	Type
Whether having Passed the Review	1=Yes； 0= No	Categorical
Age	1=18-34 years; 2=35-59 years 3=60-74 years;4= 75 years or above	Categorical
Gender	1=Male ;0=Female	Categorical
If having a Preference to pay with Insurance	1=Yes; 0=No	Categorical
Academic level of the specialist they chose,	1=Professor;2=Associate professor	Categorical
Surgical department or not	1=Yes; 0=No	Categorical
Truly fail to pass if rejected	1=Yes; 0=No	Categorical

Table S3.Distribution of departments where patients apply for specialists and application results

Rank	Department	Frequency (%)	Review results	
			Not Pass(%)	Pass(%)
1	Urinary Surgery	11142 (19.1)	6972 (62.6)	4170 (37.4)
2	Breast Surgery	10097 (17.3)	8251 (81.7)	1846 (18.3)
3	Thoracic Surgery	9332 (16.0)	6752 (72.4)	2580 (27.6)
4	Obstetrics And Gynecology	4862 (8.3)	2685 (55.2)	2177 (44.8)
5	Gastrointestinal Surgery	4716 (8.1)	2895 (61.4)	1821 (38.6)
6	Nephrology	4011 (6.9)	2328 (58.0)	1683 (42.0)
7	Head And Neck Surgery,	3256 (5.6)	1541 (47.3)	1715 (52.7)
8	Biliary And Pancreatic Surgery	3076 (5.3)	1621 (52.7)	1455 (47.3)
9	Radiotherapy	1551 (2.7)	697 (44.9)	854 (55.1)
10	Traumatic Orthopedics	1406 (2.4)	889 (63.2)	517 (36.8)
11	Vascular Surgery	835 (1.4)	617 (73.9)	218 (26.1)
12	Rheumatology And	790 (1.4)	773	17 (2.2)

	Immunology		(97.8)	
13	Cardiology	692 (1.2)	574 (82.9)	118 (17.1)
14	Joint Surgery	483 (0.8)	269 (55.7)	214 (44.3)
15	Gynecological Oncology	478 (0.8)	184 (38.5)	294 (61.5)
16	Otorhinolaryngology	470 (0.8)	313 (66.6)	157 (33.4)
17	Spine Surger	445 (0.8)	194 (43.6)	251 (56.4)
18	Ophthalmology	237 (0.4)	134 (56.5)	103 (43.5)
19	Pain Medicine	143 (0.2)	85 (59.4)	58 (40.6)
20	Functional Neurology	120 (0.2)	120 (100.0)	0 (0.0)
21	Oncology	49 (0.1)	24 (49.0)	25 (51.0)
22	Plastic Surgery	25 (0.0)	18 (72.0)	7 (28.0)
23	Digestion Medicine	21 (0.0)	21 (100.0)	0 (0.0)
24	Diagnostic Radiology	18 (0.0)	8 (44.4)	10 (55.6)
25	Endocrinology	13 (0.0)	13 (100.0)	0 (0.0)
26	General Surgery	3 (0.0)	3 (100.0)	0 (0.0)
	Total	58271 (100)	37981 (65.2)	20290 (34.8)

Table S4.Interpretation of Cluster Features in TSCA Results

	Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5	Cluster-6
	N=9892, 26.04%	N=7478, 19.69%	N=6792, 17.88%	N=6413, 16.88%	N=3752,	N=3654
Gender	Female	Female	Female	Male	Male	Male
If having a preference to pay with Insurance	Yes	Yes	No	Yes	No	No
Truely failed to pass the review If rejected	No	Yes	No	No	No	Yes

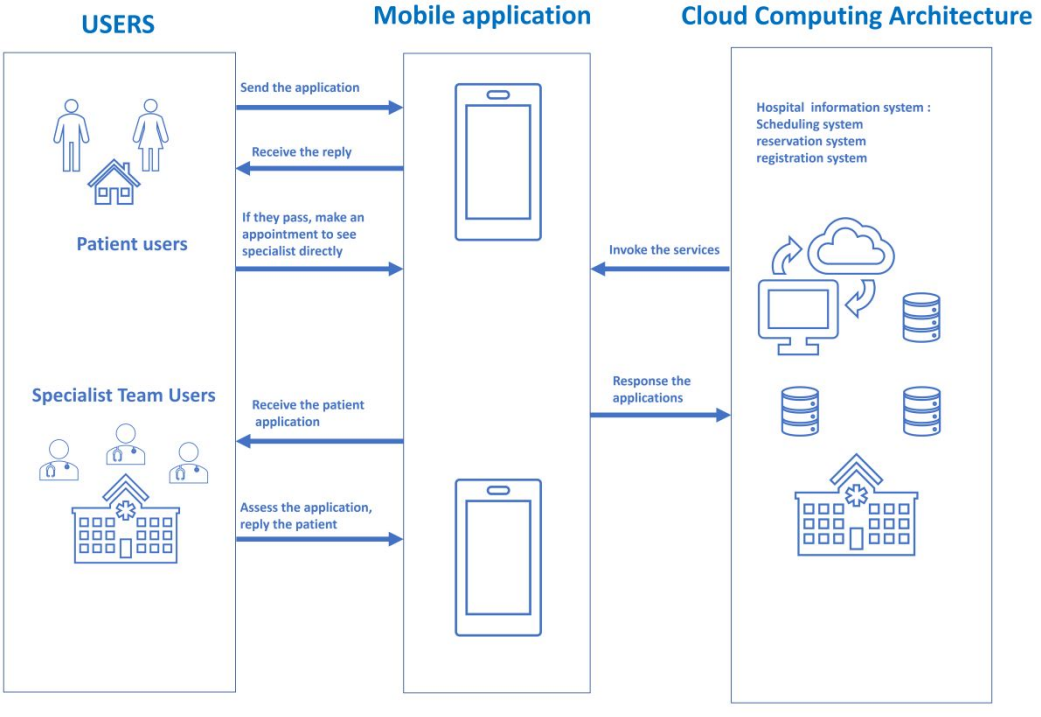

Figure S1. The PRP model architecture

Cluster Type	Records	Silhouette coefficient	Importance
Cluster-1	9,892	1.00	1.00
Cluster-2	7,478	1.00	0.93
Cluster-3	6,792	0.50	0.92
Cluster-4	6,413	1.00	0.88
Cluster-5	3,752	0.52	0.61
Cluster-6	3,654	1.00	0.56
Total	37981	0.86	/

Figure S2. The silhouette coefficient and Importance of clusters

BMJ Open

Developing, Implementing, and Evaluating an Innovative Model to Identify and shunt Patients for Mobile Outpatient Specialist Appointment Registration system: A Cloud-Based Precise Reservation Path in Shanghai, China

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Developing, Implementing, and Evaluating an Innovative Model to Identify and shunt Patients for Mobile Outpatient Specialist Appointment Registration system: A Cloud-Based Precise Reservation Path in Shanghai, China

Minjie Chen,[1] Xiaojing Zhao ,[2] Tao Zheng,[3] Binyuan Zhang,[1] Xuji Zhao,[1] Weijun Shao,[3] Li li,[4,5] Yiling Fan[1*], and Enhong Dong,[6 , 7*]

Author affiliations

[1]Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China

[2]Department of thoracic surgery department, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China

[3]Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China

[4] School of Medicine ,Shanghai Jiao Tong University ,Shanghai ,China

[5] China Hospital Development Institute ,Shanghai Jiao Tong University ,Shanghai , China

[6]School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences, Shanghai, China, 9

[7]Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University, Shanghai, China

Co-Corresponding authors:

Yiling Fan

Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University

No.160 Pujian Road, Pudong new district

Shanghai, 200127

China

Phone:+8613818458771
mail:fanyiling@163.com

Enhong Dong
School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences
No.279 Zhouzhu Road, Pudong new District
Shanghai, 210318
China
Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University
No.1594 Huashan Road, Xuhui District
Shanghai, 200230
China
Phone:+86 13761141620
E-mail: kevin8012@126.com

Abstract

Objective: The aim of this study is to introduce, implement, and evaluate the Precise Reservation Path(PRP) for scheduling shunting patients for specialist appointment registration in Shanghai, China.

Design: The PRP system was built upon the hospital's existing information system(HIS), integrated with WeChat(WeCom) for user convenience. The outcome analysis employed a mixed-methods approach, integrating quantitative analysis with statistical and machine learning techniques, including multivariate logistic regression, Random Forest(RF) analysis, and Two-Step Cluster Analysis(TSCA).

Setting:This study was conducted at Renji Hospital, a premier general tertiary care institution in Shanghai, China, where the innovative PRP system was implemented. The program was designed to efficiently connect patients requiring specialized care with the appropriate medical specialists.

Participants: The PRP encompassed both voluntary specialists at Renji hospital, as well as patients seeking outpatient specialist services.

Primary Outcome Measures: Primary Outcome Measures:The pass rates of patient for specialist applications.

Secondary Outcome Measures: Specialists ' and Patients ' individual characteristics influencing specialist approval decisions.

Results: The PRP involved specialists from 26 departments, showcasing the collaboration across various medical fields during the study period from December 1, 2020, to November 30, 2022.The RF analysis, with an accuracy of 92.31%, identified age as the most significant predictor for pass rates, highlighting the importance of age in specialist review outcomes. The univariate and multivariate logistic regression analyses revealed that older patients were more likely to pass specialist reviews, while middle-aged patients' lower pass rates suggested a need for strengthened primary care services.

Conclusions: The PRP program demonstrates the potential of digital innovation in enhancing hierarchical medical system. The study's findings also underscore the value of PRP program in healthcare systems for optimizing resource allocation, particularly for aging populations.The program's design and implementation offer a scalable model for other healthcare institutions seeking to enhance their appointment systems and specialist engagement through digital innovation.

Strengths and limitations of this study

Strengths :

▸▸The PRP program efficiently uses a popular cross-platform social app with dual iOS/Android features to minimize learning curves and maintain user sustainability.

▸▸The PRP program runs asynchronously, facilitating info exchange with time lags between patients & doctors, accommodating busy schedules to optimize processing & response to patient requests.

▸▸Holistic approach offered by study integrates dept. & patient perspectives, examining multifaceted factors affecting patient application pass rates.

▸▸Methodology integrates statistical approaches with ML algorithms(incl. Random Forest & TSCA) to handle HD data, reveal complex patterns, & offer profound insights into critical factors for patient application.

Limitations:.

▸ ▸ Budget constraints precluded structured analysis of patient condition descriptions, resulting in a lack of some disease-related variables. Future research aims to address this limitation, aiming for more comprehensive findings.

Key words: Precise Reservation Path, Appointment Registration, Specialist , Random forest , Two- Step Cluster Analysis

INTRODUCTION

Most people want affordable and dependable high-quality products and services, be it produce, electronics, auto repairs, or a massage. The same is true for the healthcare sector. High-quality healthcare is defined as care that is effective, safe, patient-centered, timely, efficient, equitable, and delivered by professionals who are respectful, communicate clearly, and involve patients in decision-making[1]. To achieve the goals of "Healthy China 2030," in recent years, China has deepened health reform by building high-quality and value-based service delivery, resulting in a series of significant improvements. However, several challenges still exist, including the uneven distribution of healthcare resources and the imbalance between supply and demand[2-3]. To the best of our knowledge, improving the efficiency of hospital care is a fundamental aspect of strengthening the health system. In China, public hospitals are the main body of the medical service system and the primary places for people to seek medical treatment. According to China Health Statistics Yearbook, in 2018, public hospitals provided 92% of outpatient services for all hospitals in China and 82% of inpatient services. According to China's health delivery structure, public hospitals are organized into a three-tier system(designated as primary, secondary, or tertiary institutions). A tertiary hospital is a comprehensive, referral, and general hospital at the city, provincial, or national level with a bed capacity exceeding 500. Tertiary hospitals are responsible for providing specialist health services, performing a larger role in

medical education and scientific research, and serving as medical hubs providing care to multiple regions[4]. As China's healthcare system does not feature a gatekeeping general practitioner system, patients can seek primary care from primary care facilities or hospital outpatient departments[5]. In light of the free choice of healthcare providers, most patients prefer to choose a specialist(who is a medical doctor, often with a senior professional title and an expert in a specific area of medicine) in clinics or private or public hospitals, particularly tertiary public hospitals. However, due to the unequal access to information between doctors and patients, the freedom to choose healthcare providers often leads patients to select doctors without adequate knowledge or understanding, potentially resulting in a significant misallocation of medical resources[6]. This is because patients may lack the necessary information to determine who is the most suitable doctor for their needs. In addition, patients with minor illnesses prefer to visit tertiary hospitals instead of prime care centers. These behaviors lead to a significant squandering of valuable medical resources, creating a dual challenge. Firstly, they impose a heavy economic burden on patients, potentially surpassing the affordability limits of the medical system. Secondly, these behaviors pose obstacles to the high-quality development of tertiary hospitals in China. Moreover, the scarcity of healthcare resources has led to fierce competition among patients[7-8]. To enable doctors to provide high-quality and timely outpatient services, many hospitals have implemented novel appointment registration systems that assist patients and increase hospital efficiency. With these systems, hospitals can only provide services to patients with limited efficacy. Under the rule of "first registration, first service" in appointment registration systems, some patients with severe diseases requiring specialist treatment may struggle to successfully book appointments with the necessary specialists. This violation of fairness in healthcare resource allocation goes against the principles addressed by China's current medical reform. Thus, optimizing the appointment registration system and improving the efficiency of medical procedures in Chinese tertiary public hospitals is imperative. Accordingly, hospitals are experimenting with novel appointment registration systems, such as mobile phones, web-based systems, bank-hospital cooperation, and clinical settings. Among these,

redesigning the appointment-scheduling system is crucial for making effective use of healthcare resources, increasing operational efficiency, reducing operational costs, and mitigating the imbalance between supply and demand for healthcare services[9].

Over the past decade, China has had the highest number of smartphones per capita among all countries[10]. Equipped with Internet Plus Medical" applications, online appointment systems have become an alternative that optimizes the appointment process, significantly improving the efficiency of hospital services. Hospitals provide various web-based services through mobile platforms, including WeChat and other independently-developed applications. Hospital services include online consultations, appointment registration, and online payments. Such mobile health initiatives can overcome geographic boundaries, enhance the equity and accessibility of healthcare resources, and provide effective and equitable access to healthcare services in hospitals[11]. A mobile appointment registration service can provide patients with an important online channel through which all patients with smart devices can access healthcare resources. With the availability of mobile appointment registration services, patients will increasingly turn to online platforms to book appointments, gradually replacing the traditional offline queuing registrations. This shift to online registration is expected to create a higher demand for services on mobile health platforms. In hospitals, the outpatient department plays a critical role in efficiently managing medical resources as it not only directs patients for timely care but also generates numerous benefits, including improved health outcomes and optimized utilization of healthcare resources. As mentioned above, optimizing appointment-registration procedures is the responsibility and commitment of hospital management. Therefore, effective scheduling of on-hand mobile appointment registration services and providing healthcare services to patients have become key priorities for outpatient departments in tertiary public hospitals in China.

This study aims to develop a precise reservation path(PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals in Shanghai, China. This study first described a specialist-led

reservation process whereby the clinical data(history, examination, and past treatment) of a reservation applicant were assessed using relevant ultrasound, laboratory, or radiological records. Subsequently, a decision was made regarding the suitability of the patient for specialist intervention. Second, employing specific statistical analysis methods, our objective was to investgate impact factors of pass rate of patients who require specialist medical services, thereby streamlining their referral to appropriate healthcare settings, such as specialized clinics or primary care institutions. This evaluation aims to strengthen and improve the implementation of the hierarchical diagnosis and treatment system in China.

MATERIALS AND METHODS

Patient and Public Involvement

This study did not involve patients or the public.

Design

Procedure of PRP

This study was conducted at Renji Hospital, School of Medicine, Shanghai Jiao Tong University, a 2,750-bed general tertiary public hospital in Shanghai, China. In an attempt to fully digitize its records, the hospital has put in place a satisfactory information infrastructure in which most medical and health records are stored electronically. The annual number of outpatient and emergency visits to the hospital exceeds 5.820 million, and the annual number of discharged patients is 172,000. This PRP program was uniquely self-developed by the management and clinical staff at Renji Hospital in Shanghai to address the current disorganized situation where outpatients schedule specialists without any restrictions. Prior to designing the precise reservation path(PRP) system, a literature search, peer-to-peer discussions, panel discussions, and specialist consultations were conducted to determine the structure and design of the system. Staff from the outpatient and emergency management department, as well assurgeons specializing and IT technicians in thoracic surgery, breast surgery, and urinary surgery, attended the meeting to design the PRP process. The PRP process was designed as follows. Our predefined main objective was to build a cloud-based medical precise reservation path(PRP) connecting all

participants(patients and specialists). Based on the PRP framework, patients with suspected severe diseases can send a specialist appointment request and submit their medical records. After a specialist reviews the patient's application and medical records, the specialist may approve or reject the patient's application. Given patients often directly schedule outpatient appointments at tertiary hospitals without undergoing primary healthcare screening, allowing for free choice of healthcare providers In the Chinese healthcare system, a total of 935625 specialist outpatient visits were identified as not progressing through the system during the study period, from December 1, 2020, to November 30, 2022 at Renji hospital. A PRP flowchart is shown in Figure 1.

Figure1.The PRP flow chart

Architecture of PRP

The architecture of the PRP model is illustrated in Figure S1. Technical support was provided to make different system modules compatible and establish a cloud-based precise reservation path(PRP) system to connect the new system to Renji Hospital's original hospital information system(HIS). Building on the original HIS, new modules and functions were added to share all specialist outpatient schedules and specialist team accounts, such as WeChat(WeCom). The PRP system was integrated with hospital scheduling systems, enabling automatic identification of appointment statuses, such as whether an appointment had been made, requested, or canceled(and changing the status to require rescheduling). The specialist team user had one-click access to review the patient's application, examine the notes in the submitted medical records, and communicate with the team regarding treatment plans, thereby determining the need for scheduling a further evaluation.

Operation of PRP

The PRP is based on the hospital's official WeChat account platform

WeChat(WeCom) is a free social networking application offering instant messaging services across all platforms. It provides basic text, voice, photos, video sharing, and web-based payments and integration with intelligent hardware. Tencent's financial report shows that the number of combined

monthly live WeChat accounts exceeded 1.2 billion by the end of March 2021. Based on the WeChat Framework, we developed a function that can operate on both iOS and Android mobile platforms. Therefore, our design had a minimum learning cost for the participants and ensured the sustainability of users.

PRP is based on an asynchronous form

The exchange of online information between patients and doctors can occur synchronously(when interactions occur in real-time) or asynchronously(when there is a lag between the information being transmitted and the response)[12-13]. We adopted an asynchronous form of PRP because doctors in hospitals are always busy and cannot guarantee that they are online in real-time. In addition, an asynchronous form makes full use of the doctors' fragmented time to process and respond to patient applications.

PRP is also based on cloud computing services

Cloud computing involves the on-demand availability of computer system resources, particularly data storage(cloud storage) and computing power, without direct active management by users. It provides on-demand network access to a shared resource pool and configurable computing resources across the network as a metered on-demand service that efficiently distributes resources. The cloud computing architecture exhibits various characteristics such as cost reduction, device and location independence, easier maintenance of the cloud environment, and on-demand self-service. Similarly, it is well known that one of the essential features of mobile health services is on-demand self-service, where users can instantly access network storage and server processing time. Therefore, we set the PRP based on cloud-computing services.

PRP Involving users of PRP

The PRP consists of two different types of users: patients and specialists. Mobile Outpatient Specialist Appointment Registration Procedures for patients and specialists were present in Table S1.

Evaluation of the PRP program

Data resources and measures

Renji Hospital began implementing PRP in December 2020. Data used in the study were retrieved from the official WeChat medical service account and HIS at Renji Hospital from December 1, 2020, to November 30, 2022. In total, 58271 samples were obtained.

The specialist's review outcomes were dichotomized into not passed(=0) or passed(=1) as the dependent variable. Independent variables included gender, age, preference for paying with insurance, academic level of the specialist they chose, surgical department involvement, and actual failure if rejected. The classifications and measures of the variables of interest are present in Table S2. Ethical approval was obtained from the Human Research Ethics Committee of Renji Hospital(LY2023-031-B).

Analysis strategy

Traditional statistical method:and multivariate logistic regression method

First, all the continuous variables of patient were tested for normality. The Kolmogorov-Smirnov method test results(Sig=0.070>0.05) showed that "age" exhibited a normal distribution in 58271 patients. Means ± standard deviations were used for variables that obeyed a normal distribution, and median and IQR were reported For non-normally distributed data. A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. Univariate analysis was then conducted to identify significant contributors to the dependent variable, that is, whether the patient passed the online specialist appointment registration confirmation. In the study, the Chi-square test was utilized for univariate analysis to assess categorical variables. Finally, to identify the main factors influencing the specialist's review outcome, a multivariate logistic regression applying the backward stepwise method was performed.

Random Forest (RF)Analysis: Based on Participating Departments

We assembled a collection of operation status of each department in the PRP project and the allocation of specialist resources.These data were designated as the input variables. We designated the pass rates for the PRP among departments as the target variable. To assess the relative significance of these input variables in predicting the target, we performed a random forest algorithm analysis. Random Forests can be applied to a diverse range of prediction problems, and are generally recognized for their accuracy in handling small sample sizes, high-dimensional feature spaces, and complex data structures[14-15].

Two-Step Cluster Analysis(TSCA): Based on "Not Pass" Patient

To further understand key demographic characteristics and activities in the "non-pass patients" group, we conducted a two-step cluster analysis(TSCA) approach accordingly. Cluster analysis is an exploratory method that identifies hidden data structures. It identifies homogenous clusters of cases based on the distribution of input variables. More importantly, cluster analysis can be performed even when the actual grouping of cases is unknown.

The TSCA was used in this study because of its ability to handle categorical variables and large sample sizes. Additionally, TSCA presents advantages beyond other methods in that the optimal number of clusters is automatically determined, and no a priori assumptions about the number of clusters are required. TSCA is a hybrid approach that uses a distance measure to separate individuals, similar to Latent Class Analysis(LCA), with the selection of an optimal subgroup model. This approach has been shown to perform better than other traditional hierarchical cluster techniques. The fitness of the models was tested using Schwarz's Bayesian Information Criterion(BIC) with a mean silhouette coefficient.

All statistical analyses were performed using SPSS software(version 23.0; IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to build the RF and TSCA models.

RESULTS

Result of operation status of each department in the PRP program

We have collected data from 26 departments , including the number of applications, pass rate, median age of patients, interquartile range of patient ages, gender proportion of patients, proportion of medical insurance patients, patient application count for senior specialist,patient application count for associate senior specialist,senior specialist applicant ratio, PRP program specialists,total specialists, PRP specialists proportion, average specialist applications. As seen from Table S3, it can comprehensively and visually understand the operation status of each department in the PRP program. The proportion of applications for senior specialists varies significantly across different departments, indicating differing levels of expert engagement in the PRP program. The average number of applications per specialist also reflects the popularity of the PRP program within each department. The eight departments with the highest number of patient applications are Urinary Surgery(11,142), Breast Surgery(10,097), Thoracic Surgery(9,332), Obstetrics and Gynecology(4,862), Gastrointestinal Surgery(4,716), Nephrology(4011), Head and Neck Surgery(3,256) and Biliary And Pancreatic Surgery(3076). The total number of applications for these departments accounts for approximately 86.65% of all applications, highlighting the importance of these departments in the PRP program and the significant demand from patients for their services.

Among these departments, those with higher pass rates include Head and Neck Surgery(52.7%), Biliary And Pancreatic Surgery(47.3%),Obstetrics and Gynecology(44.8%),Nephrology(42%),and Gastrointestinal Surgery(38.6%), with Urinary Surgery at 37.4%. Notably, Breast Surgery has the lowest pass rate at 18.3%. In terms of age distribution within these departments, Urinary Surgery has the highest median patient age(64 years old, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery(44 years old, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; Thoracic Surgery(56 years old, IQR 22) and Gastrointestinal Surgery(59 years old, IQR 26) have a broader age range, covering patients from middle age to the elderly. Gender ratio data reflects the characteristics of the gender distribution among patients served by different departments. In

terms of age distribution within these departments, Urinary Surgery has the highest median patient age(64 years old, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery(44 years old, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; Thoracic Surgery(56 years old, IQR 22) and Gastrointestinal Surgery(59 years old, IQR 26) have a broader age range, covering patients from middle age to the elderly. Gender ratio data reflects the characteristics of the gender distribution among patients served by different departments. For instance, Urinary Surgery and Breast Surgery show extreme gender ratios, indicating a clear male and female preference, respectively. In contrast, Nephrology, Biliary And Pancreatic Surgery, have more balanced gender ratios.-

Result of Random Forest(RF)Analysis

We categorize departments with a pass rate of 34.8% or higher as "pass rate high-rank" and departments with a pass rate lower than 34.8% as "pass rate low-rank," based on the evidence from the study showing that the overall pass rate across 26 departments is 34.8%. Based on this, the "pass rate rank", a binary variable, is taken as the target variable in the RF analysis. The variables, including Patients age Median, PRP specialists proportion, Average specialist applications, Total specialists, Insurance patient ratio, PRP program specialists, Patients gender ratio, Application count, Senior specialist applicant ratio, all serve as input features in the RF analysis. The accuracy of the model is 92.31%.The predictor importance values range from 0.12 to 0.93, indicating the relative significance of each variable in predicting the target variable. Patients age Median emerges as the most significant predictor with a value of 0.93, followed by PRP specialists proportion and Average specialist applications with values of 0.87 and 0.84, respectively. On the other hand, variables such as Application count and Senior specialist applicant ratio have lower importance values, indicating their lesser contribution to the prediction process. Table S4 and Figure S2 present an overview of the variables and their respective roles in a random forest model, along with their predictor importance.

Overview and basic characteristics of patients

A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. During this period, 58271 patients applied for specialist appointments through the PRP program. In the Chinese medical and health system, it is commonplace for patients to schedule outpatient appointments at tertiary hospitals without undergoing prior approval. Of these 58271 patients, 20290(34.8%) patients passed the specialist assessment, and 37981(65.2%) did not.

Of the 58271 patients, the mean age was 52.89 ± 15.73 years. The Kolmogorov-Smirnov method test results(Sig=0.070>0.05) showed that "age" exhibited a normal distribution in 58271 patients. Among them, 22412(38.5%)were male, and 35859(61.5%)were female. See Table 1 For more details of patient characteristics.

Results of univariate and multivariate logistic regression analysis in the total population sample(N=58271)

Table 2 presents results of univariate and multivariate logistic regression analysis in the total population sample. Through univariate analyses, the significant factors associated with the specialist review outcome were gender($P < 0.001$), age($P < 0.001$), Acdemic title of the specialist ($P<0.001$) and Preference to pay with Insurance or not ($P=0.95$) which were included in the multivariate logistic((using the backward stepwise method),regression model. Then, through a multivariate logistic regression model(, it indicates that those who were male and aged 60 years old or above were more likely to pass the specialist's review in the age PRP program, while those aged 35–59 years were less likely to pass the specialist's review in the likely PRP program compared to those who aged 18–34 years old(See Table 1).

Table1.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To The specialist's review outcome

Items	Characteristics		Pass the Review		Univariate Analysis	Multivariate Analysis
	Variables	Frequency(%)	Not Pass (Group A)	Pass (Group B)	Chi square test	Logistic Regression

					c^2	P	OR (95% CI)	P
					198.94	<0.001		
Gender	Male	22412(38.5)	13819(61.7)	8593(38.3)			1.161(1.119-1.205)	<0.001
	Female	35859(61.5)	24162(67.4)	11697(32.6)			1.000	
					154.93	<0.001		
	18-34	9003(15.5)	5902(65.6)	3101(34.4)			1.000	
Age(years)	35-59	26590(45.6)	17939(67.5)	8651(32.5)			0.932(0.886-0.981)	0.007
	60-74	18405(31.6)	11577(62.9)	6828(37.1)			1.075(1.018-1.134)	0.009
	Above 75	4273(7.3)	2563(60.0)	1710(40.0)			1.154(1.069-1.246)	<0.001
Acdemic title of the specialist	senior	31561 (54.2)	21854(69.2)	9707(30.8)	501.00	<0.001	1.000	
	Assosiate senior	26710(45.8)	16127(60.4)	10583(39.6)			1.423(1.374-1.474)	<0.001
If Having Preference to pay with Insurance or not	Yes	42089(72.2)	27437(65.2)	14652(34.8)	0.004	0.95	0.964(0.928-1.002)	0.061
	No	16182(27.8)	10544(65.2)	5638(34.8)			1.000	
Whether having Passed the Review	Yes	20290(34.8)		/	/		/	
	No	37981(65.2)						

Results of univariate and multivariate logistic regression analysis in group B sample(n=37981)

To further investigate the reason why patients did not pass the review by the specialist in the PRP program, we divided the total population involved in the PRP program into two groups: group A("pass" group) and group B("not-pass" group). Here, we focused on the true reason why B-group patients did not pass the review in the PRP program. We redefined the variable of the reason for

rejection as the dependent variable in this study, and it was dichotomized into "not truly fail to pass"(=0)(e.g., rejected for not preparing well, such as having no uploaded past test reports due to inability to use mobile phones or rashly deciding to see a specialist regardless of the severity of diseases) or "truly fail to pass"(=1). Table 2 presents the results of univariate and multivariate logistic regression analysis of factors related to true failure to pass in Group B. By conducting the univariate analyses and multivariate logistic regression analysis(using the backward stepwise method), the findings indicate that those patients aged 60–74 or 75 years or older were less likely to be fully rejected by the PPR program than those aged 18–34 years old.

Table 2.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To True failure to pass in Group B

Items	Characteristics		Truly failed to pass		Univariate Analysis		Multivariate Analysis	
	Variables	Frequency (%)	No	Yes	Chi square test		Logistic Regression	
					c^2	P	OR (95% CI)	P
Gender	male	13819(36.4)	8685(62.8)	5134(37.2)	157.65	<0.001	1.000	
	female	24162(63.6)	13592(56.3)	10570(43.7)			1.078(1.030-1.129)	<0.001
Age(years)	18-34	5902(15.5)	3484(59.0)	2418(41.0)	260.60	<0.001	1.000	
	35-59	17939(47.2)	9831(54.8)	8108(45.2)			1.138(1.071-1.209)	<0.001
	60-74	11577(30.5)	7236(62.5)	4341(37.5)			0.894(0.837-0.955)	0.001
	Above 75	2563(6.7)	1726(67.3)	837(32.7)			0.797(0.720-0.881)	<0.001
Acdemic title of	Senior	21854(54.2)	11037(50.5)	10817(49.5)	1409.580	<0.001	2.164(2.072-2.261)	<0.001

the specialist	Associate senior	16127(45.8)	11240(69.7)	4887(30.3)			1.000	
Preference to pay with insurance or not	yes	27437(72.2)	16305(59.4)	11132(40.6)	24.42	<0.001		1.000
	not	10544(27.8)	5972(56.6)	4572(43.4)			1.055(1.007-1.105)	<0.001
Truly failed to pass if rejected	No	22277(58.7)		/	/			/
	Yes	15704(41.3)						

Results of TSCAs: Based on Group B "Not Pass" Patient

Importance and silhouette coefficient

We set the cluster inputs for the categorical variables of gender, age, preference to pay with medical insurance, and the reasons why they were rejected. TSCA produced six clusters of 37981 patients. Gender and payment with or without insurance were the most important predictors of cluster membership(valued 1.00), followed by the reason for rejection(valued 0.66). Age was considered to have little potential to improve the overall goodness of the final model. The silhouette coefficient, or silhouette score, is a metric used to calculate the goodness of a clustering technique. Its value ranges from -1 to 1, with 1 indicating well-separated and distinct clusters, 0 indicating indifference between clusters(i.e., the distance between clusters is insignificant), and -1 indicating incorrect cluster assignment[16]. The silhouette coefficient in this study was 0.86, indicating a good cluster quality.

Specific features of the six clusters

The differences in specific features among the six clusters are present in Figures 2-3, and Table S5

Figure 2. Visualization Cluster Features In The Clusters Of TSCA Results

Figure 3. Different Cluster Distances to Each Other for Six Clusters In TSCA Results

In Figure 3, it can be observed that clusters 1, 2, and 3 were relatively closer to each other, clusters 4, 5, and 6 were relatively closer to each other. The two different types of closer-distance cluster groups were more distant from each other, which was verified by the value of the importance of gender reaching 1(See Figure S3). Moreover, the distances between clusters 1, 2, and 4 were closer to each other, which was also verified by the value of the importance of the preference to pay with insurance or not reaching 1(See Figure S3), indicating that they all belonged to the same groups having a preference to pay with medical insurance.

DISCUSSION

Digital technologies are increasingly being used to support health systems(WHO, 2018) by providing flexible options for interpersonal communication and information exchange[17]. Access, affordability, and equity are three basic goals of a well-functioning health system[18]. The findings of the study of the PRP program indicated that the mobile-health-based PRP program is a practical and innovative approach that can help patients obtain equitable access to medical specialists in hospitals precisely with less doctor-seeking costs and be treated on time and highly efficiently, facilitating the optimization of outpatient procedures in hospital management.

In this study, among 58271 patients applying for medical specialists on the PRP-based platform, 20290 patients with severe diseases(suspected or confirmed) passed reviews by specialists, helping them access specialists' medical treatment in hospitals. Moreover, through the PRP program, the remaining 37891 patients who did not pass the specialists' review were identified and advised for appropriate shunts to the hospital's other clinical departments or primary care centers for treatment by GPs, preventing them from blindly making appointments with specialists, which may waste medical resources in hospitals.

The PRP program, implemented across 26 departments, has demonstrated a diverse performance landscape, showing significant variations in operational metrics such as application volumes, pass rates, and specialist involvement. The implemented program attracted a total of 58,271 patients applying for specialist appointments during the study period, reflecting the program's extensive reach and the significant demand for specialist services from outpatients. The program's smooth implementation was highlighted by the high participation rate of 85 specialists from various fields, demonstrating a robust network of professionals eager to engage in the PRP initiative. However, the difference in the proportion of applications for senior specialists across departments indicates that the level of engagement of senior specialists varies. This difference could be attributed to several factors, such as the complexity of disease cases, the reputation of the specialists, or the clinical resources allocated to each department.

The univariate analysis revealed that age, was significantly associated with the specialist review outcome, with a Chi-square test result indicating a strong association($P < 0.001$). In the multivariate logistic regression model, age was found to be a significant factor, with patients aged 60 years or above more likely to pass the specialist's review compared to those aged 18–34 years. Conversely, patients aged 35–59 were less likely to pass the review. These findings suggest that age may be an important threshold for specialist assessment, with older patients potentially receiving more favorable reviews due to the assumption of increased health complexity or the presence of age-related conditions.

In our study, among the groups aged 60 years or older, the older the patients, the higher the probability of passing the review by a specialist in hospitals. In the RF analysis, age emerged as the most significant predictor variable, with the highest importance value of 0.93. This indicates that among all the input features considered, age is the strongest factor in predicting the outcome of the 'pass rate rank'. This may be because the elderly, who often suffer a variety of chronic diseases, may have higher medical needs than younger individuals[19].

This is consistent with the evidence that many previous studies have claimed that elderly patients have greater utilization of hospital outpatient or inpatient healthcare services than their younger counterparts because of their unfavorable health status[20]. Conversely, those aged 35–59 years had a lower probability of passing the specialist review and a higher probability of being truly rejected than those aged 18–34 years. This could be explained by the fact that middle-aged patients prefer advanced medical care regardless of their factual medical needs. These patients may see specialists in hospitals for psychological comfort or because they mistrust GPs in primary care settings, although they do not need special medical care. Many previous studies have reported that this phenomenon results from a lack of community gatekeeper systems in China[21-22]. This reflects the urgent need to strengthen primary care and family doctor services that target middle-aged groups in China. Therefore, the Shanghai government and decision-makers in the health sector should make age-specific efforts to facilitate the implementation of hierarchical diagnosis and treatment systems and family doctor services among middle-aged patients. By shunting middle-aged patients toward GPs or secondary hospitals, patient crowding caused by the" siphon effect" can be mitigated, thus improving the efficiency of procedures in tertiary hospitals.

CONCLUSION

The implementation of the mobile-health-based PRP has demonstrated significant potential in enhancing equitable access to medical specialists within the hospital system. The analysis of the PRP program's operational metrics across various departments revealed a diverse performance landscape, indicating the need for tailored approaches to maximize the program's effectiveness. The high participation rate of specialists from different fields reflects a strong professional engagement with the initiative, although variations in the engagement of senior specialists suggest the influence of factors such as case complexity and departmental resources. The study's results highlight the necessity for age-specific strategies to enhance the implementation of

hierarchical medical systems and strengthen primary care services, particularly for middle-aged populations. By redirecting middle-aged patients to general practitioners or secondary hospitals, the program aims to alleviate patient congestion in tertiary hospitals and improve the overall efficiency of the healthcare system.

In conclusion, the PRP program presents a promising approach to integrating digital health technologies in the healthcare system, offering a scalable and adaptable model for optimizing specialist appointment processes. Future research should focus on refining the program to address the specific needs of different age groups and further investigate the factors influencing specialist review outcomes to ensure equitable and efficient healthcare delivery. The findings also emphasize the importance of a robust primary care system as a critical component in the broader healthcare ecosystem, particularly in managing the healthcare needs of the aging population and optimizing resource utilization.

Abbreviations

BIC: Bayesian Information Criterion

HIS: Hospital information system

PRP: Precise reservation path

RF:Random forest

TSCA:Two- Step Cluster Analysis

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Ethics approval and consent to participate: Ethical approval was obtained from the Human Research Ethics Committee of Renji Hospital(LY2023-031-B). Written informed consent was not required in accordance with the ethics approval.

Availability of data and materials: The data sets for this manuscript are not publicly available because all our data are under regulation of Renji Hospital, School of Medicine in Shanghai Jiao Tong University. Requests to access the data sets should be directed to TZ.

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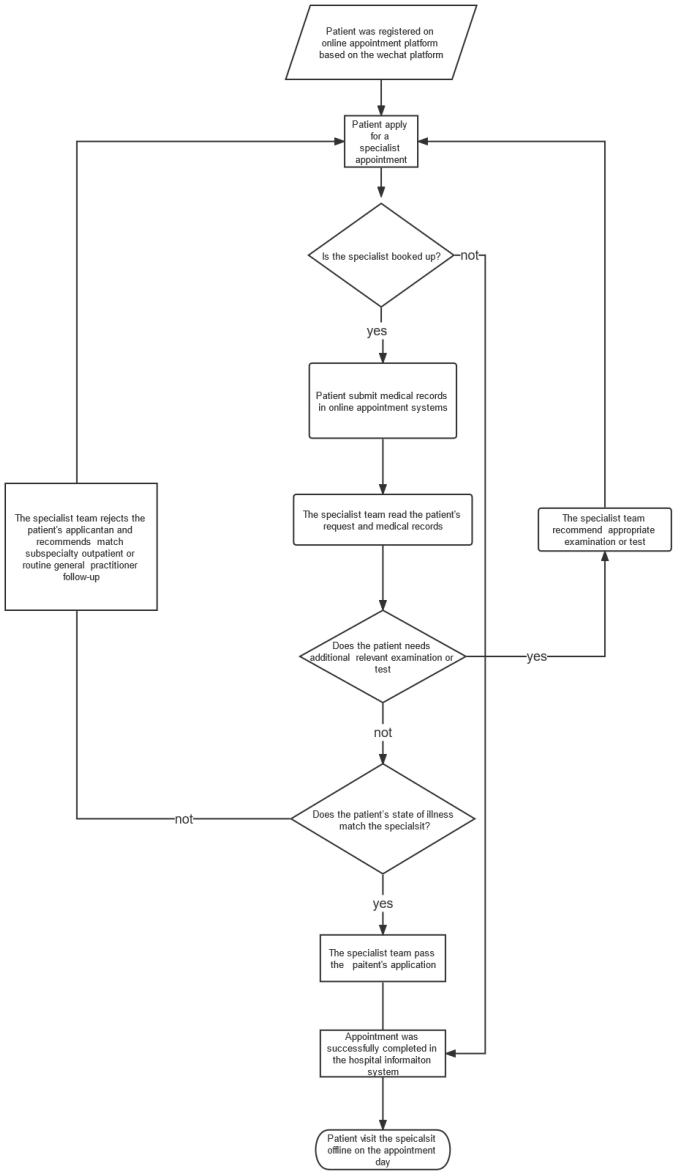

Figure1.The PRP flow chart

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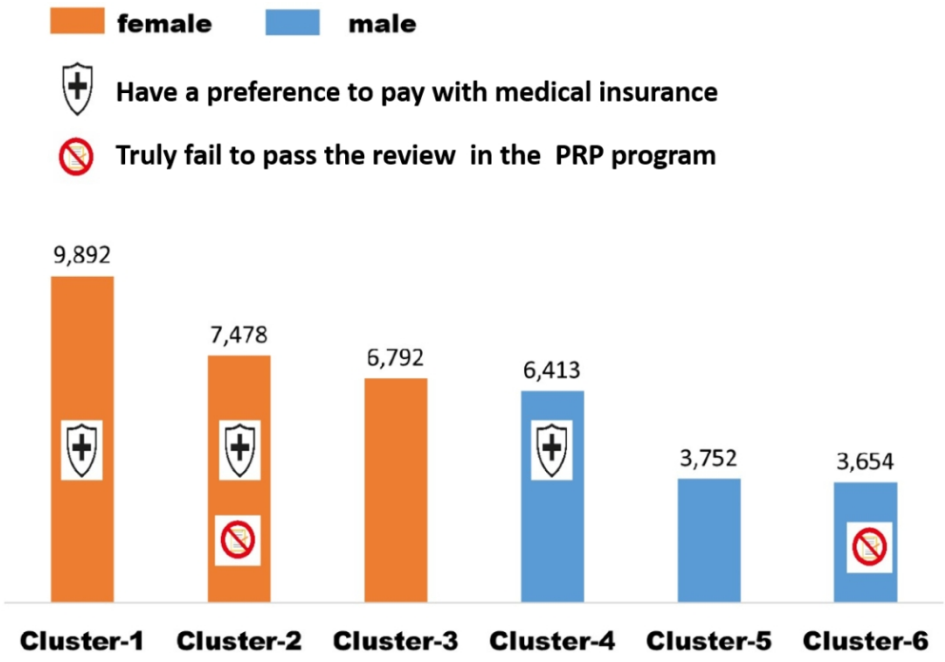

Figure 2. Visualization Cluster Features In The Clusters Of TSCA Results

516x335mm (59 x 59 DPI)

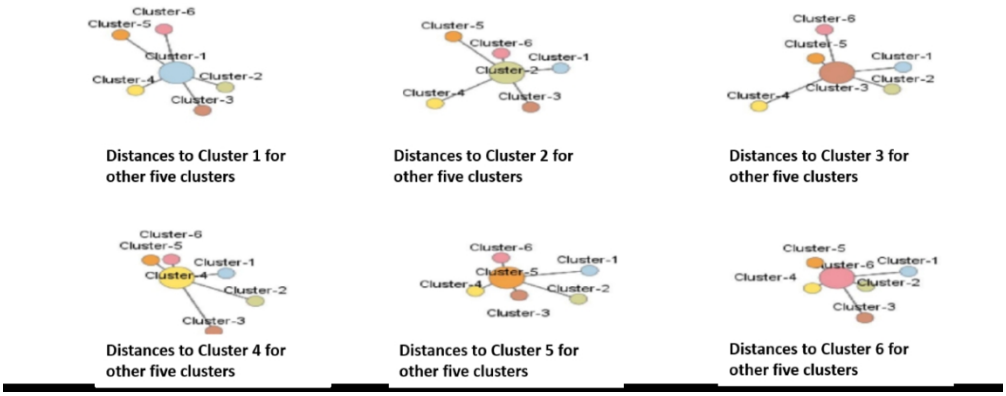

Figure 3. Different Cluster Distances to Each Other for Six Clusters In TSCA Results

516x229mm (59 x 59 DPI)

Table S1 Mobile Outpatient Specialist Appointment Registration Procedure for patients and specialists

Steps	Procedure for patients
1	The patient registers on the WeChat official medical service account of Renji Hospital using a mobile phone.
2	The patient reads the online specialist directory of the hospital and the diseases in which the specialist specializes.
3	The patient selects a specific specialist and requests an appointment by accessing the "Precise Reservation Path (PRP)" label.
4	The patient confirms the informed consent of the PRP, protocol, and submission of medical records.
5	According to the requirements of different specialist protocols, the patient also needs to submit relevant past examination reports (no earlier than 3 months), such as blood laboratory tests, ultrasound rays, computed tomography (CT), magnetic resonance imaging (MRI), and pathological reports.
6	If approval is received from the specialist users, the patient is allowed to visit the specialist offline on the appointed day.
Steps	Procedure for specialists
1	The specialist team user registers on the official WeChat accounts of Renji Hospital to build a PRP account using a mobile phone and obtains approval from the PRP system administrator.
2	The specialist team user completes their individual profile, including information about diseases in which they are specialized, past examination reports, and informed consent for patients before obtaining approval from the hospital's information administrator.
3	The specialist team user responds to patients' requests in a timely manner.
4	A specialist team user approves or rejects the patient's application. In the event of rejection, the user provides specific advice, such as recommending a well-matched subspecialty for the patient or suggesting a referral to their general practitioner.

Table S2 The classifications and measures of variables of interest

Variables	How to measure	Type
Whether having Passed the Review	1=Yes； 0= No	Categorical
Age	1=18-34 years; 2=35-59 years； 3=60-74 years; 4=75 years or above	Categorical
Gender	1=Male ;0=Female	Categorical
If having a	1=Yes; 0=No	Categorical

Preference to pay with Insurance		
Acdemic title of the specialist	1=Senior specialist; 2=Associate senior specialist	Categorical
Surgical department or not	1=Yes; 0=No	Categorical
Truly fail to pass if rejected	1=Yes; 0=No	Categorical

Table S3 Operational Profile of 26 Departments participating in the PRP Program

Clinic department	Pass rate rank	Application count	Pass rate(%)	Patients age Median	Patients age IQR	Patients gender ratio(male/female)	Insurance patient ratio (%)	Patient application count for senior specialist	Patient application count for associate senior specialist	Senior specialist applicant ratio(%)	PRP Program Specialists	Total specialists	PRP specialists proportion (%)	Average specialist applications
Urinary Surgery	high	11142	37.4*	64	17	3.85	71.6	2012	9130	18.1	14	37	38	795.9
Breast Surgery	low	10097	18.3	44	20	0.01	74.4	6397	3700	63.4	5	5	100	2019.4
Thoracic Surgery	low	9332	27.7	56	22	0.57	65.0	9332	0	100.0	1	6	17	9332.0
Obstetrics And Gynecology	high	4862	44.8*	39	19	0	76.3	3432	1430	70.6	4	35	11	1215.5
Gastrointestinal Surgery	high	4716	38.6*	59	26	1.37	71.2	2364	2352	50.1	6	29	21	786.0
Nephrology	high	4011	42.0*	57	28	0.93	82.8	1955	2056	48.7	6	17	35	668.5
Head And Neck	high	3256	52.7	49	22	0.31	77.7	126	3130	3.9	2	5	40	1628.0

Surgery,			*										
Biliary And Pancreatic			47.3										
Surgery	high	3076	*	59	25	0.83	77.0	1601	1475	52.1	25	48	256.3
Radiotherapy			55.1										
	high	1551	*	61	19	1.14	61.5	1261	290	81.3	7	43	517.0
Traumatic Orthopedics			36.8										
	high	1406	*	44	32	0.89	76.4	0	1406	0.0	10	10	1406.0
Vascular Surgery	low	835	26.1	64	18	0.96	76.3	605	230	72.5	9	44	208.8
Rheumatology And													
Immunology	low	790	2.2	47	24	0.3	40.0	720	70	91.1	20	15	263.3
Cardiology	low	692	17.1	61	27	0.81	80.1	206	486	29.8	4	25	16	173.0
Joint Surgery			44.3										
	high	483	*	55	27	0.56	72.3	421	62	87.2	4	9	44	120.8
Gynecological			61.5										
Oncology	high	478	*	47	20	0	55.0	454	24	95.0	2	3	67	239.0
Otorhinolaryngology	low	470	33.4	47	25	1.02	77.0	143	327	30.4	4	8	50	117.5
Spine Surgery			56.4										
	high	445	*	66	24	0.79	79.8	445	0	100.0	1	9	11	445.0
Ophthalmology			43.5										
	high	237	*	64	27	0.72	72.6	0	237	0.0	1	12	8	237.0
Pain Medicine			40.6										
	high	143	*	60	27	0.72	60.1	0	143	0.0	1	2	50	143.0
Functional Neurology	low	120	0.0	44	30	1.03	59.2	0	120	0.0	1	1	100	120.0

Oncology			51.0											
	high	49	*	60	19	0.96	32.7	49	0	100.0	1	12	8	49.0
Plastic Surgery	low	25	28.0	41	18	1.27	84.0	0	25	0.0		5	20	25.0
Digestion Medicine	low	21	0.0	52	20	0.91	38.1	21	0	100.0		44	2	21.0
Diagnostic Radiology			55.6											
	high	18	*	64	50	0.38	27.8	0	18	0.0		16	6	18.0
Endocrinology	low	13	0.0	41	20	1.17	53.9	13	0	100.0		10	10	13.0
General Surgery	low	3	0.0	34	/	0	100.0	3	0	100.0		8	13	3.0
Total		58271	34.8	54	26	0.63	72.2	31560	26711	54.2		369	23.04%	685.5

Note:

* indicates that the pass rate is ⩾34.8%

Patients age Median: Median age of patients applying

Patients age IQR: Age IQR of patients applying

Patients gender ratio: Gender ratio of patients applying(male/female)

Insurance patient ratio (%): Proportion of insurance among the patients applying

Senior specialist applicant Ratio(%): Proportion of patient apply for senior specialist among all applicants

PRP program specialists: Number of specialists participating in PRP program

Total specialists: Total number of specialists in department

PRP specialists proportion(%):Proportion of specialists participating in the PRP program to the total number of specialists in department

Average specialist applications: Average of patients applying for one specialist in department

Tabe S4 The Role in Random Forest Model and Result of Predictor Importance

Variables	Role in random forest model	Predictor importance
Patients age Median	input	0.93
PRP specialists proportion	input	0.87
Average specialist applications	input	0.84
Total specialists	input	0.53
Insurance patient ratio	input	0.35
PRP program specialists	input	0.35
Patients gender ratio	input	0.22
Application count	input	0.16
Senior specialist applicant ratio	input	0.12
Pass rate rank	target	/

Table S5 Interpretation of Cluster Features in TSCA Results

	Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5	Cluster-6
	N=9892，26.04%	N=7478，19.69%	N=6792，17.88%	N=6413，16.88%	N=3752，9.88%	N=3654，9.62%
Gender	Female	Female	Female	Male	Male	Male
If having a preference to pay with Insurance	Yes	Yes	No	Yes	No	No
Truely failed to pass the review If rejected	No	Yes	No	No	No	Yes

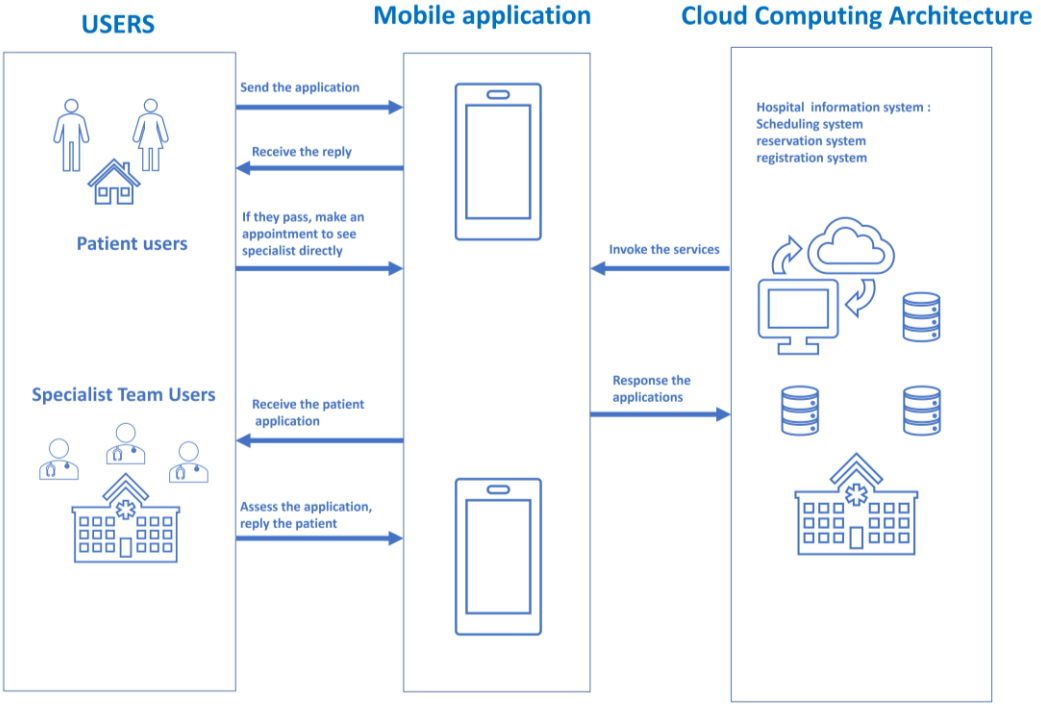

Figure S1. The PRP model architecture

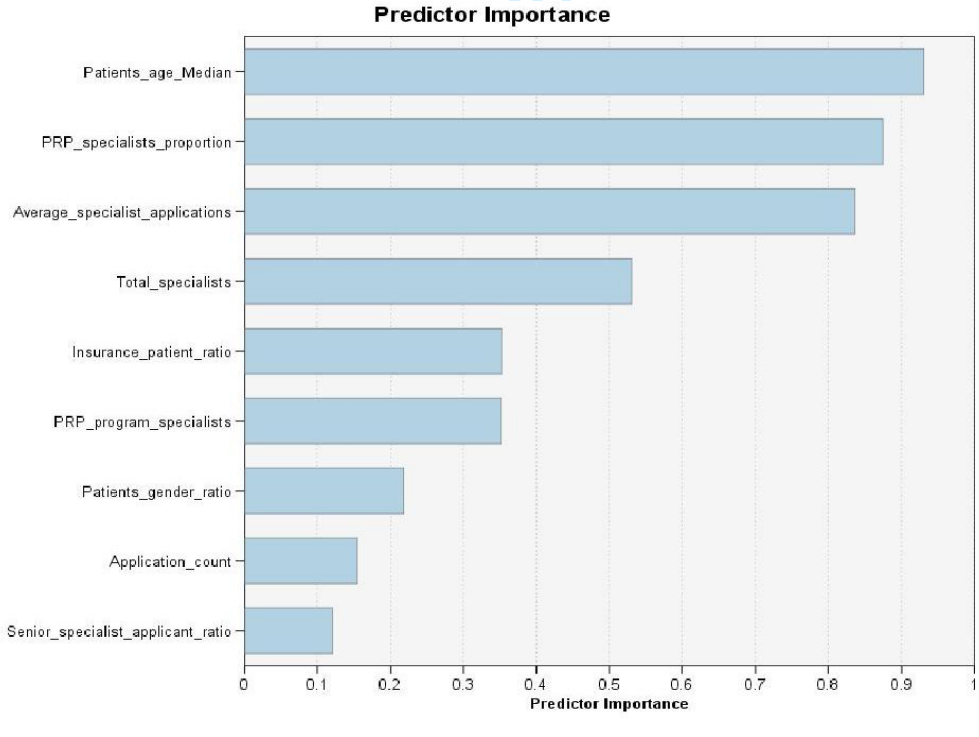

Figure S2. Result of Predictor Importance Through RF Analysis

Cluster Type	Records	Silhouette coefficient	Importance
Cluster-1	9,892	1.00	1.00
Cluster-2	7,478	1.00	0.93
Cluster-3	6,792	0.50	0.92
Cluster-4	6,413	1.00	0.88
Cluster-5	3,752	0.52	0.61
Cluster-6	3,654	1.00	0.56
Total	37981	0.86	/

Figure S3. The silhouette coefficient and Importance of clusters

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Developing, Implementing, and Investigation an Innovative Model to Identify and shunt Patients for Mobile Outpatient Specialist Appointment Registration system: A Cloud-Based Precise Reservation Path in Shanghai, China

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Developing, Implementing, and Investigating an Innovative Model to Identify and shunt Patients for Mobile Outpatient Specialist Appointment Registration system: A Cloud-Based Precise Reservation Path in Shanghai, China

Minjie Chen,[1] Xiaojing Zhao ,[2] Tao Zheng,[3] Binyuan Zhang,[1] Xuji Zhao,[1] Weijun Shao,[3] Li li,[4,5] Yiling Fan[1*], and Enhong Dong,[6 , 7*]

Author affiliations
[1]Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[2]Department of thoracic surgery department, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[3]Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[4] School of Medicine ,Shanghai Jiao Tong University ,Shanghai ,China
[5] China Hospital Development Institute ,Shanghai Jiao Tong University ,Shanghai , China
[6]School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences, Shanghai, China, 9
[7]Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University, Shanghai, China

Co-Corresponding authors:
Yiling Fan
Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University
No.160 Pujian Road, Pudong new district
Shanghai, 200127
China
Phone:+8613818458771
mail:fanyiling@163.com

Enhong Dong
School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences
No.279 Zhouzhu Road, Pudong new District
Shanghai, 210318
China
Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University
No.1594 Huashan Road, Xuhui District
Shanghai, 200230
China
Phone:+86 13761141620
E-mail: kevin8012@126.com

Abstract

Objective: The aim of this study is to develop, implement the Precise Reservation Path(PRP) and investigate its prediction function for scheduling shunting patients for specialist appointment registration in Shanghai, China.

Design: The PRP system was built upon the hospital's existing information system(HIS), integrated with WeChat(WeCom) for user convenience. The outcome analysis employed a mixed-methods approach, integrating quantitative analysis with statistical and machine learning techniques, including multivariate logistic regression, Random Forest(RF) and Artificial Neural Network (ANN) analysis.

Setting:This study was conducted at Renji Hospital, a premier general tertiary care institution in Shanghai, China, where the innovative PRP system was implemented. The program was designed to efficiently connect patients requiring specialized care with the appropriate medical specialists.

Participants: The PRP encompassed both voluntary specialists at Renji hospital, as well as patients seeking outpatient specialist services.

Primary Outcome Measures: Primary Outcome Measures:The pass rates of patient for specialist applications.

Secondary Outcome Measures: Clinic department ,Specialists' and Patients'characteristics influencing specialist review result.

Results:

From a dataset of 58,271 applicants across 26 departments between December 1, 2020, and November 30, 2022, we noted an overall pass rate of 34.8%. The departments of Urology, Breast Surgery, and Thoracic Surgery, along with five others, accounted for 86.65% of applications. Pass rates varied significantly, and demographic distributions of applicants across departments revealed distinct patient profiles, with preferences evident for age and gender.We developed a Random Forest (RF) model based on pass rates from 26 specialized departments. The RF model, with 92.31% accuracy, identified age as the primary predictor of pass rates, underscoring its impact on specialist review outcomes.Focus on patient demographics,we conducted univariate and multivariate logistic regression analyses on the 58,271 patient dataset to explore the relationship between demographic factors and review outcomes. Results indicated that older patients were more likely to be approved in specialist reviews, while middle-aged patients had lower pass rates.To understand how patient characteristics and specialist desicions affect PRP assessment results, we developed an Artificial Neural Network (ANN). The ANN identified the Specialist and Clinic Department as key predictors with relative importances of 0.44 and 0.43, respectively, achieving accuracies of 67.72% in training and 68.82% in testing.

Conclusions: The PRP program demonstrates the potential of digital innovation in enhancing hierarchical medical system. The study's findings also underscore the value of PRP program in healthcare systems for optimizing resource allocation, particularly for aging populations.The program's design and implementation offer a scalable model for other healthcare institutions seeking to enhance their appointment systems and specialist engagement through digital innovation.

Strengths and limitations of this study

Strengths：

►►The PRP program efficiently uses a popular cross-platform social app with dual iOS/Android features to minimize learning curves and maintain user sustainability.

►►The PRP program runs asynchronously, facilitating info exchange with time lags between patients & doctors, accommodating busy schedules to optimize processing & response to patient requests.

►►Holistic approach offered by study integrates dept. & patient perspectives, examining multifaceted factors affecting patient application pass rates.

►►Methodology integrates statistical approaches with ML algorithms(incl. Random Forest & Artifcial Neural Network to handle HD data, reveal complex patterns, & offer profound insights into critical factors for patient application.

Limitations:.

►►Budget constraints precluded structured analysis of patient disease condition descriptions, resulting in a lack of some disease-related variables. Future research aims to address this limitation, aiming for more comprehensive findings.

Key words: Precise Reservation Path, Appointment Registration, Specialist , Random forest, Artifcial Neural Network

INTRODUCTION

Most people want affordable and dependable high-quality products and services, be it produce, electronics, auto repairs, or a massage. The same is true for the healthcare sector. High-quality healthcare is defined as care that is effective, safe, patient-centered, timely, efficient, equitable, and delivered by professionals who are respectful, communicate clearly, and involve patients in decision-making[1]. To achieve the goals of "Healthy China 2030," in recent years, China has deepened health reform by building high-quality and value-based service delivery, resulting in a series of significant improvements. However, several challenges still exist, including the uneven distribution of healthcare resources and the imbalance between supply and demand[2-3]. To the best of our knowledge, improving the efficiency of hospital care is a fundamental aspect of strengthening the health system. In China, public hospitals are the main body of the medical service system and the primary places for people to seek medical treatment. According to China Health Statistics Yearbook, in 2018, public hospitals provided 92% of outpatient services for all hospitals in China and 82% of inpatient services. According to China's health delivery structure, public hospitals are organized into a three-tier system(designated as primary, secondary, or tertiary institutions). A tertiary hospital is a comprehensive, referral, and general hospital at the city, provincial, or national level with a bed capacity exceeding 500. Tertiary hospitals are responsible for providing specialist health services, performing a larger role in medical education and scientific research, and serving as medical hubs providing care to multiple regions[4]. As China's healthcare system does not feature a gatekeeping general practitioner system, patients can seek primary care from primary care facilities or hospital outpatient departments[5]. In light of the free choice of healthcare providers, most patients prefer to choose a specialist(who is a medical doctor, often with a senior professional title and an expert in a specific area of medicine) in clinics or private or public hospitals, particularly tertiary public hospitals. However, due to the unequal access to information

between doctors and patients, the freedom to choose healthcare providers often leads patients to select doctors without adequate knowledge or understanding, potentially resulting in a significant misallocation of medical resources[6]. This is because patients may lack the necessary information to determine who is the most suitable doctor for their needs. In addition, patients with minor illnesses prefer to visit tertiary hospitals instead of prime care centers. These behaviors lead to a significant squandering of valuable medical resources, creating a dual challenge. Firstly, they impose a heavy economic burden on patients, potentially surpassing the affordability limits of the medical system. Secondly, these behaviors pose obstacles to the high-quality development of tertiary hospitals in China. Moreover, the scarcity of healthcare resources has led to fierce competition among patients[7-8]. To enable doctors to provide high-quality and timely outpatient services, many hospitals have implemented novel appointment registration systems that assist patients and increase hospital efficiency. With these systems, hospitals can only provide services to patients with limited efficacy. Under the rule of "first registration, first service" in appointment registration systems, some patients with severe diseases requiring specialist treatment may struggle to successfully book appointments with the necessary specialists. This violation of fairness in healthcare resource allocation goes against the principles addressed by China's current medical reform. Thus, optimizing the appointment registration system and improving the efficiency of medical procedures in Chinese tertiary public hospitals is imperative. Accordingly, hospitals are experimenting with novel appointment registration systems, such as mobile phones, web-based systems, bank-hospital cooperation, and clinical settings. Among these, redesigning the appointment-scheduling system is crucial for making effective use of healthcare resources, increasing operational efficiency, reducing operational costs, and mitigating the imbalance between supply and demand for healthcare services[9].

Over the past decade, China has had the highest number of smartphones per capita among all countries[10]. Equipped with Internet Plus Medical" applications, online appointment systems have become an alternative that optimizes the appointment process, significantly improving the efficiency of hospital services. Hospitals provide various web-based services through mobile platforms, including WeChat and other independently-developed applications. Hospital services include online consultations, appointment registration, and online payments. Such mobile health initiatives can overcome geographic boundaries, enhance the equity and accessibility of healthcare resources, and provide effective and equitable access to healthcare services in hospitals[11]. A mobile appointment registration service can provide patients with an important online channel through which all patients with smart devices can access healthcare resources. With the availability of mobile appointment registration services, patients will increasingly turn to online platforms to book appointments, gradually replacing the traditional offline queuing registrations. This shift to online registration is expected to create a higher demand for services on mobile health platforms. In hospitals, the outpatient department plays a critical role in efficiently managing medical resources as it not only directs patients for timely care but also generates numerous benefits, including improved health outcomes and optimized utilization of healthcare resources. As mentioned above, optimizing appointment-registration procedures is the responsibility and commitment of hospital management. Therefore, effective scheduling of on-hand mobile appointment registration services and providing healthcare services to patients have become key priorities for outpatient departments in tertiary public hospitals in China.

This study aims to develop a precise reservation path(PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals in Shanghai, China. This study first described a specialist-led reservation process whereby the clinical data(history, examination, and past treatment) of a reservation applicant were assessed using relevant ultrasound, laboratory, or radiological records. Subsequently, a decision was made regarding the suitability of the patient for specialist intervention. Second, employing specific statistical analysis methods, our objective was to investgate impact factors of pass rate of patients who require specialist medical services, thereby streamlining their referral to appropriate healthcare settings, such as specialized clinics or primary care institutions. This system aims to strengthen and improve the implementation of the hierarchical diagnosis and treatment system in China.

MATERIALS AND METHODS

Patient and Public Involvement

This study did not involve patients or the public.

Design

Procedure of PRP

This study was conducted at Renji Hospital, School of Medicine, Shanghai Jiao Tong University, a 2,750-bed general tertiary public hospital in Shanghai, China. In an attempt to fully digitize its records, the hospital has put in place a satisfactory information infrastructure in which most medical and health records are stored electronically. The annual number of outpatient and emergency visits to the hospital exceeds 5.820 million, and the annual number of discharged patients is 172,000. This PRP program was uniquely self-developed by the management and clinical staff at Renji Hospital in Shanghai to address the current disorganized situation where outpatients schedule specialists without any restrictions. Prior to designing the precise reservation path(PRP) system, a literature search, peer-to-peer discussions, panel discussions, and specialist consultations were conducted to determine the structure and design of the system. Staff from the outpatient and emergency management department, as well assurgeons specializing and IT technicians in thoracic surgery, breast surgery, and urinary surgery, attended the meeting to design the PRP process. The PRP process was designed as follows. Our predefined main objective was to build a cloud-based medical precise reservation path(PRP) connecting all participants(patients and specialists). Based on the PRP framework, patients with suspected severe diseases can send a specialist appointment request and submit their medical records. After a specialist reviews the patient's application and medical records, the specialist may approve or reject the patient's application. Given patients often directly schedule outpatient appointments at tertiary hospitals without undergoing primary healthcare screening, allowing for free choice of healthcare providers In the Chinese healthcare system, a total of 935625 specialist outpatient visits were identified as not progressing through the system during the study period, from December 1, 2020, to November 30, 2022 at Renji hospital. A PRP flowchart is shown in Figure 1.

Architecture of PRP

The architecture of the PRP model is illustrated in Figure S1. Technical support was provided to make different system modules compatible and establish a cloud-based precise reservation path(PRP) system to connect the new system to Renji Hospital's

original hospital information system(HIS). Building on the original HIS, new modules and functions were added to share all specialist outpatient schedules and specialist team accounts, such as WeChat(WeCom). The PRP system was integrated with hospital scheduling systems, enabling automatic identification of appointment statuses, such as whether an appointment had been made, requested, or canceled(and changing the status to require rescheduling). The specialist team user had one-click access to review the patient's application, examine the notes in the submitted medical records, and communicate with the team regarding treatment plans, thereby determining the need for scheduling a further evaluation.

Operation of PRP

The PRP is based on the hospital's official WeChat account platform

WeChat(WeCom) is a free social networking application offering instant messaging services across all platforms. It provides basic text, voice, photos, video sharing, and web-based payments and integration with intelligent hardware. Tencent's financial report shows that the number of combined monthly live WeChat accounts exceeded 1.2 billion by the end of March 2021. Based on the WeChat Framework, we developed a function that can operate on both iOS and Android mobile platforms. Therefore, our design had a minimum learning cost for the participants and ensured the sustainability of users.

PRP is based on an asynchronous form

The exchange of online information between patients and doctors can occur synchronously(when interactions occur in real-time) or asynchronously(when there is a lag between the information being transmitted and the response)[12-13]. We adopted an asynchronous form of PRP because doctors in hospitals are always busy and cannot guarantee that they are online in real-time. In addition, an asynchronous form makes full use of the doctors' fragmented time to process and respond to patient applications.

PRP is also based on cloud computing services

Cloud computing involves the on-demand availability of computer system resources, particularly data storage(cloud storage) and computing power, without direct active management by users. It provides on-demand network access to a shared resource pool and configurable computing resources across the network as a metered on-demand service that efficiently distributes resources. The cloud computing architecture exhibits various characteristics such as cost reduction, device and location independence, easier maintenance of the cloud environment, and on-demand self-service. Similarly, it is well known that one of the essential features of mobile health services is on-demand self-service, where users can instantly access network storage and server processing time. Therefore, we set the PRP based on cloud-computing services.

PRP Involving users of PRP

The PRP consists of two different types of users: patients and specialists. Mobile Outpatient Specialist Appointment Registration Procedures for patients and specialists were present in Table S1.

Investigation of the PRP program

Data resources and measures

Renji Hospital began implementing PRP in December 2020. Data used in the study were retrieved from the official WeChat medical service account and HIS at Renji Hospital from December 1, 2020, to November 30, 2022. In total, 58271 samples were obtained.

The specialist's review outcomes were dichotomized into not passed(=0) or passed(=1) as the dependent variable. Independent variables included gender, age, preference for paying with insurance, title of the specialist. The classifications and measures of the variables of interest are present in Table S2. Ethical approval was obtained from the Human Research Ethics Committee of Renji Hospital(LY2023-031-B).

Analysis strategy

Traditional statistical method:and multivariate logistic regression method

First, all the continuous variables of patient were tested for normality. The Kolmogorov-Smirnov method test results(Sig=0.070>0.05) showed that "age" exhibited a normal distribution in 58271 patients. Means ± standard deviations were used for variables that obeyed a normal distribution, and median and IQR were reported For non-normally distributed data. A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. Univariate analysis was then conducted to identify significant contributors to the dependent variable, that is, whether the patient passed the online specialist appointment registration confirmation. In the study, the Chi-square test was utilized for univariate analysis to assess categorical variables. Finally, to identify the main factors influencing the specialist's review outcome, a multivariate logistic regression applying the backward stepwise method was performed.

Random Forest (RF)Analysis: Based on Participating Departments

We assembled a collection of operation status of each department in the PRP project and the allocation of specialist resources.These data were designated as the input variables. We designated the pass rates for the PRP among departments as the target variable.Considering the common use of the random forest (RF) algorithm machine learning, ML, RF can be applied to deal binary and binary, multi-classification problems or examine interactions variables. Additionally, it can could provide variable importance measures (VIMs) with mix mixture of categorical and continuous variables, even potentially involving highly noisy and significantly variables. Random Forest (RF) also demonstrates good predictive performance even for data with more variables (p) than samples (i.e., $p > n$). Due to their non-parametric nature, RFs are a robust method used in relatively straightforward applications for inexperienced users. Some previous research has included the RF analysis method in small sample sizes, even less than 20 (denoted as $N < 20$) . Therefore, to assess the relative significance of these input variables in predicting the target, we performed a random forest algorithm analysis in the study. Since training and testing a machine learning model on the same dataset can lead to several issues, collectively known as overfitting, which occurs when a model learns the training data too well, capturing noise and random fluctuations in the data rather than the underlying patterns, we applied an "out-of-bag" (OOB) technique n the study to make predictions for an observation in the original dataset using only base learners not trained on this particular observation. This method is called out-of-bag (OOB) prediction. These predictions are not prone to overfitting, as each prediction is only made by learners that did not use the observation for training. Due to the presence of OOB samples in our dataset, the OOB data can be directly used as a validation and test set, eliminating the need to pre-partition the dataset. In SPSS Modeler, the predictive accuracy is precisely the result of out-of-bag estimation[14-19].

Artifcial Neural Network(ANN)

ANNs are mathematical models based on interconnected groups of artifcial neurons. They consider nonlinear relationships between input data, which are not always identifed on traditional analysis. ANNs have several advantages, such as self-learning, adaptability, and robustness of massive parallelism. Tey generally contain three layers: input, hidden, and output layers. A multilayer perceptron (MLP) is a subtype of ANN comprising one or more hidden layers containing computation nodes, with a high capability of universal approximations; it has therefore been extensively used for modeling nonlinear and complex processes of the real world. The most widely used and effective algorithm for training an MLP network is the back-propagation (BP) algorithm [20-24].We randomly divided the dataset into training and test sets at a 70:30 ratio (40766 and 17505 records, respectively). All statistical analyses were performed using SPSS software(version 23.0; IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to build the RF and BP-ANN models.

RESULTS

Result of operation status of each department in the PRP program

From a dataset encompassing 58,271 applicants, we observed an overall pass rate of 34.8%.We have collected data from 26 departments , including the number of applications, pass rate, median age of patients, interquartile range of patient ages, gender proportion of patients, proportion of medical insurance patients, patient application count for senior specialist,patient application count for associate senior specialist,senior specialist applicant ratio, PRP program specialists,total specialists, PRP specialists proportion, average specialist applications. As seen from Table S3, it can comprehensively and visually understand the operation status of each department in the PRP program. The proportion of applications for senior specialists varies significantly across different departments, indicating differing levels of expert engagement in the PRP program. The average number of applications per specialist also reflects the popularity of the PRP program within each department. The eight departments with the highest number of patient applications are Urinary Surgery(11,142), Breast Surgery(10,097), Thoracic Surgery(9,332), Obstetrics and Gynecology(4,862), Gastrointestinal Surgery(4,716), Nephrology(4011), Head and Neck Surgery(3,256) and Biliary And Pancreatic Surgery(3076). The total number of applications for these departments accounts for approximately 86.65% of all applications, highlighting the importance of these departments in the PRP program and the significant demand from patients for their services.

Among these departments, those with higher pass rates include Head and Neck Surgery(52.7%), Biliary And Pancreatic Surgery(47.3%),Obstetrics and Gynecology(44.8%),Nephrology(42%),and Gastrointestinal Surgery(38.6%), with Urinary Surgery at 37.4%. Notably, Breast Surgery has the lowest pass rate at 18.3%. In terms of age distribution within these departments, Urinary Surgery has the highest median patient age(64 years old, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery(44 years old, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; Thoracic Surgery(56 years old, IQR 22) and Gastrointestinal Surgery(59 years old, IQR 26) have a broader age range, covering patients from middle age to the elderly. Gender ratio data reflects the characteristics of the gender distribution among patients served by different departments. In terms of age distribution within these departments, Urinary Surgery has the highest median patient age(64 years old, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery(44 years old, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; Thoracic Surgery(56 years

old, IQR 22) and Gastrointestinal Surgery(59 years old, IQR 26) have a broader age range, covering patients from middle age to the elderly. Gender ratio data reflects the characteristics of the gender distribution among patients served by different departments. For instance, Urinary Surgery and Breast Surgery show extreme gender ratios, indicating a clear male and female preference, respectively. In contrast, Nephrology, Biliary And Pancreatic Surgery, have more balanced gender ratios.

Result of Random Forest(RF)Analysis-based on 26 department

Based on the pass rates from 26 specialized clinical departments,we utilized IBM SPSS Modeler version 18.0 to develop a Random Forest(RF) model. Under the guidance of a statistical expert, The model's parameters were calibrated, with the number of models to build set to 7, and the sample size meticulously configured to 1. To enhance the model's efficacy and feature selection, we activated the "Handle imbalanced data" feature and the "Use weighted sampling for variable selection" option. For the tree growth parameters, we retained the default settings provided by the software, which included a maximum number of nodes set to 10,000, a maximum tree depth of 10, and a minimum child node size of 5.

Based on the study, the overall pass rate is 34.8%. We've set the "Pass Rate Interval" field to categorize departments as either "high-rank group" or "low-rank group" based on this rate. Based on this, the "Pass Rate Interval" , a binary variable, is taken as the target variable in the RF analysis. The variables, including Patients age Median, PRP specialists proportion, Average specialist applications, Total specialists, Insurance patient ratio, PRP program specialists, Patients gender ratio, Application count, Senior specialist applicant ratio, all serve as input features in the RF analysis.The accuracy of the model is 92.31%.The predictor importance values range from 0.12 to 0.93, indicating the relative significance of each variable in predicting the target variable. Patients age Median emerges as the most significant predictor with a value of 0.93, followed by PRP specialists proportion and Average specialist applications with values of 0.87 and 0.84, respectively. On the other hand, variables such as Application count and Senior specialist applicant ratio have lower importance values, indicating their lesser contribution to the prediction process. Table S4 and Figure S2 present an overview of the variables and their respective roles in a random forest model, along with their predictor importance.

Overview and basic characteristics of patients

A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. During this period, 58271 patients applied for specialist appointments through the PRP program. In the Chinese medical and health system, it is commonplace for patients to schedule outpatient appointments at tertiary hospitals without undergoing prior approval. Of these 58271 patients, 20290(34.8%) patients passed the specialist assessment, and 37981(65.2%) did not.

Of the 58271 patients, the mean age was 52.89 ± 15.73 years. The Kolmogorov-Smirnov method test results(Sig=0.070>0.05) showed that "age" exhibited a normal distribution in 58271 patients. Among them, 22412(38.5%)were male, and 35859(61.5%)were female. See Table 1 For more details of patient characteristics.

Results of univariate and multivariate logistic regression analysis in the total population sample(N=58271)

Focus on patient demographics,we conducted univariate and multivariate logistic regression analyses on the 58,271 patient dataset to explore the relationship between demographic factors and assessment outcomes.The findings are detailed in Table

1.Through univariate analyses, the significant factors associated with the specialist review outcome were gender($P < 0.001$), age($P < 0.001$),title of the specialist ($P<0.001$). The factors of age, gender, and the title of the specialist were found to be significant in the univariate analyses and were subsequently included in the multivariate logistic regression model. This model was constructed using the backward stepwise method to refine the selection of variables.Then, through a multivariate logistic regression model, it indicates that those who were male and aged 60 years old or above were more likely to pass the specialist's review in the age PRP program, while those aged 35–59 years were less likely to pass the specialist's review in the likely PRP program compared to those who aged 18–34 years old. It also found that those who had title Assosiate senior were more likely to pass the specialist's review in the age PRP program relative to those who had title of senior specialist. (See Table 1).

Table1.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To The specialist's review outcome

Items	Characteristics		Pass the Review		Univariate Analysis		Multivariate Analysis	
					Chi square test		Logistic Regression	
	Variables	Frequency(%)	Not Pass (Group A)	Pass (Group B)	c^2	P	OR (95% CI)	P
Gender					198.94	<0.001		
	Female	35859(61.5)	24162(67.4)	11697(32.6)			1.000	
	Male	22412(38.5)	13819(61.7)	8593(38.3)			1.161(1.119-1.205)	<0.001
Age (years)					154.93	<0.001		
	18-34	9003(15.5)	5902(65.6)	3101(34.4)			1.000	
	35-59	26590(45.6)	17939(67.5)	8651(32.5)			0.933(0.886-0.981)	0.007
	60-74	18405(31.6)	11577(62.9)	6828(37.1)			1.075(1.018-1.134)	0.009
	Above 75	4273(7.3)	2563(60.0)	1710(40.0)			1.151(1.066-1.243)	<0.001
Title of the specialist	senior	31561 (54.2)	21854(69.2)	9707(30.8)	501.00	<0.001	1.000	
	Assosiate senior	26710(45.8)	16127(60.4)	10583(39.6)			1.420(1.371-1.471)	<0.001
If Having Preference to pay with	Yes	42089(72.2)	27437(65.2)	14652(34.8)	0.004	0.95	N/A	N/A

Insurance or not	No	16182(27.8)	10544(65.2)	5638(34.8)		N/A
Whether having Passed the Review	Yes	20290(34.8)		N/A	N/A	N/A
	No	37981(65.2)				
Nagelkerke R Square						**0.016**

Result of ANN analysis

To understand how patient characteristics and specialist choices affect PRP assessment results, we developed an Artificial Neural Network (ANN) model with a Multilayer Perceptron (MLP) structure.We maintained all other parameters at their default values as specified by the software.In the ANN analysis depicted in Table 2, the input features encompass Specialist (Patient Request For), Clinic Department (Patient Request For), Patient Age Group, Title of the Specialist, and Patient Gender, with Assessment Result (Yes or No) serving as the target variable. Table 2 further delineates the key variables influencing the Assessment Result within the ANN model, ranking Specialist and Clinic Department as the most impactful with relative importances of 0.44 and 0.43, respectively. The Patient Age Group, Title of the Specialist, and Patient Gender follow with lesser influences at 0.07, 0.04, and 0.02, respectively. Additionally, Figure 2 provides an illustration of the ANN model's topology architecture. The model's accuracy is delineated in Table 3, with scores of 67.72% for the training dataset and 68.82% for the test dataset.

Tabe 2 The Role in ANN Model and Result of Predictor Importance

Variables	Role in ANN model	Predictor importance
Specialist(patient request for)	input	0.44
Clinic Department(patient request for)	input	0.43
Patient Age Group	input	0.07
Title of the Specialist	input	0.04
Patient Gender	input	0.02
Assessment Result(yes or no)	target	/

Table 3. Accuracy of ANN model

Partition	Training Dataset		Testing Dataset	
	Records	Accuracy	Records	Accuracy
Correct	27607		11952	
Wrong	13159	67.72%	5553	68.28%
Total	40766		17505	

DISCUSSION

Digital technologies are increasingly being used to support health systems(WHO, 2018) by providing flexible options for interpersonal communication and information exchange[25]. Access, affordability, and equity are three basic goals of a well-functioning health system[26]. In this study, among the 58,271 patients who applied for medical specialists on the PRP-based platform, 20,290 patients successfully passed reviews conducted by specialists, thereby gaining access to specialized medical treatment in hospitals. This indicates that the mobile-health-based PRP program is a practical and innovative approach. It enables patients to obtain convenient access to medical specialists in hospitals with reduced doctor-seeking costs, ensuring timely and highly efficient treatment. Furthermore, the remaining 37,891 patients who did not pass the specialists' review were identified through the PRP program. They were advised to be appropriately directed to other clinical departments within the hospital or to primary care centers for treatment by general practitioners (GPs). This guidance helps prevent the inefficiency of patients blindly seeking appointments with specialists, which could otherwise lead to the waste of valuable medical resources in hospitals.

The PRP program, implemented across 26 departments, has demonstrated a diverse performance landscape, showing significant variations in operational metrics such as application volumes, pass rates, and specialist involvement. The implemented program attracted a total of 58,271 patients applying for specialist appointments during the study period, reflecting the program's extensive reach and the significant demand for specialist services from outpatients. The program's smooth implementation was highlighted by the high participation rate of 85 specialists from various fields, demonstrating a robust network of professionals eager to engage in the PRP initiative.

Univariate analysis found that age is significantly linked to the outcomes of specialist reviews ($P < 0.001$). Logistic regression showed that individuals aged 60 and above are more likely to pass reviews compared to the 18–34 age group, while the 35–59 age group is less likely to do so. RF analysis also identified applicant age as the most important predictor, with a 0.93 importance value, in explaining the differences in pass rates in 26 clinic departments. This may be because the elderly, who often suffer a variety of chronic diseases, may have higher medical needs than younger individuals[27].This is consistent with the evidence that many previous studies have claimed that elderly patients have greater utilization of hospital outpatient or inpatient healthcare services than their younger counterparts because of their unfavorable health status[28]. Conversely, those aged 35–59 years had a lower probability of passing the specialist review and a higher probability of being truly rejected than those aged 18–34 years. This could be explained by the fact that middle-aged patients prefer advanced medical care regardless of their factual medical needs. These patients may see specialists in hospitals for psychological comfort or because they mistrust GPs in primary care settings, although they do not need special medical care. Many previous studies have reported that this phenomenon results from a lack of community gatekeeper systems in China[29-30]. This reflects the urgent need to strengthen primary care and family doctor services that target middle-aged groups in China. Additionally, male patients were more likely to pass the review compared to their female counterparts. This may be explained by the higher prevalence of chronic diseases in males than in females in China[3]. However, this finding was not consistent with previous studies, all of which reported a higher prevalence of chronic diseases in females, especially those aging 60 years and above in China[32-33]. Gender ratios in the prevalence of chronic

diseases are inconclusive. Therefore, the Shanghai government and decision-makers in the health sector should make gender and age-specific efforts to facilitate the implementation of hierarchical diagnosis and treatment systems and family doctor services among middle-aged patients. By shunting middle-aged patients toward GPs or secondary hospitals, patient crowding caused by the" siphon effect" can be mitigated, thus improving the efficiency of procedures in tertiary hospitals.

More interestingly, regarding the specialist title, those specialists who hold associate senior titles were more likely to approve patients' applications compared to senior specialists. This may be due to the intense competition for title promotion in medicine. In Chinese society, job hierarchy plays a significant role, which is evident in the use of professional titles[34-35]. Professional titles often signify one's seniority, experience, or level of authority within a government-funded organization. In Given the pressure for promotion promotion, specialists with associate senior titles prefer to accept more patients to enhance their professional skills and prepare for promotion to senior professional titles.

The ANN model's analysis reveals a distinct prioritization of specialist and departmental factors within the PRP program, surpassing the emphasis on patient age and gender. This prioritization may stem from a complex array of reasons as follows:

Firstly, the unique expertise of specialists is of paramount importance; for instance, urologists may specialize in different subspecialties, with some focusing on kidney conditions, others on prostate issues, and still others on bladder diseases, all of which significantly shape patient requests and the outcomes of assessments.

Secondly, certain clinical departments have a more concentrated age range among their applicants, with a gender demographic that is notably skewed. For instance, the breast surgery department is characterized by a significant prevalence of middle-aged women, with a median age of 44 and a gender ratio of 0.01 among its applicants. In contrast, the urology department has a predominantly male applicant base, with a gender ratio of 3.85, and applicants are generally older, with a median age of 68, which exceeds the overall median age of the PRP applicant pool by 14 years. Together, these two departments make up a considerable portion of the entire PRP applicant pool, constituting 36.45% of the total. The unique demographic characteristics of these specific departments may profoundly influence the predictive factors.

Thirdly, the potential personal subjectivity inherent in expert reviews could be significant. In the future, we will integrate rule-based systems alongside multimodal artificial intelligence reviews to mitigate the influence of individual subjective biases. The current Artificial Neural Network (ANN) model, with a testing dataset accuracy, indicates significant potential for enhancing and augmenting its predictive accuracy. Additionally, the existing budget constraints impeded the inclusion of structured analysis of patient disease condition descriptions, necessitating further studies. A prospective approach is needed to develop a more robust, comprehensive, and all-encompassing predictive model by including this important variable.

CONCLUSION

In conclusion, the PRP program offers a promising approach to integrating digital health technologies into the healthcare system. It provides a scalable and adaptable model for optimizing specialist appointment processes. Moving forward, our prospective study goal is to enhance and expand the program by involving more specialists and hospitals to reach a larger number of patients. Other healthcare entities looking to improve their appointment processes and specialist engagement through digital advancements can refer to the program's design and implementation.

Figure1. The PRP flow chart
Figure.2 Topology architecture of the ANN model

Abbreviations

BIC: Bayesian Information Criterion
HIS: Hospital information system
PRP: Precise reservation path
RF:Random forest
ANN:Artifcial Neural Network

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Availability of data and materials: The data sets for this manuscript are not publicly available because all our data are under regulation of Renji Hospital, School of Medicine in Shanghai Jiao Tong University. Requests to access the data sets should be directed to MC.

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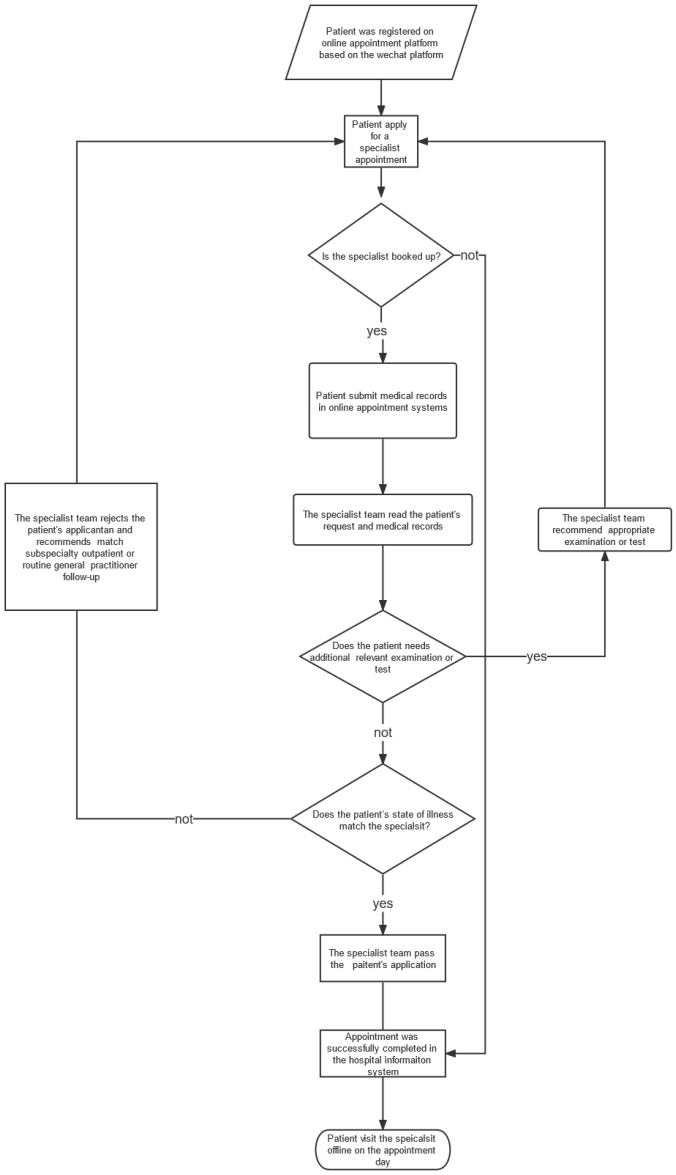

Figure1.The PRP flow chart

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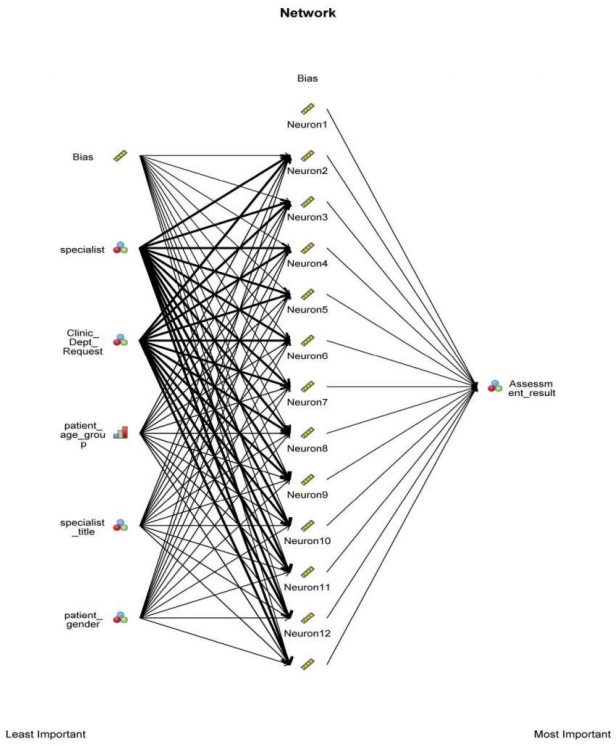

Topology architecture of the ANN model

158x191mm (220 x 220 DPI)

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Developing, Implementing, and Investigating an Innovative Model to Identify and shunt Patients for Mobile Outpatient Specialist Appointment Registration system: A Cloud-Based Precise Reservation Path in Shanghai, China

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Developing, Implementing, and Investigating an Innovative Model to Identify and shunt Patients for Mobile Outpatient Specialist Appointment Registration system: A Cloud-Based Precise Reservation Path in Shanghai, China

Minjie Chen,[1] Xiaojing Zhao ,[2] Tao Zheng,[3] Binyuan Zhang,[1] Xuji Zhao,[1] Weijun Shao,[3] Li li,[4,5] Yiling Fan[1*], and Enhong Dong,[6 , 7*]

Author affiliations
[1]Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[2]Department of thoracic surgery department, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[3]Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[4] School of Medicine ,Shanghai Jiao Tong University ,Shanghai ,China
[5] China Hospital Development Institute ,Shanghai Jiao Tong University ,Shanghai , China
[6]School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences, Shanghai, China, 9
[7]Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University, Shanghai, China

Co-Corresponding authors:
Yiling Fan
Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University
No.160 Pujian Road, Pudong new district
Shanghai, 200127
China
Phone:+8613818458771
mail:fanyiling@163.com

Enhong Dong
School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences
No.279 Zhouzhu Road, Pudong new District
Shanghai, 210318
China
Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University
No.1594 Huashan Road, Xuhui District
Shanghai, 200230
China
Phone:+86 13761141620
E-mail: kevin8012@126.com

Abstract

Objective: The aim of this study is to develop, implement the Precise Reservation Path(PRP) and investigate its prediction function for scheduling shunting patients for specialist appointment registration in Shanghai, China.

Design: The PRP system was built upon the hospital's existing information system(HIS), integrated with WeChat(WeCom) for user convenience. The outcome analysis employed a mixed-methods approach, integrating quantitative analysis with statistical and machine learning techniques, including multivariate logistic regression, Random Forest(RF) and Artificial Neural Network (ANN) analysis.

Setting:This study was conducted at Renji Hospital, a premier general tertiary care institution in Shanghai, China, where the innovative PRP system was implemented. The program was designed to efficiently connect patients requiring specialized care with the appropriate medical specialists.

Participants: The PRP encompassed both voluntary specialists at Renji hospital, as well as patients seeking outpatient specialist services.

Primary Outcome Measures: Primary Outcome Measures:The pass rates of patient for specialist applications.

Secondary Outcome Measures: Clinic department ,Specialists' and Patients'characteristics influencing specialist review result.

Results:

From a dataset of 58,271 applicants across 26 departments between December 1, 2020, and November 30, 2022, we noted an overall pass rate of 34.8%. The departments of Urology, Breast Surgery, and Thoracic Surgery, along with five others, accounted for 86.65% of applications. Pass rates varied significantly, and demographic distributions of applicants across departments revealed distinct patient profiles, with preferences evident for age and gender.We developed a Random Forest (RF) model based on pass rates from 26 specialized departments. The RF model, with 92.31% accuracy, identified age as the primary predictor of pass rates, underscoring its impact on specialist review outcomes.Focus on patient demographics,we conducted univariate and multivariate logistic regression analyses on the 58,271 patient dataset to explore the relationship between demographic factors and review outcomes. Key findings from logistic regression included significant associations with gender, age, and specialist title. Results indicated that older patients were more likely to be approved in specialist reviews, while middle-aged patients had lower pass rates.The GLM model, enhanced with specialis and clinic department variables, showed superior predictive accuracy (67.86%-68.26%) and model fit over the previous logistic model. An ANN model also identified specialis" and clinic department as the most influential, achieving comparable accuracy (67.72%-68.28%).

Conclusions: The PRP program demonstrates the potential of digital innovation in enhancing hierarchical medical system. The study's findings also underscore the value of PRP program in healthcare systems for optimizing resource allocation, particularly for aging populations.The program's design and implementation offer a scalable model for other healthcare institutions seeking to enhance their appointment systems and specialist engagement through digital innovation.

Strengths and limitations of this study

Strengths：

►►The PRP program efficiently uses a popular cross-platform social app with dual iOS/Android features to minimize learning curves and maintain user sustainability.

►►The PRP program runs asynchronously, facilitating info exchange with time lags between patients & doctors, accommodating busy schedules to optimize processing & response to patient requests.

►►Holistic approach offered by study integrates dept. & patient perspectives, examining multifaceted factors affecting patient application pass rates.

►►Methodology integrates statistical approaches with ML algorithms(incl. Random Forest & Artifcial Neural Network to handle HD data, reveal complex patterns, & offer profound insights into critical factors for patient application.

Limitations:.

►►Budget constraints precluded structured analysis of patient disease condition descriptions, resulting in a lack of some disease-related variables. Future research aims to address this limitation, aiming for more comprehensive findings.

Key words: Precise Reservation Path, Appointment Registration, Specialist , Random forest, Artifcial Neural Network

INTRODUCTION

Most people want affordable and dependable high-quality products and services, be it produce, electronics, auto repairs, or a massage. The same is true for the healthcare sector. High-quality healthcare is defined as care that is effective, safe, patient-centered, timely, efficient, equitable, and delivered by professionals who are respectful, communicate clearly, and involve patients in decision-making[1]. To achieve the goals of "Healthy China 2030," in recent years, China has deepened health reform by building high-quality and value-based service delivery, resulting in a series of significant improvements. However, several challenges still exist, including the uneven distribution of healthcare resources and the imbalance between supply and demand[2-3]. To the best of our knowledge, improving the efficiency of hospital care is a fundamental aspect of strengthening the health system. In China, public hospitals are the main body of the medical service system and the primary places for people to seek medical treatment. According to China Health Statistics Yearbook, in 2018, public hospitals provided 92% of outpatient services for all hospitals in China and 82% of inpatient services. According to China's health delivery structure, public hospitals are organized into a three-tier system(designated as primary, secondary, or tertiary institutions). A tertiary hospital is a comprehensive, referral, and general hospital at the city, provincial, or national level with a bed capacity exceeding 500. Tertiary hospitals are responsible for providing specialist health services, performing a larger role in medical education and scientific research, and serving as medical hubs providing care to multiple regions[4]. As China's healthcare system does not feature a gatekeeping general practitioner system, patients can seek primary care from primary care facilities or hospital outpatient departments[5]. In light of the free choice of healthcare providers, most patients prefer to choose a specialist(who is a medical doctor, often with a senior professional title and an expert in a specific area of medicine) in clinics or private or public hospitals, particularly tertiary public hospitals. However, due to the unequal access to information

between doctors and patients, the freedom to choose healthcare providers often leads patients to select doctors without adequate knowledge or understanding, potentially resulting in a significant misallocation of medical resources[6]. This is because patients may lack the necessary information to determine who is the most suitable doctor for their needs. In addition, patients with minor illnesses prefer to visit tertiary hospitals instead of prime care centers. These behaviors lead to a significant squandering of valuable medical resources, creating a dual challenge. Firstly, they impose a heavy economic burden on patients, potentially surpassing the affordability limits of the medical system. Secondly, these behaviors pose obstacles to the high-quality development of tertiary hospitals in China. Moreover, the scarcity of healthcare resources has led to fierce competition among patients[7-8]. To enable doctors to provide high-quality and timely outpatient services, many hospitals have implemented novel appointment registration systems that assist patients and increase hospital efficiency. With these systems, hospitals can only provide services to patients with limited efficacy. Under the rule of "first registration, first service" in appointment registration systems, some patients with severe diseases requiring specialist treatment may struggle to successfully book appointments with the necessary specialists. This violation of fairness in healthcare resource allocation goes against the principles addressed by China's current medical reform. Thus, optimizing the appointment registration system and improving the efficiency of medical procedures in Chinese tertiary public hospitals is imperative. Accordingly, hospitals are experimenting with novel appointment registration systems, such as mobile phones, web-based systems, bank-hospital cooperation, and clinical settings. Among these, redesigning the appointment-scheduling system is crucial for making effective use of healthcare resources, increasing operational efficiency, reducing operational costs, and mitigating the imbalance between supply and demand for healthcare services[9].

Over the past decade, China has had the highest number of smartphones per capita among all countries[10]. Equipped with Internet Plus Medical" applications, online appointment systems have become an alternative that optimizes the appointment process, significantly improving the efficiency of hospital services. Hospitals provide various web-based services through mobile platforms, including WeChat and other independently-developed applications. Hospital services include online consultations, appointment registration, and online payments. Such mobile health initiatives can overcome geographic boundaries, enhance the equity and accessibility of healthcare resources, and provide effective and equitable access to healthcare services in hospitals[11]. A mobile appointment registration service can provide patients with an important online channel through which all patients with smart devices can access healthcare resources. With the availability of mobile appointment registration services, patients will increasingly turn to online platforms to book appointments, gradually replacing the traditional offline queuing registrations. This shift to online registration is expected to create a higher demand for services on mobile health platforms. In hospitals, the outpatient department plays a critical role in efficiently managing medical resources as it not only directs patients for timely care but also generates numerous benefits, including improved health outcomes and optimized utilization of healthcare resources. As mentioned above, optimizing appointment-registration procedures is the responsibility and commitment of hospital management. Therefore, effective scheduling of on-hand mobile appointment registration services and providing healthcare services to patients have become key priorities for outpatient departments in tertiary public hospitals in China.

This study aims to develop a precise reservation path(PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals in Shanghai, China. This study first described a specialist-led reservation process whereby the clinical data(history, examination, and past treatment) of a reservation applicant were assessed using relevant ultrasound, laboratory, or radiological records. Subsequently, a decision was made regarding the suitability of the patient for specialist intervention. Second, employing specific statistical analysis methods, our objective was to investgate impact factors of pass rate of patients who require specialist medical services, thereby streamlining their referral to appropriate healthcare settings, such as specialized clinics or primary care institutions. This system aims to strengthen and improve the implementation of the hierarchical diagnosis and treatment system in China.

MATERIALS AND METHODS

Patient and Public Involvement

This study did not involve patients or the public.

Design

Procedure of PRP

This study was conducted at Renji Hospital, School of Medicine, Shanghai Jiao Tong University, a 2,750-bed general tertiary public hospital in Shanghai, China. In an attempt to fully digitize its records, the hospital has put in place a satisfactory information infrastructure in which most medical and health records are stored electronically. The annual number of outpatient and emergency visits to the hospital exceeds 5.820 million, and the annual number of discharged patients is 172,000. This PRP program was uniquely self-developed by the management and clinical staff at Renji Hospital in Shanghai to address the current disorganized situation where outpatients schedule specialists without any restrictions. Prior to designing the precise reservation path(PRP) system, a literature search, peer-to-peer discussions, panel discussions, and specialist consultations were conducted to determine the structure and design of the system. Staff from the outpatient and emergency management department, as well as surgeons specializing and IT technicians in thoracic surgery, breast surgery, and urinary surgery, attended the meeting to design the PRP process. The PRP process was designed as follows. Our predefined main objective was to build a cloud-based medical precise reservation path(PRP) connecting all participants(patients and specialists). Based on the PRP framework, patients with suspected severe diseases can send a specialist appointment request and submit their medical records. After a specialist reviews the patient's application and medical records, the specialist may approve or reject the patient's application. Given patients often directly schedule outpatient appointments at tertiary hospitals without undergoing primary healthcare screening, allowing for free choice of healthcare providers In the Chinese healthcare system, a total of 935625 specialist outpatient visits were identified as not progressing through the system during the study period, from December 1, 2020, to November 30, 2022 at Renji hospital. A PRP flowchart is shown in Figure 1.

Architecture of PRP

The architecture of the PRP model is illustrated in Figure S1. Technical support was provided to make different system modules compatible and establish a cloud-based precise reservation path(PRP) system to connect the new system to Renji Hospital's

original hospital information system(HIS). Building on the original HIS, new modules and functions were added to share all specialist outpatient schedules and specialist team accounts, such as WeChat(WeCom). The PRP system was integrated with hospital scheduling systems, enabling automatic identification of appointment statuses, such as whether an appointment had been made, requested, or canceled(and changing the status to require rescheduling). The specialist team user had one-click access to review the patient's application, examine the notes in the submitted medical records, and communicate with the team regarding treatment plans, thereby determining the need for scheduling a further evaluation.

Operation of PRP

The PRP is based on the hospital's official WeChat account platform

WeChat(WeCom) is a free social networking application offering instant messaging services across all platforms. It provides basic text, voice, photos, video sharing, and web-based payments and integration with intelligent hardware. Tencent's financial report shows that the number of combined monthly live WeChat accounts exceeded 1.2 billion by the end of March 2021. Based on the WeChat Framework, we developed a function that can operate on both iOS and Android mobile platforms. Therefore, our design had a minimum learning cost for the participants and ensured the sustainability of users.

PRP is based on an asynchronous form

The exchange of online information between patients and doctors can occur synchronously(when interactions occur in real-time) or asynchronously(when there is a lag between the information being transmitted and the response)[12-13]. We adopted an asynchronous form of PRP because doctors in hospitals are always busy and cannot guarantee that they are online in real-time. In addition, an asynchronous form makes full use of the doctors' fragmented time to process and respond to patient applications.

PRP is also based on cloud computing services

Cloud computing involves the on-demand availability of computer system resources, particularly data storage(cloud storage) and computing power, without direct active management by users. It provides on-demand network access to a shared resource pool and configurable computing resources across the network as a metered on-demand service that efficiently distributes resources. The cloud computing architecture exhibits various characteristics such as cost reduction, device and location independence, easier maintenance of the cloud environment, and on-demand self-service. Similarly, it is well known that one of the essential features of mobile health services is on-demand self-service, where users can instantly access network storage and server processing time. Therefore, we set the PRP based on cloud-computing services.

PRP Involving users of PRP

The PRP consists of two different types of users: patients and specialists. Mobile Outpatient Specialist Appointment Registration Procedures for patients and specialists were present in Table S1.

Investigation of the PRP program

Data resources and measures

Renji Hospital began implementing PRP in December 2020. Data used in the study were retrieved from the official WeChat medical service account and HIS at Renji Hospital from December 1, 2020, to November 30, 2022. In total, 58271 samples were obtained.

The specialist's review outcomes were dichotomized into not passed(=0) or passed(=1) as the dependent variable. Independent variables included gender, age, preference for paying with insurance, title of the specialist. The classifications and measures of the variables of interest are present in Table S2. Ethical approval was obtained from the Human Research Ethics Committee of Renji Hospital(LY2023-031-B).

Analysis strategy

Traditional statistical method:and multivariate logistic regression method

First, all the continuous variables of patient were tested for normality. The Kolmogorov-Smirnov method test results(Sig=0.070>0.05) showed that "age" exhibited a normal distribution in 58271 patients. Means ± standard deviations were used for variables that obeyed a normal distribution, and median and IQR were reported For non-normally distributed data. A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. Univariate analysis was then conducted to identify significant contributors to the dependent variable, that is, whether the patient passed the online specialist appointment registration confirmation. In the study, the Chi-square test was utilized for univariate analysis to assess categorical variables. Finally, to identify the main factors influencing the specialist's review outcome, a multivariate logistic regression applying the backward stepwise method was performed.

Random Forest (RF)Analysis: Based on Participating Departments

We assembled a collection of operation status of each department in the PRP project and the allocation of specialist resources.These data were designated as the input variables. We designated the pass rates for the PRP among departments as the target variable.Considering the common use of the random forest (RF) algorithm machine learning, ML, RF can be applied to deal binary and binary, multi-classification problems or examine interactions variables. Additionally, it can could provide variable importance measures (VIMs) with mix mixture of categorical and continuous variables, even potentially involving highly noisy and significantly variables. Random Forest (RF) also demonstrates good predictive performance even for data with more variables (p) than samples (i.e., $p > n$). Due to their non-parametric nature, RFs are a robust method used in relatively straightforward applications for inexperienced users. Some previous research has included the RF analysis method in small sample sizes, even less than 20 (denoted as $N < 20$) . Therefore, to assess the relative significance of these input variables in predicting the target, we performed a random forest algorithm analysis in the study. Since training and testing a machine learning model on the same dataset can lead to several issues, collectively known as overfitting, which occurs when a model learns the training data too well, capturing noise and random fluctuations in the data rather than the underlying patterns, we applied an "out-of-bag" (OOB) technique n the study to make predictions for an observation in the original dataset using only base learners not trained on this particular observation. This method is called out-of-bag (OOB) prediction. These predictions are not prone to overfitting, as each prediction is only made by learners that did not use the observation for training. Due to the presence of OOB samples in our dataset, the OOB data can be directly used as a validation and test set, eliminating the need to pre-partition the dataset. In SPSS Modeler, the predictive accuracy is precisely the result of out-of-bag estimation[14-19].

Generalized linear model (GLM)

The GLM model identifies the dependent variable that is linearly related to the factors and covariates via a specified link function. Moreover, the model allows for the dependent variable to have a non-normal distribution. It covers widely used statistical models, such as linear regression for normally distributed responses, logistic models for binary data, loglinear models for count data, complementary log-log models for interval-censored survival data, plus many other statistical models through its very general model formulation.

Artifcial Neural Network(ANN)

ANNs are mathematical models based on interconnected groups of artifcial neurons. They consider nonlinear relationships between input data, which are not always identifed on traditional analysis. ANNs have several advantages, such as self-learning, adaptability, and robustness of massive parallelism. Tey generally contain three layers: input, hidden, and output layers. A multilayer perceptron (MLP) is a subtype of ANN comprising one or more hidden layers containing computation nodes, with a high capability of universal approximations; it has therefore been extensively used for modeling nonlinear and complex processes of the real world. The most widely used and effective algorithm for training an MLP network is the back-propagation (BP) algorithm [20-24].We randomly divided the dataset into training and test sets at a 70:30 ratio (40766 and 17505 records, respectively). All statistical analyses were performed using SPSS software(version 23.0; IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to build the RF ,GLM and BP-ANN models.

RESULTS

Result of operation status of each department in the PRP program

From a dataset encompassing 58,271 applicants, we observed an overall pass rate of 34.8%.We have collected data from 26 departments , including the number of applications, pass rate, median age of patients, interquartile range of patient ages, gender proportion of patients, proportion of medical insurance patients, patient application count for senior specialist,patient application count for associate senior specialist,senior specialist applicant ratio, PRP program specialists,total specialists, PRP specialists proportion, average specialist applications. As seen from Table S3, it can comprehensively and visually understand the operation status of each department in the PRP program. The proportion of applications for senior specialists varies significantly across different departments, indicating differing levels of expert engagement in the PRP program. The average number of applications per specialist also reflects the popularity of the PRP program within each department. The eight departments with the highest number of patient applications are Urinary Surgery(11,142), Breast Surgery(10,097), Thoracic Surgery(9,332), Obstetrics and Gynecology(4,862), Gastrointestinal Surgery(4,716), Nephrology(4011), Head and Neck Surgery(3,256) and Biliary And Pancreatic Surgery(3076). The total number of applications for these departments accounts for approximately 86.65% of all applications, highlighting the importance of these departments in the PRP program and the significant demand from patients for their services.

Among these departments, those with higher pass rates include Head and Neck Surgery(52.7%), Biliary And Pancreatic Surgery(47.3%),Obstetrics and Gynecology(44.8%),Nephrology(42%),and Gastrointestinal Surgery(38.6%), with Urinary Surgery at 37.4%. Notably, Breast Surgery has the lowest pass rate at 18.3%. In terms of age distribution within these departments, Urinary Surgery has the highest

median patient age(64 years old, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery(44 years old, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; Thoracic Surgery(56 years old, IQR 22) and Gastrointestinal Surgery(59 years old, IQR 26) have a broader age range, covering patients from middle age to the elderly. Gender ratio data reflects the characteristics of the gender distribution among patients served by different departments. In terms of age distribution within these departments, Urinary Surgery has the highest median patient age(64 years old, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery(44 years old, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; Thoracic Surgery(56 years old, IQR 22) and Gastrointestinal Surgery(59 years old, IQR 26) have a broader age range, covering patients from middle age to the elderly. Gender ratio data reflects the characteristics of the gender distribution among patients served by different departments. For instance, Urinary Surgery and Breast Surgery show extreme gender ratios, indicating a clear male and female preference, respectively. In contrast, Nephrology, Biliary And Pancreatic Surgery, have more balanced gender ratios.

Result of Random Forest(RF)Analysis-based on 26 department

Based on the pass rates from 26 specialized clinical departments,we utilized IBM SPSS Modeler version 18.0 to develop a Random Forest(RF) model. Under the guidance of a statistical expert, The model's parameters were calibrated, with the number of models to build set to 7, and the sample size meticulously configured to 1. To enhance the model's efficacy and feature selection, we activated the "Handle imbalanced data" feature and the "Use weighted sampling for variable selection" option. For the tree growth parameters, we retained the default settings provided by the software, which included a maximum number of nodes set to 10,000, a maximum tree depth of 10, and a minimum child node size of 5.

Based on the study, the overall pass rate is 34.8%. We've set the "Pass Rate Interval" field to categorize departments as either "high-rank group" or "low-rank group" based on this rate. Based on this, the "Pass Rate Interval", a binary variable, is taken as the target variable in the RF analysis. The variables, including Patients age Median, PRP specialists proportion, Average specialist applications, Total specialists, Insurance patient ratio, PRP program specialists, Patients gender ratio, Application count, Senior specialist applicant ratio, all serve as input features in the RF analysis.The accuracy of the model is 92.31%.The predictor importance values range from 0.12 to 0.93, indicating the relative significance of each variable in predicting the target variable. Patients age Median emerges as the most significant predictor with a value of 0.93, followed by PRP specialists proportion and Average specialist applications with values of 0.87 and 0.84, respectively. On the other hand, variables such as Application count and Senior specialist applicant ratio have lower importance values, indicating their lesser contribution to the prediction process. Table S4 and Figure S2 present an overview of the variables and their respective roles in a random forest model, along with their predictor importance.

Overview and basic characteristics of patients

A total of 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. During this period, 58271 patients applied for specialist appointments through the PRP program. In the Chinese medical and health system, it is commonplace for patients to schedule outpatient appointments at tertiary

hospitals without undergoing prior approval. Of these 58271 patients, 20290(34.8%) patients passed the specialist assessment, and 37981(65.2%) did not.

Of the 58271 patients, the mean age was 52.89 ± 15.73 years. The Kolmogorov-Smirnov method test results(Sig=0.070>0.05) showed that "age" exhibited a normal distribution in 58271 patients. Among them, 22412(38.5%)were male, and 35859(61.5%)were female. See Table 1 For more details of patient characteristics.

Results of univariate and multivariate logistic regression analysis in the total population sample(N=58271)

Focus on patient demographics,we conducted univariate and multivariate logistic regression analyses on the 58,271 patient dataset to explore the relationship between demographic factors and assessment outcomes.The findings are detailed in Table 1.Through univariate analyses, the significant factors associated with the specialist review outcome were gender($P < 0.001$), age($P < 0.001$),title of the specialist ($P<0.001$). The factors of age, gender, and the title of the specialist were found to be significant in the univariate analyses and were subsequently included in the multivariate logistic regression model. This model was constructed using the backward stepwise method to refine the selection of variables.Then, through a multivariate logistic regression model, it indicates that those who were male and aged 60 years old or above were more likely to pass the specialist's review in the age PRP program, while those aged 35–59 years were less likely to pass the specialist's review in the likely PRP program compared to those who aged 18–34 years old. It also found that those who had title Assosiate senior were more likely to pass the specialist's review in the age PRP program relative to those who had title of senior specialist. (See Table 1).

Nagelkerke R Square ranges from 0 to 1, with values closer to 1 indicating a better fit of the model. However, from Table 1 we learn the value of Nagelkerke R Square was 0.016 .From this, we speculate that there are more "strong' variables that are not included in the predictive model of the expert review results (Table 1). Therefore, we added a GLM to further identify other predictors that are not included in the multivariate logistic regression model enhancing the model fit.

Table1.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To The specialist's review outcome

Items	Characteristics		Pass the Review		Univariate Analysis		Multivariate Analysis	
					Chi square test		Logistic Regression	
	Variables	Frequency(%)	Not Pass (Group A)	Pass (Group B)	c^2	P	OR (95% CI)	P
Gender					198.94	<0.001		
	Female	35859(61.5)	24162(67.4)	11697(32.6)			1.000	
	Male	22412(38.5)	13819(61.7)	8593(38.3)			1.161(1.119-1.205)	<0.001
Age (years)					154.93	<0.001		
	18-34	9003(15.5)	5902(65.6)	3101(34.4)			1.000	

	35-59	26590(45.6)	17939(67.5)	8651(32.5)			0.933(0.886-0.981)	0.007
	60-74	18405(31.6)	11577(62.9)	6828(37.1)			1.075(1.018-1.134)	0.009
	Above 75	4273(7.3)	2563(60.0)	1710(40.0)			1.151(1.066-1.243)	<0.001
Title of the specialist	senior	31561 (54.2)	21854(69.2)	9707(30.8)	501.00	<0.001	1.000	
	Assosiate senior	26710(45.8)	16127(60.4)	10583(39.6)			1.420(1.371-1.471)	<0.001
If Having Preference to pay with Insurance or not	Yes	42089(72.2)	27437(65.2)	14652(34.8)	0.004	0.95	N/A	N/A
	No	16182(27.8)	10544(65.2)	5638(34.8)			N/A	
Whether having Passed the Review	Yes	20290(34.8)		N/A	N/A		N/A	
	No	37981(65.2)						
Nagelkerke R Square							**0.016**	
Akaike information criterion (AIC)							**52335.946**	

Result of GLM analysis

In our enhanced analysis, we incorporated two additional variables—specialist and clinic department—into the independent variables of the GLM and ANN models. The target variable is the assessment result, categorized as dummy variables. According to the results of the GLM regression analyses, the specialist and clinic department were the most significant variables, with relative importances of 0.71 and 0.26, respectively. In contrast, age and the title of the specialist exert a comparatively minor influence, each with an importance of 0.02 (see Table 2). Furthermore, the model's predictive accuracy is outlined in Table 3, demonstrating scores of 67.86% for the training dataset and 68.26% for the test dataset. The Akaike Information Criterion (AIC) value for the GLM, which stands at 48,433.067, is notably lower than the AIC value of 52,335.946 for the multivariate logistic model. This decrease in AIC indicates that the GLM, with its five input variables, outperforms the multivariate logistic model, which has only three inputs, in terms of model fit and explanatory power.

Result of ANN analysis

To further understand how patient characteristics and specialist choices affect PRP assessment results, we developed an ANN model with a Multilayer Perceptron (MLP) structure.We maintained all other parameters at their default values as specified by the software.In the ANN analysis depicted in Table 2, the input features encompass specialist ,clinic department, age, title of the specialist, and gender, with assessment

result (Yes or No) serving as the target variable. Table 2 further delineates the key variables influencing the assessment result within the ANN model, ranking specialist and clinic Department as the most impactful with relative importances of 0.44 and 0.43, respectively. Age, title of the specialist, and gender follow with lesser influences at 0.07, 0.04, and 0.02, respectively. Additionally, Figure 2 provides an illustration of the ANN model's topology architecture. The model's accuracy is delineated in Table 3, with scores of 67.72% for the training dataset and 68.28% for the test dataset.

Tabe 2 The Role in GLM and ANN Model and Result of Predictor Importance

Variables	Role in model	Predictor importance in GLM	Predictor importance in ANN
Specialist	input	0.71	0.44
Clinic Department	input	0.26	0.43
Age	input	0.02	0.07
Title of the Specialist	input	0.02	0.04
Gender	input	0.00	0.02
Assessment Result(Yes or No)	target	/	/

Table 3. Accuracy of GLM and ANN analyses

	GLM				ANN			
Partition	Training Dataset		Testing Dataset		Training Dataset		Testing Dataset	
	Records	Accuracy	Records	Accuracy	Records	Accuracy	Records	Accuracy
Correct	27662	67.86%	11949	68.26%	27607	67.72%	11952	68.28%
Wrong	13104	32.14%	5556	31.74%	13159	32.38%	5553	31.72%
Total	40766		17505		40766		17505	

DISCUSSION

Digital technologies are increasingly being used to support health systems(WHO, 2018) by providing flexible options for interpersonal communication and information exchange[25]. Access, affordability, and equity are three basic goals of a well-functioning health system[26]. In this study, among the 58,271 patients who applied for medical specialists on the PRP-based platform, 20,290 patients successfully passed reviews conducted by specialists, thereby gaining access to specialized medical treatment in hospitals. This indicates that the mobile-health-based PRP program is a practical and innovative approach. It enables patients to obtain convenient access to medical specialists in hospitals with reduced doctor-seeking costs, ensuring timely and highly efficient treatment. Furthermore, the remaining 37,891 patients who did not pass the specialists' review were identified through the PRP program. They were advised to be appropriately directed to other clinical departments within the hospital or to primary care centers for treatment by general practitioners (GPs). This guidance helps prevent

the inefficiency of patients blindly seeking appointments with specialists, which could otherwise lead to the waste of valuable medical resources in hospitals.

The PRP program, implemented across 26 departments, has demonstrated a diverse performance landscape, showing significant variations in operational metrics such as application volumes, pass rates, and specialist involvement. The implemented program attracted a total of 58,271 patients applying for specialist appointments during the study period, reflecting the program's extensive reach and the significant demand for specialist services from outpatients. The program's smooth implementation was highlighted by the high participation rate of 85 specialists from various fields, demonstrating a robust network of professionals eager to engage in the PRP initiative.

Univariate analysis found that age is significantly linked to the outcomes of specialist reviews ($P < 0.001$). Logistic regression showed that individuals aged 60 and above are more likely to pass reviews compared to the 18–34 age group, while the 35–59 age group is less likely to do so. RF analysis also identified applicant age as the most important predictor, with a 0.93 importance value, in explaining the differences in pass rates in 26 clinic departments. This may be because the elderly, who often suffer a variety of chronic diseases, may have higher medical needs than younger individuals[27].This is consistent with the evidence that many previous studies have claimed that elderly patients have greater utilization of hospital outpatient or inpatient healthcare services than their younger counterparts because of their unfavorable health status[28]. Conversely, those aged 35–59 years had a lower probability of passing the specialist review and a higher probability of being truly rejected than those aged 18–34 years. This could be explained by the fact that middle-aged patients prefer advanced medical care regardless of their factual medical needs. These patients may see specialists in hospitals for psychological comfort or because they mistrust GPs in primary care settings, although they do not need special medical care. Many previous studies have reported that this phenomenon results from a lack of community gatekeeper systems in China[29-30]. This reflects the urgent need to strengthen primary care and family doctor services that target middle-aged groups in China. Additionally, male patients were more likely to pass the review compared to their female counterparts. This may be explained by the higher prevalence of chronic diseases in males than in females in China[3]. However, this finding was not consistent with previous studies, all of which reported a higher prevalence of chronic diseases in females, especially those aging 60 years and above in China[32-33]. Gender ratios in the prevalence of chronic diseases are inconclusive. Therefore, the Shanghai government and decision-makers in the health sector should make gender and age-specific efforts to facilitate the implementation of hierarchical diagnosis and treatment systems and family doctor services among middle-aged patients. By shunting middle-aged patients toward GPs or secondary hospitals, patient crowding caused by the" siphon effect" can be mitigated, thus improving the efficiency of procedures in tertiary hospitals.

More interestingly, regarding the specialist title, those specialists who hold associate senior titles were more likely to approve patients' applications compared to senior specialists. This may be due to the intense competition for title promotion in medicine. In Chinese society, job hierarchy plays a significant role, which is evident in the use of professional titles[34-35]. Professional titles often signify one's seniority, experience, or level of authority within a government-funded organization. In Given the pressure for promotion promotion, specialists with associate senior titles prefer to accept more patients to enhance their professional skills and prepare for promotion to senior professional titles.The analyses of the GLM and ANN models reveal a distinct prioritization of specialist and departmental factors within the PRP program, surpassing

the predictive power of patient age and gender.This prioritization may stem from a complex array of reasons as follows:Firstly, the unique expertise of specialists is of paramount importance; for instance, urologists may specialize in different subspecialties, with some focusing on kidney conditions, others on prostate issues, and still others on bladder diseases, all of which significantly shape patient requests and the outcomes of assessments.

Secondly, certain clinical departments have a more concentrated age range among their applicants, with a gender demographic that is notably skewed. For instance, the breast surgery department is characterized by a significant prevalence of middle-aged women, with a median age of 44 and a gender ratio of 0.01 among its applicants. In contrast, the urology department has a predominantly male applicant base, with a gender ratio of 3.85, and applicants are generally older, with a median age of 68, which exceeds the overall median age of the PRP applicant pool by 14 years. Together, these two departments make up a considerable portion of the entire PRP applicant pool, constituting 36.45% of the total. The unique demographic characteristics of these specific departments may profoundly influence the predictive factors.

Thirdly, the potential personal subjectivity inherent in expert reviews could be significant. In the future, we will integrate rule-based systems alongside multimodal artificial intelligence reviews to mitigate the influence of individual subjective biases.

The GLM Model scored 67.86% on the training set and 68.26% on the test set, while the ANN Model scored 67.72% on the training set and 68.28% on the test set, indicating nearly identical predictive performance.The current GLM and ANN model, with a testing dataset accuracy, indicates significant potential for enhancing and augmenting its predictive accuracy. Additionally, the existing budget constraints impeded the inclusion of structured analysis of patient disease condition descriptions, necessitating further studies. A prospective approach is needed to develop a more robust, comprehensive, and all-encompassing predictive model by including this important variable.

CONCLUSION

In conclusion, the PRP program offers a promising approach to integrating digital health technologies into the healthcare system. It provides a scalable and adaptable model for optimizing specialist appointment processes. Moving forward, our prospective study goal is to enhance and expand the program by involving more specialists and hospitals to reach a larger number of patients. Other healthcare entities looking to improve their appointment processes and specialist engagement through digital advancements can refer to the program's design and implementation.

Figure1. The PRP flow chart

Figure.2 Topology architecture of the ANN model

Abbreviations

BIC: Bayesian Information Criterion
HIS: Hospital information system
PRP: Precise reservation path
RF:Random forest
GLM:Generalized linear model
AIC:Akaike Information Criterion
ANN:Artifcial Neural Network

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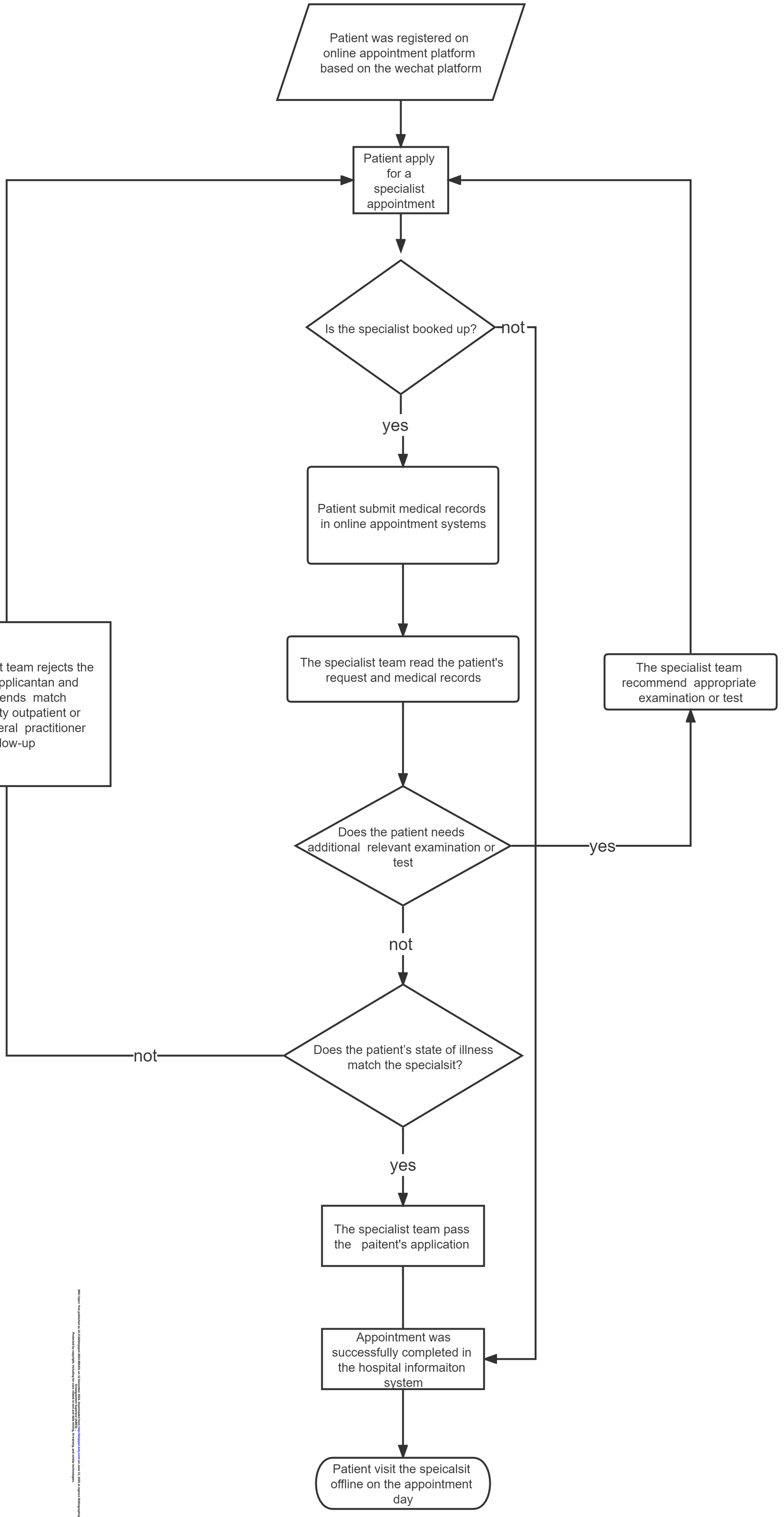

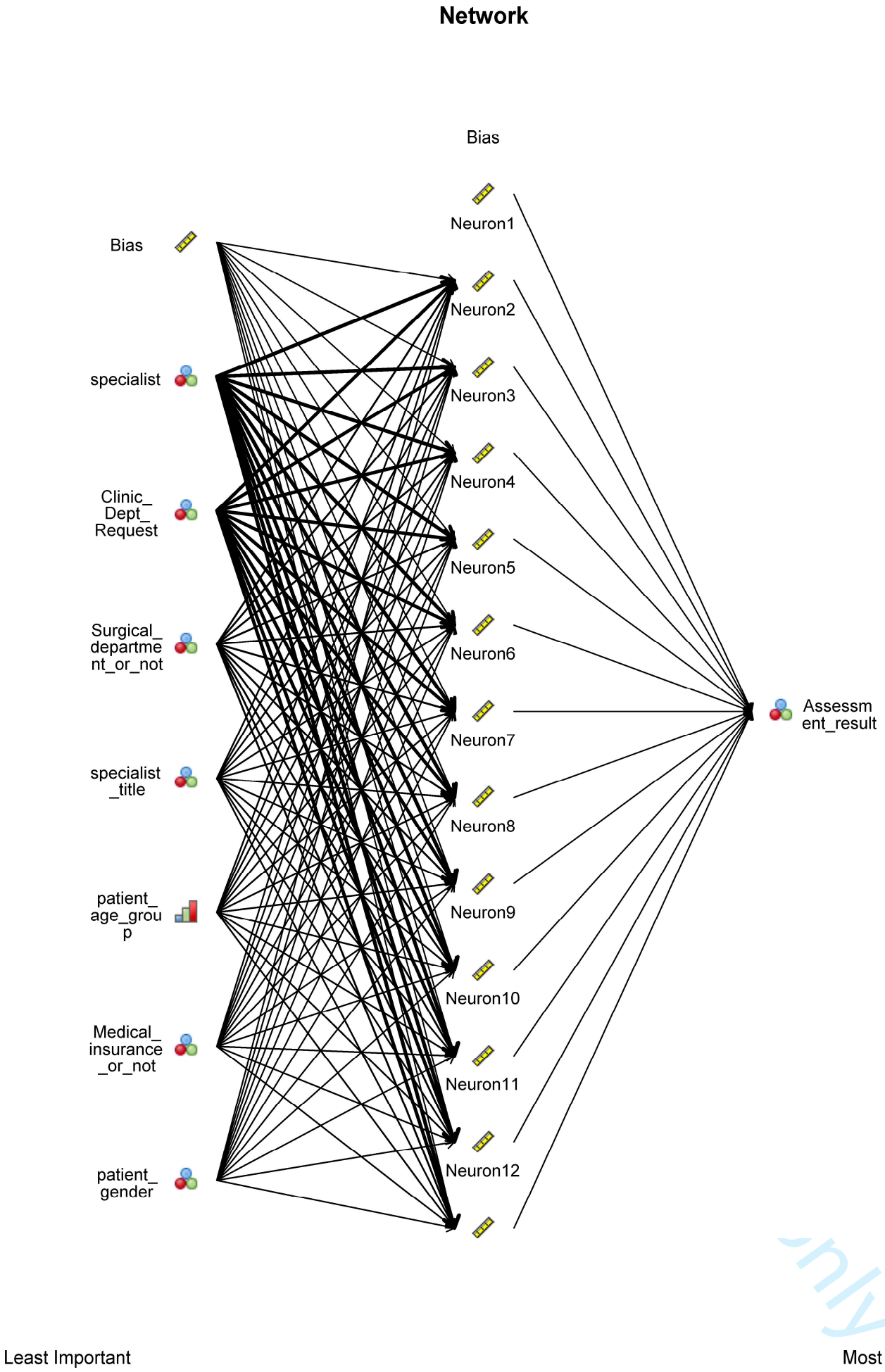

Table S1 Mobile Outpatient Specialist Appointment Registration Procedure for patients and specialists

Steps	Procedure for patients
1	The patient registers on the WeChat official medical service account of Renji Hospital using a mobile phone.
2	The patient reads the online specialist directory of the hospital and the diseases in which the specialist specializes.
3	The patient selects a specific specialist and requests an appointment by accessing the "Precise Reservation Path (PRP)" label.
4	The patient confirms the informed consent of the PRP, protocol, and submission of medical records.
5	According to the requirements of different specialist protocols, the patient also needs to submit relevant past examination reports (no earlier than 3 months), such as blood laboratory tests, ultrasound rays, computed tomography (CT), magnetic resonance imaging (MRI), and pathological reports.
6	If approval is received from the specialist users, the patient is allowed to visit the specialist offline on the appointed day.
Steps	Procedure for specialists
1	The specialist team user registers on the official WeChat accounts of Renji Hospital to build a PRP account using a mobile phone and obtains approval from the PRP system administrator.
2	The specialist team user completes their individual profile, including information about diseases in which they are specialized, past examination reports, and informed consent for patients before obtaining approval from the hospital's information administrator.
3	The specialist team user responds to patients' requests in a timely manner.
4	A specialist team user approves or rejects the patient's application. In the event of rejection, the user provides specific advice, such as recommending a well-matched subspecialty for the patient or suggesting a referral to their general practitioner.

Table S2 The classifications and measures of variables of interest

Variables	How to measure	Type
Whether having Passed the Review	1=Yes； 0= No	Categorical
Age	1=18-34 years; 2=35-59 years； 3=60-74 years; 4=75 years or above	Categorical
Gender	1=Male ;0=Female	Categorical
If having a Preference to pay with Insurance	1=Yes; 0=No	Categorical
Acdemic title of the specialist	1=Senior specialist; 2=Associate senior specialist	Categorical
Surgical department or not	1=Yes; 0=No	Categorical

Table S3 Operational Profile of 26 Departments participating in the PRP Program

Clinic department	Application count	Pass rate(%)	Patients age Median	Patients age IQR	Patients gender ratio(male/female)	Insurance patient ratio (%)	Patient application count for senior specialist	Patient application count for associate senior specialist	Senior specialist applicant ratio(%)	Integrated specialists	Total specialists	PRP specialists proportion(%)	Average specialist applications
Urinary Surgery	11142	37.4*	64	17	3.85	71.6	2012	9130	18.1	1	37	38	795.9
Breast Surgery	10097	18.3	44	20	0.01	74.4	6397	3700	63.4	1	5	100	2019.4
Thoracic Surgery	9332	27.7	56	22	0.57	65.0	9332	0	100.0	1	6	17	9332.0
Obstetrics And Gynecology	4862	44.8*	39	19	0	76.3	3432	1430	70.6	4	35	11	1215.5
Gastrointestinal Surgery	4716	38.6*	59	26	1.37	71.2	2364	2352	50.1	6	29	21	786.0
Nephrology	4011	42.0*	57	28	0.93	82.8	1955	2056	48.7	6	17	35	668.5
Head And Neck Surgery,	3256	52.7*	49	22	0.31	77.7	126	3130	3.9	2	5	40	1628.0
Biliary And Pancreatic Surgery	3076	47.3*	59	25	0.83	77.0	1601	1475	52.1	12	25	48	256.3
Radiotherapy	1551	55.1*	61	19	1.14	61.5	1261	290	81.3	3	7	43	517.0
Traumatic Orthopedics	1406	36.8*	44	32	0.89	76.4	0	1406	0.0	1	10	10	1406.0
Vascular Surgery	835	26.1	64	18	0.96	76.3	605	230	72.5	4	9	44	208.8
Rheumatology And Immunology	790	2.2	47	24	0.3	40.0	720	70	91.1	3	20	15	263.3
Cardiology	692	17.1	61	27	0.81	80.1	206	486	29.8	4	25	16	173.0
Joint Surgery	483	44.3*	55	27	0.56	72.3	421	62	87.2	4	9	44	120.8
Gynecological Oncology	478	61.5*	47	20	0	55.0	454	24	95.0	2	3	67	239.0

Otorhinolaryngology	470	33.4	47	25	1.02	77.0	143	327	30.4	4	8	50	117.5
Spine Surgery	445	56.4 *	66	24	0.79	79.8	445	0	100.0	9	11	445.0	
Ophthalmology	237	43.5 *	64	27	0.72	72.6	0	237	0.0	12	8	237.0	
Pain Medicine	143	40.6*	60	27	0.72	60.1	0	143	0.0	2	50	143.0	
Functional Neurology	120	0.0	44	30	1.03	59.2	0	120	0.0	1	100	120.0	
Oncology	49	51.0*	60	19	0.96	32.7	49	0	100.0	12	8	49.0	
Plastic Surgery	25	28.0	41	18	1.27	84.0	0	25	0.0	5	20	25.0	
Digestion Medicine	21	0.0	52	20	0.91	38.1	21	0	100.0	44	2	21.0	
Diagnostic Radiology	18	55.6*	64	50	0.38	27.8	0	18	0.0	16	6	18.0	
Endocrinology	13	0.0	41	20	1.17	53.9	13	0	100.0	10	10	13.0	
General Surgery	3	0.0	34	/	0	100.0	3	0	100.0	8	13	3.0	
Total	58271	34.8	54	26	0.63	72.2	31560	26711	54.2	369	23.04%	685.5	

Note:

Patients age Median: Median age of patients applying

Patients age IQR: Age IQR of patients applying

Patients gender ratio: Gender ratio of patients applying(male/female)

Insurance patient ratio (%): Proportion of insurance among the patients applying

Senior specialist applicant Ratio(%): Proportion of patient apply for senior specialist among all applicants

PRP program specialists: Number of specialists participating in PRP program

Total specialists: Total number of specialists in department

PRP specialists proportion(%):Proportion of specialists participating in the PRP program to the total number of specialists in department

Average specialist applications: Average of patients applying for one specialist in department

Tabe S4 The Role in Random Forest Model and Result of Predictor Importance

Variables	Role in random forest model	Predictor importance
Patients age Median	input	0.93
PRP specialists proportion	input	0.87
Average specialist applications	input	0.84
Total specialists	input	0.53
Insurance patient ratio	input	0.35
PRP program specialists	input	0.35
Patients gender ratio	input	0.22
Application count	input	0.16
Senior specialist applicant ratio	input	0.12
Pass Rate Interval	target	/

Tabe S5 The Role in ANN Model and Result of Predictor Importance

Variables	Role in ANN model	Predictor importance
Specialist	input	0.44
Clinic department	input	0.43
Patient age group	input	0.07
Acdemic title of the specialist	input	0.04
Gender	input	0.02
Assessment result(yes or no)	target	/

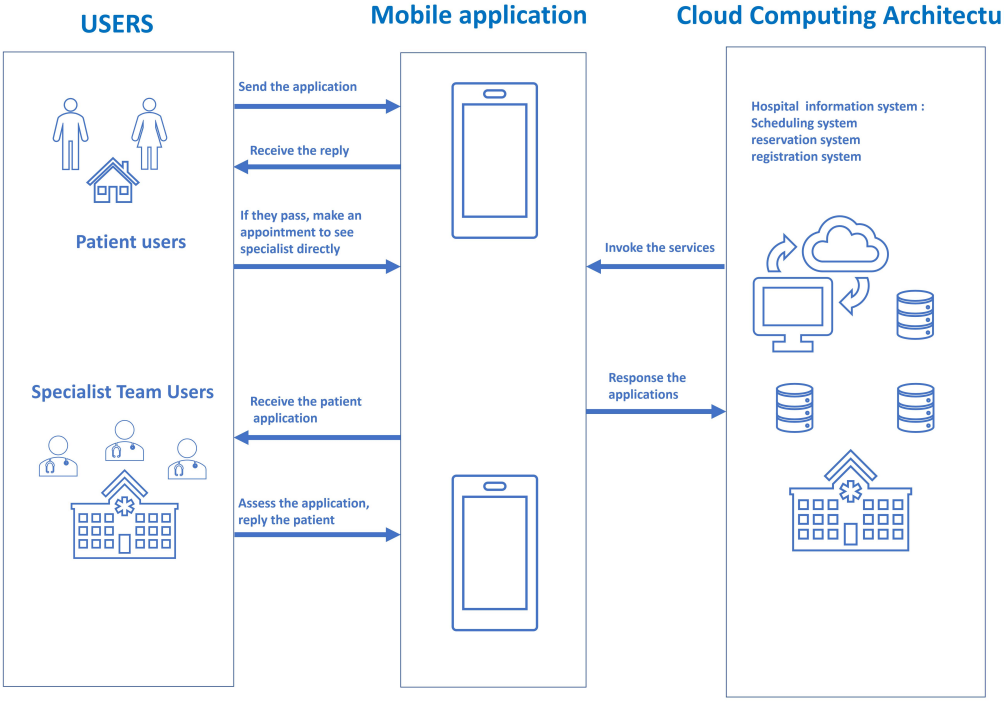

Figure S1. The PRP model architecture

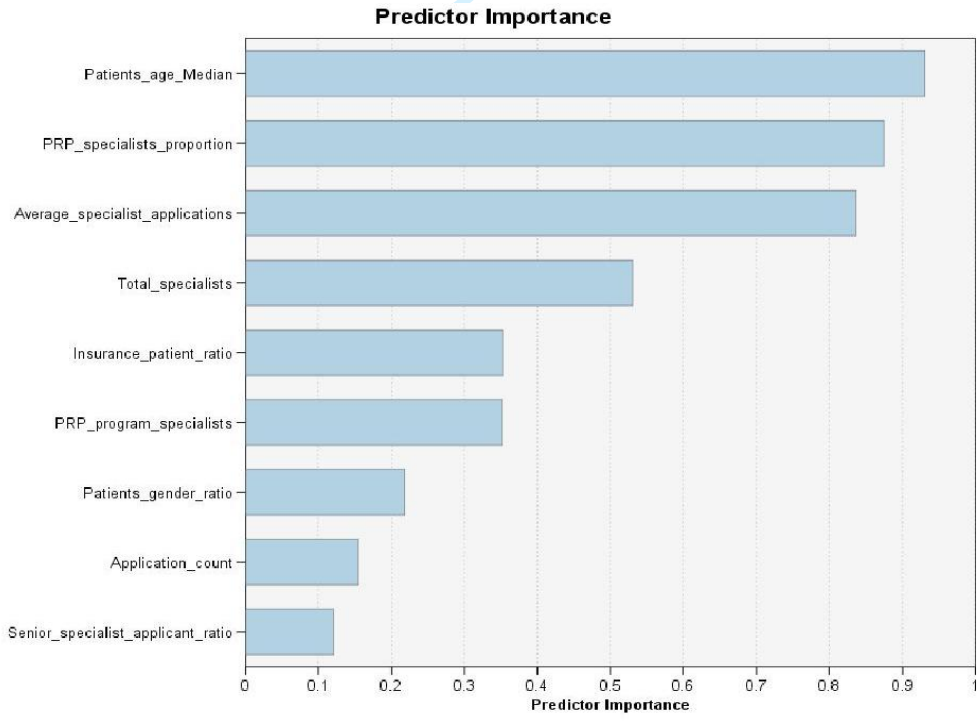

Figure S2. Result of Predictor Importance Through RF Analysis

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Optimizing Specialist Appointment Access in Tertiary Healthcare: A Precise Reservation Path Framework Using Digital Health Technologies

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Optimizing Specialist Appointment Access in Tertiary Healthcare: A Precise Reservation Path Framework Using Digital Health Technologies

Minjie Chen,[1] , Xiaojing Zhao ,[2] Tao Zheng,[3] Binyuan Zhang,[1] Xuji Zhao,[1] Weijun Shao,[3] Li li,[4,5] Yiling Fan, [1*] and Enhong Dong,[6, 7*]

Author affiliations
[1]Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[2]Department of thoracic surgery department, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[3]Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[4] School of Medicine ,Shanghai Jiao Tong University ,Shanghai ,China
[5] China Hospital Development Institute ,Shanghai Jiao Tong University ,Shanghai， China
[6]School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences, Shanghai, China,
[7]Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University, Shanghai, China

Co-Corresponding authors:
Yiling Fan
Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University
No.160 Pujian Road, Pudong new district
Shanghai, 200127
China
Phone:+8613818458771
mail:fanyiling@163.com

Enhong Dong
School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences
No.279 Zhouzhu Road, Pudong new District
Shanghai, 210318
China
Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University
No.1594 Huashan Road, Xuhui District
Shanghai, 200230
China
Phone:+86 13761141620
E-mail: kevin8012@126.com

Abstract

Objective: The aim of this study is to develop, implement the Precise Reservation Path(PRP) and investigate its prediction function for scheduling shunting patients for specialist appointment registration in Shanghai, China.
Design: The PRP system was built upon the hospital's existing information system(HIS), integrated with WeChat(WeCom) for user convenience. The outcome analysis employed a mixed-methods approach, integrating quantitative analysis with statistical and machine learning techniques, including multivariate logistic regression, Random Forest(RF) and Artificial Neural Network (ANN) analysis.
Setting:This study was conducted at Renji Hospital, a premier general tertiary care institution in Shanghai, China, where the innovative PRP system was implemented. The program was designed

to efficiently connect patients requiring specialized care with the appropriate medical specialists.
Participants: The PRP encompassed both voluntary specialists at Renji hospital, as well as patients seeking outpatient specialist services.
Primary Outcome Measures: Primary Outcome Measures:The pass rates of patient for specialist applications.
Secondary Outcome Measures: Clinic department ,Specialists' and Patients'characteristics influencing specialist review result.
Results:
From a dataset of 58,271 applicants across 26 departments between December 1, 2020, and November 30, 2022, we noted an overall pass rate of 34.8%. The departments of Urology, Breast Surgery, and Thoracic Surgery, along with five others, accounted for 86.65% of applications. Pass rates varied significantly, and demographic distributions of applicants across departments revealed distinct patient profiles, with preferences evident for age and gender.We developed a Random Forest (RF) model based on pass rates from 26 specialized departments. The RF model, with 92.31% accuracy, identified age as the primary predictor of pass rates, underscoring its impact on specialist review outcomes.Focus on patient demographics,we conducted univariate and multivariate logistic regression analyses on the 58,271 patient dataset to explore the relationship between demographic factors and review outcomes. Key findings from logistic regression included significant associations with gender, age, and specialist title. Results indicated that older patients were more likely to be approved in specialist reviews, while middle-aged patients had lower pass rates.The GLM model, enhanced with specialis and clinic department variables, showed superior predictive accuracy (67.86%-68.26%) and model fit over the previous logistic model. An ANN model also identified specialis" and clinic department as the most influential, achieving comparable accuracy (67.72%-68.28%).
Conclusions: The PRP program demonstrates the potential of digital innovation in enhancing hierarchical medical system. The study's findings also underscore the value of PRP program in healthcare systems for optimizing resource allocation, particularly for aging populations.The program's design and implementation offer a scalable model for other healthcare institutions seeking to enhance their appointment systems and specialist engagement through digital innovation.

Strengths and limitations of this study

►►Holistic approach offered by study integrates dept. & patient perspectives, examining multifaceted factors affecting patient application pass rates.
►►Methodology integrates statistical approaches with ML algorithms(incl. Random Forest & Artifcial Neural Network to handle HD data, reveal complex patterns, & offer profound insights into critical factors for patient application.
►►Future studies should incorporate rule-based systems and multimodal AI assessments to reduce individual biases in expert evaluations.

Key words: Precise Reservation Path, Appointment Registration, Specialist， Random forest, Artifcial Neural Network

INTRODUCTION

Most people seek affordable, dependable, and high-quality products and services such as electronics, auto repairs, and massage. This is also true of the healthcare sector. High-quality healthcare is defined as care that is effective, safe,

patient-centered, timely, efficient, equitable, and delivered by professionals who communicate respectfully, communicate clearly, and involve patients in decision-making[1]. To achieve the goals of "Healthy China 2030," China has deepened health reforms in recent years to establish high-quality, value-based service delivery, resulting in a series of significant improvements. However, several challenges persist, including the uneven distribution of healthcare resources and the imbalance between supply and demand[2–3]. Improving the efficiency of hospital care is, to the best of our knowledge, a fundamental aspect of strengthening the health system. In China, public hospitals are the main body of the medical service system and the primary places for people to seek medical treatment. According to the China Health Statistics Yearbook, in 2018, public hospitals provided 92% of outpatient services and 82% of the inpatient services among all hospitals in China. According to China's health delivery structure, public hospitals are organized into a three-tier system (designated as primary, secondary, or tertiary institutions). A tertiary hospital is a comprehensive, referral, and general hospital at the city, provincial, or national level with a bed capacity exceeding 500. Tertiary hospitals are responsible for providing specialist health services, performing a more significant role in medical education and scientific research, and serving as medical hubs that offer care in multiple regions[4]. Since China's healthcare system does not feature a gatekeeping general practitioner system, patients can seek primary care from primary care facilities or hospital outpatient departments[5]. Considering the free choice of healthcare providers, most patients prefer to select a specialist (who is a medical doctor, often with a senior professional title and an expert in a specific area of medicine) in clinics, private hospitals, or public hospitals, particularly tertiary public hospitals. However, due to unequal access to information between doctors and patients, the freedom to choose healthcare providers often leads patients to select doctors without adequate knowledge or understanding, potentially resulting in a significant misallocation of medical resources[6]. This is because patients may lack the necessary information to determine the most suitable doctor for their needs. Additionally, patients with minor illnesses preferred to visit tertiary hospitals instead of primary care centers. These behaviors lead to the substantial misuse of valuable medical resources, creating a dual challenge. First, it imposes a heavy economic burden on patients, potentially exceeding the affordability limits of the medical system. Second, these behaviors pose obstacles to the high-quality development of tertiary hospitals in China. Moreover, the scarcity of healthcare resources has led to fierce competition among patients[7–8]. To support the provision of high-quality and timely outpatient services, many hospitals have implemented innovative appointment registration systems to assist patients and increase hospital efficiency. These systems allow hospitals to provide services more efficiently. Under the rule of "first registration, first service" in appointment registration systems, some patients with severe diseases requiring specialist treatment may struggle to book appointments with the necessary specialists successfully. This inequity in healthcare resource allocation contradicts the principles of China's current medical reform. Thus, it is imperative to optimize the appointment registration system and improve the efficiency of medical procedures in Chinese tertiary public hospitals. Accordingly, hospitals are testing novel appointment registration systems, such as mobile phones, web-based systems, bank hospital partnerships, and clinical settings. Among these, redesigning the appointment-scheduling system is crucial for effectively utilizing healthcare resources, increasing operational efficiency, reducing operational costs, and mitigating the imbalance between supply and demand for healthcare services[9].

Over the past decade, China has had the highest number of smartphones per capita among all the countries[10]. Equipped with “Internet Plus Medical" applications, online appointment systems have become an alternative that optimizes scheduling processes, significantly improving the efficiency of hospital services. Hospitals provide various web-based services through mobile platforms, including WeChat and other independently developed applications. Hospital services include online consultations, appointment registration, and payments. Such mobile health initiatives can overcome geographical boundaries, enhance the equity and accessibility of healthcare resources, and provide practical and equitable access to healthcare services in hospitals[11]. Mobile appointment registration services provide patients with an essential online channel through which those with smart devices can access healthcare resources. With the availability of mobile appointment registration services, patients will increasingly turn to online platforms for booking appointments, gradually replacing traditional offline queuing registrations. This shift to online registration is expected to create a higher demand for services on mobile health platforms. In hospitals, the outpatient department plays a critical role in efficiently managing medical resources, as it not only directs patients toward timely care but also generates numerous benefits, including improved health outcomes and optimized utilization of healthcare resources. As discussed, optimizing appointment registration procedures is the responsibility and commitment of hospital management. Thus, the effective scheduling of mobile appointment services and the provision of healthcare services to patients have become critical priorities for outpatient departments in tertiary public hospitals in China.

This study aims to develop a precise reservation path (PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals in Shanghai, China. This study first describes a specialist-led reservation process in which the clinical data (history, examination, and past treatment) of a reservation applicant are assessed using relevant ultrasound, laboratory, or radiological records. Subsequently, a decision is made regarding the suitability of the patient for specialist intervention. Second, by employing specific statistical analysis methods, our objective is to investigate the factors affecting the pass rate of patients who require specialist medical services, thereby streamlining their referral to appropriate healthcare settings, such as specialized clinics or primary care institutions. This system aims to strengthen and improve the hierarchical diagnostic and treatment systems in China.

MATERIALS AND METHODS

Patient and Public Involvement

This study did not involve direct patient or public participation.

Design

Procedure of PRP

This study was conducted at the Renji Hospital, School of Medicine, Shanghai Jiao Tong University, a 2,750-bed general tertiary public hospital in Shanghai, China. To fully digitize its records, the hospital has established an information infrastructure in which most medical and health records are stored electronically. The annual number of outpatient and emergency visits to hospitals exceeds 5.82 million, and the annual number of discharged patients is 172,000. The PRP program was developed by the management and clinical staff at Renji Hospital in Shanghai to address the disorganized system in which outpatients schedule specialists without restrictions. Before designing the PRP system, a literature search, peer discussions, panel

discussions, and specialist consultations were conducted to determine its structure and design. Staff from the outpatient and emergency management departments, as well as specialized surgeons and IT technicians in thoracic surgery, breast surgery, and urinary surgery, attended meetings to design the PRP process. The PRP process was designed as follows: Our main objective was to build a cloud-based, precise medical reservation path connecting all participants (patients and specialists). Based on the PRP framework, patients with suspected severe disease can request a specialist appointment and submit their medical records. After a specialist reviews the patient's application and medical records, the specialist may approve or reject the patient's application. Given that patients often directly schedule outpatient appointments at tertiary hospitals without undergoing primary healthcare screening, there is a free choice of healthcare providers. In the Chinese healthcare system, 935,625 specialist outpatient visits were identified as not progressing through the system during the study period, from December 1, 2020, to November 30, 2022, at Renji Hospital. The PRP flowchart is shown in Figure 1.

Architecture of PRP

The architecture of the PRP model is shown in Figure S1. Technical support ensured that different system modules were compatible and established a cloud-based PRP system that connected it to the original hospital information system (HIS) of Renji Hospital. Building on the original HIS, new modules and functions were added to share all specialist outpatient schedules and specialist team accounts, such as WeChat (WeCom). The PRP system was integrated with hospital scheduling systems, enabling the automatic identification of appointment statuses, including whether an appointment had been made, requested, or canceled (and changing the status if rescheduling is required). The specialist team user has one-click access to review the patient's application, examine the notes in the submitted medical records, and communicate with the team regarding the treatment plans, thereby determining the need for scheduling further evaluation.

Operation of PRP

The PRP is based on the official WeChat account platform of the hospital

WeChat (WeCom) is a free social networking application that offers instant messaging services across all platforms. It provides basic text, voice, photos, video sharing, web-based payments, and integration with intelligent hardware. A financial report from Tencent indicates that the number of combined monthly live WeChat accounts exceeded 1.2 billion by the end of March 2021. Using the WeChat Framework, we developed a function that is compatible with both iOS and Android platforms. Therefore, our design had a minimum learning cost for the participants and ensured the sustainability of users.

PRP is based on an asynchronous form

Online information exchange between patients and doctors can occur synchronously (when interactions arise in real time) or asynchronously (with a delay between transmission and response)[12–13]. We adopted an asynchronous form of PRP because doctors in hospitals are always busy and cannot guarantee that they are available online in real time. Additionally, the asynchronous format maximizes doctors' fragmented time to process and respond to patient applications.

PRP is also based on cloud computing services

Cloud computing provides on-demand access to computer system resources, particularly data storage (cloud storage) and computing power, without requiring active user management. It offers network access to a shared pool of configurable computing resources as a metered, on-demand service that efficiently distributes resources. The cloud-computing architecture offers several benefits, such as cost reduction, device and location independence, easier maintenance, and on-demand self-service. Similarly, an essential feature of mobile health services is on-demand self-service, where users can instantly access network storage and server processing. Therefore, the PRP was designed using cloud computing services.

PRP Involving users of PRP

PRP consists of two types of users: patients and specialists. The Mobile Outpatient Specialist Appointment Registration Procedures are presented in Table S1.

Investigation of the PRP program

Data resources and measures

Renji Hospital began implementing PRP in December 2020. Data used in the study were retrieved from the official WeChat medical service account and HIS at Renji Hospital from December 1, 2020, to November 30, 2022. In total, 58271 samples were obtained.

The specialist review outcomes were dichotomized as either unpassed (=0) or passed (=1) as the dependent variable. The independent variables included sex, age, preference for paying insurance, and the title of the specialist. The classifications and measures of the variables of interest are listed in Table S2. Ethical approval was obtained from the Human Research Ethics Committee of the Renji Hospital (LY2023-031-B).

Analysis strategy

Traditional statistical method and multivariate logistic regression method

First, all continuous variables were tested for normality. The Kolmogorov–Smirnov test results (Sig=0.070>0.05) showed that "age" was normally distributed in the 58,271 patients. Means ± standard deviations were used for variables that had a normal distribution, and median and interquartile ranges (IQRs) were reported for non-normally distributed data. 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. Univariate analysis was conducted to identify significant contributors to the dependent variable, that is, whether the patient passed the online specialist appointment registration confirmation. In this study, the chi-square test was used for univariate analysis to assess categorical variables. Finally, multivariate logistic regression, with the backward stepwise method, was performed to identify the main factors influencing the specialists' review outcomes.

Random Forest (RF) Analysis: Based on Participating Departments

We collected the operational status of each department in the PRP project and the allocation of specialist resources, which were designated as input variables. The pass rates for the PRP among departments were defined as the target variable. Due to its everyday use in the RF algorithm machine learning (ML), RF can be applied to handle binary and multi-classification problems or examine interaction variables. Additionally, it can provide variable importance measures (VIMs) for categorical and

continuous variables, potentially involving those with high noise and significance. RF also demonstrates strong predictive performance, even for data with more variables (p) than samples (i.e., p > n). Due to their nonparametric nature, RFs are a robust method used in relatively straightforward applications for inexperienced users. Previous research included the RF analysis method for small sample sizes, even fewer than 20 (denoted as N < 20). Therefore, to assess the relative significance of these input variables in predicting the target, we performed an RF algorithm analysis. Since training and testing an ML model on the same dataset can lead to overfitting—when a model captures noise and random fluctuations instead of underlying patterns—an "out-of-bag" (OOB) technique was applied to make predictions using only base learners not trained on each particular observation. This method is known as the OOB prediction. These predictions are not prone to overfitting because each prediction is made only by learners that do not use observations for training. Due to the presence of OOB samples in our dataset, the OOB data can be used directly as a validation and test set, eliminating the need to prepare the dataset. In the SPSS Modeler, the predictive accuracy is precisely the result of OOB estimation[14–19].

Generalized linear model (GLM)

GLM identifies the dependent variable as linearly related to the factors and covariates via a specified link function. Moreover, the model allows the dependent variable to have a non-normal distribution. It covers widely used statistical models such as linear regression for normally distributed responses, logistic models for binary data, log–linear models for count data, complementary log–log models for interval-censored survival data, and many other statistical models through its general model formulation.

Artificial Neural Network (ANN)

ANNs are mathematical models that are based on interconnected groups of artificial neurons. They considered nonlinear relationships between the input data, which are not always identified in traditional analyses. ANNs have several advantages, including self-learning, adaptability, and robustness due to massive parallelism. They generally consist of three layers: input, hidden, and output layers. A multilayer perceptron (MLP) is a subtype of an ANN comprising one or more hidden layers with computation nodes capable of universal approximations. Therefore, it has been extensively used for modeling nonlinear and complex processes as well as real-world processes. The most widely used algorithm for training an MLP network is the back-propagation (BP) algorithm [20–24]. The dataset was randomly divided into training and test sets in a 70:30 ratio (40,766 and 17,505 records, respectively). All statistical analyses were performed using SPSS software (version 23.0; IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to construct the RF, GLM, and BP-ANN models.

RESULTS

Result of operation status of each department in the PRP program

From a dataset encompassing 58,271 applicants, we observed an overall passing rate of 34.8%. We collected data from 26 departments, including the number of applications, pass rate, median age of patients, interquartile range of patient ages, sex ratio, proportion of medical insurance patients, patient application count for senior specialists, patient application count for associate senior specialists, senior specialist

applicant ratio, PRP program specialists, total specialists, PRP specialists, and average specialist applications. As shown in Table S3, the operational status of each department in the PRP program can be comprehensively and visually understood. The proportion of senior specialist applications varied significantly across departments, indicating different levels of expert engagement in the PRP program. The average number of applications per specialist also reflects the popularity of the PRP programs within each department. The eight departments with the highest number of patient applications were Urinary Surgery (11,142), Breast Surgery (10,097), Thoracic Surgery (9,332), Obstetrics and Gynecology (4,862), Gastrointestinal Surgery (4,716), Nephrology (4,011), Head and Neck Surgery (3,256), and Biliary and Pancreatic Surgery (3,076). The total number of applications for these departments accounted for approximately 86.7% of all applications, highlighting the importance of their importance in the PRP program and the significant demand from patients for their services.

Among these departments, those with high pass rates included Head and Neck Surgery (52.7%), Biliary And Pancreatic Surgery (47.3%), Obstetrics and Gynecology (44.8%), nephrology (42%), Gastrointestinal Surgery (38.6%), and Urinary Surgery (37.4%). Breast Surgery had the lowest pass rate (18.3%). In terms of age distribution within these departments, Urinary Surgery had the highest median patient age (64 years, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery (44 years, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; and Thoracic Surgery (56 years, IQR 22) and Gastrointestinal Surgery (59 years, IQR 26) have a broader age range, covering patients from middle age to the elderly. The sex ratio data reflected the characteristics of sex distribution among patients served by different departments. In terms of age distribution within these departments, Urinary Surgery had the highest median patient age (64 years, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery (44 years, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; and Thoracic Surgery (56 years, IQR 22) and Gastrointestinal Surgery (59 years, IQR 26) have a broader age range, covering patients from middle age to the elderly. The sex ratio data reflected the characteristics of sex distribution among patients served by different departments. For instance, Urinary Surgery and Breast Surgery show extreme sex ratios, indicating clear male and female preferences, respectively. In contrast, nephrology and biliary and pancreatic surgeries have more balanced sex ratios.

Result of RF analysis based on 26 department

Based on the pass rates from 26 specialized clinical departments, we utilized IBM SPSS Modeler version 18.0 to develop an RF model. Under the guidance of a statistical expert, model parameters were calibrated, with the number of models to build set to seven and the sample size meticulously configured to 1. To enhance the efficacy and feature selection of the model, we activated the "Handle imbalanced data" feature and the "Use weighted sampling for variable selection" option. For tree growth parameters, we retained the default settings provided by the software, which included a maximum number of nodes set to 10,000, a maximum tree depth of 10, and a minimum child node size of 5.

In this study, the overall pass rate was 34.8%. We've set the "Pass Rate Interval" field to categorize departments as either "high-rank group" or "low-rank group" based on this rate. Based on this, the "Pass Rate Interval," a binary variable, is taken as the target variable in the RF analysis. The variables, including patient age Median, PRP

specialist proportion, average specialist applications, total specialists, insurance patient ratio, PRP program specialists, patient sex ratio, application count, and senior specialist applicant ratio, all served as input features in the RF analysis. The accuracy of the model was 92.31%. The predictor importance values range from 0.12 to 0.93, indicating the relative significance of each variable in predicting the target variable. Median patient age emerged as the most significant predictor with a value of 0.93, followed by PRP specialist proportion and average specialist applications with values of 0.87 and 0.84, respectively. However, variables such as application count and senior specialist applicant ratio had lower importance values, indicating their smaller contribution to the prediction process. Table S4 and Figure S2 present an overview of the variables and their respective roles in an RF model, along with their predictor importance.

Overview and basic characteristics of patients

85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. During this period, 58,271 patients applied for specialist appointments through the PRP program. In China, patients typically schedule outpatient appointments at tertiary hospitals without prior approval. Of these 58,271 patients, 20,290 (34.8%) passed the specialist assessment, and 37,981 (65.2%) did not.

Of the 58271 patients, the mean age was 52.89 ± 15.73 years. The Kolmogorov–Smirnov method test results (Sig=0.070>0.05) showed that "age" was normally distributed in the 58,271 patients. Among them, 22,412 (38.5%) were male, and 35,859 (61.5%) were female. See Table 1 for more details on patient characteristics.

Results of univariate and multivariate logistic regression analysis in the total population sample (N=58,271)

Focusing on patient demographics, we conducted univariate and multivariate logistic regression analyses of a dataset of 58,271 patients to explore relationships between demographic factors and assessment outcomes (Table 1). Univariate analyses revealed that the significant factors associated with specialist review outcomes were sex ($P < 0.001$), age ($P < 0.001$), and specialist title ($P < 0.001$). Age, sex, and specialist title were found to be significant in the univariate analyses and were subsequently included in the multivariate logistic regression model. This model was constructed using the backward stepwise method to refine variable selection. Then, through a multivariate logistic regression model, it indicates that those who were male and aged 60 years old or above were more likely to pass the specialist's review in the PRP program. At the same time, those aged 35–59 years were less likely to pass the specialist's review in the likely PRP program compared to those aged 18–34 years old. Additionally, those who had the title Associate Senior were more likely to pass the specialist's review than those who had the title of senior specialist (See Table 1).

Nagelkerke's R-squared ranged from 0 to 1, with values closer to 1 indicating a better model fit. However, as shown in Table 1, the value of Nagelkerke's R-squared was 0.016. From this, we speculate that more "strong" variables are not included in the predictive model of the expert review results (Table 1). Therefore, we added a GLM to identify additional predictors not included in the multivariate logistic regression model to enhance model fit.

Table1.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of Factors Related To The specialist's review outcome

Items	Characteristics		Pass the Review		Univariate Analysis		Multivariate Analysis	
					Chi square test		Logistic Regression	
	Variables	Frequency(%)	Not Pass (Group A)	Pass (Group B)	c^2	P	OR (95% CI)	P
Gender					198.94	<0.001		
	Female	35859(61.5)	24162(67.4)	11697(32.6)			1.000	
	Male	22412(38.5)	13819(61.7)	8593(38.3)			1.161(1.119-1.205)	<0.001
Age (years)					154.93	<0.001		
	18-34	9003(15.5)	5902(65.6)	3101(34.4)			1.000	
	35-59	26590(45.6)	17939(67.5)	8651(32.5)			0.933(0.886-0.981)	0.007
	60-74	18405(31.6)	11577(62.9)	6828(37.1)			1.075(1.018-1.134)	0.009
	Above 75	4273(7.3)	2563(60.0)	1710(40.0)			1.151(1.066-1.243)	<0.001
Title of the specialist	senior	31561 (54.2)	21854(69.2)	9707(30.8)	501.00	<0.001	1.000	
	Assosiate senior	26710(45.8)	16127(60.4)	10583(39.6)			1.420(1.371-1.471)	<0.001
If Having Preference to pay with Insurance or not					0.004	0.95		
	Yes	42089(72.2)	27437(65.2)	14652(34.8)			N/A	N/A
	No	16182(27.8)	10544(65.2)	5638(34.8)			N/A	
Whether having Passed the Review	Yes	20290(34.8)		N/A	N/A		N/A	
	No	37981(65.2)						
Nagelkerke R Square							**0.016**	
Akaike information criterion (AIC)							**52335.946**	

Result of GLM analysis

In this enhanced analysis, we incorporated two additional variables, specialist and clinic, into the independent variables of the GLM and ANN models. The target variable was the assessment result, which was categorized as a dummy variable. The

GLM regression results show the specialist and clinic as the most significant variables, with a relative importance of 0.71 and 0.26, respectively. In contrast, age and specialist title exerted a comparatively minor influence, each with a significance of 0.02 (see Table 2). Furthermore, the predictive accuracy of the model is outlined in Table 3, with scores of 67.86% and 68.26% for the training and test datasets, respectively. The Akaike information criterion (AIC) value for the GLM, 48,433.067, was significantly lower than the AIC value of 52,335.946 for the multivariate logistic model. This decrease in the AIC indicates that the GLM, with its five input variables, outperforms the multivariate logistic model, which has only three inputs in terms of model fit and explanatory power.

Result of ANN analysis

To further understand how patient characteristics and specialist choices affect PRP assessment results, we developed an ANN model with an MLP structure. We maintained all other parameters at their default values as specified by the software. In the ANN analysis shown in Table 2, the input features encompass specialist, clinic department, age, title of the specialist, and sex, with assessment result (Yes or No) serving as the target variable. Table 2 further delineates the key variables influencing the assessment result within the ANN model, ranking specialist and clinic department as the most impactful, with the relative importance of 0.44 and 0.43, respectively. Age, specialist title, and sex had less influence at 0.07, 0.04, and 0.02, respectively. Figure 2 illustrates the topological architecture of the ANN model. The accuracy of the model is shown in Table 3, with scores of 67.72% and 68.28% for the training and test datasets, respectively.

Tabe 2 The Role in GLM and ANN Model and Result of Predictor Importance

Variables	Role in model	Predictor importance in GLM	Predictor importance in ANN
Specialist	input	0.71	0.44
Clinic Department	input	0.26	0.43
Age	input	0.02	0.07
Title of the Specialist	input	0.02	0.04
Gender	input	0.00	0.02
Assessment Result(Yes or No)	target	/	/

Table 3. Accuracy of GLM and ANN analyses

	GLM				ANN			
Partition	Training Dataset		Testing Dataset		Training Dataset		Testing Dataset	
	Records	Accuracy	Records	Accuracy	Records	Accuracy	Records	Accuracy
Correct	27662	67.86%	11949	68.26%	27607	67.72%	11952	68.28%
Wrong	13104	32.14%	5556	31.74%	13159	32.38%	5553	31.72%
Total	40766		17505		40766		17505	

DISCUSSION

Digital technologies increasingly support health systems (WHO, 2018) by providing flexible options for interpersonal communication and information exchange[25]. Access, affordability, and equity are the three primary goals of a well-functioning health system[26]. In this study, among the 58,271 patients who applied to medical specialists on the PRP-based platform, 20,290 successfully passed reviews conducted by specialists, thereby gaining access to specialized medical treatment in hospitals. This indicates that the mobile health-based PRP program is a practical and innovative approach. This enables patients to obtain convenient access to medical specialists in hospitals, with reduced doctor-seeking costs, thereby ensuring timely and highly efficient treatment. The remaining 37,891 patients who did not pass the specialist review were identified through the PRP program. General practitioners (GPs) advised them to be appropriately directed to other clinical departments within the hospital or primary care centers for treatment by GPs. This guidance helps prevent inefficiency by discouraging patients from blindly seeking specialist appointments, which could otherwise lead to a waste of valuable medical resources in hospitals.

Implemented across 26 departments, the PRP program demonstrated diverse performance, with significant variations in operational metrics such as application volumes, pass rates, and specialist involvement. The implemented program attracted 58,271 patients who applied for specialist appointments during the study period, reflecting the extensive reach and the significant demand of the program for specialist services from outpatients. The smooth implementation of the program was highlighted by the high participation rate of 85 specialists from various fields, demonstrating a robust network of professionals eager to engage in the PRP initiative.

Univariate analysis revealed that age was significantly associated with the outcomes of specialist reviews ($P < 0.001$). Logistic regression showed that individuals aged 60 years and above were more likely to pass reviews compared to the 18–34 age group, whereas the 35–59 age group was less likely to do so. The RF analysis identified applicant age as the most important predictor, with an importance value of 0.93, in explaining differences in pass rates among the 26 clinic departments. This may be because the elderly, who often suffer a variety of chronic diseases, may have higher medical needs than younger individuals[27]. This is consistent with the evidence that many previous studies have claimed that elderly patients have more significant utilization of hospital outpatient or inpatient healthcare services than their younger counterparts because of their unfavorable health status[28]. Conversely, those aged 35–59 had a lower probability of passing the specialist review and a higher likelihood of being genuinely rejected than those aged 18–34. This could be explained by the fact that middle-aged patients prefer advanced medical care regardless of their medical needs. These patients may see specialists in hospitals for psychological comfort or because they mistrust GPs in primary care settings even though they do not require special medical care. Many previous studies have reported that this phenomenon results from the lack of community gatekeeper systems in China[29–30]. This reflects the urgent need to strengthen primary care and family doctor services for middle-aged people in China. Additionally, male patients were more likely to pass the review than their female counterparts were. This may be explained by the higher prevalence of chronic diseases among males than among females in China[31]. However, this finding was not consistent with previous studies, all of which reported a higher prevalence of chronic diseases in females, especially in those aged 60 years and above in China[32–33]. However, the sex ratios in the prevalence of chronic diseases remain inconclusive.

Therefore, the Shanghai government and decision-makers in the health sector should make gender- and age-specific efforts to facilitate the implementation of hierarchical diagnosis and treatment systems and family doctor services for middle-aged patients. By shunting middle-aged patients to GPs or secondary hospitals, patient crowding caused by the" siphon effect" can be mitigated, thus improving the efficiency of procedures in tertiary hospitals.

More interestingly, specialists who held senior associate titles were more likely to approve patients' applications than senior specialists were. This may be due to the intense competition for title promotion in medicine. In Chinese society, job hierarchy plays a significant role, which is evident in the use of professional titles[34–35]. Professional titles often signify seniority, experience, or level of authority within government-funded organizations. Given the pressure for promotion, specialists with associate senior titles prefer to accept more patients to enhance their professional skills and prepare for promotion to senior professional titles. The analyses of the GLM and ANN models reveal a distinct prioritization of specialist and departmental factors within the PRP program, surpassing the predictive power of patient age and gender, which may stem from a complex array of reasons as follows: First, the unique expertise of specialists is of paramount importance; for instance, urologists may specialize in different subspecialties, with some focusing on kidney conditions, others on prostate issues, and still others on bladder diseases, all of which substantially shape patient requests and the outcomes of assessments.

Second, specific clinical departments have a more concentrated age range among their applicants, with notably skewed gender demographics. For instance, the breast surgery department is characterized by a significant prevalence of middle-aged women, with a median age of 44 years and a sex ratio of 0.01 among its applicants. In contrast, the urology department has a predominantly male applicant base, with a sex ratio of 3.85, and applicants are mostly older, with a median age of 68 years, which exceeds the overall median age of the PRP applicant pool by 14 years. Together, these two departments constitute a considerable portion of the PRP applicant pool (36.45%). The unique demographic characteristics of these specific departments may profoundly influence predictive factors.

This study has several significant limitations. First, the potential for personal bias in expert evaluations may be considerable. In the future, we plan to incorporate rule-based systems with multimodal artificial intelligence assessments to reduce the impact of individual biases. The GLM Model achieved a score of 67.86% on the training set and 68.26% on the test set, whereas the ANN Model achieved a score of 67.72% on the training set and 68.28% on the test set, showing a nearly equivalent predictive performance. The accuracy of the GLM and ANN models on the testing dataset suggests a significant opportunity to improve and enhance their predictive accuracy. Second, existing budget limitations hinder the ability to conduct a structured analysis of patient–disease condition descriptions, highlighting the need for further research. A forward-looking approach is essential for creating a more robust, comprehensive, and inclusive predictive model by incorporating this crucial variable.

CONCLUSION

The PRP program offers a promising approach to integrating digital health technologies into healthcare systems. It provides a scalable and adaptable model for optimizing specialist appointment processes. Our future goal is to enhance and expand the program by involving more specialists and hospitals, thereby including a larger

number of patients. Healthcare entities seeking to improve appointment processes and specialist engagement through digital advancements may refer to the design and implementation of the program.

Figure1. The PRP flow chart
Figure.2 Topology architecture of the ANN model

Abbreviations

BIC: Bayesian Information Criterion
HIS: Hospital information system
PRP: Precise reservation path
RF:Random forest
GLM:Generalized linear model
AIC:Akaike Information Criterion
ANN:Artifcial Neural Network

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Availability of data and materials: The data sets for this manuscript are not publicly available because all our data are under regulation of Renji Hospital, School of Medicine in Shanghai Jiao Tong University. Requests to access the data sets should be directed to MC.

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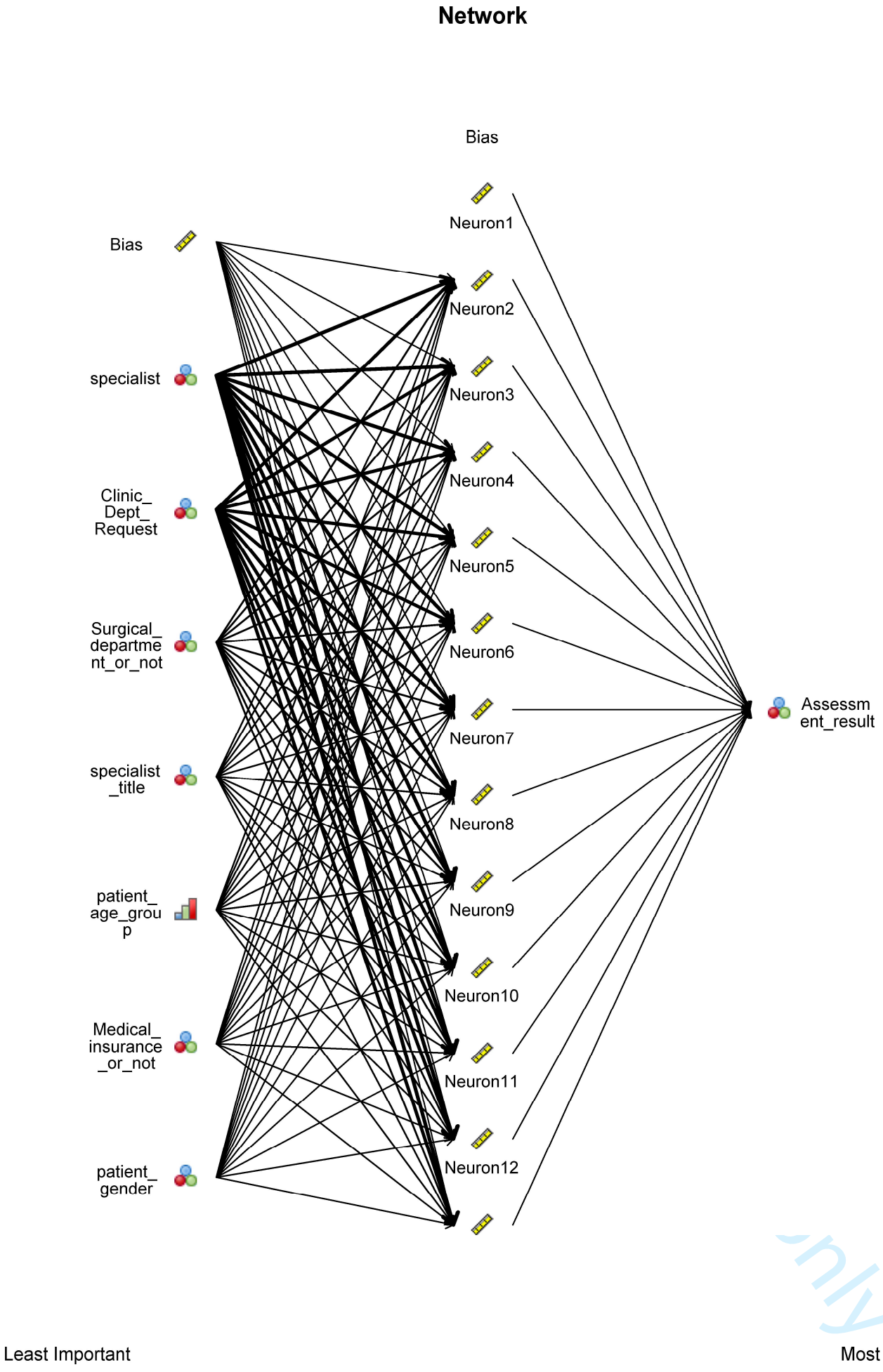

Table S1 Mobile Outpatient Specialist Appointment Registration Procedure for patients and specialists

Steps	Procedure for patients
1	The patient registers on the WeChat official medical service account of Renji Hospital using a mobile phone.
2	The patient reads the online specialist directory of the hospital and the diseases in which the specialist specializes.
3	The patient selects a specific specialist and requests an appointment by accessing the "Precise Reservation Path (PRP)" label.
4	The patient confirms the informed consent of the PRP, protocol, and submission of medical records.
5	According to the requirements of different specialist protocols, the patient also needs to submit relevant past examination reports (no earlier than 3 months), such as blood laboratory tests, ultrasound rays, computed tomography (CT), magnetic resonance imaging (MRI), and pathological reports.
6	If approval is received from the specialist users, the patient is allowed to visit the specialist offline on the appointed day.
Steps	Procedure for specialists
1	The specialist team user registers on the official WeChat accounts of Renji Hospital to build a PRP account using a mobile phone and obtains approval from the PRP system administrator.
2	The specialist team user completes their individual profile, including information about diseases in which they are specialized, past examination reports, and informed consent for patients before obtaining approval from the hospital's information administrator.
3	The specialist team user responds to patients' requests in a timely manner.
4	A specialist team user approves or rejects the patient's application. In the event of rejection, the user provides specific advice, such as recommending a well-matched subspecialty for the patient or suggesting a referral to their general practitioner.

Table S2 The classifications and measures of variables of interest

Variables	How to measure	Type
Whether having Passed the Review	1=Yes； 0= No	Categorical
Age	1=18-34 years; 2=35-59 years； 3=60-74 years; 4=75 years or above	Categorical
Gender	1=Male ;0=Female	Categorical
If having a Preference to pay with Insurance	1=Yes; 0=No	Categorical
Acdemic title of the specialist	1=Senior specialist; 2=Associate senior specialist	Categorical
Surgical department or not	1=Yes; 0=No	Categorical

Table S3 Operational Profile of 26 Departments participating in the PRP Program

Clinic department	Application count	Pass rate(%)	Patients age Median	Patients age IQR	Patients gender ratio(male/female)	Insurance patient ratio (%)	Patient application count for senior specialist	Patient application count for associate senior specialist	Senior specialist applicant ratio(%)	Integrated specialists	Total specialists	PRP specialists proportion(%)	Average specialist applications
Urinary Surgery	11142	37.4*	64	17	3.85	71.6	2012	9130	18.1	1	37	38	795.9
Breast Surgery	10097	18.3	44	20	0.01	74.4	6397	3700	63.4	1	5	100	2019.4
Thoracic Surgery	9332	27.7	56	22	0.57	65.0	9332	0	100.0	1	6	17	9332.0
Obstetrics And Gynecology	4862	44.8*	39	19	0	76.3	3432	1430	70.6	4	35	11	1215.5
Gastrointestinal Surgery	4716	38.6*	59	26	1.37	71.2	2364	2352	50.1	6	29	21	786.0
Nephrology	4011	42.0*	57	28	0.93	82.8	1955	2056	48.7	6	17	35	668.5
Head And Neck Surgery,	3256	52.7*	49	22	0.31	77.7	126	3130	3.9	2	5	40	1628.0
Biliary And Pancreatic Surgery	3076	47.3*	59	25	0.83	77.0	1601	1475	52.1	12	25	48	256.3
Radiotherapy	1551	55.1*	61	19	1.14	61.5	1261	290	81.3	3	7	43	517.0
Traumatic Orthopedics	1406	36.8*	44	32	0.89	76.4	0	1406	0.0	1	10	10	1406.0
Vascular Surgery	835	26.1	64	18	0.96	76.3	605	230	72.5	4	9	44	208.8
Rheumatology And Immunology	790	2.2	47	24	0.3	40.0	720	70	91.1	3	20	15	263.3
Cardiology	692	17.1	61	27	0.81	80.1	206	486	29.8	4	25	16	173.0
Joint Surgery	483	44.3*	55	27	0.56	72.3	421	62	87.2	4	9	44	120.8
Gynecological Oncology	478	61.5*	47	20	0	55.0	454	24	95.0	2	3	67	239.0

Otorhinolaryngology	470	33.4	47	25	1.02	77.0	143	327	30.4	4	8	50	117.5
Spine Surgery	445	56.4 *	66	24	0.79	79.8	445	0	100.0	9	11	445.0	
Ophthalmology	237	43.5 *	64	27	0.72	72.6	0	237	0.0	12	8	237.0	
Pain Medicine	143	40.6*	60	27	0.72	60.1	0	143	0.0	2	50	143.0	
Functional Neurology	120	0.0	44	30	1.03	59.2	0	120	0.0	1	100	120.0	
Oncology	49	51.0*	60	19	0.96	32.7	49	0	100.0	12	8	49.0	
Plastic Surgery	25	28.0	41	18	1.27	84.0	0	25	0.0	5	20	25.0	
Digestion Medicine	21	0.0	52	20	0.91	38.1	21	0	100.0	44	2	21.0	
Diagnostic Radiology	18	55.6*	64	50	0.38	27.8	0	18	0.0	16	6	18.0	
Endocrinology	13	0.0	41	20	1.17	53.9	13	0	100.0	10	10	13.0	
General Surgery	3	0.0	34	/	0	100.0	3	0	100.0	8	13	3.0	
Total	58271	34.8	54	26	0.63	72.2	31560	26711	54.2	369	23.04%	685.5	

Note:

Patients age Median: Median age of patients applying

Patients age IQR: Age IQR of patients applying

Patients gender ratio: Gender ratio of patients applying(male/female)

Insurance patient ratio (%): Proportion of insurance among the patients applying

Senior specialist applicant Ratio(%): Proportion of patient apply for senior specialist among all applicants

PRP program specialists: Number of specialists participating in PRP program

Total specialists: Total number of specialists in department

PRP specialists proportion(%):Proportion of specialists participating in the PRP program to the total number of specialists in department

Average specialist applications: Average of patients applying for one specialist in department

Tabe S4 The Role in Random Forest Model and Result of Predictor Importance

Variables	Role in random forest model	Predictor importance
Patients age Median	input	0.93
PRP specialists proportion	input	0.87
Average specialist applications	input	0.84
Total specialists	input	0.53
Insurance patient ratio	input	0.35
PRP program specialists	input	0.35
Patients gender ratio	input	0.22
Application count	input	0.16
Senior specialist applicant ratio	input	0.12
Pass Rate Interval	target	/

Tabe S5 The Role in ANN Model and Result of Predictor Importance

Variables	Role in ANN model	Predictor importance
Specialist	input	0.44
Clinic department	input	0.43
Patient age group	input	0.07
Acdemic title of the specialist	input	0.04
Gender	input	0.02
Assessment result(yes or no)	target	/

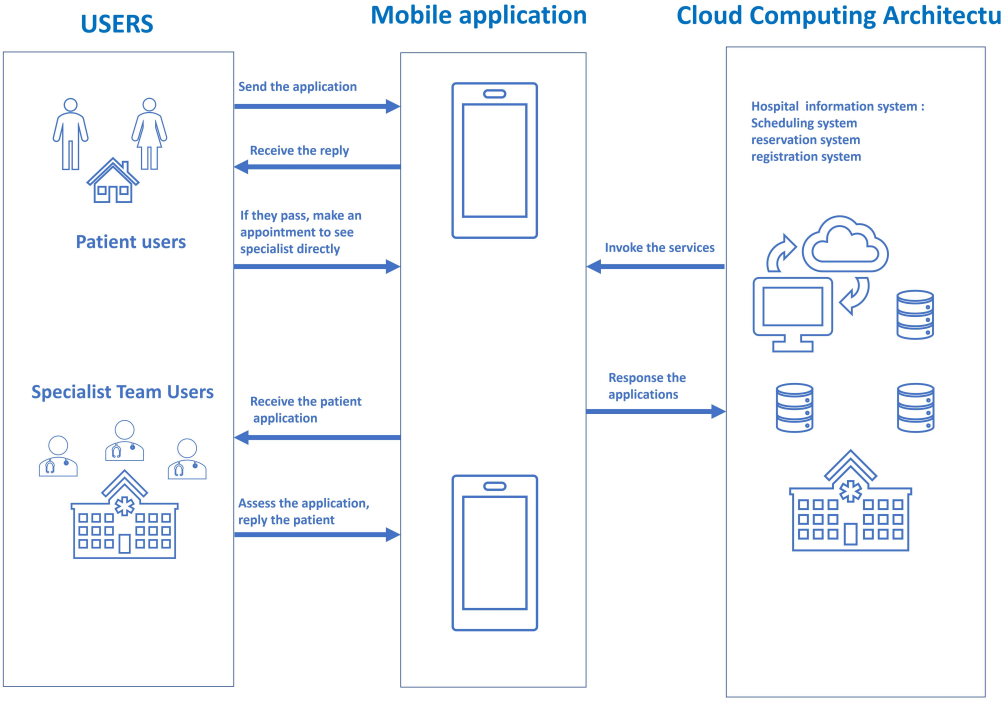

Figure S1. The PRP model architecture

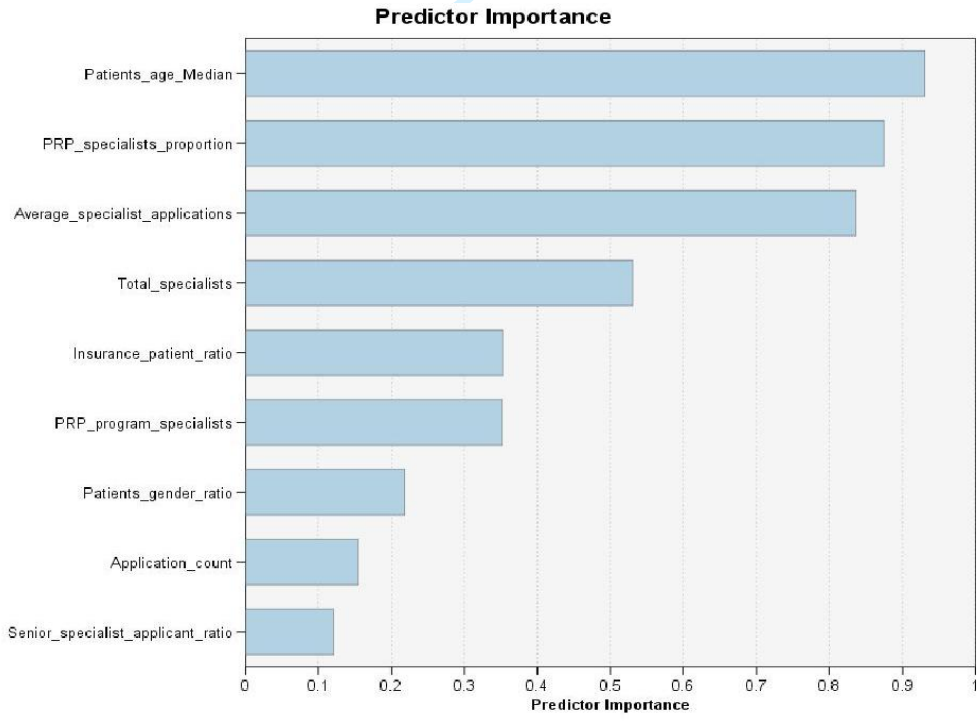

Figure S2. Result of Predictor Importance Through RF Analysis

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Enhancing Access to Specialist Appointments in Tertiary Healthcare in Shanghai, China: A Structured Reservation Pathway Utilizing Digital Health Technologies.

Minjie Chen,[1] , Xiaojing Zhao ,[2] Tao Zheng,[3] Binyuan Zhang,[1] Xuji Zhao,[1] Weijun Shao,[3] Li li,[4,5] Yiling Fan, [1*] and Enhong Dong,[6, 7*]

Author affiliations
[1]Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[2]Department of thoracic surgery department, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[3]Department of information technology, Renji Hospital, School of Medicine in Shanghai Jiao Tong University, Shanghai, China
[4] School of Medicine ,Shanghai Jiao Tong University ,Shanghai ,China
[5] China Hospital Development Institute ,Shanghai Jiao Tong University ,Shanghai， China
[6]School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences, Shanghai, China,
[7]Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University, Shanghai, China

Co-Corresponding authors:
Yiling Fan
Department of Outpatient and Emergency Management, Renji Hospital, School of Medicine in Shanghai Jiao Tong University
No.160 Pujian Road, Pudong new district
Shanghai, 200127
China
Phone:+8613818458771
mail:fanyiling@163.com

Enhong Dong
School of Nursing and Health Management, Shanghai University of Medicine and Health Sciences
No.279 Zhouzhu Road, Pudong new District
Shanghai, 210318
China
Institute of Healthy Yangtze River Delta, Shanghai Jiao Tong University
No.1594 Huashan Road, Xuhui District
Shanghai, 200230
China
Phone:+86 13761141620
E-mail: kevin8012@126.com

Abstract

Objective: The aim of this study is to develop, implement the Precise Reservation Path(PRP) and investigate its prediction function for scheduling shunting patients for specialist appointment registration in Shanghai, China.
Design: The PRP system was built upon the hospital's existing information system(HIS), integrated with WeChat(WeCom) for user convenience. The outcome analysis employed a mixed-methods approach, integrating quantitative analysis with statistical and machine learning techniques, including multivariate logistic regression, Random Forest(RF) and Artificial Neural Network (ANN) analysis.

Setting:This study was conducted at Renji Hospital, a premier general tertiary care institution in Shanghai, China, where the innovative PRP system was implemented. The program was designed to efficiently connect patients requiring specialized care with the appropriate medical specialists.
Participants: The PRP encompassed both voluntary specialists at Renji hospital, as well as patients seeking outpatient specialist services.
Primary Outcome Measures: Primary Outcome Measures:The pass rates of patient for specialist applications.
Secondary Outcome Measures: Clinic department ,Specialists' and Patients'characteristics influencing specialist review result.
Results:
From a dataset of 58,271 applicants across 26 departments between December 1, 2020, and November 30, 2022, we noted an overall pass rate of 34.8%. The departments of Urology, Breast Surgery, and Thoracic Surgery, along with five others, accounted for 86.65% of applications. Pass rates varied significantly, and demographic distributions of applicants across departments revealed distinct patient profiles, with preferences evident for age and gender.We developed a Random Forest (RF) model based on pass rates from 26 specialized departments. The RF model, with 92.31% accuracy, identified age as the primary predictor of pass rates, underscoring its impact on specialist review outcomes.Focus on patient demographics,we conducted univariate and multivariate logistic regression analyses on the 58,271 patient dataset to explore the relationship between demographic factors and review outcomes. Key findings from logistic regression included significant associations with gender, age, and specialist title. Results indicated that older patients were more likely to be approved in specialist reviews, while middle-aged patients had lower pass rates.The GLM model, enhanced with specialis and clinic department variables, showed superior predictive accuracy (67.86%-68.26%) and model fit over the previous logistic model. An ANN model also identified specialis" and clinic department as the most influential, achieving comparable accuracy (67.72%-68.28%).
Conclusions: The PRP program demonstrates the potential of digital innovation in enhancing hierarchical medical system. The study's findings also underscore the value of PRP program in healthcare systems for optimizing resource allocation, particularly for aging populations.The program's design and implementation offer a scalable model for other healthcare institutions seeking to enhance their appointment systems and specialist engagement through digital innovation.

Strengths and limitations of this study

►►The study takes a comprehensive approach by integrating perspectives from both departments and patients, leading to a more complete analysis than if only one viewpoint were considered.
► ► The research employs a combination of traditional statistical methods (such as logistic regression), machine learning techniques (like Random Forest), and artificial neural networks (ANN) to analyze the data, offering a well-rounded understanding of the elements influencing specialist appointment outcomes.
► ► There was a possibility of personal bias in expert assessments, which could affect the precision of the specialist review findings.
► ► Financial constraints limited the capacity to conduct a more detailed analysis of patient-disease condition descriptions, which could be crucial for improving predictive models.

Key words: Precise Reservation Path, Appointment Registration, Specialist， Random forest, Artifcial Neural Network

INTRODUCTION

Most people seek affordable, dependable, and high-quality products and services such as electronics, auto repairs, and massage. This is also true of the healthcare sector. High-quality healthcare is defined as care that is effective, safe, patient-centered, timely, efficient, equitable, and delivered by professionals who communicate respectfully, communicate clearly, and involve patients in decision-making[1]. To achieve the goals of "Healthy China 2030," China has deepened health reforms in recent years to establish high-quality, value-based service delivery, resulting in a series of significant improvements. However, several challenges persist, including the uneven distribution of healthcare resources and the imbalance between supply and demand[2–3]. Improving the efficiency of hospital care is, to the best of our knowledge, a fundamental aspect of strengthening the health system. In China, public hospitals are the main body of the medical service system and the primary places for people to seek medical treatment. According to the China Health Statistics Yearbook, in 2018, public hospitals provided 92% of outpatient services and 82% of the inpatient services among all hospitals in China. According to China's health delivery structure, public hospitals are organized into a three-tier system (designated as primary, secondary, or tertiary institutions). A tertiary hospital is a comprehensive, referral, and general hospital at the city, provincial, or national level with a bed capacity exceeding 500. Tertiary hospitals are responsible for providing specialist health services, performing a more significant role in medical education and scientific research, and serving as medical hubs that offer care in multiple regions[4]. Since China's healthcare system does not feature a gatekeeping general practitioner system, patients can seek primary care from primary care facilities or hospital outpatient departments[5]. Considering the free choice of healthcare providers, most patients prefer to select a specialist (who is a medical doctor, often with a senior professional title and an expert in a specific area of medicine) in clinics, private hospitals, or public hospitals, particularly tertiary public hospitals. However, due to unequal access to information between doctors and patients, the freedom to choose healthcare providers often leads patients to select doctors without adequate knowledge or understanding, potentially resulting in a significant misallocation of medical resources[6]. This is because patients may lack the necessary information to determine the most suitable doctor for their needs. Additionally, patients with minor illnesses preferred to visit tertiary hospitals instead of primary care centers. These behaviors lead to the substantial misuse of valuable medical resources, creating a dual challenge. First, it imposes a heavy economic burden on patients, potentially exceeding the affordability limits of the medical system. Second, these behaviors pose obstacles to the high-quality development of tertiary hospitals in China. Moreover, the scarcity of healthcare resources has led to fierce competition among patients[7–8]. To support the provision of high-quality and timely outpatient services, many hospitals have implemented innovative appointment registration systems to assist patients and increase hospital efficiency. These systems allow hospitals to provide services more efficiently. Under the rule of "first registration, first service" in appointment registration systems, some patients with severe diseases requiring specialist treatment may struggle to book appointments with the necessary specialists successfully. This inequity in healthcare resource allocation contradicts the principles of China's current medical reform. Thus, it is imperative to optimize the appointment registration system and improve the efficiency of medical procedures in Chinese tertiary public hospitals. Accordingly, hospitals are testing novel appointment registration systems, such as mobile phones, web-based systems, bank hospital partnerships, and clinical settings. Among these, redesigning the appointment-scheduling system is crucial for

effectively utilizing healthcare resources, increasing operational efficiency, reducing operational costs, and mitigating the imbalance between supply and demand for healthcare services[9].

Over the past decade, China has had the highest number of smartphones per capita among all the countries[10]. Equipped with “Internet Plus Medical" applications, online appointment systems have become an alternative that optimizes scheduling processes, significantly improving the efficiency of hospital services. Hospitals provide various web-based services through mobile platforms, including WeChat and other independently developed applications. Hospital services include online consultations, appointment registration, and payments. Such mobile health initiatives can overcome geographical boundaries, enhance the equity and accessibility of healthcare resources, and provide practical and equitable access to healthcare services in hospitals[11]. Mobile appointment registration services provide patients with an essential online channel through which those with smart devices can access healthcare resources. With the availability of mobile appointment registration services, patients will increasingly turn to online platforms for booking appointments, gradually replacing traditional offline queuing registrations. This shift to online registration is expected to create a higher demand for services on mobile health platforms. In hospitals, the outpatient department plays a critical role in efficiently managing medical resources, as it not only directs patients toward timely care but also generates numerous benefits, including improved health outcomes and optimized utilization of healthcare resources. As discussed, optimizing appointment registration procedures is the responsibility and commitment of hospital management. Thus, the effective scheduling of mobile appointment services and the provision of healthcare services to patients have become critical priorities for outpatient departments in tertiary public hospitals in China.

This study aims to develop a precise reservation path (PRP) framework to ensure timely and efficient treatment for patients with severe diseases in tertiary public hospitals in Shanghai, China. This study first describes a specialist-led reservation process in which the clinical data (history, examination, and past treatment) of a reservation applicant are assessed using relevant ultrasound, laboratory, or radiological records. Subsequently, a decision is made regarding the suitability of the patient for specialist intervention. Second, by employing specific statistical analysis methods, our objective is to investigate the factors affecting the pass rate of patients who require specialist medical services, thereby streamlining their referral to appropriate healthcare settings, such as specialized clinics or primary care institutions. This system aims to strengthen and improve the hierarchical diagnostic and treatment systems in China.

MATERIALS AND METHODS

Patient and Public Involvement

This study did not involve direct patient or public participation.

Design

Procedure of PRP

This study was conducted at the Renji Hospital, School of Medicine, Shanghai Jiao Tong University, a 2,750-bed general tertiary public hospital in Shanghai, China. To fully digitize its records, the hospital has established an information infrastructure in which most medical and health records are stored electronically. The annual number of outpatient and emergency visits to hospitals exceeds 5.82 million, and the annual number of discharged patients is 172,000. The PRP program was developed by the

management and clinical staff at Renji Hospital in Shanghai to address the disorganized system in which outpatients schedule specialists without restrictions. Before designing the PRP system, a literature search, peer discussions, panel discussions, and specialist consultations were conducted to determine its structure and design. Staff from the outpatient and emergency management departments, as well as specialized surgeons and IT technicians in thoracic surgery, breast surgery, and urinary surgery, attended meetings to design the PRP process. The PRP process was designed as follows: Our main objective was to build a cloud-based, precise medical reservation path connecting all participants (patients and specialists). Based on the PRP framework, patients with suspected severe disease can request a specialist appointment and submit their medical records. After a specialist reviews the patient's application and medical records, the specialist may approve or reject the patient's application. Given that patients often directly schedule outpatient appointments at tertiary hospitals without undergoing primary healthcare screening, there is a free choice of healthcare providers. In the Chinese healthcare system, 935,625 specialist outpatient visits were identified as not progressing through the system during the study period, from December 1, 2020, to November 30, 2022, at Renji Hospital. The PRP flowchart is shown in Figure 1.

Architecture of PRP

The architecture of the PRP model is shown in Figure S1. Technical support ensured that different system modules were compatible and established a cloud-based PRP system that connected it to the original hospital information system (HIS) of Renji Hospital. Building on the original HIS, new modules and functions were added to share all specialist outpatient schedules and specialist team accounts, such as WeChat (WeCom). The PRP system was integrated with hospital scheduling systems, enabling the automatic identification of appointment statuses, including whether an appointment had been made, requested, or canceled (and changing the status if rescheduling is required). The specialist team user has one-click access to review the patient's application, examine the notes in the submitted medical records, and communicate with the team regarding the treatment plans, thereby determining the need for scheduling further evaluation.

Operation of PRP

The PRP is based on the official WeChat account platform of the hospital

WeChat (WeCom) is a free social networking application that offers instant messaging services across all platforms. It provides basic text, voice, photos, video sharing, web-based payments, and integration with intelligent hardware. A financial report from Tencent indicates that the number of combined monthly live WeChat accounts exceeded 1.2 billion by the end of March 2021. Using the WeChat Framework, we developed a function that is compatible with both iOS and Android platforms. Therefore, our design had a minimum learning cost for the participants and ensured the sustainability of users.

PRP is based on an asynchronous form

Online information exchange between patients and doctors can occur synchronously (when interactions arise in real time) or asynchronously (with a delay between transmission and response)[12–13]. We adopted an asynchronous form of PRP because doctors in hospitals are always busy and cannot guarantee that they are available online in real time. Additionally, the asynchronous format maximizes doctors' fragmented time to process and respond to patient applications.

PRP is also based on cloud computing services

Cloud computing provides on-demand access to computer system resources, particularly data storage (cloud storage) and computing power, without requiring active user management. It offers network access to a shared pool of configurable computing resources as a metered, on-demand service that efficiently distributes resources. The cloud-computing architecture offers several benefits, such as cost reduction, device and location independence, easier maintenance, and on-demand self-service. Similarly, an essential feature of mobile health services is on-demand self-service, where users can instantly access network storage and server processing. Therefore, the PRP was designed using cloud computing services.

PRP Involving users of PRP

PRP consists of two types of users: patients and specialists. The Mobile Outpatient Specialist Appointment Registration Procedures are presented in Table S1.

Investigation of the PRP program

Data resources and measures

Renji Hospital began implementing PRP in December 2020. Data used in the study were retrieved from the official WeChat medical service account and HIS at Renji Hospital from December 1, 2020, to November 30, 2022. In total, 58271 samples were obtained.

The specialist review outcomes were dichotomized as either unpassed (=0) or passed (=1) as the dependent variable. The independent variables included sex, age, preference for paying insurance, and the title of the specialist. The classifications and measures of the variables of interest are listed in Table S2. Ethical approval was obtained from the Human Research Ethics Committee of the Renji Hospital (LY2023-031-B).

Analysis strategy

Traditional statistical method and multivariate logistic regression method

First, all continuous variables were tested for normality. The Kolmogorov–Smirnov test results (Sig=0.070>0.05) showed that "age" was normally distributed in the 58,271 patients. Means ± standard deviations were used for variables that had a normal distribution, and median and interquartile ranges (IQRs) were reported for non-normally distributed data. 85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. Univariate analysis was conducted to identify significant contributors to the dependent variable, that is, whether the patient passed the online specialist appointment registration confirmation. In this study, the chi-square test was used for univariate analysis to assess categorical variables. Finally, multivariate logistic regression, with the backward stepwise method, was performed to identify the main factors influencing the specialists' review outcomes.

Random Forest (RF) Analysis: Based on Participating Departments

We collected the operational status of each department in the PRP project and the allocation of specialist resources, which were designated as input variables. The pass rates for the PRP among departments were defined as the target variable. Due to its everyday use in the RF algorithm machine learning (ML), RF can be applied to handle binary and multi-classification problems or examine interaction variables.

Additionally, it can provide variable importance measures (VIMs) for categorical and continuous variables, potentially involving those with high noise and significance. RF also demonstrates strong predictive performance, even for data with more variables (p) than samples (i.e., p > n). Due to their nonparametric nature, RFs are a robust method used in relatively straightforward applications for inexperienced users. Previous research included the RF analysis method for small sample sizes, even fewer than 20 (denoted as N < 20). Therefore, to assess the relative significance of these input variables in predicting the target, we performed an RF algorithm analysis. Since training and testing an ML model on the same dataset can lead to overfitting—when a model captures noise and random fluctuations instead of underlying patterns—an "out-of-bag" (OOB) technique was applied to make predictions using only base learners not trained on each particular observation. This method is known as the OOB prediction. These predictions are not prone to overfitting because each prediction is made only by learners that do not use observations for training. Due to the presence of OOB samples in our dataset, the OOB data can be used directly as a validation and test set, eliminating the need to prepare the dataset. In the SPSS Modeler, the predictive accuracy is precisely the result of OOB estimation[14–19].

Generalized linear model (GLM)

GLM identifies the dependent variable as linearly related to the factors and covariates via a specified link function. Moreover, the model allows the dependent variable to have a non-normal distribution. It covers widely used statistical models such as linear regression for normally distributed responses, logistic models for binary data, log–linear models for count data, complementary log–log models for interval-censored survival data, and many other statistical models through its general model formulation.

Artificial Neural Network (ANN)

ANNs are mathematical models that are based on interconnected groups of artificial neurons. They considered nonlinear relationships between the input data, which are not always identified in traditional analyses. ANNs have several advantages, including self-learning, adaptability, and robustness due to massive parallelism. They generally consist of three layers: input, hidden, and output layers. A multilayer perceptron (MLP) is a subtype of an ANN comprising one or more hidden layers with computation nodes capable of universal approximations. Therefore, it has been extensively used for modeling nonlinear and complex processes as well as real-world processes. The most widely used algorithm for training an MLP network is the back-propagation (BP) algorithm [20–24]. The dataset was randomly divided into training and test sets in a 70:30 ratio (40,766 and 17,505 records, respectively). All statistical analyses were performed using SPSS software (version 23.0; IBM Corp., Armonk, NY, USA). IBM SPSS Modeler 18.0 was used to construct the RF, GLM, and BP-ANN models.

RESULTS

Result of operation status of each department in the PRP program

From a dataset encompassing 58,271 applicants, we observed an overall passing rate of 34.8%. We collected data from 26 departments, including the number of applications, pass rate, median age of patients, interquartile range of patient ages, sex ratio, proportion of medical insurance patients, patient application count for senior

specialists, patient application count for associate senior specialists, senior specialist applicant ratio, PRP program specialists, total specialists, PRP specialists, and average specialist applications. As shown in Table S3, the operational status of each department in the PRP program can be comprehensively and visually understood. The proportion of senior specialist applications varied significantly across departments, indicating different levels of expert engagement in the PRP program. The average number of applications per specialist also reflects the popularity of the PRP programs within each department. The eight departments with the highest number of patient applications were Urinary Surgery (11,142), Breast Surgery (10,097), Thoracic Surgery (9,332), Obstetrics and Gynecology (4,862), Gastrointestinal Surgery (4,716), Nephrology (4,011), Head and Neck Surgery (3,256), and Biliary and Pancreatic Surgery (3,076). The total number of applications for these departments accounted for approximately 86.7% of all applications, highlighting the importance of their importance in the PRP program and the significant demand from patients for their services.

Among these departments, those with high pass rates included Head and Neck Surgery (52.7%), Biliary And Pancreatic Surgery (47.3%), Obstetrics and Gynecology (44.8%), nephrology (42%), Gastrointestinal Surgery (38.6%), and Urinary Surgery (37.4%). Breast Surgery had the lowest pass rate (18.3%). In terms of age distribution within these departments, Urinary Surgery had the highest median patient age (64 years, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery (44 years, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; and Thoracic Surgery (56 years, IQR 22) and Gastrointestinal Surgery (59 years, IQR 26) have a broader age range, covering patients from middle age to the elderly. The sex ratio data reflected the characteristics of sex distribution among patients served by different departments. In terms of age distribution within these departments, Urinary Surgery had the highest median patient age (64 years, IQR 17), primarily serving middle-aged and elderly patients; Breast Surgery (44 years, IQR 20) caters to a relatively younger patient population with a more dispersed age distribution; and Thoracic Surgery (56 years, IQR 22) and Gastrointestinal Surgery (59 years, IQR 26) have a broader age range, covering patients from middle age to the elderly. The sex ratio data reflected the characteristics of sex distribution among patients served by different departments. For instance, Urinary Surgery and Breast Surgery show extreme sex ratios, indicating clear male and female preferences, respectively. In contrast, nephrology and biliary and pancreatic surgeries have more balanced sex ratios.

Result of RF analysis based on 26 department

Based on the pass rates from 26 specialized clinical departments, we utilized IBM SPSS Modeler version 18.0 to develop an RF model. Under the guidance of a statistical expert, model parameters were calibrated, with the number of models to build set to seven and the sample size meticulously configured to 1. To enhance the efficacy and feature selection of the model, we activated the "Handle imbalanced data" feature and the "Use weighted sampling for variable selection" option. For tree growth parameters, we retained the default settings provided by the software, which included a maximum number of nodes set to 10,000, a maximum tree depth of 10, and a minimum child node size of 5.

In this study, the overall pass rate was 34.8%. We've set the "Pass Rate Interval" field to categorize departments as either "high-rank group" or "low-rank group" based on this rate. Based on this, the "Pass Rate Interval," a binary variable, is taken as the

target variable in the RF analysis. The variables, including patient age Median, PRP specialist proportion, average specialist applications, total specialists, insurance patient ratio, PRP program specialists, patient sex ratio, application count, and senior specialist applicant ratio, all served as input features in the RF analysis. The accuracy of the model was 92.31%. The predictor importance values range from 0.12 to 0.93, indicating the relative significance of each variable in predicting the target variable. Median patient age emerged as the most significant predictor with a value of 0.93, followed by PRP specialist proportion and average specialist applications with values of 0.87 and 0.84, respectively. However, variables such as application count and senior specialist applicant ratio had lower importance values, indicating their smaller contribution to the prediction process. Table S4 and Figure S2 present an overview of the variables and their respective roles in an RF model, along with their predictor importance.

Overview and basic characteristics of patients

85 specialists from 26 specialties participated in the PRP program from December 1, 2020, to November 30, 2022. During this period, 58,271 patients applied for specialist appointments through the PRP program. In China, patients typically schedule outpatient appointments at tertiary hospitals without prior approval. Of these 58,271 patients, 20,290 (34.8%) passed the specialist assessment, and 37,981 (65.2%) did not.

Of the 58271 patients, the mean age was 52.89 ± 15.73 years. The Kolmogorov–Smirnov method test results (Sig=0.070>0.05) showed that "age" was normally distributed in the 58,271 patients. Among them, 22,412 (38.5%) were male, and 35,859 (61.5%) were female. See Table 1 for more details on patient characteristics.

Results of univariate and multivariate logistic regression analysis in the total population sample (N=58,271)

Focusing on patient demographics, we conducted univariate and multivariate logistic regression analyses of a dataset of 58,271 patients to explore relationships between demographic factors and assessment outcomes (Table 1). Univariate analyses revealed that the significant factors associated with specialist review outcomes were sex ($P < 0.001$), age ($P < 0.001$), and specialist title ($P < 0.001$). Age, sex, and specialist title were found to be significant in the univariate analyses and were subsequently included in the multivariate logistic regression model. This model was constructed using the backward stepwise method to refine variable selection. Then, through a multivariate logistic regression model, it indicates that those who were male and aged 60 years old or above were more likely to pass the specialist's review in the PRP program. At the same time, those aged 35–59 years were less likely to pass the specialist's review in the likely PRP program compared to those aged 18–34 years old. Additionally, those who had the title Associate Senior were more likely to pass the specialist's review than those who had the title of senior specialist (See Table 1).

Nagelkerke's R-squared ranged from 0 to 1, with values closer to 1 indicating a better model fit. However, as shown in Table 1, the value of Nagelkerke's R-squared was 0.016. From this, we speculate that more "strong" variables are not included in the predictive model of the expert review results (Table 1). Therefore, we added a GLM to identify additional predictors not included in the multivariate logistic regression model to enhance model fit.

Table1.Patient Characteristics, Univariate And Multivariate Logistic Regression Analysis Of

Factors Related To The specialist's review outcome

Items	Characteristics		Pass the Review		Univariate Analysis		Multivariate Analysis	
					Chi square test		Logistic Regression	
	Variables	Frequency(%)	Not Pass (Group A)	Pass (Group B)	c^2	P	OR (95% CI)	P
Gender					198.94	<0.001		
	Female	35859(61.5)	24162(67.4)	11697(32.6)			1.000	
	Male	22412(38.5)	13819(61.7)	8593(38.3)			1.161(1.119-1.205)	<0.001
Age (years)					154.93	<0.001		
	18-34	9003(15.5)	5902(65.6)	3101(34.4)			1.000	
	35-59	26590(45.6)	17939(67.5)	8651(32.5)			0.933(0.886-0.981)	0.007
	60-74	18405(31.6)	11577(62.9)	6828(37.1)			1.075(1.018-1.134)	0.009
	Above 75	4273(7.3)	2563(60.0)	1710(40.0)			1.151(1.066-1.243)	<0.001
Title of the specialist	senior	31561 (54.2)	21854(69.2)	9707(30.8)	501.00	<0.001	1.000	
	Assosiate senior	26710(45.8)	16127(60.4)	10583(39.6)			1.420(1.371-1.471)	<0.001
If Having Preference to pay with Insurance or not	Yes	42089(72.2)	27437(65.2)	14652(34.8)	0.004	0.95	N/A	N/A
	No	16182(27.8)	10544(65.2)	5638(34.8)			N/A	
Whether having Passed the Review	Yes	20290(34.8)		N/A	N/A		N/A	
	No	37981(65.2)						
Nagelkerke R Square							**0.016**	
Akaike information criterion (AIC)							**52335.946**	

Result of GLM analysis

In this enhanced analysis, we incorporated two additional variables, specialist and clinic, into the independent variables of the GLM and ANN models. The target

variable was the assessment result, which was categorized as a dummy variable. The GLM regression results show the specialist and clinic as the most significant variables, with a relative importance of 0.71 and 0.26, respectively. In contrast, age and specialist title exerted a comparatively minor influence, each with a significance of 0.02 (see Table 2). Furthermore, the predictive accuracy of the model is outlined in Table 3, with scores of 67.86% and 68.26% for the training and test datasets, respectively. The Akaike information criterion (AIC) value for the GLM, 48,433.067, was significantly lower than the AIC value of 52,335.946 for the multivariate logistic model. This decrease in the AIC indicates that the GLM, with its five input variables, outperforms the multivariate logistic model, which has only three inputs in terms of model fit and explanatory power.

Result of ANN analysis

To further understand how patient characteristics and specialist choices affect PRP assessment results, we developed an ANN model with an MLP structure. We maintained all other parameters at their default values as specified by the software. In the ANN analysis shown in Table 2, the input features encompass specialist, clinic department, age, title of the specialist, and sex, with assessment result (Yes or No) serving as the target variable. Table 2 further delineates the key variables influencing the assessment result within the ANN model, ranking specialist and clinic department as the most impactful, with the relative importance of 0.44 and 0.43, respectively. Age, specialist title, and sex had less influence at 0.07, 0.04, and 0.02, respectively. Figure 2 illustrates the topological architecture of the ANN model. The accuracy of the model is shown in Table 3, with scores of 67.72% and 68.28% for the training and test datasets, respectively.Table S5 present an overview of the variables and their respective roles in an ANN model, along with their predictor importance.

Tabe 2 The Role in GLM and ANN Model and Result of Predictor Importance

Variables	Role in model	Predictor importance in GLM	Predictor importance in ANN
Specialist	input	0.71	0.44
Clinic Department	input	0.26	0.43
Age	input	0.02	0.07
Title of the Specialist	input	0.02	0.04
Gender	input	0.00	0.02
Assessment Result(Yes or No)	target	/	/

Table 3. Accuracy of GLM and ANN analyses

	GLM				ANN			
Partition	Training Dataset		Testing Dataset		Training Dataset		Testing Dataset	
	Records	Accuracy	Records	Accuracy	Records	Accuracy	Records	Accuracy
Correct	27662	67.86%	11949	68.26%	27607	67.72%	11952	68.28%
Wrong	13104	32.14%	5556	31.74%	13159	32.38%	5553	31.72%
Total	40766		17505		40766		17505	

DISCUSSION

Digital technologies increasingly support health systems (WHO, 2018) by providing flexible options for interpersonal communication and information exchange[25]. Access, affordability, and equity are the three primary goals of a well-functioning health system[26]. In this study, among the 58,271 patients who applied to medical specialists on the PRP-based platform, 20,290 successfully passed reviews conducted by specialists, thereby gaining access to specialized medical treatment in hospitals. This indicates that the mobile health-based PRP program is a practical and innovative approach. This enables patients to obtain convenient access to medical specialists in hospitals, with reduced doctor-seeking costs, thereby ensuring timely and highly efficient treatment. The remaining 37,891 patients who did not pass the specialist review were identified through the PRP program. General practitioners (GPs) advised them to be appropriately directed to other clinical departments within the hospital or primary care centers for treatment by GPs. This guidance helps prevent inefficiency by discouraging patients from blindly seeking specialist appointments, which could otherwise lead to a waste of valuable medical resources in hospitals.

Implemented across 26 departments, the PRP program demonstrated diverse performance, with significant variations in operational metrics such as application volumes, pass rates, and specialist involvement. The implemented program attracted 58,271 patients who applied for specialist appointments during the study period, reflecting the extensive reach and the significant demand of the program for specialist services from outpatients. The smooth implementation of the program was highlighted by the high participation rate of 85 specialists from various fields, demonstrating a robust network of professionals eager to engage in the PRP initiative.

Univariate analysis revealed that age was significantly associated with the outcomes of specialist reviews ($P < 0.001$). Logistic regression showed that individuals aged 60 years and above were more likely to pass reviews compared to the 18–34 age group, whereas the 35–59 age group was less likely to do so. The RF analysis identified applicant age as the most important predictor, with an importance value of 0.93, in explaining differences in pass rates among the 26 clinic departments. This may be because the elderly, who often suffer a variety of chronic diseases, may have higher medical needs than younger individuals[27]. This is consistent with the evidence that many previous studies have claimed that elderly patients have more significant utilization of hospital outpatient or inpatient healthcare services than their younger counterparts because of their unfavorable health status[28]. Conversely, those aged 35–59 had a lower probability of passing the specialist review and a higher likelihood of being genuinely rejected than those aged 18–34. This could be explained by the fact that middle-aged patients prefer advanced medical care regardless of their medical needs. These patients may see specialists in hospitals for psychological comfort or because they mistrust GPs in primary care settings even though they do not require special medical care. Many previous studies have reported that this phenomenon results from the lack of community gatekeeper systems in China[29–30]. This reflects the urgent need to strengthen primary care and family doctor services for middle-aged people in China. Additionally, male patients were more likely to pass the review than their female counterparts were. This may be explained by the higher prevalence of chronic diseases among males than among females in China[31]. However, this finding was not consistent with previous studies, all of which reported a higher prevalence of

chronic diseases in females, especially in those aged 60 years and above in China[32–33]. However, the sex ratios in the prevalence of chronic diseases remain inconclusive. Therefore, the Shanghai government and decision-makers in the health sector should make gender- and age-specific efforts to facilitate the implementation of hierarchical diagnosis and treatment systems and family doctor services for middle-aged patients. By shunting middle-aged patients to GPs or secondary hospitals, patient crowding caused by the" siphon effect" can be mitigated, thus improving the efficiency of procedures in tertiary hospitals.

More interestingly, specialists who held senior associate titles were more likely to approve patients' applications than senior specialists were. This may be due to the intense competition for title promotion in medicine. In Chinese society, job hierarchy plays a significant role, which is evident in the use of professional titles[34–35]. Professional titles often signify seniority, experience, or level of authority within government-funded organizations. Given the pressure for promotion, specialists with associate senior titles prefer to accept more patients to enhance their professional skills and prepare for promotion to senior professional titles. The analyses of the GLM and ANN models reveal a distinct prioritization of specialist and departmental factors within the PRP program, surpassing the predictive power of patient age and gender, which may stem from a complex array of reasons as follows: First, the unique expertise of specialists is of paramount importance; for instance, urologists may specialize in different subspecialties, with some focusing on kidney conditions, others on prostate issues, and still others on bladder diseases, all of which substantially shape patient requests and the outcomes of assessments.

Second, specific clinical departments have a more concentrated age range among their applicants, with notably skewed gender demographics. For instance, the breast surgery department is characterized by a significant prevalence of middle-aged women, with a median age of 44 years and a sex ratio of 0.01 among its applicants. In contrast, the urology department has a predominantly male applicant base, with a sex ratio of 3.85, and applicants are mostly older, with a median age of 68 years, which exceeds the overall median age of the PRP applicant pool by 14 years. Together, these two departments constitute a considerable portion of the PRP applicant pool (36.45%). The unique demographic characteristics of these specific departments may profoundly influence predictive factors.

This study has several significant limitations. First, the potential for personal bias in expert evaluations may be considerable. In the future, we plan to incorporate rule-based systems with multimodal artificial intelligence assessments to reduce the impact of individual biases. The GLM Model achieved a score of 67.86% on the training set and 68.26% on the test set, whereas the ANN Model achieved a score of 67.72% on the training set and 68.28% on the test set, showing a nearly equivalent predictive performance. The accuracy of the GLM and ANN models on the testing dataset suggests a significant opportunity to improve and enhance their predictive accuracy. Second, existing budget limitations hinder the ability to conduct a structured analysis of patient–disease condition descriptions, highlighting the need for further research. A forward-looking approach is essential for creating a more robust, comprehensive, and inclusive predictive model by incorporating this crucial variable.

CONCLUSION

The PRP program offers a promising approach to integrating digital health technologies into healthcare systems. It provides a scalable and adaptable model for

optimizing specialist appointment processes. Our future goal is to enhance and expand the program by involving more specialists and hospitals, thereby including a larger number of patients. Healthcare entities seeking to improve appointment processes and specialist engagement through digital advancements may refer to the design and implementation of the program.

Figure1. The PRP flow chart
Figure.2 Topology architecture of the ANN model

Abbreviations

BIC: Bayesian Information Criterion
HIS: Hospital information system
PRP: Precise reservation path
RF:Random forest
GLM:Generalized linear model
AIC:Akaike Information Criterion
ANN:Artifcial Neural Network

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Availability of data and materials: The data sets for this manuscript are not publicly available because all our data are under regulation of Renji Hospital, School of Medicine in Shanghai Jiao Tong University. Requests to access the data sets should be directed to MC.

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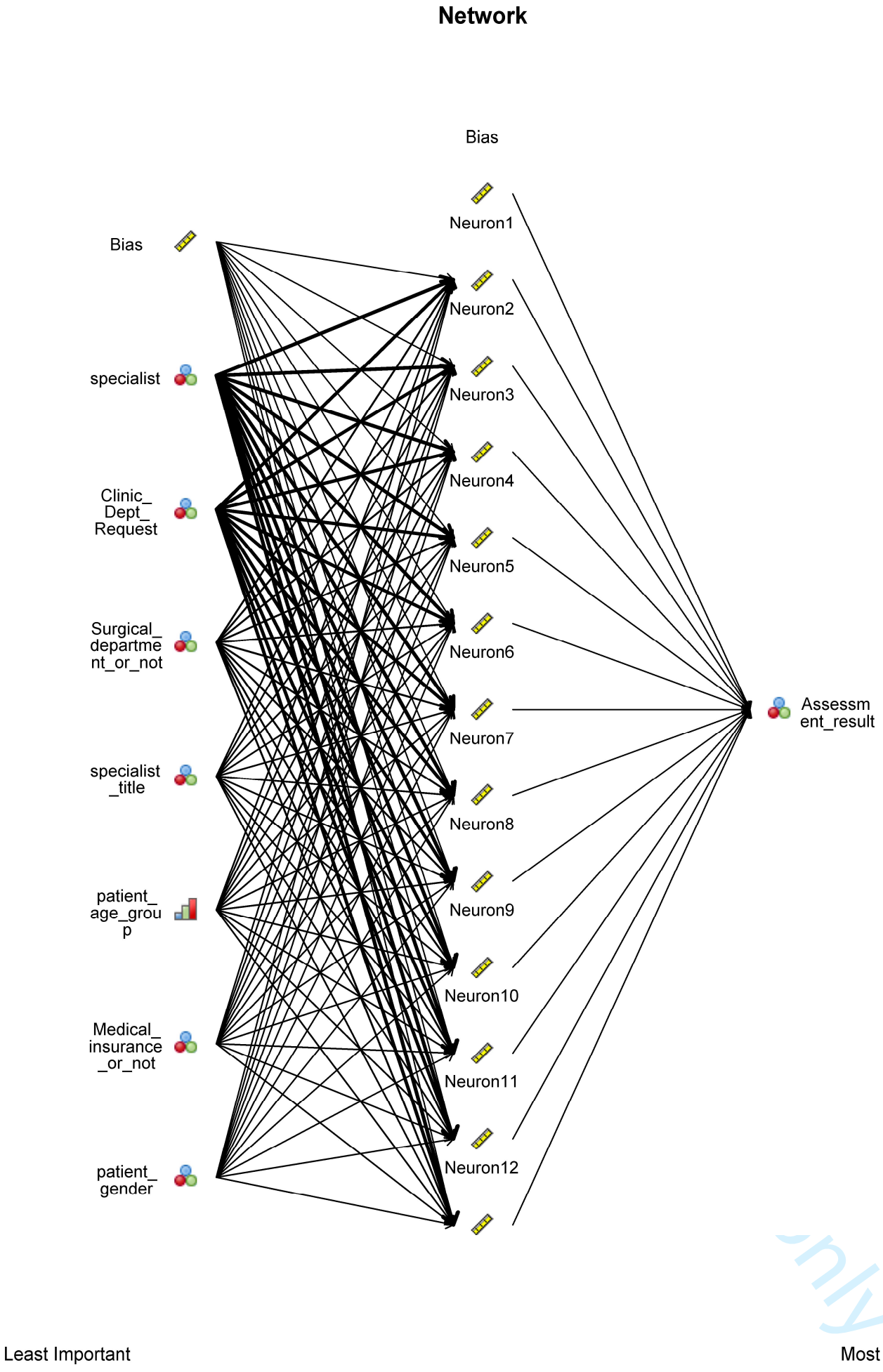

Table S1 Mobile Outpatient Specialist Appointment Registration Procedure for patients and specialists

Steps	Procedure for patients
1	The patient registers on the WeChat official medical service account of Renji Hospital using a mobile phone.
2	The patient reads the online specialist directory of the hospital and the diseases in which the specialist specializes.
3	The patient selects a specific specialist and requests an appointment by accessing the "Precise Reservation Path (PRP)" label.
4	The patient confirms the informed consent of the PRP, protocol, and submission of medical records.
5	According to the requirements of different specialist protocols, the patient also needs to submit relevant past examination reports (no earlier than 3 months), such as blood laboratory tests, ultrasound rays, computed tomography (CT), magnetic resonance imaging (MRI), and pathological reports.
6	If approval is received from the specialist users, the patient is allowed to visit the specialist offline on the appointed day.
Steps	Procedure for specialists
1	The specialist team user registers on the official WeChat accounts of Renji Hospital to build a PRP account using a mobile phone and obtains approval from the PRP system administrator.
2	The specialist team user completes their individual profile, including information about diseases in which they are specialized, past examination reports, and informed consent for patients before obtaining approval from the hospital's information administrator.
3	The specialist team user responds to patients' requests in a timely manner.
4	A specialist team user approves or rejects the patient's application. In the event of rejection, the user provides specific advice, such as recommending a well-matched subspecialty for the patient or suggesting a referral to their general practitioner.

Table S2 The classifications and measures of variables of interest

Variables	How to measure	Type
Whether having Passed the Review	1=Yes； 0= No	Categorical
Age	1=18-34 years; 2=35-59 years； 3=60-74 years; 4=75 years or above	Categorical
Gender	1=Male ;0=Female	Categorical
If having a Preference to pay with Insurance	1=Yes; 0=No	Categorical
Acdemic title of the specialist	1=Senior specialist; 2=Associate senior specialist	Categorical
Surgical department or not	1=Yes; 0=No	Categorical

Table S3 Operational Profile of 26 Departments participating in the PRP Program

Clinic department	Application count	Pass rate(%)	Patients age Median	Patients age IQR	Patients gender ratio(male/female)	Insurance patient ratio (%)	Patient application count for senior specialist	Patient application count for associate senior specialist	Senior specialist applicant ratio(%)	Integrated specialists	Total specialists	PRP specialists proportion(%)	Average specialist applications
Urinary Surgery	11142	37.4*	64	17	3.85	71.6	2012	9130	18.1	1	37	38	795.9
Breast Surgery	10097	18.3	44	20	0.01	74.4	6397	3700	63.4	1	5	100	2019.4
Thoracic Surgery	9332	27.7	56	22	0.57	65.0	9332	0	100.0	1	6	17	9332.0
Obstetrics And Gynecology	4862	44.8*	39	19	0	76.3	3432	1430	70.6	4	35	11	1215.5
Gastrointestinal Surgery	4716	38.6*	59	26	1.37	71.2	2364	2352	50.1	6	29	21	786.0
Nephrology	4011	42.0*	57	28	0.93	82.8	1955	2056	48.7	6	17	35	668.5
Head And Neck Surgery,	3256	52.7*	49	22	0.31	77.7	126	3130	3.9	2	5	40	1628.0
Biliary And Pancreatic Surgery	3076	47.3*	59	25	0.83	77.0	1601	1475	52.1	12	25	48	256.3
Radiotherapy	1551	55.1*	61	19	1.14	61.5	1261	290	81.3	3	7	43	517.0
Traumatic Orthopedics	1406	36.8*	44	32	0.89	76.4	0	1406	0.0	1	10	10	1406.0
Vascular Surgery	835	26.1	64	18	0.96	76.3	605	230	72.5	4	9	44	208.8
Rheumatology And Immunology	790	2.2	47	24	0.3	40.0	720	70	91.1	3	20	15	263.3
Cardiology	692	17.1	61	27	0.81	80.1	206	486	29.8	4	25	16	173.0
Joint Surgery	483	44.3*	55	27	0.56	72.3	421	62	87.2	4	9	44	120.8
Gynecological Oncology	478	61.5*	47	20	0	55.0	454	24	95.0	2	3	67	239.0

Otorhinolaryngology	470	33.4	47	25	1.02	77.0	143	327	30.4	4	8	50	117.5
Spine Surgery	445	56.4 *	66	24	0.79	79.8	445	0	100.0	9	11	445.0	
Ophthalmology	237	43.5 *	64	27	0.72	72.6	0	237	0.0	12	8	237.0	
Pain Medicine	143	40.6*	60	27	0.72	60.1	0	143	0.0	2	50	143.0	
Functional Neurology	120	0.0	44	30	1.03	59.2	0	120	0.0	1	100	120.0	
Oncology	49	51.0*	60	19	0.96	32.7	49	0	100.0	12	8	49.0	
Plastic Surgery	25	28.0	41	18	1.27	84.0	0	25	0.0	5	20	25.0	
Digestion Medicine	21	0.0	52	20	0.91	38.1	21	0	100.0	44	2	21.0	
Diagnostic Radiology	18	55.6*	64	50	0.38	27.8	0	18	0.0	16	6	18.0	
Endocrinology	13	0.0	41	20	1.17	53.9	13	0	100.0	10	10	13.0	
General Surgery	3	0.0	34	/	0	100.0	3	0	100.0	8	13	3.0	
Total	58271	34.8	54	26	0.63	72.2	31560	26711	54.2	369	23.04%	685.5	

Note:

Patients age Median: Median age of patients applying

Patients age IQR: Age IQR of patients applying

Patients gender ratio: Gender ratio of patients applying(male/female)

Insurance patient ratio (%): Proportion of insurance among the patients applying

Senior specialist applicant Ratio(%): Proportion of patient apply for senior specialist among all applicants

PRP program specialists: Number of specialists participating in PRP program

Total specialists: Total number of specialists in department

PRP specialists proportion(%):Proportion of specialists participating in the PRP program to the total number of specialists in department

Average specialist applications: Average of patients applying for one specialist in department

Tabe S4 The Role in Random Forest Model and Result of Predictor Importance

Variables	Role in random forest model	Predictor importance
Patients age Median	input	0.93
PRP specialists proportion	input	0.87
Average specialist applications	input	0.84
Total specialists	input	0.53
Insurance patient ratio	input	0.35
PRP program specialists	input	0.35
Patients gender ratio	input	0.22
Application count	input	0.16
Senior specialist applicant ratio	input	0.12
Pass Rate Interval	target	/

Tabe S5 The Role in ANN Model and Result of Predictor Importance

Variables	Role in ANN model	Predictor importance
Specialist	input	0.44
Clinic department	input	0.43
Patient age group	input	0.07
Acdemic title of the specialist	input	0.04
Gender	input	0.02
Assessment result(yes or no)	target	/

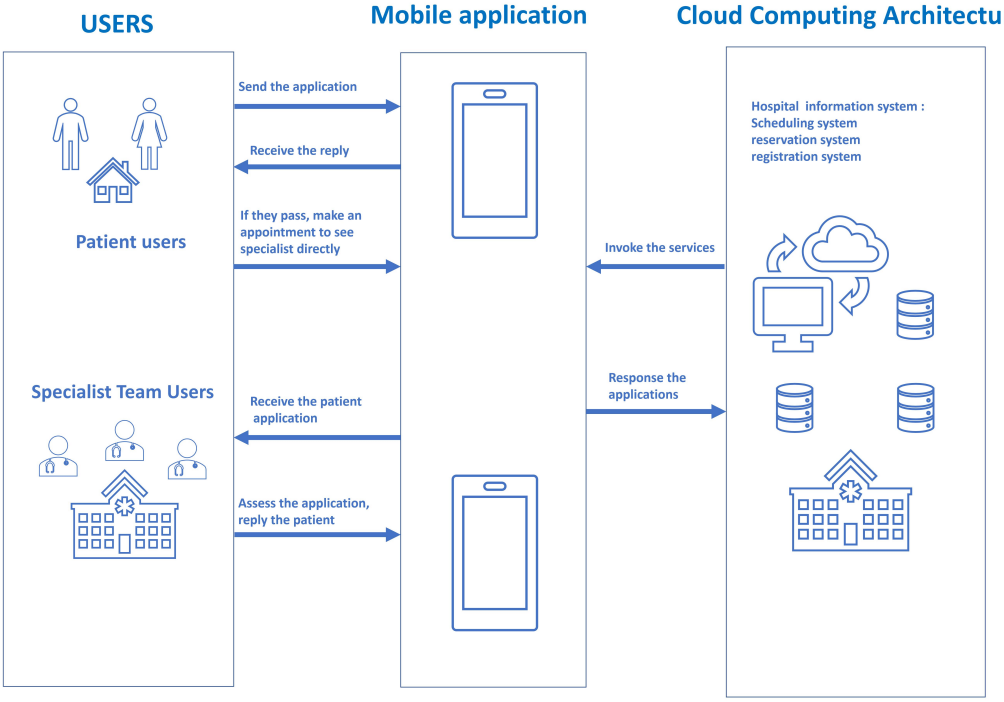

Figure S1. The PRP model architecture

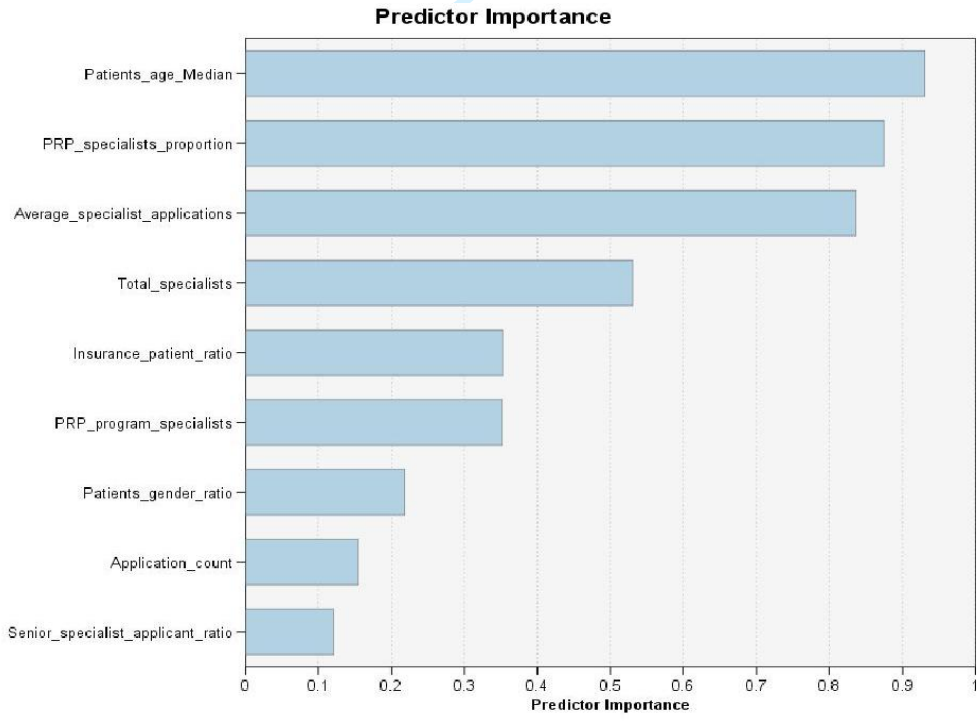

Figure S2. Result of Predictor Importance Through RF Analysis