國立臺灣大學管理學院碩士在職專班商學組

碩士論文

Executive MBA Program in Business Administration

College of Management

National Taiwan University

Master’s Thesis

健康檢查中心的磁振造影排程優化：
榮科醫學影像中心個案研究

Optimization of Scheduling in Imaging Health Checkups:

High-Tech Imaging Center Case Study

林重榮

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中華民國 112 年 12 月

December, 2023

doi:10.6342/NTU202400044

國立臺灣大學碩士學位論文

口試委員會審定書

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本論文係林重榮君（學號 P10748002）在國立臺灣大學管理學院碩士在職專班商學組完成之碩士學位論文，於民國一百一十二年十二月二十九日承下列考試委員審查通過及口試及格，特此證明

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doi:10.6342/NTU202400044

Acknowledgement

本論文可以順利完成. 首先，我想深深地感謝郭佳瑋教授。在這項研究的初期，當我面對困惑和挑戰時，郭教授即使在美國，仍然不辭辛苦，花費了大量的時間幫助我釐清問題的重要性和可能解決的機會，並為我重新聚焦明確的研究方向。他的指導不僅使我在學術上有了突破，更使我在面對問題時學會了用管理和工程數學的探索來探索臨床醫學挑戰。孔令傑教授的幫助也是不可或缺的。面對我提出的問題，孔教授迅速地找到了適職的學生來協助我。這些學生不僅積極投入研究，還發現了一些我未曾注意的細節問題。他們的參與，使我對中心的實際問題有了更深入的了解，並使用權重來處理一些軟性限制。

我必須說，台大管院師長和學生的熱情和勤奮，不僅解決了我當前的問題，更使我對整個研究過程有了更全面的認識。他們的付出，使我看到了許多之前忽略的細節和盲點，為我的研究帶來了巨大的實質幫助。最後，我再次感謝所有支持我、指導我的老師和同學。是你們使我的研究之旅更加充實和有意義。希望在未來，我們能根據現有的研究基礎上有更多的合作機會，共同為學術和實務界帶來更多的貢獻。

林重榮　謹識

于臺大管理學院

民國 112 年 9 月

doi:10.6342/NTU202400044

Chinese Abstract

背景介紹：自費影像健檢是醫療業的一個利潤豐厚的領域，涉及一系列的檢查。為了提高顧客滿意度和維護穩定的顧客基礎，有效的工作流程整合至關重要。手動排程基於經驗數據，相對較不靈活，但容易監控工作流程。但是，每次排程的最佳化會因多種變量而異，例如檢查類型、顧客合作和員工協調，這在臨床實踐中很難管理。此研究主旨在利用導入整數規劃(Integral Programming)改善優化顧客等待時間和工作流程的可行性。

材料和方法：我們基於整體規劃算法設計了一種排程方法。而人工手動排程方法則作為對造組。磁振造影(MR)和醫師(MD)分別被視為主要的機器資源和人力資源；時間限制包括工作時間，前置時間等限制。基於工作經驗，我們提供5種場景包含不同顧客數和不同健檢組套來測試兩種方法的性能。客人可以選取六種不同組套之一，其中總時長超過100分的為大程序包，反之為小程序包。目標式為最小化顧客閒置時間和資源超時時間。MR閒置和MD閒置時間則列為資源使用率作為參考指標。

結果：相較於手動方法，整數規劃方法在各種情境中通常導致整體客戶閒置時間略有增加。可能的原因是我們限制了整數規劃程式尋找最佳解決方案的運行時間為20分鐘。在客戶較少的情況下，整數規劃方法在減少客戶超時時間方面比手動方法更有效率，在20分鐘就達到接近100%的最佳化結果，比手動方式約2小時明顯較省時。相反，在客戶數量爆量的場景中，手動方法在減少客戶超時方面反而更為有效。經內部分析，主要衝突是由於MD解釋時間的重疊所引起的，凸顯了MD可用性的重要性。在MR閒置時間方面，整數規劃方法在5個場景中的3個場景表現比手動方法優越。另一方面，對於減少MD閒置時間，手動方法在5個案例中有3個比整數規劃方法更為有效。不過，值得注意的是，這些差異通常都是微小的。整體而言，隨機案例場景的目的是測試整數規劃方法對於不可預測狀況的適應能力，和手動方法比較顯示出相對穩定的結果。

結論：我們首次嘗試在有限時間內使用整數規劃方法安排影像健康檢查排程，雖然比傳統人工方法稍微遜色一些，但是不失為一個減少對人工勞力的依

doi:10.6342/NTU202400044

賴，並量化資源利用等有效方法，這樣的數位化有助於我們能夠適應動態的不可預見因素，如緊急情況或設備故障，為更精密和以顧客為中心的解決方案展開解決之道。通過縮短等待時間，我們最終能提升當代健康檢查服務中的顧客體驗。

關鍵字：健康檢查；影像學；整數規劃；磁振造影;定量分析；排程

doi:10.6342/NTU202400044

THESIS ABSTRACT

BUSSINESS ADMINISTRATION
COLLEGE OF MANAGEMENT
NATIONAL TAIWAN UNIVERSITY

NAME：Chung-Jung Lin MONTH/YEAR：Dec, 2023

ADVISER：Chia-Wei Kuo, Ph.D.

TITLE：Optimization of Scheduling in Imaging Health Checkups: High-Tech Imaging Center Case Study

Introduction: Out-of-pocket Imaging health checkups are a lucrative aspect of the medical industry that involves a range of examinations. Effective workflow integration is crucial for enhancing customer satisfaction and maintaining a consistent customer base. Manual scheduling is based on empirical data and is relatively inflexible, allowing for easy monitoring of workflow. However, the duration of each examination varies depending on multiple variables, such as the type of examination, customer cooperation, and staff coordination, making it difficult to manage in clinical practice. This study aims to utilize integral programming (IP) to design a workflow that optimizes customer waiting time and workflow simultaneously.

Materials and Methods: We designed a IP scheduling method based on the overall planning algorithm, with the manual scheduling method as a control method. Magnetic Resonance (MR) and Medical Doctors (MD) are considered as the main machine resources and human resources respectively; time constraints include working hours, lead time, etc. Based on work experience, we provide 5 scenarios that contain different numbers of customers and different health check-up packages to test the performance of the two methods. Customers can select one of six different packages,

doi:10.6342/NTU202400044

where those with a total duration of over 100 minutes are considered large packages, and those less are small packages. The objective is to minimize customer idle time and resource overtime. MR idle and MD idle times are listed as resource utilization rates for reference.

Results: Results: Compared to the manual method, the IP method typically leads to a slight increase in overall customer idle time across various scenarios. A possible reason is that we limited the run time of the IP process to find the best solution to 20 minutes. In cases with fewer customers, the IP method is more effective in reducing customer overtime and reaches close to 100% optimization in just 20 minutes, which is significantly more time-efficient than the manual method that takes about 2 hours. Conversely, in scenarios with a large number of customers, the manual method is actually more effective in reducing customer overtime. Internal analysis revealed that the main conflict was caused by the overlap of MD interpretation times, highlighting the importance of MD availability. In terms of MR idle time, the IP method performed better than the manual method in 3 out of 5 scenarios. On the other hand, for reducing MD idle time, the manual method was more effective in 3 out of 5 cases. However, it's worth noting that these differences are usually minimal. Overall, the purpose of the random case scenarios is to test the adaptability of the IP method to unpredictable situations, and when compared with the manual method, it demonstrates relatively stable results.

Conclusion: This is our first attempt to use the IP method to arrange imaging health check-up scheduling within a limited time, and although it is slightly inferior to the traditional manual method, it is still an effective way to reduce reliance on manual

doi:10.6342/NTU202400044

labor and quantify resource utilization. Such digitization helps us adapt to dynamic unforeseen factors such as emergencies or equipment failures, paving the way for more precise and customer-centered solutions. By shortening waiting times, we ultimately improve the customer experience in contemporary health check services.

Keyword: Health checkup; Heuristic algorithm, Imaging, Integral programming, MR, Quantitative analysis, Scheduling

doi:10.6342/NTU202400044

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Chapter 1 Introduction

1.1 Evolution of health checkups in Taiwan

Health checkups in Taiwan began with the service provided by the National Taiwan University Hospital in 1956. In the early days, due to the lack of awareness about disease prevention among the public, health checkups were time-consuming, and the public had to share medical equipment with customers. In addition, health checkup fees were expensive. As a result, only about 100 people used this service until 1958 (張宏名 & 董和銳, 2008). Following the development of economy, and increased awareness of health, more people started to use health checkups. According to a national survey conducted by the Ministry of the Interior in 2017, the proportion of respondents who reported having undergone health checkups in the past three years is 54.6% in the group aged 40-64 and 64.8 % in the group above 65 (衛生福利部國民健康署, 2023).

Over the past few decades, the average life expectancy of Taiwanese people has increased. In 2021, the average life expectancy was 77.6 years for males and 84.5 years for females. As of March 2021, the population aged 65 and over accounted for 16.2% of the total population. （內政部統計處, 2017）Increased life expectancy also indicated more chronic disease and malignancy. Preventive healthcare helps improve people's health. By visiting medical institutions in the absence of diseases and undergoing preventive checkups, people can discover risk factors or early signs of disease that are not conducive to their health. Proper interventions can be given before clinical

doi:10.6342/NTU202400044

symptoms appear. Extending life expectancy, reducing disability rates, and minimizing personal and familial distress are significant health objectives and national policy goals. (Liss, Uchida, Wilkes, Radakrishnan, & Linder, 2021).

Since self-paid health checkup is a preventive measure, the budget is highly correlated with national income and macro economy (Chu & Lawana, 2021). Over the past 3 years, the global economy has experienced significant ups and downs, largely due to the COVID-19 pandemic. In early 2020, the pandemic caused a global economic downturn as countries implemented lockdowns and businesses were forced to close. However, governments and central banks implemented various stimulus measures to mitigate the impact of the pandemic on the economy（行政院, 2021）

High-end Imaging Checkup in Taiwan

Self-paid imaging checkups refer to medical imaging exams that are paid for by customers out-of-pocket, without the assistance of health insurance. These exams are typically used as a preventative measure for early detection of diseases, or as a way for customers to monitor their health status. In recent years, there has been a growing trend of people opting for self-paid imaging checkups, which has led to the growth of the self-paid imaging check-up market.

Cancer has been the top ten cause of death for 30 consecutive years in Taiwan. The top ten mortality rates are lung cancer, liver cancer, colorectal cancer, female breast cancer, oral cancer, stomach cancer, prostate cancer, pancreatic cancer, esophagus cancer, and cervical cancer. Colorectal cancer, stomach and esophageal cancer can be

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effectively screened by endoscopy (Cancer, 2021; Januszewicz, Turkot, Malfertheiner, & Regula, 2023). For rest cancers, the accuracy of serum marker such as alpha-fetal protein, CA 19-9, are not adequate to detect early hepatic cancer and pancreatic cancers respectively (Rückert, Pilarsky, & Grützmann, 2010; Zhang et al., 2020). There are not effective serum tumor markers to detect lung cancer, female breast cancer, oral cancer. Imaging medicine, due to the invention of computerized tomography (CT) and magnetic resonance imaging (MRI), coupled with the advancement of other medical imaging equipment, has dramatically increase the probability to detect early stage lung, breast and oral cancer(Adams et al., 2023; Tollens et al., 2022). However, due to various reasons, such as limited availability, high expenditure per examination, the rationale to use imaging for cancer screening in oncology medicine is still disputable. On the contrary, in the field of out-of-pocket preventive medicine, this timesaving, high accuracy imaging test immediate draws the attention of health check-up providers and enter the market in the early 2000.

We can divide the health check-up market into three levels: basic, mid-level, and high-end. Basic health checkup includes serum blood test, and x-ray of chest and abdomen, usually under NTD 6,000. The mid-level health checkup will include above-mentioned tests, and add ultrasound of single organ, gastroenteroscopy or enteroscopy. The price ranges between NTD 8,000 to 25,000. The high-end health checkup will include all above tests and add CT or MR scan examinations. If gene test is added, the overall price can go beyond NTD 100,000. Evidently, the customer segments are completely different. The self-paid imaging check-up market has been growing 62%-123% in the past two decades, due to several factors. One of the main drivers of this growth is the increasing health consciousness among people, who are becoming more

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proactive in managing their health (Choksi, Mukherjee, Sadigh, & Duszak, 2023). Another factor is the rising prevalence of chronic diseases such as cancer, heart disease, and diabetes, which has led to a greater demand for early detection and monitoring.

RMIC (Ronke Medical Imaging Center) was founded in 1999 by Dr. Zeng Huizheng, who proposed the concept of "one-stop shopping" and "reverse pyramid of imaging workflow." RMIC is the world's first medical imaging center that uses MRI for health checkups. In 2000, RMIC introduced nanoparticle contrast agents to complement MR technology. In March 2002, RMIC's whole-body magnetic resonance imaging screening results for cancer and stroke were mentioned in the editorial comments of the American Journal of Radiology. In 2007, Dr. Ke Shiqi from RMIC published the latest research report on breast MRI screening for Asian women's breast cancer screening. In 2009, RMIC changed the 1.5 T MR scanner to a new model, 3.0 T MR scanner. In late 2012, RMIC was merged into Taipei Veterans General Hospital due to the government's revision. In Oct 2016, RMIC expanded its service to fetus screening. (***Table 1-1*****)**

Table 1-1Chronicles of Ronke Medical Imaging Center

Year	**Event**
1999	Dr. Zeng Huizheng proposed the concept of one stop shopping and reverse pyramid of imaging workflow.
	Dr. Zheng visited Siemens company to discuss the plan, and H. Requardt, President of Siemens Magnetic Resonance Imaging, agreed to transport the latest MRI machine to Taipei.
	RMIC was approved by the Public Works Committee and the Guidance Committee of Veterans, and became the first Taipei Veterans General Hospital clinical industry-university cooperation project.

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Year	Event
2000	RMIC Medical Imaging Center started to operate as the world's first medical imaging center that uses magnetic resonance imaging (MRI) for health checkups.
	Prof. Hennig cooperated with RMIC and led an international seminar to introduce the latest development of magnetic resonance imaging MRI.
	RMIC introduced the state of the art, nanoparticle contrast agents to complement the MR technology.
	RMIC received the "National Biotechnology Quality Excellence Award" of the Republic of China.
2002	RMIC's screening results for cancer and stroke were mentioned in the editorial comments in American Journal of Radiology, pointing out that whole-body magnetic resonance (WB-MR) imaging is the trend of future imaging.
	RMIC entered the international stage when Professor Debatin of Germany established Europe's first "Magnetic Resonance Imaging Systemic Cancer and Vascular Screening Center" at the Affiliated Hospital of Essen University using the RMIC Medical Imaging Center as a model.
	RMIC was introduced in detail as the world's first MRI imaging health examination center in Germany's Siemens Magnetic Resonance Imaging Magazine.
	RMIC's achievements were introduced to radiologists from all over the world at the World Magnetic Resonance Imaging (MRI) Summit hosted by Siemens Medical Solution in Miami.
	RMIC's report was selected as the "key paper" of the Radiological Congress of North America (RSNA) and became the front page news of the "Daily Report" of the conference.
2003	The world's first "Whole body magnetic resonance imaging: clinical applications and new developments" seminar was held in Freiburg, Germany. RMIC Medical Imaging Center was specially invited to share the results report of "the world's only application of whole-body magnetic resonance imaging in health examination" with global experts.
2007	Dr. Ke Shiqi published "Breast MRI Screening for Asian Women's Breast Cancer Screening in Breast MRI Screening for Asian Women" report
July 2009	RMIC combined "water molecule diffusion imaging" with whole-body MRI screening to enhance diagnostic accuracy of detecting cancers in WB-MR without contrast

doi:10.6342/NTU202400044

Year	Event
August 2009	RMIC installed new 3.0 T MR scanner to shorten examination time, increase imaging contrast, and enhance customer experience and diagnostic accuracy
Late 2012	RMIC merged into Taipei Veterans General Hospital
Oct 2016	RMIC expanded screening population to include fetus for second opinion with MR imaging

doi:10.6342/NTU202400044

1.2 External environmental analysis of RMIC

The external environmental analysis is a vital component of the strategic planning process. It provides the necessary context to make informed decisions regarding competitive strategy, operational improvements, and customer relationship management. **Political Factors:** Taiwan's prior experience with SARS has led to commendable public health measures during the COVID-19 pandemic, allowing the domestic economy to remain relatively stable. Government policies, including tax incentives and support for healthcare infrastructure, bolster the health check-up industry, helping providers to navigate through the pandemic with minimal economic contraction. **Economic Factors**: Despite global economic challenges, Taiwan's healthcare market has shown resilience. The persistence of a strong self-paid customer base, accounting for approximately 69-71% of examinees during the pandemic, underlines the sector's economic robustness (**Figure 1-1**). This economic stability provides a solid foundation for sustained investment and growth in high-end health checkups. **Social Factors**: Customer discernment is on the rise, with a premium placed on health check-up quality and satisfaction. The consistent demand, even during economic downturns, reflects a social commitment to health and wellness, underpinning the need for providers to prioritize customer experience and service excellence. **Technological Factors**: The health check-up market in Taiwan is witnessing intensifying competition, driven by technological advancements and the entrance of new market players. Current providers are expanding services and integrating new technologies to meet the heightened expectations of technologically savvy consumers. In conclusion, the market for premium health checkups is expanding. In the face of emerging competition, alongside moderate supplier bargaining power, and increasingly

doi:10.6342/NTU202400044

discerning customers, it is imperative to enhance customer satisfaction. Below is our analysis.

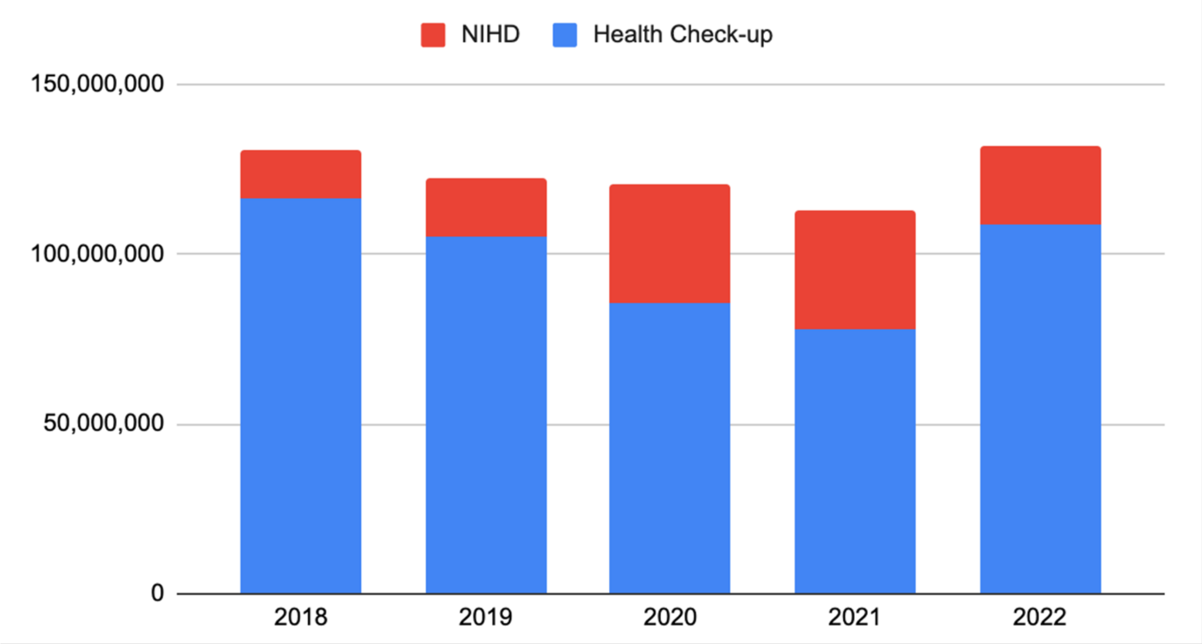

Figure 1-1 Annual Income Statement of RMIC from 2017-2022

Industry Rivalry: Before era of 2010, RMIC Imaging is the only facility who provide MR physical examinations. Gradually, other medical centers, or private clinics also set up organizations to execute the high-end imaging checkups. The flexibility of pricing in private clinics becomes the new threat.

The New Entrants: Genetic examination has been the novel technology to participate in preventive medicine (Nielsen & Cummings, 2016). The price ranges from USD $999 to $399, like WB-MR. With serum sample, the test can tell the examinee what kind of "disease" genes he or she carries, to avoid the onset of the disease, the individual can accept the consultations of life modification from the family practitioners, nutrition specialists or physical therapists. Other emerging competitor runs the preventive medicine in the eco-system. They combine sports, healthy food, and

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health check-up facilities together. They run the fans clubs in the social media or using the membership to attract more customers (Marquez et al., 2014).

The Substitutes: There are no exact substitutes with equivalent efficacy to have the similar customer experience for this business. However, there are some alternatives, either going to the hospitals to request self-paid health checkups; in general, the examination will cover the whole body, and the report won't be provided until next consultation.

Bargaining Power of Buyers: Before 2010, the buyers have only one place to visit. After 2010, there are more organizations providing similar services, and therefore, the customers have more bargaining powers. Nevertheless, only hospitals can own MR scanners, thus, unlike other normal health checkups, WB-MR health checkup still favors the service providers.

Bargaining power of suppliers: Only three MR manufacturers will produce MR scanners. Siemens has better quality than GE healthcare and Philips. Siemens Taiwan has little autonomy to determine the price of the MR scanners and is usually centralized. Despite we have close relationship with Siemens company in early 2000, we still cannot have a favorable contract when purchasing the new 3.0 T MR scanners. Siemens has a well-established research development highly responsive to the market. If we need new imaging sequences, we can apply for the trial license for 3-6 months. There are different imaging characteristics of imaging of different MR scanners. It is extremely important to use the MR scanners from the same manufacturer. Both reasons increase our dependence upon Siemens. MR contrasts are used since 2008 to increase

doi:10.6342/NTU202400044

the diagnostic accuracy, especially in brain and liver. There are no distinct difference upon imaging characteristics among different contrasts, therefore, the bargaining power of suppliers are low. Among different staff, the consulting radiologists are the most difficult to find, in general, the radiologists prefer to work outside the spotlights and avoid drawing attention from the customers. In our institution, the radiologist has to behave like the family practitioners: kind, friendly, and easy to understand for the customers/customers. Those characteristics need some extra-training after the general radiologists getting their boards. It is not easier for the other specialists to replace the radiologists in this job because real-time interpretation of imaging still needs radiologist expertise.

doi:10.6342/NTU202400044

1.3 Core competence of RMIC

As the first-ever founded Imaging health check-up center, we keep innovative in Radiology and Business models since we founded. In 2012, our profit center was merged into the Taipei Veterans General Hospital due to the government regulations. Therefore, we summarize the current core competences of our center, RMIC.

Medical center: the branding effect, our customer segment prefers the top, excellence medical care. : a) Medical centers have trained healthcare professionals who can provide a professional assessment of a person's overall health status. These professionals are equipped with the knowledge and tools necessary to detect early signs of illnesses, which can be missed during self-diagnosis. B) Comprehensive checkups: Medical centers offer comprehensive health checkups that include tests, examinations, and consultations with healthcare professionals. These checkups provide a thorough evaluation of a person's physical, emotional, and mental health. C) Access to medical equipment: Medical centers have access to all advanced medical equipment that can be used to diagnose and treat various health conditions. These include X-rays, CT scans, MR scans, ultrasound, and blood tests, among others. D) Gapless referral: Regular checkups at medical centers can help detect and prevent health problems before they become serious. This can result in early intervention, which can improve the chances of successful treatment and recovery. In case of detected probably malignancy (1.5-2%), RMIC can immediate refer the customer precisely to the appropriate specialist with all the information of examinations ready. This dramatically reduce the anxiety during seeking proper referrals. Overall, people choose to go to medical centers for health checkups because it provides a comprehensive evaluation of their health status, access

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to medical equipment and expertise, prevention and early detection of health issues, and peace of mind (Fujita, Sato, Nagashima, Takahashi, & Hata, 2017).

Amiable Radiologist: a) An amiable radiologist can effectively communicate the results of imaging tests to the customer in a clear and understandable manner. Comparing to family practitioners, radiologists can better help the customers understand their health condition by illustrating their body by imaging (Brady et al., 2022). B) Customer comfort: An amiable radiologist can help put the customer at ease during the consultation, making them feel more comfortable discussing their health concerns and answering questions about their condition. Comparing to conventional radiologists, they are used to work behind the scenes, and communicate with other medical professionals. Our radiologists working in RMIC have not only professional imaging interpretation professions but also friendly and customer to the customers. C)
Trust: An amiable radiologist can help build trust between the customer and the healthcare provider. This can lead to a stronger doctor-customer relationship, which can improve customer satisfaction and adherence to treatment plans. D) **Collaboration:** An amiable radiologist can work collaboratively with other healthcare professionals, such as specialist, to ensure that the customer receives the best possible care. E) Empathy: An amiable radiologist can show empathy towards the customer, which can help the customer feel heard and understood. This can also help the radiologist better understand the customer's concerns and tailor their communication and treatment recommendations accordingly.

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Immediate Consultation: a) Addressing concerns; the results of imaging tests can be a source of anxiety and concern for customers, especially if they are not familiar with medical terminology. Immediate consultation can help address the customer's concerns and provide clarity about their test results. B) Timely treatment: In cases where the imaging tests have identified a health problem, immediate consultation is important for timely treatment. Delay in diagnosis or treatment can lead to complications and worsened health outcomes.

Understanding treatment options: Immediate consultation can help the customer understand their treatment options and make informed decisions about their health. This can include discussing the benefits and risks of different treatment options and answering any questions the customer may have. C) Improved customer satisfaction: Immediate consultation can improve customer satisfaction by providing timely and clear information about their health status. This can also help the customer feel more involved in their healthcare, which can lead to better adherence to treatment plans. D) Efficient use of resources: Immediate consultation can help avoid unnecessary follow-up appointments or testing, which can save time and resources for both the customer and the healthcare provider, which is invaluable for high-end customers.

In summary, immediate consultation is important for an imaging checkup because it can address customer concerns, lead to timely treatment, improve customer satisfaction, provide clarity about treatment options, and save time and resources.

doi:10.6342/NTU202400044

Honorable Courtesy: Conventionally, the medical center is too confident with their own professionalism and pay little attention to the ambient and environment of the examinations. Most of time, the reception area is not neat, and overcrowded; the staff is distant and cold. Honorable courtesy demonstrate respect to the customers, with comfortable lounge for waiting, rest. It shows that the healthcare provider values the customer's time, concerns, and dignity. A warm, relaxed ambience facilitate effective communication, and they are more willing to discuss their private health concerns. The honorable courtesy is also essential part of professionalism in healthcare. It helps medical professionals maintain a high level of integrity and ethics, which is important for building trust with customers and providing high-quality healthcare with warmth. Honorable courtesy enhances the customer's amusement because it demonstrates respect for customers, helps build trust, promotes effective communication, enhances customer comfort, and is an essential part of professionalism in healthcare (Mosadeghrad, 2014).

doi:10.6342/NTU202400044

1.4 Business canvas

Value propositions*:* One-stop high quality health checkup. a comprehensive medical examination that aims to provide individuals with a comprehensive assessment of their overall health with one visit. It typically includes a variety of tests and assessments, such as blood tests, imaging studies, and physical examinations, to identify any potential health risks or issues. The goal of a one-stop health checkup is to provide individuals with a complete understanding of their health status, as well as to identify any areas that may need further attention or treatment. Additionally, this checkup can help to establish a baseline of an individual's health and serves as a reference point for future health assessments (Lu, 2022).

Customer Relationships: An amiable health consultant. In contrast to the stereotype of medical doctor, who is more sympathetic. Our staff works as a professional team to provide guidance and health-rated matters. Through more intuitive, comprehensive imaging, we facilitate the self-motivation of the customers to improve their health.

Customer* segments:* Chief manager, chief executive officer, member of director boards of the enterprises etc., or those with annual income ranging above USD 100,000 etc.

Channels: The interaction is kept primarily by the word of mouth (Huete-Alcocer, 2017). Lately we renewed the website and set up the Facebook account to increase the visibility in internet. We still did not run the fan club. The individual health

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condition is relative more private than food, clothing, or travelling, and most of our target customers do not like to share in public. We refocused our target audience in the internet to those who are more health-coconscious.

Key Activities: precision preventive medicine, based on the individual family history, medical history, and current lifestyle, we recommend custom-made checkup. The examination duration is 2.5-4 hours, depending on the kind of the examination. We will exam the customers based on his or her individual health condition ((ESR), 2015).

Key Resources: Radiologists who provide immediate health consultation after health checkups. Two high end 3.0 T MR scanners (Siemens Skyra, Siemens Healthcare); and one CT scanner (Force, Siemens Healthcare, Forcheim, Germany) for coronary angiography and low dose CT.

Key Partners: RMIC was an independent cost center, we cooperated with the health and service center, where the endoscopy was performed. The radiologists in the radiology department provide timely second opinions. Occasionally, some third party prevention medicine would make connections with us but no officially contract was done.

Cost Structure: We have no budget for marketing. The personnel costs was around 30%, including radiologists, radiologic technicians, nurses, and logistic assistants. The depreciation and amortization is around 14-18%. The amortization and depreciation increased from 7.14% to 14% after October 2018 because we installed a new 3-T MR scanner. The materials including contrast, papers etc. was 7%. The

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support and common cost to Taipei Veterans General hospital are 1 %, respectively. The net revenue is 39-49% (Table 1-3).

Revenue Streams*:* The net profit comes from the main service: one-stop health-checkup. For the rest of time slots, we will fill-up the Taiwan healthcare insurance-covered MR examinations and cut 25% share of the income per examination.

RMIC, as the pioneering Imaging health center, has continuously innovated in both Radiology and business models. With its merger into the Taipei Veterans General Hospital in 2012 due to government regulations, RMIC has fine-tuned its core competencies to meet the evolving needs of its clientele. The utilization of MR imaging in the health checkups offers multiple benefits. In essence, MR imaging checkups at RMIC stand out in the high-end health examination sector due to their comprehensive nature, precision, immediate consultations, and the upscale experience they offer. The center's integration with a reputable medical institution and its focus on continuous innovation further solidify its competitive edge in the market. (Figure *1-2*)

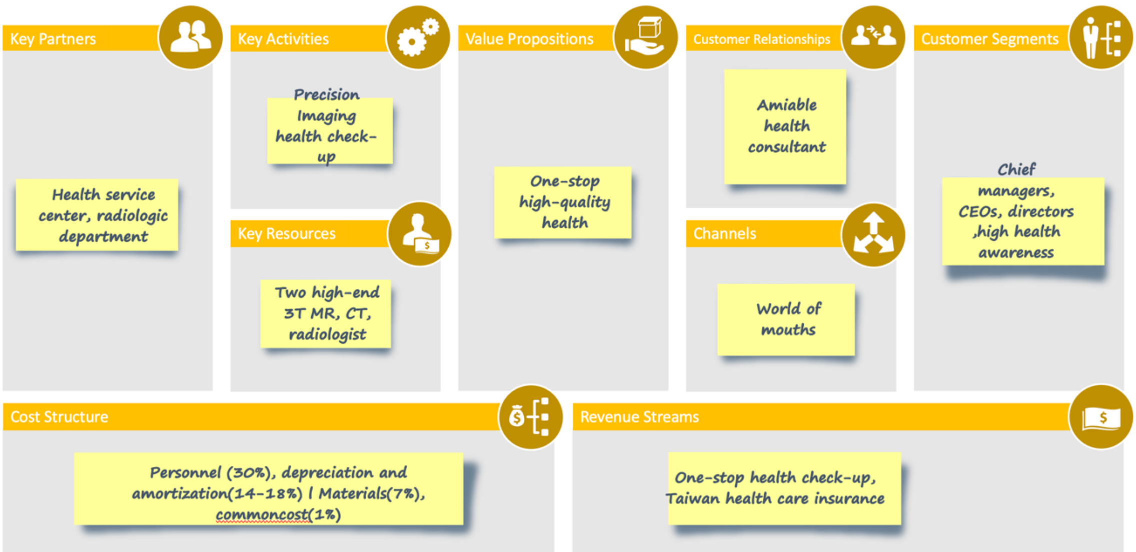

Figure 1-2 Business Canvas of RMIC

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1.5 Cost Analysis of RMIC

In Table 1-2, we delve into the cost structure of RMIC, which is instrumental in informing our strategic planning. A nuanced understanding of the costs associated with each activity allows us to enhance operational efficiency by channeling resources into the most profitable activities while scaling back on those with lower returns, thereby safeguarding our competitive edge. This approach supports different executive goals: for instance, supervisors aiming to maximize net profits may view resource allocation differently from staff who favor a reduced customer turnover to lessen the workload. Analyzing RMIC's cost structure enables us to balance these objectives, ensuring that resource distribution aligns with both profitability and operational efficiency.

There are 5 main health activities in RMIC: WB-MR; MR of Head and Neck (MR-HN); MR-Breast; National insurance Healthcare MR (NIH-MR); and CT of lung and heart (CT). Based one different requirement of manpower multiple by demanded duration, consumed materials, duration of MR, CT, sonography machines. We re-calculated the cost of individual service (Activity-based cost) as the Table 1-2. We found out NIHD has the highest net revenue (42.2%), followed by MR_HN (40.3%), MR_WB (37.2%), MR-HN (25.3%), and CT (22.4%). NIHD has the highest margin is because the activity only involves the logistic assistant without medical professionals such as physicians. Furthermore, the depreciation is covered by the superior department instead of RMIC. The reason why there is a considerable decrease of profit margin is because we must split the cost with another cost center. Nevertheless, the department policy only allowed our center to assist NIHD tasks when our out-of-package services did not reach full capacity. The second highest of net revenue is NIH-MR because this

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activity only involved nurses and radiologic technicians, not physicians. MR-breast is surprising low because it takes physicians a lot of time to interpret and radiologic technician decent time to perform ultrasound. **The most important finding** is that we confirmed MR_HN (45.7%) is cost effective than WB_MR (37.2%).

Table 1-2 Brief cost analysis of overall services in RMIC between 2018-2022

	2022	**2021**	**2020**	**2019**	**2018**
Income (NTD)	**140,912,030**	**106,148,555**	**111,218,495**	**123,953,111**	**130,631,381**
Staff	40,044,304	33,776,172	34,644,724	30,737,227	37,307,868
	28.42%	31.82%	31.15%	24.80%	28.56%
Materials	**8,606,991**	**8,670,933**	**8,505,243**	**7,531,396**	**9,694,267**
	6.11%	8.17%	7.65%	6.08%	7.42%
Depreciation & amortization	**19,873,923**	**19,771,105**	**19,389,011**	**13,467,459**	**9,323,843**
	14.10%	18.63%	17.43%	10.86%	7.14%
Support cost	**1,412,909**	**1,441,210**	**1,429,405**	**688,241**	**1,053,643**
	1.00%	1.36%	1.29%	0.56%	0.81%
Shared cost	**1,434,061**	**904,090**	**817,898**	**863,429**	**809,226**
	1.02%	0.85%	0.74%	0.70%	0.62%
Gross Margin	**69,578,596**	**41,596,866**	**46,432,213**	**70,672,634**	**72,442,534**
	49.38%	39.19%	41.75%	57.02%	55.46%

Table 1-3Activity-based cost of each health check-up service of 2022

	MR_WB	MR_HN	MR_breast	NIHD	CT	convention
count	1554	1389	397	2913	1764	
Gross profit margin	50.6%	53.3%	38.2%	67.2%	79.1%	43.8%
Net profit margin	37.2%	40.3%	25.3%	35.2%*	22.4%*	41.7%

MR_WB: whole body MR; MR_HN: MR of head and neck; MR_breast: MR of breast; NIHD: MR reimbursed by national healthcare system; CT: CT scan of lung and heart * indicated split the profit with other cost center.

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1.6 SWOT Analysis of Imaging Health Check-up Center in a Public Medical Center

Strengths:

High-Quality Machines and Staff*:* The center possesses cutting-edge imaging equipment, ensuring the highest diagnostic accuracy. This technological edge, combined with the expertise of seasoned professionals, allows for unparalleled diagnostic precision. The commitment to quality ensures customers receive reliable and conclusive results, fostering trust and confidence in the center's capabilities.

One-Stop Shop Service: As a comprehensive diagnostic facility, customers benefit from the convenience of accessing a myriad of imaging services in one location. This eliminates the need for multiple appointments across different centers, saving time and reducing logistical challenges for customers (Schäfer, Boerma, Schellevis, & Groenewegen, 2018)

Weaknesses:

Strict Public Sector Regulations: Operating within a public framework often entails navigating a maze of bureaucratic regulations. These regulations, while ensuring customer safety and service quality, can sometimes stymie rapid innovation or adaptation to emerging diagnostic trends.

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Inefficient Integral Scheduling: Despite the center's capabilities, it grapples with optimizing the scheduling of appointments and resources. An efficient and integral scheduling system can streamline customer flow, maximize machine usage, and enhance overall operational efficiency.

Limited Digitalization: In an increasingly digital age, the center's lag in adopting advanced digital solutions can impede its ability to provide seamless customer experiences, such as digital appointment bookings, virtual consultations, or instant access to digital medical records (Verily et al., 2022).

Inadequate After-Sale Customer Service: Comprehensive customer care extends beyond the diagnostic procedure. A void in post-check-up support can leave customers with lingering questions or concerns, potentially affecting the center's reputation and customer satisfaction.

Stagnant Product Offerings: Relying on traditional diagnostic methods without infusing newer, innovative solutions can render the center less appealing to customers who seek the latest in medical diagnostics.

Opportunities:

Heavy Particle Therapy: This advanced form of radiation therapy holds promise for treating certain types of cancers with greater accuracy and fewer side effects than conventional methods. By integrating heavy particle therapy, the center can position itself at the forefront of cancer treatment, expanding its service portfolio.

doi:10.6342/NTU202400044

Post-Pandemic Era: The global health crisis has heightened public awareness of health and wellness. This renewed focus presents an opportunity for the center to cater to a surge in individuals seeking comprehensive health assessments and diagnostics.

New South Entry Policy: This policy may usher in collaborations or partnerships with institutions from southern regions, potentially broadening the center's customer base and fostering cross-regional medical collaborations (Jazieh & Kozlakidis, 2020).

Integrated Health Check-Up Alliance with Wellness Industry: Merging diagnostic services with wellness solutions can offer customers a holistic health journey. Such collaborations can elevate the center's appeal, making it a one-stop destination for both diagnostic and preventive health care.

Threats

Alternative Health Checkups (PET, Gene): The rise of advanced diagnostic modalities like PET scans and genetic screenings may divert a segment of customers looking for these specialized services. Staying abreast of these advancements and integrating them can be crucial to retain and attract customers (Nielsen & Cummings, 2016).

Artificial Intelligence Empowered Competitors: AI-driven diagnostic centers can provide rapid, and in some cases, more accurate interpretations of imaging results.

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If competitors leverage this technology effectively, they might gain a competitive edge, drawing tech-savvy towards their services (Davenport & Kalakota, 2019) (Figure 1-3).

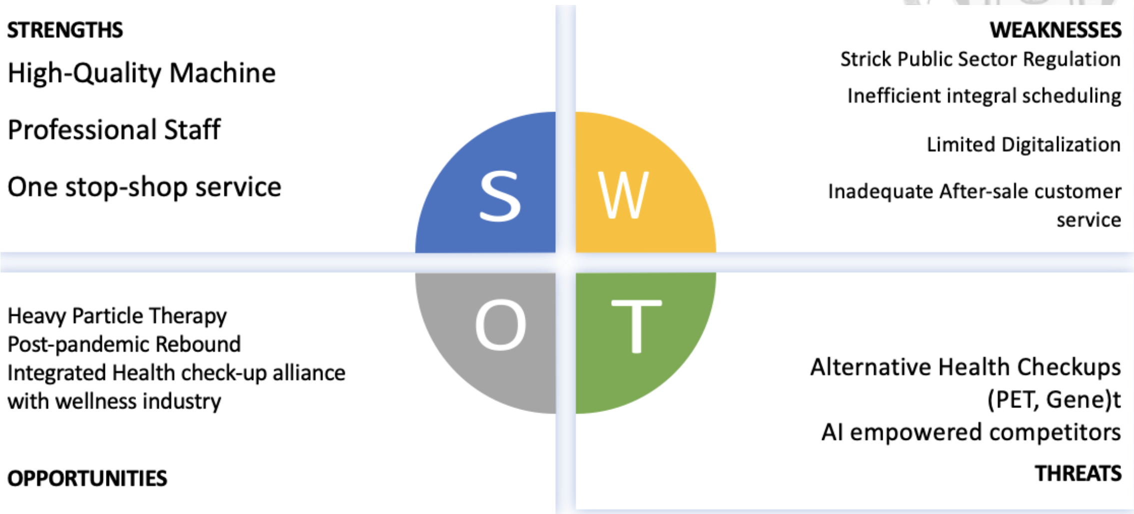

Figure 1-3 SWOT analysis or RMIC

Summary of RMIC: Improved awareness of disease prevention has led to increased popularity of HC, with the self-paid imaging check-up market growing steadily, focusing on cancer due to high mortality rates; RMIC has been a pioneer in medical imaging for HC since its founding in 1999. While new players have entered the market and the government supports healthcare industry development, 69-71% of the out-of-pocket imaging check-up market in Taiwan consists of over examinees, with competitors such as private clinics and eco-system competitors, and no exact substitutes. RMIC's core competencies include providing a one-stop, high-quality health checkups with comprehensive assessments, having amiable radiologists who build trust and communicate effectively, providing immediate consultation for timely treatment, improved customer satisfaction, saving time and resources, and offering honorable courtesy. The target customers are high-income individuals such as CEOs, with precision preventive medicine and custom-made checkups as key activities, primarily

doi:10.6342/NTU202400044

relying on word-of-mouth for customer interaction, with CT having the highest net revenue followed by NIH-MR, MR-breast, MR-HN, and WB-MR based on activity-based costing.

doi:10.6342/NTU202400044

1.7 Study Initiative

With the continuous advancement of modern medical technology and the increasing awareness of health among people, health checkups have become one of the important means for people to pay attention to their health. Over time, the items of health checkups have become increasingly diverse and numerous (楊基譽, 2003). Not only the increased services extended the examination time, but also the complexity of different packages strains the hospital resources (Chern, Chien, & Chen, 2008). Under the premise of ensuring the quality of medical care, the actual inspection time cannot be compressed, and the process improvement has become an important issue for health checkups. This article aims to explore the motivation and future development direction of health check-up research.

Traditionally, health checkups lacked an automated management mechanism, and there were many manual operations and tedious paper-based work in the process, which increased the workload and error rate of doctors and inspection personnel. In addition, in terms of large-scale reforms, due to the lack of sufficient experience and long-term familiarization and design, the process reform of health checkups often faced many challenges. Therefore, we need to refer to the operating procedures of the same industry and explore how to respond quickly, improve feasibility and universality, and make effective use of resources and time.

The primary purpose of the research motivation is to improve the efficiency and quality of health checkups. By introducing an automated management mechanism, reducing manual operations and paper-based work, the speed and accuracy of

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inspections can be greatly improved, and the error rate can be reduced. At the same time, process improvement can also allow doctors and inspection personnel to pay more attention to the needs and conditions of customers, improve customer satisfaction and treatment effectiveness.

Secondly, the purpose of this study aims to explore the feasible algorithms to optimize the scheduling of health checkups. In terms of technology, we can consider using advanced technologies such as artificial intelligence and big data to combine health checkups with personalized medical care and provide each customer with the most suitable health check-up plan. We expected to achieve a flexible and rapid response to cope with uncertainties and different medical conditions. In addition, we can also study how to promote health checkups to a wider range of people to help them maintain their health.

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1.8 Study purpose

Image health checkups is an important method of health examination that can help detect diseases early, improve treatment effectiveness, and enhance the quality of life of customers (Januszewicz et al., 2023; Schmidt et al., 2016). The net profit is (41.7%) of our profit center. The monthly profit is around 5 million NTD. It is very important to increase the revenue and improve the customer satisfaction. However, the current scheduling management of image health checkups has many problems, such as improper scheduling and waste of time, which may affect the efficiency and quality of the examination. Therefore, this study aims to establish an optimized scheduling model to improve the efficiency and quality of image health checkups.

One of the important objectives of this study is to establish an optimized scheduling model to effectively utilize time and resources. Through a systematic scheduling model, the scheduling can be adjusted based on different needs, such as changes in the number of examination items, the number of people to be examined, and resource availability, to ensure smooth progress of the examination. An optimized scheduling model can also reduce 1) unnecessary waiting time and examinations and 2) improve the efficiency and quality of image health checkups.

Another important objective is to develop a system with simulation capabilities that can estimate the results of scheduling changes in advance. This system can help managers understand the impact of scheduling changes in advance and make optimal decisions. For example, when the number of examination items increases, the system can estimate the required time and resources based on the number of items and resource

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availability and adjust the scheduling in advance to ensure the smooth progress of the examination.

In summary, the main objective of this study is to establish an optimized scheduling model to improve the efficiency and quality of image health checkups. Goal 1: to minimize the idle time and delay time of the customers; Goal 2: to monitor the idle time of the MR and MD. We have successfully developed a scheduling system utilizing Integer Programming (IP) to offer efficient solutions for various scenarios, typically within a 20-minute timeframe. Saving more manpower and labor time, we can dynamically tailor the scheduling to meet diverse requirements, ensuring the seamless conduct of examinations. In the future, we can further explore how to combine advanced technologies such as artificial intelligence to improve the efficiency and accuracy of scheduling management.

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1.9 Scope of study

The scope of this study will focus on the "examination workflow", i.e. scheduling during the actual examination. We will not discuss the appointment and follow-up. The overall customer numbers and their personalized health check-up packages are pre-planned and fixed on the scheduling day. We will not consider the unexpected events such as customer absence and machine malfunction. The individual variation of a single examination (such as the process of performing an actual MR) is not within the scope of this study. Health checkups involve performing many single examinations on a group of people. In this study, the process of a single examination for a single examinee (such as a MR or ultrasound) is viewed as an activity, and health checkups are the sum of many different activities. The time required to perform an activity is referred to as work time, and there is potentially waiting time between activities. The overall work time is assumed in this study. The transferred time between two activities is neglected since all the equipment are in the same area.

The scheduling of examinations is subject to four limitations such as 1) time (single activity time, overall time, etc.; 2) medical staff such as specialists, nurses, technicians; 3) medical disposables; and 4) medical special requirements (examination sequence). These limiting factors are referred to as constraints in this study. Using algorithms as a tool, the basic requirement is to satisfy the constraints, and through step-by-step exploration and revision, the goal is to find the optimal scheduling model with the shortest idle time (for medical personnel and examinees) and the fastest deadline. This model can not only handle changes in daily work (such as different genders and ages of examinees) but also serve as an important basis for future changes (such as

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increases in the number of examinees and examination items, shorter deadlines, or changes in medical resources).

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Chapter 2 literature review

2.1 Medical Scheduling

Organizing tasks, selecting appropriate equipment, and time management are the cornerstones of scheduling, aiming to incorporate all essential tasks and complete them within a set timeframe. (Liebowitz & Potter, 1995) The ultimate goal of scheduling is to devise a method that efficiently allocates resources and boosts system performance (楊基譽, 2003). To tackle scheduling dilemmas, decision support mechanisms prove invaluable, offering insights to gauge the significance of tasks and clientele. (Bistline, Banerjee, & Banerjee, 1998; Force, 2014)

The intricacies of planning in the medical field far surpass those in conventional production. This complexity is attributed predominantly to the unique characteristics of healthcare. Medical operations, unlike standard procedures, place a heightened emphasis on safety and peak quality. Each customer, unlike uniform machines, has their distinct requirements. The healthcare realm is characterized by its unpredictability, urgency, and inherent uncertainties (Mitra, 2016). Therefore, designing an adept medical schedule necessitates not just a deep-rooted understanding of healthcare intricacies but also the skill to manage diverse constraints and the flexibility to adapt as situations demand (Smith, 1994). Health check-up scheduling is pre-planned; all activities, times, and resources are predetermined, eliminating the need for real-time adjustments. Therefore, sudden changes like cancellations or equipment malfunctions don't factor into the scheduling considerations. Flexibility is vital during the scheduling process, allowing for parametrization of all influencing factors. Historically, humans

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have been at the forefront of managing medical schedules, relying on fundamental analytical tools and years of practical experience (Dash, Shakyawar, Sharma, & Kaushik, 2019) Acquiring such expertise is a time-intensive endeavor, much like honing the art of scheduling. With the continuous evolution of the medical sector, ensuring efficient resource management, especially in an economically mindful age, becomes increasingly challenging. Modern advancements have ushered in the application of artificial intelligence in the realm of medical scheduling, heralding a new era of optimized and efficient scheduling solutions (Haleel & Dawood, 2023).

Oddi et al developed an interactive scheduling system that deserves our attention. Oddi's research presents medical issues as constraint satisfaction problems. (Oddi & Cesta, 2000) Users of the system interact with algorithms to make decisions. The study first defines relaxable and non-relaxable constraints, with the goal of minimizing constraint violations. The research initially identifies solutions using a greedy procedure and then adjusts using local research. The study also uses a hybrid initialization tool to observe constraint violations and identify the causes of these violations."

In the scheduling problem of our center, we still directly use experience and specialized knowledge to manually design the daily schedulers. A scheduling table is proposed in Rongke High-tech Imaging Center (Imaging) However, many problems will occur with this manual method of: 1) inefficiency, and only compatible with small number of examinees ,2) the planning process may have different results under the same items due to different experts. 3) because of the lack of systematic assistance, it is also

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difficult to evaluate which method is the best and manual scheduling. 4) The manual process takes much more time than the automatic processing of the system once the number of inspection items or the number of inspections increases, manual scheduling will encounter bottlenecks.5) It is next to impossible for human brain to come up with a solution meeting all the restrictions. What is even worse, we presumed this manual solution is flawless until some errors come up. If manual scheduling is used, it will take more time than required to systematize it in a standard way. Therefore, the direct manual scheduling method cannot completely and effectively solve the problem of health inspection homework scheduling.

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2.2 Similar medial scenarios for comparisons

Nurse scheduling and health check-up scheduling are two different issues that cannot be simply confused with each other. Nurse scheduling usually refers to assigning nurses to appropriate working hours and locations to meet the needs of customers and healthcare institutions. Health check-up scheduling, on the other hand, involves multiple aspects, including examination items, examination time, examination location, medical resources, and customer needs, among others. Nurse scheduling methods are typically applicable to fixed working hours and locations, such as fixed shifts and work locations within a week. However, health check-up scheduling needs to be adjusted according to different customer needs and medical resources, and therefore cannot use the same method.(Valouxis & Housos, 2000) Health check-up scheduling needs to consider many factors, such as examination time for examination items, availability of medical resources, and customer needs and preferences. Therefore, a more detailed and personalized method is needed to develop the best health check-up scheduling plan. A reference use integral linear programming with local search to find the solution for nursing schedule (Suppiah, 2023)

Continuous planning and scheduling refer to continuously adjusting and optimizing plans and schedules in the production process to adapt to the production environment and customer demand. (Berger & Cowen, 1995; Marinagi, Spyropoulos, Papatheodorou, & Kokkotos, 2000) This method is usually applied in the manufacturing and supply chain management fields to improve production efficiency and meet customer demand. However, for health check-up scheduling design, continuous

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planning and scheduling methods may have several limitations. This method uses interactive decision support systems to fine-tune the system However, the time and sequence of inspection items are usually relatively fixed, making it difficult to adjust and optimize them immediately based on the actual production environment and customer demand, especially in the details. Health checkups need to consider multiple factors, such as the availability of medical resources, customer's special requirements and needs, and these factors may be limited by continuous planning and scheduling methods. Continuous planning and scheduling methods usually require a large amount of data and algorithms to derive better solutions, requiring high technical expertise and resource investment, making it difficult to widely apply in the health check-up scheduling design with less diverse data. Therefore, continuous planning and scheduling methods cannot be fully applied in the scheduling design of health checkups. Instead, health check-up scheduling design needs to combine actual situations, consider the needs of customers, the availability of medical resources, and the actual situation of medical institutions, and use personalized methods for scheduling and design to meet the needs of customers and medical institutions.

Management of medical resources refers to the unified management and scheduling of personnel, equipment, materials, and other resources in medical institutions, to achieve optimal utilization and improve the level of medical services. (Al-Jaroodi, Mohamed, & Abukhousa, 2020) Although this method has a wide range of applications in medical services, it is not entirely applicable to health check-up scheduling.

On the one hand, health checkups involve multiple departments and various types of examinations, and there is a certain degree of interdependence and impact between

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different departments and examination items. Therefore, it is difficult to achieve targeted scheduling and optimization solely through the management of medical resources. Additionally, health checkups typically do not have many changes in resources. Moreover, while the method can use an interactive decision support system to adjust the system (scheduling algorithms that limit variations and minimize violations), it may be appropriate for the soft constraints of health checkups but does not conform to the rigid constraints.

On the other hand, the purpose of health checkups is to detect customers' physical conditions and disease risks, so it is necessary to consider customers' needs and the guarantee of medical quality. The method of managing medical resources may focus more on improving resource utilization and increasing the profits of medical institutions. Therefore, simply adopting this method for health check-up scheduling may overlook customers' needs and the guarantee of medical quality, which could affect the effectiveness of health checkups and customers' satisfaction. Of course, it is possible to make trade-offs in the constraints. Therefore, health check-up scheduling needs to adopt a more personalized and comprehensive approach, considering factors such as customers' needs, the availability of medical resources, and the actual situation of medical institutions, to achieve better examination results and improve customer satisfaction.

The integral programming flow-shop method is a mathematical optimization approach that aims to minimize the make span of a set of jobs processed on a set of machines. In this method, each job has a specific processing time on each machine, and

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the goal is to determine the optimal sequence of jobs on each machine to minimize the total processing time. (Brah & Loo, 1999; Hall, 1998; Liu & Chang, 2000)

However, this method may not be suitable for health check-up scheduling due to several reasons. First, the processing time of each job in health check-up scheduling is not always fixed and may vary depending on the customer's health condition and the type of exam. Second, the order of the exams may not be interchangeable and may be predetermined by medical standards and protocols. Third, the number of customers and the type of exams may vary, and the integral programming flow-shop method may not be flexible enough to handle such variations. Previous studies showed even bender decomposition or Lagrangian relaxation cannot effectively solve the problem. (Bragin, 2023; Oddi & Cesta, 2000) Fourth, as the numbers of variable increase, the chance of no solution increase.

Furthermore, the integral programming flow-shop method requires a lot of data and computational resources to find the optimal solution. It is also time consuming. This may not be feasible in the context of health check-up scheduling, where there are many uncertainties and the scheduling needs to be done in real-time to accommodate emergency cases and unexpected events. Therefore, more heuristic, and flexible scheduling methods, such as genetic algorithms, simulated annealing, and tabu search, may be more suitable for health check-up scheduling. (張冠群, 2010) These methods can quickly generate good solutions and are adaptable to changes in the scheduling parameters. Simulated annealing is solved by using the simulation mode, but this method of simulation is often used in the uncertainty mode, while the health check operation scheduling problem of this study belongs to the deterministic mode.

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(Crescenzio & Vito, 2019) The information required in all modes is known values and converted into parameter values and passed into the mode. On the other hand, the method of variable-depth search is not applicable to the current study.

The heuristic algorithm here is composed of the principle of the greedy method and the opinions of experts. (Chern et al., 2008; Park, Kim, & Kang, 1996). The problem solved is the health inspection operation scheduling of the National Taiwan University Health Management Center. (台大醫院健康管理中心, 2023) The goal is to meet the limit and the maximum efficiency. The operation method first sorts all the examinees according to their personal characteristics and special choices, and then uses the inspection items. The heuristic algorithm is suitable to solve the health check-up scheduling because it is a problem-solving approach that uses practical rules and approximations to find a good solution when an exact solution is impractical or impossible. In the case of health check-up scheduling, there are many complex factors to consider, such as the availability of medical resources, the scheduling of medical staff, and the needs and preferences of customers. It is difficult to develop an exact algorithm to solve this problem. However, heuristic algorithms can use practical rules and approximations to quickly generate feasible schedules that meet the constraints of the problem. The heuristic algorithm can also be adapted to different scenarios and updated as needed to improve the quality of the scheduling solution. Overall, the heuristic algorithm is a practical and effective tool for solving the health check-up scheduling problem. (Table **2-1)**

Table 2-1 Comparative Analysis of Scheduling Algorithms for Health Check-Up Centers

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Algorithm/Method	Main Characteristics	Advantages	Disadvantages
Nurse Scheduling	Assigns nurses to shifts and locations based on needs of customers and healthcare institutions.	Applicable to fixed working hours and locations tried-and-tested in healthcare settings.	Not flexible enough for dynamic health check-up scheduling such as varying examination times
Continuous Planning and Scheduling	continuous adjustments to adapt to the environment and demand, with heavy reliance on data and algorithms.	compatible with fine-tune systems with decision support.	requires substantial data and technical resources, making it less applicable to health check-up scheduling with less diverse data.
Management of Medical Resources	Unified management of medical personnel, equipment, and materials to optimize utilization and service levels.	Aims to improve resource utilization and medical service levels.	May focus more on resource optimization over individual customer needs; soft constraints may be manageable, but rigid constraints present challenges.
Integral Programming Flow-Shop	A mathematical optimization to minimize the makespan in a job processing sequence.	determine the optimal job sequence for minimal processing time.	Not flexible for the variable nature of health check-up timings and sequences; complexity and data requirements increase with more variables, potentially leading to unsolvable scenarios.
Heuristic Algorithm	Problem-solving based on practical rules and expert opinions, tailored for scheduling at the National Taiwan University Health Management Center.	Provides quick, feasible solutions adaptable to changes in scheduling parameters handle complex factors effectively.	May not always produce the optimal solution due to its approximate nature; solutions are based on heuristics rather than deterministic optimization.

To the extent of our knowledge, scheduling methods have not been prominently tailored to the specific context of imaging checkups. Our imaging checkups exhibit distinct characteristics that set them apart from conventional health checkups, which

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have been the primary focus of existing research. Specifically, our checkups involve a narrower spectrum of examinations, bypassing more extensive procedures like colonoscopy, gastroscopy, mammography, and specialist consultations that are commonly integrated into broader health assessments. Additionally, the daily throughput for our imaging checkups is relatively limited, with the capacity to handle only about 10-12 clients per day—a scale that is considerably smaller than that addressed in previous studies. Lastly, the variable duration of each imaging activity, which can range from a brief 20 minutes to an extensive 120 minutes, introduces a layer of complexity to the scheduling process that cannot be overlooked. Those difference prompts us to investigate whether IP can surpass the traditional manual method in terms of efficiency and flexibility, while also reducing the need for extensive manpower for scheduling in the smaller scale. Through this study, we aim to ascertain if the implementation of IP can deliver a superior scheduling system tailored to our center's unique operation size and service offerings, thereby optimizing resource allocation, and enhancing overall service quality.

doi:10.6342/NTU202400044

Chapter 3 Methodology

3.1 Definition of Health check-up scheduling

Scheduling is to organize the necessary activities and complete all the work within the expected time. The goal of scheduling is to be able to plan an efficient and effective workflow by using the available resources (Liebowitz & Potter, 1995). Valuable approaches have been used to assist scheduling such as best practice, decision support system (Bistline et al., 1998; Oddi & Cesta, 2000). Good scheduling can quantify all the variables to remain flexible to accommodate personalized health checkups, therefore enhances the customer experiences and improves work efficacy. Medical activities will be more complicated than general production scheduling activities, because the object of the service is human, and the variability is quite large, but the health examination activity is the least fluctuated of all medical treatment industry (張冠群, 2010; 楊基譽, 2003; 簡佩思, 2004), the health checkups only involves examination, no treatment. Nevertheless, examination scheduling operation still has a certain complexity.

Package: a combination of different health examinations that is tailored to an individual's specific needs and health condition. During a personalized imaging checkup, imaging tests such as CT scans, MRI scans, and ultrasound may be performed to detect any potential health issues or abnormalities. Based on the individual's medical history and health status, the imaging tests may be customized to focus on specific areas of concern or to provide a comprehensive evaluation of their overall health. This type of health checkups can provide valuable insights into an individual's health and can help detect potential health issues early, allowing for prompt and effective treatment. The

doi:10.6342/NTU202400044

service time refers to the time from the beginning to the end of providing a complete health examination service.

Activity: In a single service; they customer need to complete different examinations; those activities can be randomly ordered; but certain activities have time sequences, such as meal should be after ultrasound or CT. Examination a special activity involving machines including CT, MR, or US. Other activities without scanners are registration, preparation, meal, and consultation.

Summary for Imaging Health checkups: There are several factors influence scheduling's: time, scanner, MD availability. The time-related variables include the service time and the individual examination time. Consumable medical supplies are not considered because they are low cost and readily available. The major resource restraints of this study will be scanners, and MD availability. From the perspective of activity, time and resources, the health examination schedule must be complied to all three requirements. In other words, when planning the health examination, each examinee must plan and complete the activities required by the examinee within the total time, and meet the resource limit in the planning process, including the resource limit of the number of doctors and the instrument. Quantity limit.

doi:10.6342/NTU202400044

At our facility, we recognize the diverse health needs and concerns of our customers, which is why we offer specialized imaging packages tailored to address specific requirements. To accommodate all the examinees, with their different requirements, in one day, a detailed schedule of the time needed to perform each examination procedure for each examinee is very important.

Whole Body MRI (WB_MRI): This comprehensive package is designed for those seeking a detailed overview of their health status. Given the diverse health risks associated with different age groups and medical histories, a **whole-body MRI** provides an overview of the major eight organs: brain, neck, lung, liver, spleen, pancreas, kidneys, spine, helping detect early signs of conditions that might be missed in routine checkups.

MR Angiography of Head and Neck (MR_HN): This package caters to individuals concerned about vascular health in the head and neck region. It's especially relevant for those with a family history of vascular diseases, individuals in professions with unique health risks that could impact cerebral circulation, or those who've experienced symptoms suggestive of vascular abnormalities.

MR of Breast (MR_BREAST): Recognizing the gender-specific health concerns, the MR of the breast is tailored primarily for women, especially those with a familial risk of breast cancer or personal medical histories that warrant closer surveillance. This package offers a detailed assessment, complementing other screening methods like mammography, especially in dense breast tissues.

doi:10.6342/NTU202400044

CT Coronary angiography and low dose CT(CT): Lifestyle choices, occupational hazards, and genetic predispositions can significantly influence heart and lung health. This combined package is designed for individuals keen on evaluating their cardiovascular health or those with potential lung concerns, possibly due to exposure to risk factors like smoking. Low dose CT can detect smaller lung nodules comparing to MR but carries radiation exposure. We reserve those for customer with high risk of lung cancer such as family history of lung cancer or heavy smoker.

By offering these distinct packages, we aim to provide personalized care, ensuring that everyone can select a package that best addresses their health concerns, risks, and needs. Whether it's a broad health overview or a focused assessment of a specific region, our goal is to offer the highest standard of care tailored to individual requirements. An imaging health examination package includes 6 basic activities. According to different focuses, i.e.: cancer prevention, neuro risk evaluation, coronary risk evaluation, and breast prevention (exclusively for females) will be combined into different packages. The customer cannot choose CT coronary angiography and low dose CT only. **The length of activities will vary according to different packages individual chose.**

In our methodology, we focus on the top six most commonly selected health check-up packages by our customers, which together represent 98% of all chosen packages. These packages are combinations of various examinations tailored to meet diverse health screening needs. Specifically, Package 1 includes MR Whole Body (MR_WB); Package 2 combines MR Whole Body with MR Head and Neck (MR_HN); Package 3 pairs MR Whole Body with MR Breast; Package 4 offers MR Head and

doi:10.6342/NTU202400044

Neck alone; Package 5 consists solely of MR Breast; and Package 6 provides a comprehensive trio of MR Whole Body, MR Head and Neck, and MR Breast. Additionally, CT scans are available as an optional adjunct to any package should the customer opt to integrate it into their selected set of examinations.

Table 3-1 Activities of six different packages

Package #	MR_WBMRI	MR_HN	MR_breast	CT
1	O			
2	O	O		
3	O		O	
4		O		
5			O	
6	O	O	O	
1’	O			O
2’	O	O		O
3’	O		O	O
4’		O		O
5’			O	O
6’	O	O	O	O

MR_WBMRI: whole body MRI; MR_HN: MR angiography of head and neck; MR_breast: MR of breast; CT: coronary angiography and low dose CT. O indicated activities involved.

doi:10.6342/NTU202400044

3.2 Logistic Design

The workflow for an imaging checkup may vary depending on the different service packages they chose. However, a general outline of the process could be as follow:

1.Appointment: Appointments for health checkups can be conveniently scheduled by customers on-site, via our website, or by telephone. Our dedicated customer service team, comprised of trained nurses, provides personalized package recommendations based on the customer's family and personal medical history, risk factors such as malignancy and cardiovascular disease, and budget considerations. Upon selecting the optimal package, we collaborate with the customer to finalize the appointment date and time. Following this, a basic confirmation notification is sent out. Detailed pre-appointment instructions are dispatched one week prior to the scheduled date to ensure customers are well-prepared, and a reminder is sent one day in advance through phone, message, or email to minimize no-shows and facilitate a smooth examination process.

2. Registration: On the day of the appointment, the customer registers at the reception desk, During the registration phase of a health checkup, customers provide personal details such as name, date of birth, and contact information, which are used to create or update their medical records. Key medical history, including known allergies, chronic conditions, and medications, is recorded, along with the specific reasons for the checkup. Insurance details are collected for billing purposes, and any necessary consent forms related to upcoming procedures or tests are signed. Payments or co-pays are

doi:10.6342/NTU202400044

processed, and customers might receive identification wristbands, change their clothes to facilitate their movement through the facility. After completing the registration, customers are directed to the waiting area or the next relevant department, ensuring a streamlined and informed check-up process.

3. Preparation: The customer is then escorted to a room where a healthcare professional records their vital signs, including blood pressure, heart rate, temperature, and oxygen saturation. The healthcare professional will then ask the customer about their medical history, current health status, and any symptoms they may be experiencing. In our center, we do not perform routine physical examinations as this doesn't not improve cancer detection rate.

4.Laboratory Tests: Depending on service packages, the customer may be asked to provide blood, urine, or other specimens for laboratory testing. These tests can help identify any underlying health conditions or risk factors. Tumor markers are substances in the body that may be elevated due to certain diseases, including cancers. Some common markers include Prostate-Specific Antigen (PSA) for prostate cancer, Alpha-fetoprotein (AFP) for liver cancer, CA 125 for ovarian cancer, and CA 19-9 for pancreatic or colorectal cancer. However, it's important to note that these markers are not definitive on their own and should be considered alongside other diagnostic tools. Serum biomarkers, commonly included in routine health checkups, offer insights into overall health. These include the Complete Blood Count (CBC) to check for anemia or inflammation, Lipid Profile for cardiovascular risk, Blood Glucose for diabetes, Liver and Kidney Function Tests to assess organ health, and Thyroid Function Tests to

doi:10.6342/NTU202400044

evaluate the thyroid gland. As with tumor markers, these serum biomarkers should be interpreted in conjunction with clinical assessment and other diagnostic procedures.

5.MR: The customer is positioned supine on the MRI table. Some quick scans will plan the subsequent detailed sequences, and the customer is positioned supine on the MRI table. The coverage areas are separately acquired: head, neck, chest, abdomen, and pelvis. In Asian countries, we have very few bone tumor and melanoma, and therefore thighs and lower legs are not covered. Non-contrast scan includes axial T1-weighted imaging(T1WI), T2-weighteed imaging (T2WI), and diffusion weighted imaging will cover form vertex to the thigh. Post-contrast scan with axial T1 with fat saturation of the whole body, and coronal scan of chest and abdomen.

6.Ultrasound (US): Similar to MR, sonography is auxiliary to MR. Ultrasound may be better for certain applications, like visualizing gallstones, while MRI provides more detailed soft tissue contrast and can offer different imaging sequences (e.g., MRCP for bile ducts). As MR is insensitive to detect calcification, and surface organ. Sonography can better detect thyroid lesions, breast lesions, gallstones, and renal stones. Nevertheless, gastrointestinal tract abnormality is still beyond the scope of combination of sonography and MR.

7. Meal (optional): We provide meals to honor the all the customers after all the necessary examinations are done. The customers sometimes decided not to have the meals.

doi:10.6342/NTU202400044

8. CT (optional): CT examination is designed for coronary artery disease detection and fine lung nodule detections. Because MR_WBMRI also provide basic lung nodule detection in screening scenario. Logistically, the CT scanner doesn't belong to our division. The CT capacity is big enough to accommodate more than 2 customers.

9. Consultation: After all tests and examinations are completed, the MD will review the results and discuss any findings with the customer. The MD may also provide recommendations for follow-up care or treatment if necessary.

10. Follow-up: Depending on the results of the health checkup, the healthcare provider may recommend further tests, appointments, or lifestyle changes to improve the customer's health. The customer may also be advised to schedule regular health checkups to monitor their health and detect any potential issues early on.

In the following of this study, we focus on the optimization of workflow currently inside the RMIC. Therefore, will not discuss the interaction of appointing and scheduling, or follow-up. Because registration, preparation and laboratory test contain a lot short-interval activities, we combined those three togethers to facilitate the following estimation. The workflow for an imaging check-up on the day of the appointment is depicted in Figure 3-1. Each package includes the following activities: registration, MR imaging, sonography, and consultation, with CT scanning and meals being optional. The duration of MR imaging and sonography varies depending on the package, while the duration of registration, meals, CT scanning, and consultation is consistent across all packages. Although registration must be the initial step and consultation the final one, the sequence of MR imaging, sonography, and CT scanning can be altered. A

doi:10.6342/NTU202400044

complimentary meal is offered as a courtesy to all our customers, although they may choose to decline it. If declined, the time allocated for the meal is not considered idle time. The duration of MR, sonography, and CT scans varies depending on the selected package. To ensure customers fully understand their results, we provide the most extensive consultation possible (i.e.,40 minutes in our center), regardless of the package differences. (Figure 3.2)

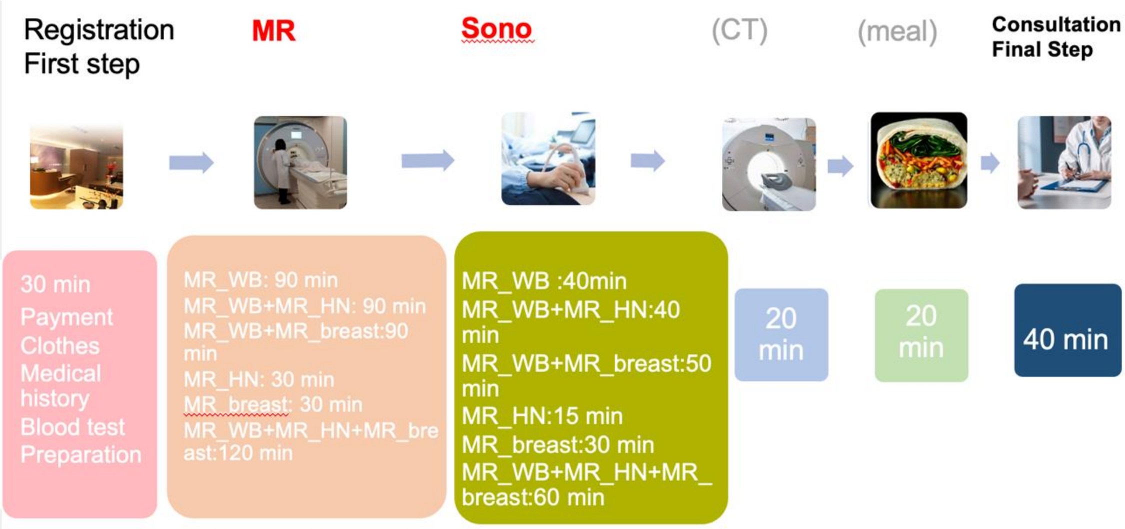

Figure 3-1 Workflow of imaging health-check on the appointment day

MR and sonography (in red) are packages dependent. Registration CT and meal are packages independent. Meal and CT are optional.

Code for IP program	1,2,3,6 →large package 4,5 →small package	Registration &preparation	MR	US	CT (if)	Meal (if)	Interpretation	Consultation
1	MR_WB	30	90	40	15	15	30	40
2	MR_WB+MR_HN	30	90	40	15	15	40	40
3	MR_WB + MR_breast	30	120	50	15	15	45	40
4	MR_HN	30	30	15	15	15	10	40
5	MR_Breast	30	30	30	15	15	15	40
6	MR_WB+MR_HN+BREAST(6)	30	120	60	15	15	55	40

doi:10.6342/NTU202400044

Figure 3-2 durations of each activity in 6 major packages

MR_WB: whole body MR; MR_HN: MR of head and neck; MR_breast: MR of breast

doi:10.6342/NTU202400044

3.3 Descriptions of Problems &Constraints

Within the parameters set by our study, we won't delve into unforeseen events such as unexpected cancellations by customers, equipment malfunctions, or urgent additional services for VIPs. Instead, with limited time frame and resource (equipment, and MD) our primary focus remains on addressing scheduling challenges with two primary objectives: 1) Minimizing customer idle time. We take the customer's satisfaction as the top priority and increased idle time is confirmed to decrease the customer's satisfaction. 2) Reducing overtime for both the MD and MR. Not only delayed finished hours will cause inconvenience, but also will increase the cost of MD and MR. Our objective is to optimize the utilization of both human and technical resources, ensuring efficiency throughout the process."

Effective Utilization of Resources: Every health facility, regardless of its size or capacity, has a finite set of resources at its disposal, ranging from human resources such as radiologists and technicians to equipment like MRI and CT scanners. Being aware of the availability and limitations of these resources ensures that they are utilized to their fullest potential, maximizing output while minimizing idle time. This not only improves the efficiency of the facility but also ensures that the available resources are not overburdened or underutilized.

Enhanced Customer Experience: Time is a valuable commodity for both the healthcare provider and the customer. An optimized schedule, cognizant of all constraints, ensures minimal waiting times and smooth transitions between different examinations. This leads to a better customer experience, as the individual undergoes

doi:10.6342/NTU202400044

the required tests without unnecessary delays or rescheduling, which can be both time-consuming and anxiety-inducing.

Operational Efficiency: A well-planned schedule that considers all time and resource constraints can significantly streamline operations. It aids in predicting potential bottlenecks, allowing for preemptive solutions. This results in smoother day-to-day operations, reduced chances of overbooking or double-booking resources, and a more harmonious workflow within the facility. In conclusion, understanding time and resource constraints is not just a logistical necessity but a cornerstone for ensuring high-quality customer care, operational efficiency, and the overall success of a health check-up facility. Proper management and optimization of these constraints lead to a win-win situation for both healthcare providers and the customers they serve. In this cession, we will disclose the constraints.

Operational Hours:

MR operations: 8:30 AM to 5:30 PM.

CT operations: 8:30 AM to 4:00 PM.

Medical Doctors (MDs) for consultations and interpretations: 8:30 AM to 5:30 PM, with 3 to 4 MDs being the maximum available at a time.

The following conditions and restrictions, including hard and optional, are designed to ensure efficient facility operations while upholding the highest standards of customer care and safety.

doi:10.6342/NTU202400044

Hard Time-Based constraints:

Hard Constraints of sequence

a. Registration Priority**:** Registration/preparation has been the first: Registration is always the initial step for every customer before any subsequent examination or consultation.

b. The order of MR, US, CT can be random: *Flexibility in Imaging Sequence***:** While MR (A2), US (A3), and CT (A4) scans can be carried out in any order, specific sequences are essential for other activities.

c. MD Consultation Sequence must be after MR, US, CT: An MD consultation should follow MR and ultrasound examinations, ensuring the doctor has all pertinent imaging information. However, if CT is part of the customer's plan, MD consultation can optionally precede the CT scan. *In our experience, during the consultation, the imaging will be available, and our experienced physicians can provide real-time imaging interpretation.*

d. Meal has to be after MR, US, CT: If not skipped, meals should be taken after the ultrasound and CT scans to ensure clear and accurate imaging. Alternatively, meals can also be placed at the end of all procedures.

e. Sequence for MD Interpretation: It is essential for the MD to complete the interpretation of diagnostic results before proceeding with customer consultation. The interpretation is set to commence subsequent to the initiation of the MR scan. Given that

doi:10.6342/NTU202400044

this constraint synchronizes the actions of both the patient and the MD, it adds a layer of complexity to the scheduling challenge.

Relaxable Time-Based Restrictions:

a. Consultation Interval: If required, the time gap between consultations can be minimized to 30 minutes.

b. Film Interpretation Interval: The time taken for interpreting imaging can also be optionally reduced to 30 minutes.

c. Meal Flexibility: Meals can either be skipped entirely or scheduled at the end of all check-up procedures.

Hard Resource-Based Restrictions:

Physician Limit: The facility has maximum of 3 radiologists on duty. Medical Doctors (MDs) are available for consultations and interpretations from 8:30 AM to 5:30 PM

Registration Capacity: A maximum of 2 guests should be at the registration desk at any given time to ensure a streamlined process.

Meal is unlimited resource: meal is considered as unlimited resource since we have enough space for all the examinees. In other words, the meal will take the certain time interval in each individual, but there will be no que time for meal because the restaurant is full.

doi:10.6342/NTU202400044

No wearing time is needed: in many medical centers, certain medical check-up categories necessitate a waiting period, or an "interval period," after specific preceding checkups. This is often to allow for factors such as the wearing off of anesthesia or the digestion of food. For instance, before certain procedures like internal surgeries, customers might need to take oral anesthesia which affects meal intake. As a result, some centers might require a waiting time, usually an hour or more, post the intake of anesthesia before customers can eat. Furthermore, certain tests, like post-meal blood sugar levels, might be conducted a specific duration after meals, necessitating another "interval period". However, in our center, such interval periods are not necessary. This is because we do not offer procedures that require anesthesia for endoscopy, nor do we conduct post-meal blood sugar examinations. Therefore, our customers do not encounter these waiting times, ensuring a smoother and more efficient check-up process."

doi:10.6342/NTU202400044

3.4 Manual Scheduling for Imaging checkups

To create a scheduling algorithm for imaging checkups based on the provided constraints and the references, we need to integrate the constraints mentioned earlier with the concepts and methodologies presented in the uploaded paper. Here's our intuitive suggested algorithm:

Initialization: Assign individual customers (numbered 1 to n) to their specific dates. Define the varying examination durations based on the chosen set.
For each customer, load all available time slots according to operational hours.
Ready all limited resources (MR, US, MD interpretation, and MD consultation) and unlimited resources (CT scanners, registration, metals).

Resource Allocation: Every customer's process begins with registration. Start with the primary constraint: Allocate MD, radiologists and equipment based on their availability and the customer's needs. Consider absolute resource limitations, such as a maximum of 3.5 radiologists at once, two MR scanners, and two US machines.

Time Slot Allocation: Assign time slots for MR, US, and CT scans with flexibility. Ensure that MD interpretation precedes MD consultation, and that MD consultation follows MR and ultrasound exams. If CT is part of the plan, the MD consultation can optionally come before it. Allow a 30-minute buffer after two major or three minor examinations. If a meal break is taken, schedule it post US and CT scans, or optionally at the conclusion.

doi:10.6342/NTU202400044

Gap and Overlap Analysis: Inspect the schedule for any gaps or overlaps. First address overlaps due to absolute resource constraints, then work to minimize idle times. Re-arrange time slots as needed. If a CT scan is part of the plan but hasn't been scheduled, ensure it's factored in while maintaining the consultation sequence.

Overtime Analysis: Review the schedule for any instances of overtime. Endeavor to rearrange the customers to minimize overtime without introducing overlaps. Overtime carries a weight that's three times that of idle time. Typically, resolving overtime issues might lead to overlaps instead of idle times.

Finalization: Once all examinations and consultations are scheduled without overlaps and within the set constraints, solidify the schedule. Provide the customer with a detailed itinerary.

Feedback Loop: Post-checkup, gather feedback regarding the schedule's feasibility and customer satisfaction. Utilize this feedback to further refine and enhance the scheduling algorithm.

Termination Criteria: The maneuver halts its refinement process either when an optimal or near-optimal schedule is achieved, or if further iterations fail to yield significant improvements, such as reduced overtime or idle time. Another reason to reject a solution is if the rearrangement requires excessive effort, like having to reschedule numerous customers.

doi:10.6342/NTU202400044

Empirically, we started the packages with the longest overall examination time. Then continue to those with shorter overall examination time because the customer with big services cannot have food until all the examinations are done. Our maneuver inherently functions as a greedy algorithm. We employ the "Round Robin" priority system, where the moment an examinee is ready, they are instantly assigned to the next available machine, and doctor. The "Round Robin" method dictates that if an examinee faces delays or becomes unavailable, they are repositioned to the back of the queue. (33) systematically schedules each examinee for their respective examination procedure consecutively, without any retracing of steps, dictating the sequence of the process.

P1: Identify and organize each customer's examination procedures.

P2: Divide customers into groups with either big or small examination packages.

P3: Schedule the first customer with a big package.

P4: Sequentially schedule other customers with big packages until all such appointments are arranged.

P5: Schedule all customers with small examination packages.

P6: Review and adjust the schedule to minimize idle and overtime by reallocating customers with small packages where possible.

In the initial step (P1), we confirm the procedures included in each package and the total duration needed, independent of the customer's gender or age. In step (P2), customers are sorted into big (1, 2, 3, 6) and small (4, 5) package groups, with small packages involving MR scans under 30 minutes. We then schedule the first customer from the big package group (P3), setting the start times for their procedures and continuing this process for the rest in the group (P4), typically starting with two big packages per MR scanner. Once all customers with big packages are scheduled, we proceed to allocate

doi:10.6342/NTU202400044

times for those with small packages (P5). Lastly, we aim to reduce idle and overtime by strategically shifting customers with small packages (P6).

doi:10.6342/NTU202400044

3.5 Integral programming algorithm for Imaging checkups

Integer programming is a type of mathematical optimization where solutions for the decision variables are restricted to integer values. IP can model a wide range of combinatorial problems, where decisions are binary (yes/no) or where resources are indivisible, such as scheduling. Applying Integral Programming to health check-up scheduling. There are several benefits to use IP. 1) Optimality: Integer programming can provide an optimal solution based on the given objective and constraints.
2) Flexibility: It can handle a variety of constraints, making it adaptable to different scheduling scenarios. 3)Efficiency: Especially for large-scale problems, IP can quickly find solutions that might be time-consuming or infeasible with manual methods. Therefore, we based on prior mentioned principles, we started to solve scheduling problem by IP method:

Set:

- $I = \{1, 2, ..., n_I\}$: the set of patients
- $J = \{1, 2, ..., n_J\}$: the set of examination sets
- $K = \{1, 2, ..., n_K\}$: the set of activities
- $T = \{1, 2, ..., n_T\}$: the set of time
- $T_2 = \{1, 2, ..., n_T + 9\}$: the set of expected end time

Subset:

- K_i: the set of activities patient $i \in I$ need

doi:10.6342/NTU202400044

Decision Variables:

$$x_{ikt} = \begin{cases} 1, \text{ activity } k \in K \text{ of patient } i \in I \text{ is ongoing in period } t \in T \\ 0, \text{ otherwise} \end{cases}$$

$$y_{ikt} = \begin{cases} 1, \text{ activity } k \in K \text{ of patient } i \in I \text{ starts in period } t \in T \\ 0, \text{ otherwise} \end{cases}$$

$$v_{ik} = \begin{cases} 1\text{，patient } i \in I \text{ needs to do activity } k \in K \\ 0, \text{ otherwise} \end{cases}$$

$$w_{ikt} = \begin{cases} 1, \text{ activity } k \in K \text{ of patient } i \in I \text{ ends in period } t \in T_2 \\ 0, \text{ otherwise} \end{cases}$$

z_{ik}: the start time of patient i's $\in I$ activity $k \in K$

s_i: the start time of patient i's $\in I$ registration

e_i: the end time of patient i's $\in I$ registration

u_{ik}: the tardiness time of patient i's $\in I$ activity $k \in K_i$

Parameters:

M_i: patient $i \in I$ needs to have a meal

C_i: patient $i \in I$ needs to do CT

$$S_{ij} = \begin{cases} 1, \text{ patient } i \in I \text{ order set } j \in J \\ 0, \text{ otherwise} \end{cases}$$

L_{jk}: the time period activity $k \in J$ in set $j \in J$ takes

T_M: the time period having a meal takes (same in all sets)

T_C: the time period doing CT takes (same in all sets)

T_I: the time period for one registration takes (same in all sets)

T_B: allocated buffer time duration (same in all sets)

P_k: the maximum number of patients the activity $k \in K$ can serve simultaneously

T_j: the overall expected time required for set $j \in J$, excluding meal times and CT scans

O_k^S: the start time of activity $k \in K$

O_k^E: the expected end time of activity $k \in K$

W_k: the weight of punishment for activity k's $\in K$ delay

D_{ik}: the time period doing activity $k \in K$ patient $i \in I$ takes

R_i: the overall expected time for doing all activities patient $i \in I$ needs

OD_t: the number of doctors available in time $t \in T$

doi:10.6342/NTU202400044

Formulation:

$$\min \quad \sum_{i \in I}(e_i - s_i - R_i + \sum_{k \in K_i} u_{ik} W_k)$$

The objective is to minimize the sum of the differences between the required overall duration $(e_i - s_i)$ and the summation of individual examinations of every customer (R_i). However, if any customer overtime happens, a penalty will be applied. This penalty will be the value of the overtime of this customer times a constant for every activity $(u_{ik}W_k)$.

The constraints can be divided into five major categories, including execution order issues, capacity issues, other essential issues, overtime issues, and buffer issues. Next, it will be divided into five paragraphs to provide corresponding explanations.

s.t. $z_{i,1} \leq z_{ik} \quad \forall i \in I \quad \forall k \in K_i$ (All patients must register before undergoing an activity)

$\sum_{t \in T} y_{i,4,t} = C_i \quad \forall i \in I$ (If a patient chooses to undergo a CT, ensure the patient has a CT activity)

$\sum_{t \in T} y_{i,5,t} = M_i \quad \forall i \in I$ (If a patient chooses to have a meal, ensure the patient has a time for meal)

$\sum_{s=1}^{t-1} y_{i,2,s} \geq y_{i,7,t} \quad \forall i \in I \quad \forall t \in T$ (MR must precede consultation with the doctor)

$\sum_{s=1}^{t-1} y_{i,3,s} \geq y_{i,7,t} \quad \forall i \in I \quad \forall t \in T$ (Sono must precede consultation with the doctor)

$\sum_{s=1}^{t-1} y_{i,3,s} \geq M_i y_{i,5,t} \quad \forall i \in I \quad \forall t \in T$ (If patient chooses to have a meal, sono must precede the meal)

$\sum_{s=1}^{t-1} y_{i,4,s} \geq M_i C_i y_{i,5,t} \quad \forall i \in I \quad \forall t \in T$ (If patient chooses to have a meal, CT must precede the meal)

$\sum_{s=1}^{t-1} y_{i2s} \geq y_{i,6,t} \quad \forall i \in I \quad \forall t \in T$ (If patient chooses to have a meal, CT must precede the meal)

$\sum_{s=1}^{t-1} y_{i3s} \geq y_{i,6,t} \quad \forall i \in I \quad \forall t \in T$ (Sono must precede consultation with the doctor)

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$$\sum_{s=1}^{t-1} y_{i6s} \geq y_{i,7,t} \quad \forall i \in I \quad \forall t \in T$$ (Interpretation of the doctor must precede consultation with the doctor)

$$z_{i,2} + D_{i,2} \leq z_{i,6} \quad \forall i \in I$$ (MR must precede the interpretation of the doctor)

$$z_{i,3} + D_{i,3} \leq z_{i,6} \quad \forall i \in I$$ (Sono must precede the interpretation of the doctor)

$$z_{i,6} + D_{i,6} \leq z_{i,7} \quad \forall i \in I$$ (Interpretation of the doctor must precede consultation with the doctor)

This part of the constraints will address issues related to the sequence of actions. For example, the check-in process must be the first procedure, whether to execute the CT or dining process. Each health check participant must undergo an MR before the doctor can interpret. If a meal is required, the MR must be completed before the meal, and the doctor must finish the interpretation of the patient's examination data before conducting a consultation, among other items.

$$\sum_{k \in k_i \setminus \{6\}} x_{ikt} \leq 1 \quad \forall i \in I \quad \forall t \in T$$ (A patient can only undergo one activity at a time , excluding the doctor's interpretation)

$$\sum_{i \in I} x_{ikt} \leq P_k \quad \forall k \in K \setminus \{6,7\} \quad \forall t \in T$$ (Each activity’s quantity in any period must not exceed the maximum number, except interpretation and consultation)

$$\sum_{i \in I} (x_{i,6,t} + x_{i,7,t}) \leq OD_t \quad \forall t \in T$$ (Each doctor's quantity in any period must not exceed the maximum)

The second part of the constraints addresses the issue of maximum capacity, ensuring that each health check participant can only undergo one test at a time, and the number of tests for an examination within the same period will be, at most, the upper limit for that examination.

$$\sum_{s=t}^{t+D_{ik}-1} x_{iks} \geq D_{ik} y_{ikt} \quad \forall i \in I \quad \forall k \in K_i \quad \forall t \in (1, n_T - D_{ik} - 1)$$

(The period of each activity for every patient must not exceed the time limit)

$$\sum_{t \in T} y_{ikt} = 1 \quad \forall i \in I \quad \forall k \in K_i$$ (Each patient can undergo each activity exactly once)

$$z_{ik} \geq O_k^S \quad \forall i \in I \quad \forall k \in K_i$$ (The start time for each activity for every patient must be after the respective start time of the activity)

$$z_{ik} = \sum_{t \in T} t y_{ikt} \quad \forall i \in I \quad \forall k \in K_i$$ (the conversion formulas for z_ik and y_ikt)

doi:10.6342/NTU202400044

$s_i = z_{i,1} \quad \forall i \in I$ (The start time of a patient's registration is the start time of the patient's first activity)

$e_i \geq z_{ik} + D_{ik} \quad \forall i \in I \quad \forall k \in K_i$ (The end time of a patient's schedule is the start time of the patient's last activity plus the period of doing the activity)

$e_i - s_i - R_i \geq 0 \quad \forall i \in I$ (The end time of the patient's registration minus the start time of the patient's registration must be longer than expected for all activities the patient needs)

The third part deals with some fundamental issues, ensuring that the examination time is not too short, each required task is executed exactly once, the testing time is within the timeframe when the test is available, recording the start time for each task of every health check participant, recording the start time of each health check participant's examination, recording the end time of each health check participant's examination, and ensuring that the end time is not earlier than the expected optimal.

$u_{ik} \geq 0 \quad \forall i \in I \quad \forall k \in K_i$ (Tardiness time for each activity of a patient must not be negative)

$u_{ik} \geq z_{ik} + D_{ik} - O_k^E \quad \forall i \in I \quad \forall k \in K_i$ (The tardiness time for each patient's activity is greater Than the difference between the end time of the patient's activity and the expected end time of that activity.)

This part tackles the overtime issues. Here, we use the concept of tardiness to calculate the total overtime.

$y_{ikt} = w_{i,k,t+D_{ik}-1} \quad \forall i \in I \quad \forall k \in K \quad \forall t \in T \setminus \{64\}$ Record buffer time

$$\sum_{i \in I} (w_{ikt} + x_{i,k,t+1}) \leq P_k \quad \forall k \in \{1,2,3,4\} \quad \forall t \in T \setminus \{64\}$$

$$\sum_{k=6}^{7} \sum_{i \in I} (w_{ikt} + x_{i,k,t+1}) \leq OD_t \quad \forall t \in T \setminus \{64\}$$

The number of patients finish the activities plus The number of patients undergo the activities Cannot exceed maximum

The last part of the constraints addresses the issue of the buffer. By recording the end times of each task, it is only necessary to ensure that the sum of the individuals currently undergoing a task and those who have just completed it does not exceed the upper limit for that task. After completing each task, this will generate the buffer for the testing machine or doctor.

doi:10.6342/NTU202400044

Chapter 4 Result

Our study aims to compare the effectiveness of a manual scheduling algorithm against an integral programming (IP) algorithm under various conditions. Our objective consists of two components: customer idle time and resource overtime. Idle time refers to periods when a customer waits without active engagement in any service. Overtime accounts for the additional time taken by MR and MD to complete their designated tasks beyond the scheduled period. As a disincentive for service delays, we introduce an overtime penalty factor. The total objective value is calculated by summing the idle time with the overtime factor, where the latter is weighted threefold.

In order to thoroughly assess the efficiency of manual scheduling and IP methods, it's essential to test them across various conditions that mimic the complexities of real-world health check-up scheduling. This approach enables a comprehensive evaluation of the algorithms, highlighting their robustness and identifying areas that may require optimization. Below is the rationale for each scenario: Scenario 1: This scenario establishes a baseline by considering the simultaneous utilization of MR machines and the availability of MDs for interpretation. It illustrates the fundamental dynamics between critical resources in the scheduling process. Scenario 2: Here we simulate a situation with a random mix of 12 health check-up packages handled by two MDs. The aim is to observe the algorithms' handling of potential MD resource shortages, a challenge that our center has historically overlooked due to a focus on MRI utilization rates. Scenario 3: Drawing from experience, we predict that three MDs should suffice to eliminate idle time for customers. This scenario is designed to test the

doi:10.6342/NTU202400044

performance of both methods when MR and MD resources are adequately provided. Scenario 4: By maintaining the same number of customers but increasing the service volume, we can scrutinize how both scheduling methods cope with intensified service demands without altering customer flow. Scenario 5: This scenario escalates both the number of customers and service volume, further challenging the scheduling methods. It aims to understand the algorithms' scalability and efficiency under increased operational pressure. Scenario 6: Characterized by its innovative approach, this scenario is populated exclusively with small packages, allowing us to evaluate how the manual method adapts to new and potentially more flexible scheduling situations. It also tests the system's capacity to accommodate a greater number of customers opting for smaller packages.

Table 4-1 The testing purposes of difference scenario

Scenario	Description	Purpose	What It Tests
1	Demonstration of the workflow	Establish a baseline for resource utilization.	How well both methods manage critical resources concurrently.
2	Random 12 packages serviced by two MDs.	Observe algorithm performance under MD resource shortages.	Adaptability to potential shortages and emphasis on MD importance.
3	Scenario 2 with three 3MDs	Test performance with sufficient resources.	Efficiency of both methods in ideal resource conditions.
4	Same number of customers with increased service volume.	Evaluate handling of increased service demands.	Method's capability to cope with increased operational intensity.
5	Increased number of customers and service volume.	Understand scalability and efficiency under pressure.	Algorithms’ scalability and performance under high demand.
6	Exclusively small packages to accommodate more customers.	Test response to new, flexible scheduling situations.	Flexibility and capacity of manual method for innovative scheduling.

doi:10.6342/NTU202400044

In all scenarios, the manual method generally scored slightly better than the IP method in terms of object scores, with the exception of scenarios featuring an overload of service capacity where the IP method outperformed by 48 points. Specifically, in Scenario 4, the IP method demonstrated a reduction in overtime by 1 point. In the innovative Scenario 6, both methods exhibited equivalent outcomes. The table 4.2 provided summarizes this overall performance. Detailed comparisons for each scenario [1]will also be included to offer a comprehensive view of the strengths and weaknesses of IP and manual methods.

Table 4-2 Comparison of performance of manual and IP method in difference scenarios.

	Method	Objective	Idle time								Delay time
Resource			Customers			MR1	MR2	MD1	MD2	MD3	Customer
			Minimum	Maximum	total	total	total	total	total	total	total
Scenario 2 (12-6-6)[2] 2MD	Manual	8	1	4	5	6	11	5	5	0	1
Scenario 2 (12-6-6) 2MD	IP	12	0	3	10	8	11	6	3	0	1
Scenario 3 (12-6-6) 2MD	Manual	0	0	0	0	8	6	10	8	13	0
Scenario 3 (12-6-6) 2MD	IP	5	1	2	5	7	5	5	6	14	0

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Scenario 4 (10-8-2)	Manual	4	0	1	4	0	11	9	5	3	1
Scenario 4 (10-8-2)	IP	12	1	3	12	8	12	0	2	0	0
Scenario 5 (12-10-2)	Manual	46	0	5	16	5	5	8	6	0	10
Scenario 5 (12-10-2)	IP	94	0	3	19	6	5	3	8	5	25
Scenario 6 (16-0-16)	Manual	0	0	0	0	22	21	5	5	0	0
Scenario6 (16-0-16)	IP	5	0	1	5	18	21	5	7	5	0

[1]The objective = total customer idle time + customer delay time*3.
[2]For all scenarios, the format is as follows: for (*i*-*j*-*k*), *i* indicates overall customer numbers in the scenario, *j* indicates the numbers of customers who chose the large packages in this scenario; *k* indicates the number of customers who chose the small packages in this scenario.

doi:10.6342/NTU202400044

Scenario 1 (Demonstration)

In each scenario, we will provide 1 table, and 2 figures. The table lists individual customers by their identity number and the package they have chosen whether they have opted for a CT scan (CT_YN), and whether they have a meal included (MEAL_YN). Each row corresponds to a different customer. For example, Customer 1 chose package 4, did not opt for a CT scan (0), and has a meal included (1). Customer 2 chose package 3, opted for a CT scan (1), and did not have a meal included (0) (Table 4-3). The first figure of each scenario represents the schedule of activities for each patient over a given time period, with different colors indicating different activities such as Register, MR, US, CT, Meal, and Consultation. Time is represented on the horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes. For example, in the Figure 4-1, for Customer 1, we can see that they begin with registration, followed by a series of tests and activities in a specific sequence, ending with a consultation. In the case of customer 2, there is a similar sequence of events, but the colors and lengths of the boxes vary according to their package choice and whether they have opted for a CT scan or meal. In the second figure of each scenario, the horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline, signifying intervals when the resource is not in use. The black vertical lines serve as terminators, marking the completion of operations for each resource within the schedule.

doi:10.6342/NTU202400044

The chosen health package by the second customer, identified as Package 4, results in a scheduling conflict when it comes to the MD's availability for interpreting imaging results. After Customer 2 completes the necessary imaging procedures, the MD remains engaged with interpreting results for Customer 1. This situation creates a mandatory waiting period for Customer 2, as there is no opportunity to allocate this time to other services like CT scans or meals without disrupting the schedule (Figure 4-2). The critical bottleneck in this scenario is the MD's capacity, not the imaging equipment. Selecting a different package, such as Package 6, would have aligned the conclusion of Customer 2's imaging services with the end of Customer 1's interpretation session, thus eliminating idle time. However, in our present schedule, the full extent of the MD's commitments is not visible, making the management of time constraints more challenging. Contrary to the usual focus on maximizing the use of imaging machinery like MRIs, this case demonstrates the significance of optimizing MD time to enhance overall scheduling efficiency.

Table 4-3 Packages and choices of additional CT or meal of two customers

Customer ID	Package	CT_YN	MEAL_YN
1	4	0	1
2	3	1	0

CT_YN: Indicates if the customer underwent a CT examination.

MEAL_YN: Denotes whether the customer had a meal.

Package: Represents the specific package chosen by the customer.

doi:10.6342/NTU202400044

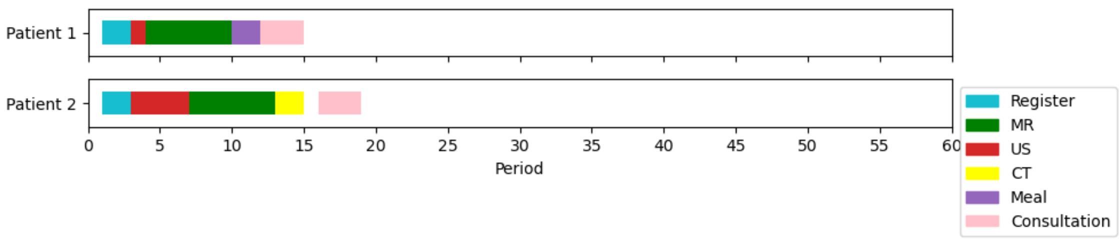

Figure 4-1 time allocation of customer activity in scenario 1

Different colors indicating different activities such as Register, MR, US, CT, Meal, and Consultation. Time is represented on the horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes.

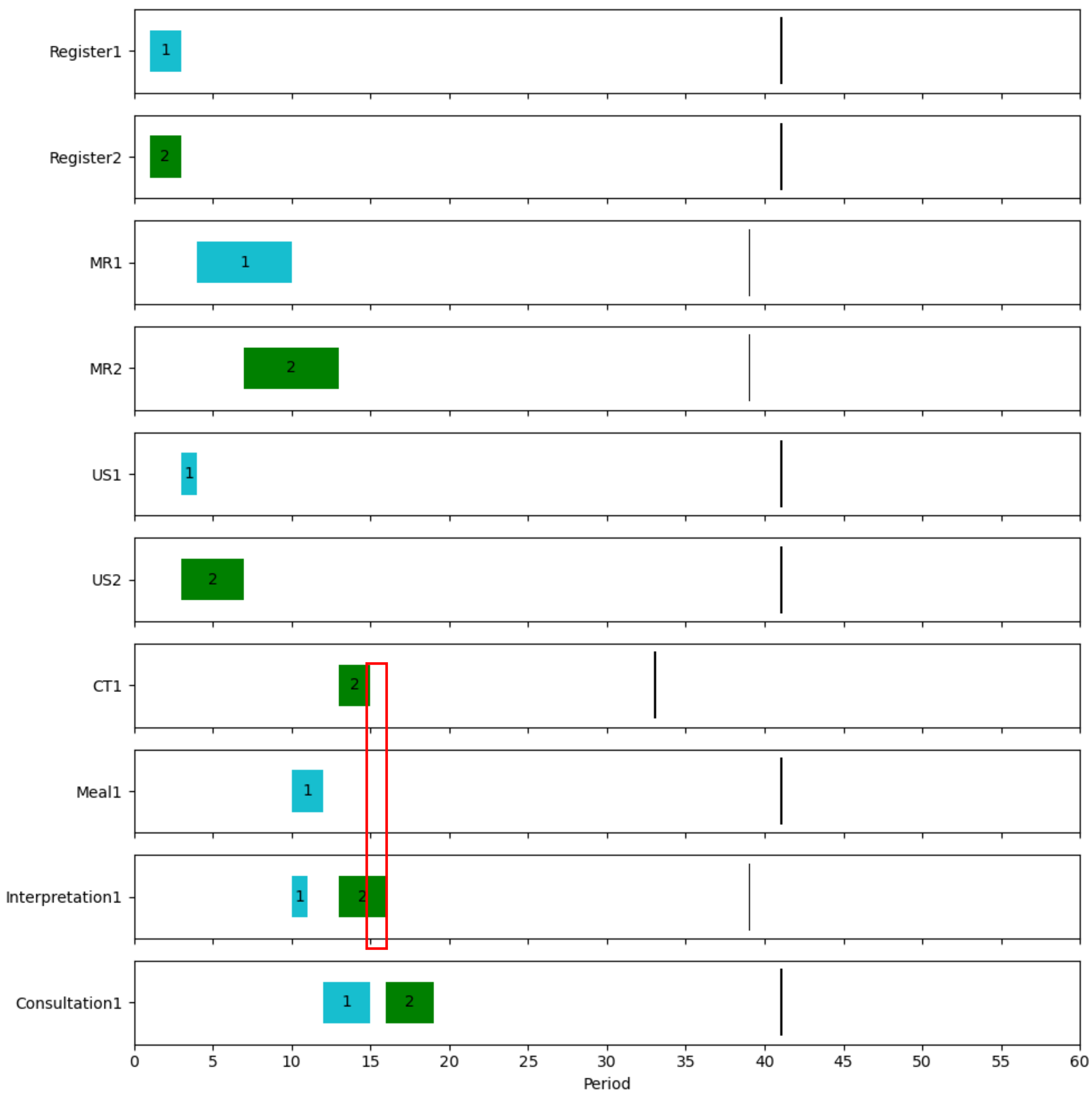

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Figure 4-2 Resource utilization timeline with patient allocation in scenario 1
The horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline. 1period =15 minutes. The red rectangle indicated the time slot when the second guest waiting for the MD interpreting the imaging.

doi:10.6342/NTU202400044

Scenario 2: Random cases with random MD working hours

Without prospective control of schedule, based on first come, first serve policies from the customer service, and random work hours from MD. This is the basic template to examine the efficacy of integral programming scheduling. By introducing randomness in service selection, this scenario aims to replicate the unpredictability of real-world operations one day before operation day. It will help determine the flexibility and adaptability of the algorithms when faced with non-standard or unexpected tasks. Due to the regulations of working hours of staff, we only allow one MD to work overtime in the current setting.

Table 4-4 Packages and choices of additional CT or meal of scenario 2

ID	SET	CT_YN	MEAL_YN
1	6	1	1
2	5	0	1
3	4	0	1
4	5	1	1
5	2	1	0
6	5	1	0
7	1	1	1
8	6	1	1
9	3	0	1
10	4	1	0
11	6	0	1
12	5	1	0

doi:10.6342/NTU202400044

CT_YN: Indicates if the customer underwent a CT examination.

MEAL_YN: Denotes whether the customer had a meal.

Package: Represents the specific package chosen by the customer.

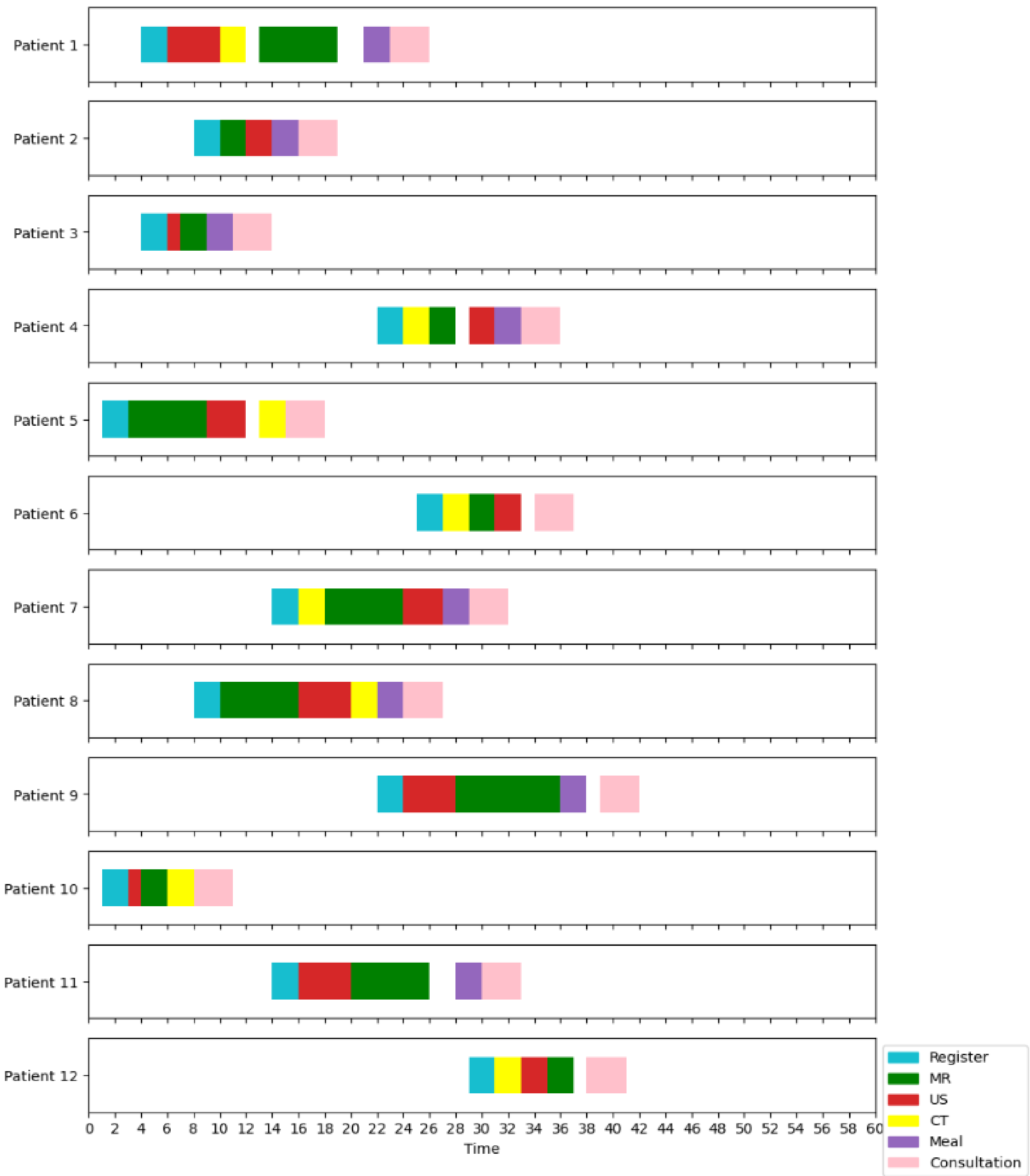

Figure 4-3 time allocation of customer activity in scenario 2

doi:10.6342/NTU202400044

Different colors indicating different activities such as Register (blue), MR (green), US (red), CT (yellow), Meal (purple), and Consultation (pink). Time is represented on the horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes.

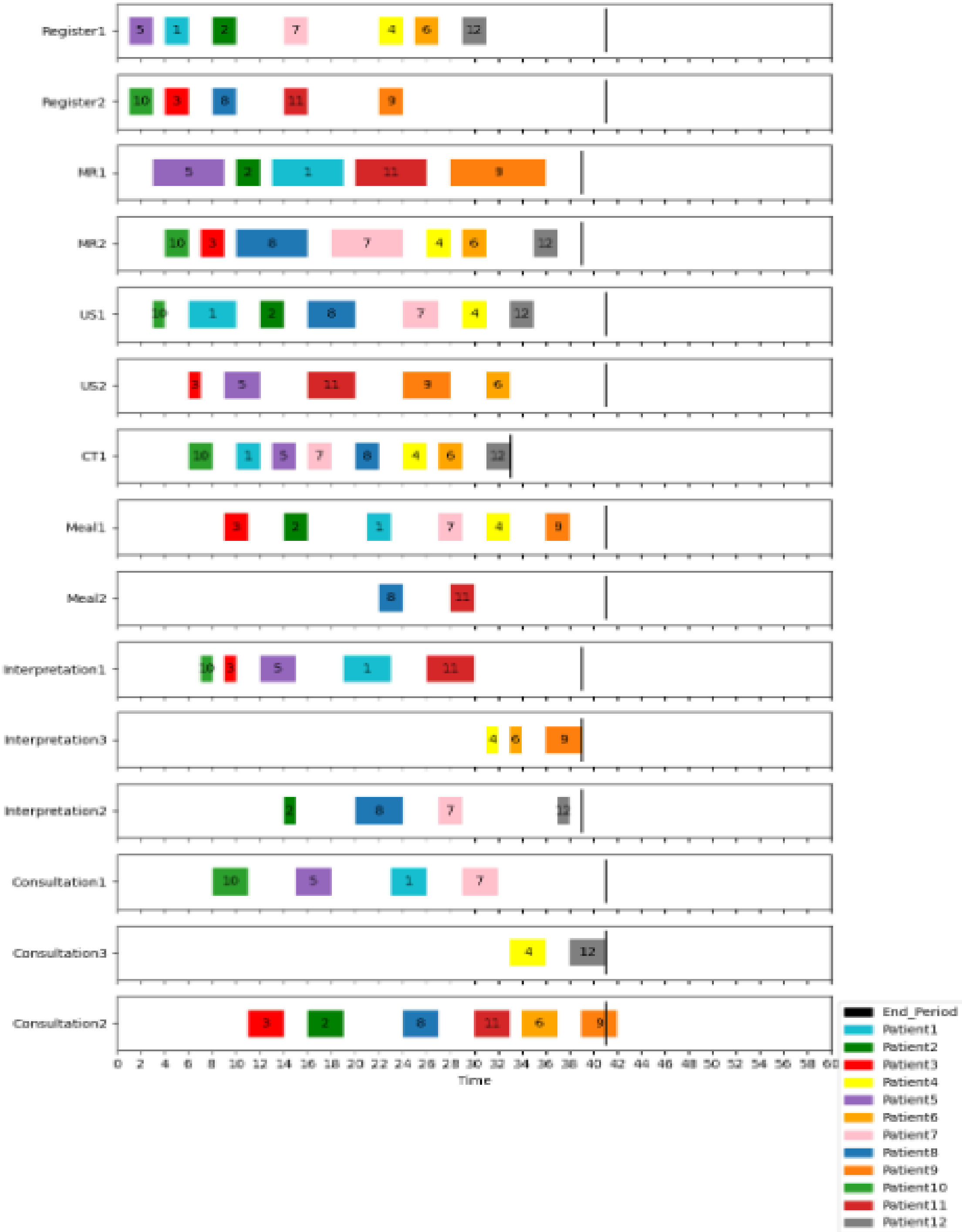

Figure 4-4 Resource utilization timeline with patient allocation in scenario 2

doi:10.6342/NTU202400044

The horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline. 1period =15 minutes.

Table 0-1 Comparison of performance of manual and IP method in scenario 2

Performance	object	Idle time								Delay time
		Customers			MR1	MR2	MD1	MD2	MD3	
		Minimum	Maximum	Total						
Manual	8	1	4	5	6	11	5	5	0	1
IP	12	0	3	10	8	11	6	3	0	1

Comments: the Integral Programming method tends to result in higher idle times for customers. However, the differences in overtime are similar or slightly less in IP method than in manual method. The Manual method appears to be more efficient in terms of minimizing idle time for customers and MR in this specific scenario, but the differences in overall performance are relatively subtle.

doi:10.6342/NTU202400044

Scenario 3: Random cases with adequate MDs

We have tried different random scenario by keeping overall customer number of 12 and found that the idle time is still relatively high. It seems the bottle neck is insufficient MD working hours. We design to allow all the MDs to work overtime if necessary, and allow more big packages to schedule to see if this can decrease the idle time of customer and machine)

Table

Table 4-6 10 Packages and choices of additional CT or meal of scenario 3

ID	SET	CT_YN	MEAL_YN
1	6	1	1
2	5	0	1
3	4	0	1
4	5	1	1
5	2	1	0
6	5	1	0
7	1	1	1
8	6	1	1
9	3	0	1
10	4	1	0
11	6	0	1
12	5	1	0

CT_YN: Indicates if the customer underwent a CT examination.

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MEAL_YN: Denotes whether the customer had a meal.

Package: Represents the specific package chosen by the customer.

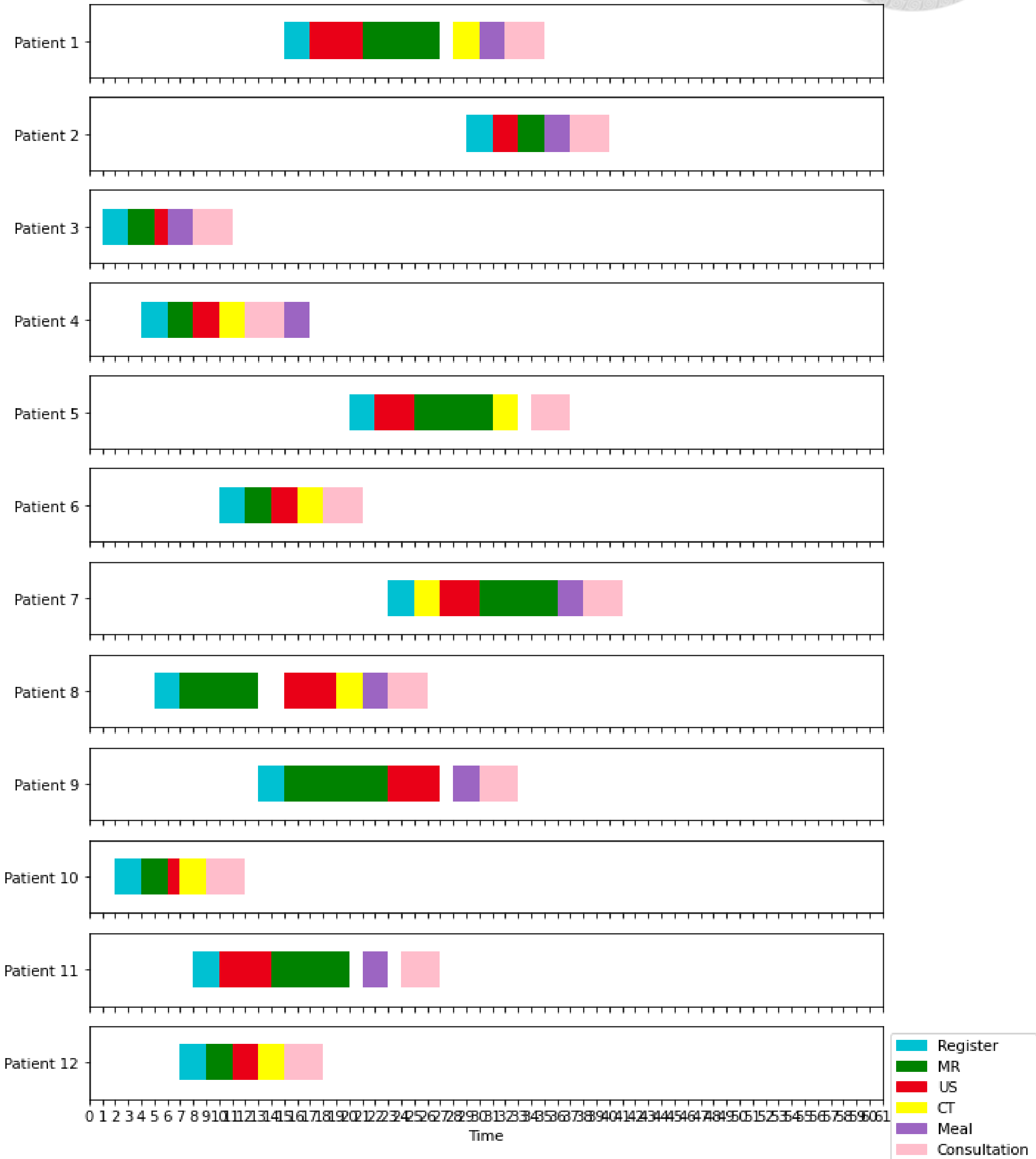

Figure 4-5 time allocation of customer activity in scenario 3

Different colors indicating different activities such as Register (blue), MR (green), US (red), CT (yellow), Meal (purple), and Consultation (pink). Time is represented on the

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horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes.

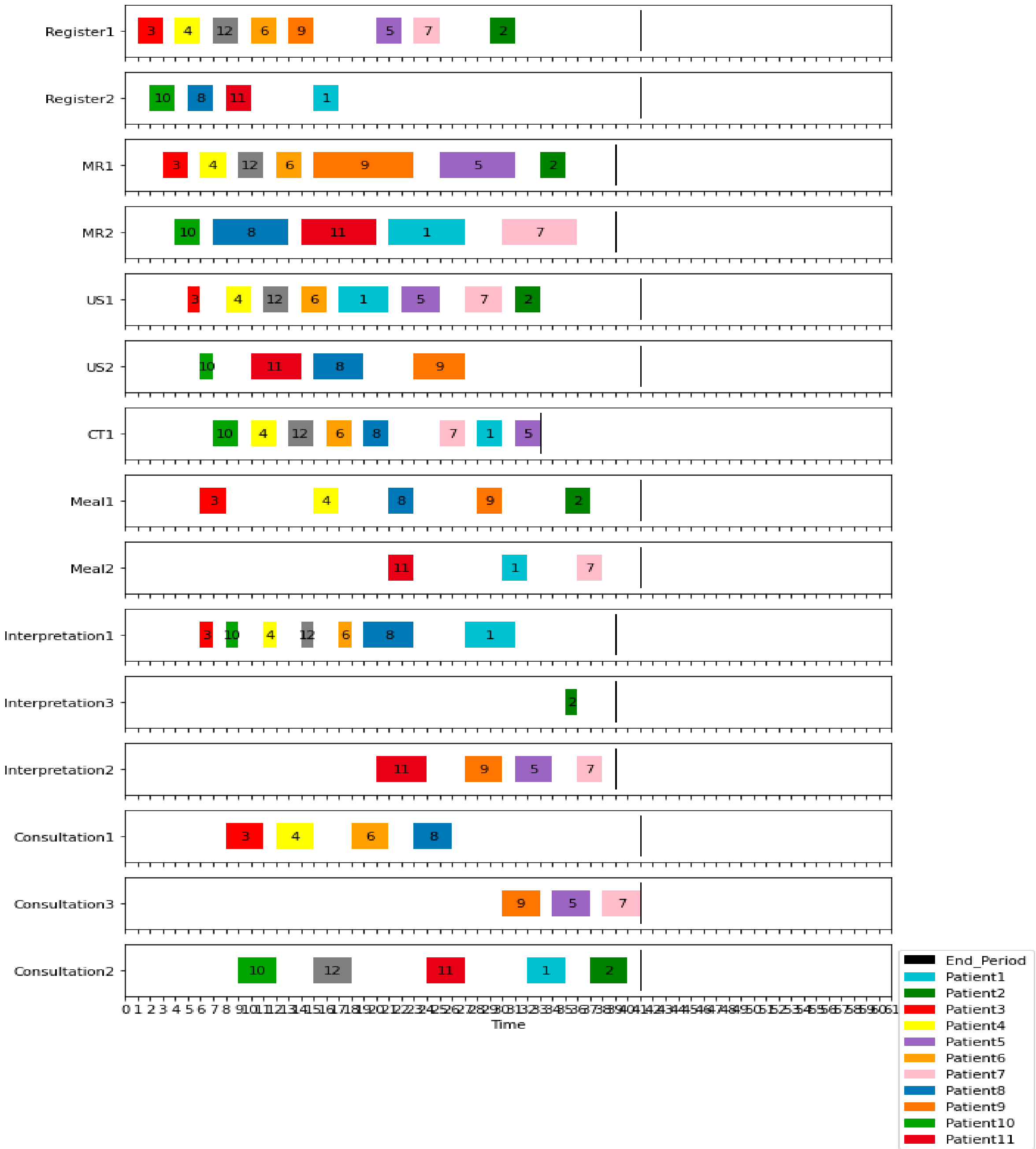

Figure 4-6 Resource utilization timeline with patient allocation in scenario 3

The horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different

doi:10.6342/NTU202400044

customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline. 1period =15 minutes.

Table 4-7 Comparison of performance of manual and IP method in scenario 3

Performance	object	Idle time								Delay time
		Customers			MR1	MR2	MD1	MD2	MD3	
		Minimum	Maximum	Total						
Manual	0	0	0	0	8	6	10	8	13	0
IP	5	1	2	5	7	5	5	6	14	0

In the current scenario, the Integral Programming approach leads to increased customer overtime and MR idle time compared to the manual method. While the manual method has a slight uptick in MD idle time, both methods have shorter customer idle times in this scenario than in a less populated setting, as seen in Example 2. Similarly, MR idle times are reduced in this scenario for both methods compared to Example 2. Overall, **the manual method proves to be more efficient** in minimizing customer overtime and MR idle time, with only minor differences observed in MD idle time between the two methods.

When we consider the possibility of extending MD working hours, there's a noticeable reduction in customer idle time. This extension does lead to an increase in MD idle time. Yet, interestingly, there's no corresponding rise in MD overtime. This could potentially be attributed to the optimization algorithm's efficacy during computation, even if its results aren't always evident in the final outcomes.

doi:10.6342/NTU202400044

doi:10.6342/NTU202400044

Scenario 4: Eight large packages with two small packages

Like the previous scenario, this one further reduces the number of services, with more big packages. It will shed lights on how each algorithm performs when there’s a slight increase in service volume, emphasizing their adaptability to changing workloads, and impact on delay time.

Table 4-8 12 Package and choices of additional CT or meal of scenario 4

ID	SET	CT_YN	MEAL_YN
1	4	1	1
2	5	1	1
3	6	1	1
4	6	0	1
5	1	1	0
6	2	1	0
7	1	0	0
8	2	0	0
9	2	1	0
10	1	0	0

CT_YN: Indicates if the customer underwent a CT examination.

MEAL_YN: Denotes whether the customer had a meal.

Package: Represents the specific package chosen by the customer

doi:10.6342/NTU202400044

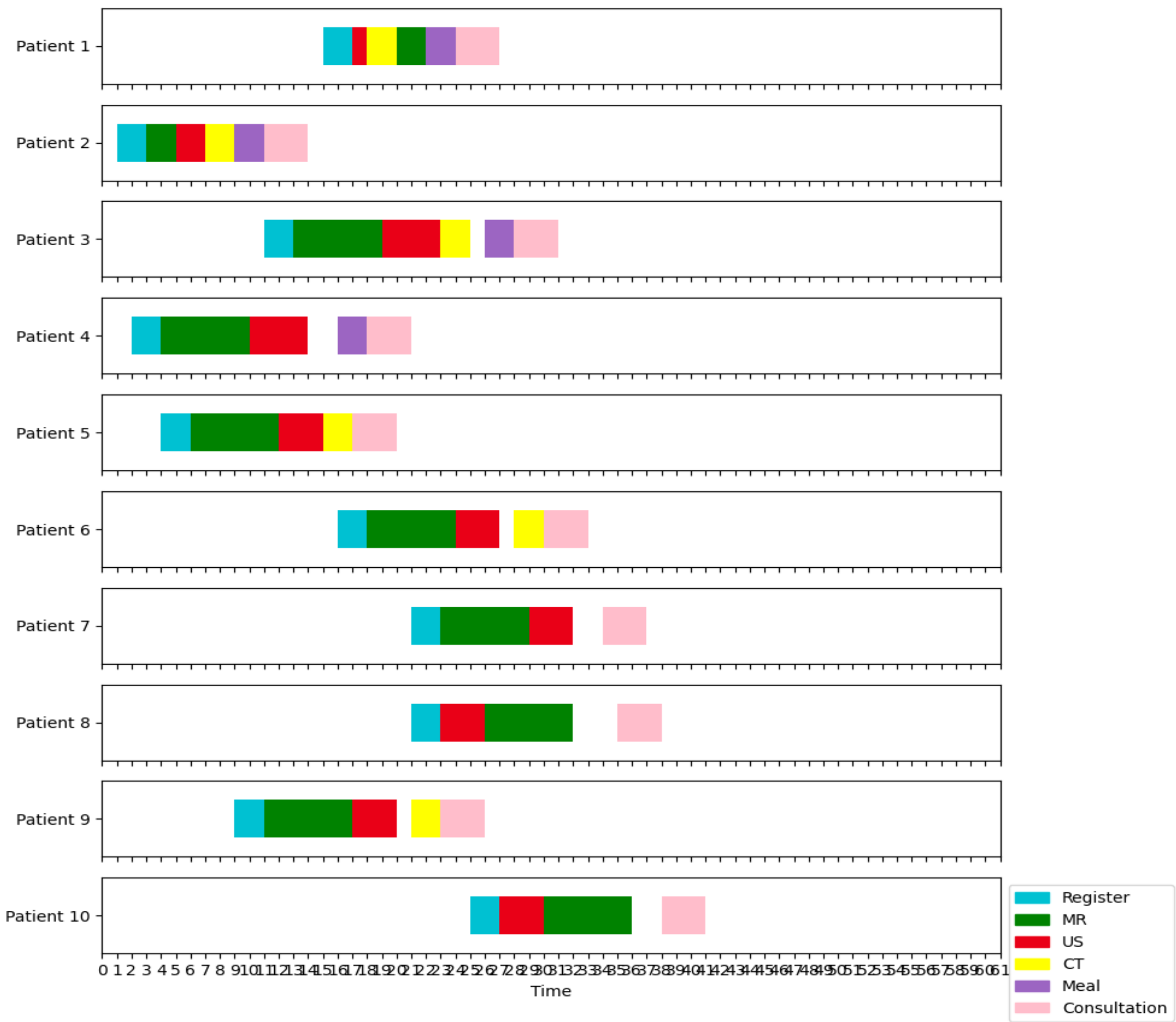

Figure 4-7 time allocation of customer activity in scenario 4

Different colors indicating different activities such as Register (blue), MR (green), US (red), CT (yellow), Meal (purple), and Consultation (pink). Time is represented on the horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes.

doi:10.6342/NTU202400044

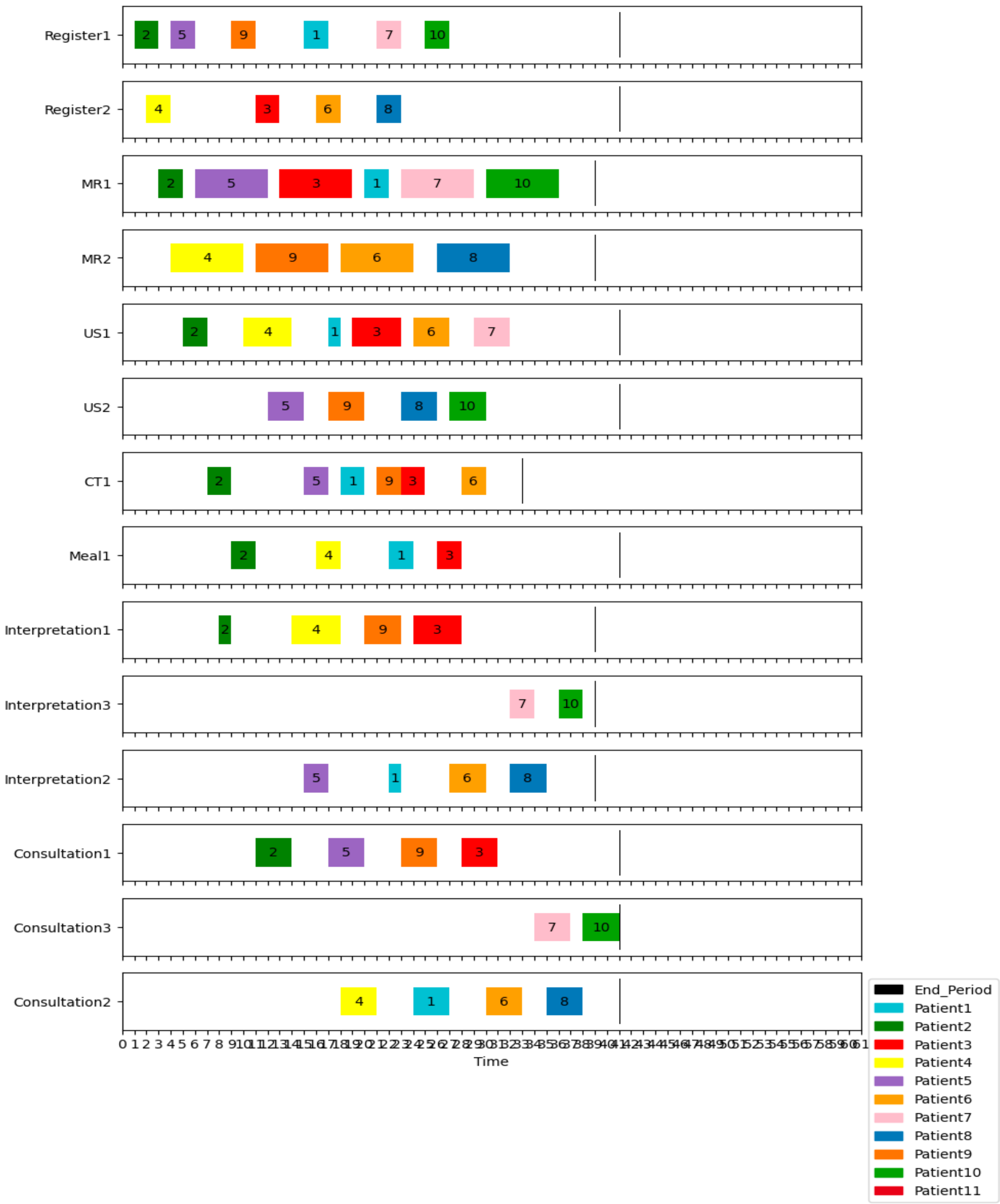

Figure 4-8 Resource utilization timeline with patient allocation in scenario 4

doi:10.6342/NTU202400044

The horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline. 1period =15 minutes.

Table 4-9 Comparison of performance of manual and IP method in scenario 4

Performance	object	Idle time								Delay time
		Customers			MR1	MR2	MD1	MD2	MD3	
		Minimum	Maximum	Total						
Manual	4	0	1	4	0	11	9	5	3	1
IP	12	1	3	12	8	12	0	2	0	0

Comments: In the current scenario, Example 4, with the inclusion of more extensive services, the Integral Programming approach exhibits slightly higher idle times for both MR and MD. Conversely, the Manual method manifests marginally increased customer overtime. While both the Integral Programming and Manual methods appear to be on par in minimizing customer waiting times, the Manual method demonstrates superior efficiency in resource utilization, particularly concerning MD.

Contrasting this with Example 3, we observe that the total operational time for MD has expanded from 840 to 870 minutes, and the active working time for MD has grown from 770 to 845 minutes. Notably, neither method indicates an uptick in overtime. This observation suggests that the resources, especially MR and MD, are not

doi:10.6342/NTU202400044

being fully leveraged in the current setup. There's a clear opportunity to accommodate more guests through astute scheduling without compromising efficiency.

doi:10.6342/NTU202400044

Scenario 5: Ten large packages with 2 small packages

From the outcomes observed in Example 4, it seems feasible to incorporate an additional 1 or 2 packages to optimize revenue, given the underutilization of available resources. A blend of larger and smaller packages is typically favored, reflecting real-world scenarios where service sizes exhibit variation. This mixed approach aligns with our routine daily practice template. Such a configuration also serves as a litmus test for the algorithms, evaluating their proficiency in effectively balancing and prioritizing tasks of varying magnitudes.

Table 4-10 Packages and choices of additional CT or meal of scenario 5

ID	SET	CT_YN	MEAL_YN
1	1	1	1
2	2	1	1
3	4	0	0
4	2	1	0
5	4	1	0
6	2	1	0
7	1	0	0
8	1	0	0
9	6	1	1
10	3	1	0
11	2	0	0
12	1	0	0

CT_YN: Indicates if the customer underwent a CT examination.

MEAL_YN: Denotes whether the customer had a meal.

doi:10.6342/NTU202400044

Package: Represents the specific package chosen by the customer.

Figure 4-9 time allocation of customer activity in scenario 5

Different colors indicating different activities such as Register (blue), MR (green), US (red), CT (yellow), Meal (purple), and Consultation (pink). Time is represented on the horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes.

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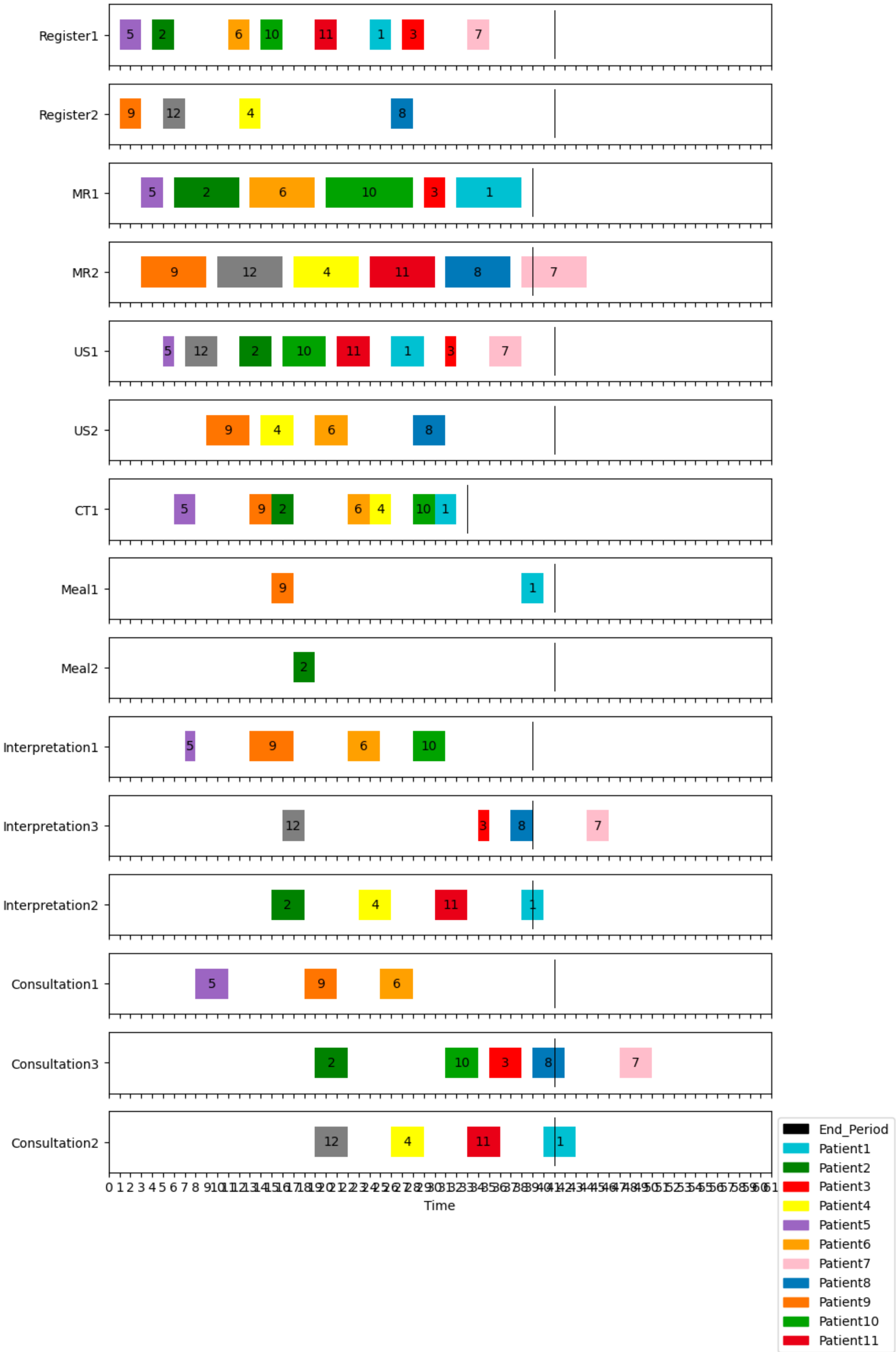

Figure 4.10 Resource utilization timeline with patient allocation in scenario 5

doi:10.6342/NTU202400044

The horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline. 1period =15 minutes.

Table 4-11 Comparison of performance of manual and IP method in scenario 5

Performance	object	Idle time								Delay time
		Customers			MR1	MR2	MD1	MD2	MD3	
		Minimum	Maximum	Total						
Manual	46	0	5	16	5	5	8	6	0	15
IP	94	0	3	19	6	5	3	8	5	25

In the given context, the Integral Programming approach tends to exhibit marginally increased customer overtime and a noticeable MD overtime compared to the Manual method. Although disparities in idle times for MR and MD are negligible, the elevated overtimes, especially for customers, spotlight potential inefficiencies inherent to the Integral Programming method for this scenario. The Manual method, while not without its flaws, seemingly outperforms in minimizing both customer and MD overtimes. The simultaneous occurrence of idle time and overtime suggests workflow suboptimization, which, in theory, can be mitigated by bridging gaps between distinct services. It's noteworthy that both methods show a pronounced rise in overtime in the current example (12 guests) compared to the previous one (10 guests). This suggests that the current example might be impractical, predisposing the system to inevitable overtime.

doi:10.6342/NTU202400044

doi:10.6342/NTU202400044

Scenario 6: All small packages

Due to cheaper price of small package, they have more demands, and sometimes the convention schedule will not fit them smoothly into the schedule. Therefore, sometimes the waiting time is delayed. We sometimes must schedule one or two days to accommodate those extra demand of small package comparing to large package. Focusing exclusively on smaller tasks, this scenario will help us understand how the algorithms manage finer-grained operations. It's essential to determine whether the algorithms can handle numerous smaller tasks as efficiently as they handle fewer, larger tasks.

Table 4-12 16 Packages and choices of additional CT or meal of scenario 6

ID	SET	CT_YN	MEAL_YN
1	4	1	1
2	5	0	1
3	4	0	1
4	5	1	0
5	4	1	0
6	5	0	0
7	4	1	1
8	5	1	0
9	4	1	0
10	5	1	0

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11	4	0	0
12	5	0	0
13	4	1	0
14	5	0	0
15	4	1	0
16	5	0	0

CT_YN: Indicates if the customer underwent a CT examination.

MEAL_YN: Denotes whether the customer had a meal.

Package: Represents the specific package chosen by the customer.

doi:10.6342/NTU202400044

Figure 4-11 time allocation of customer activity in scenario 6

Different colors indicating different activities such as Register (blue), MR (green), US (red), CT (yellow), Meal (purple), and Consultation (pink). Time is represented on the horizontal axis, with each box representing the duration of an activity. Each interval is equivalent to 15 minutes.

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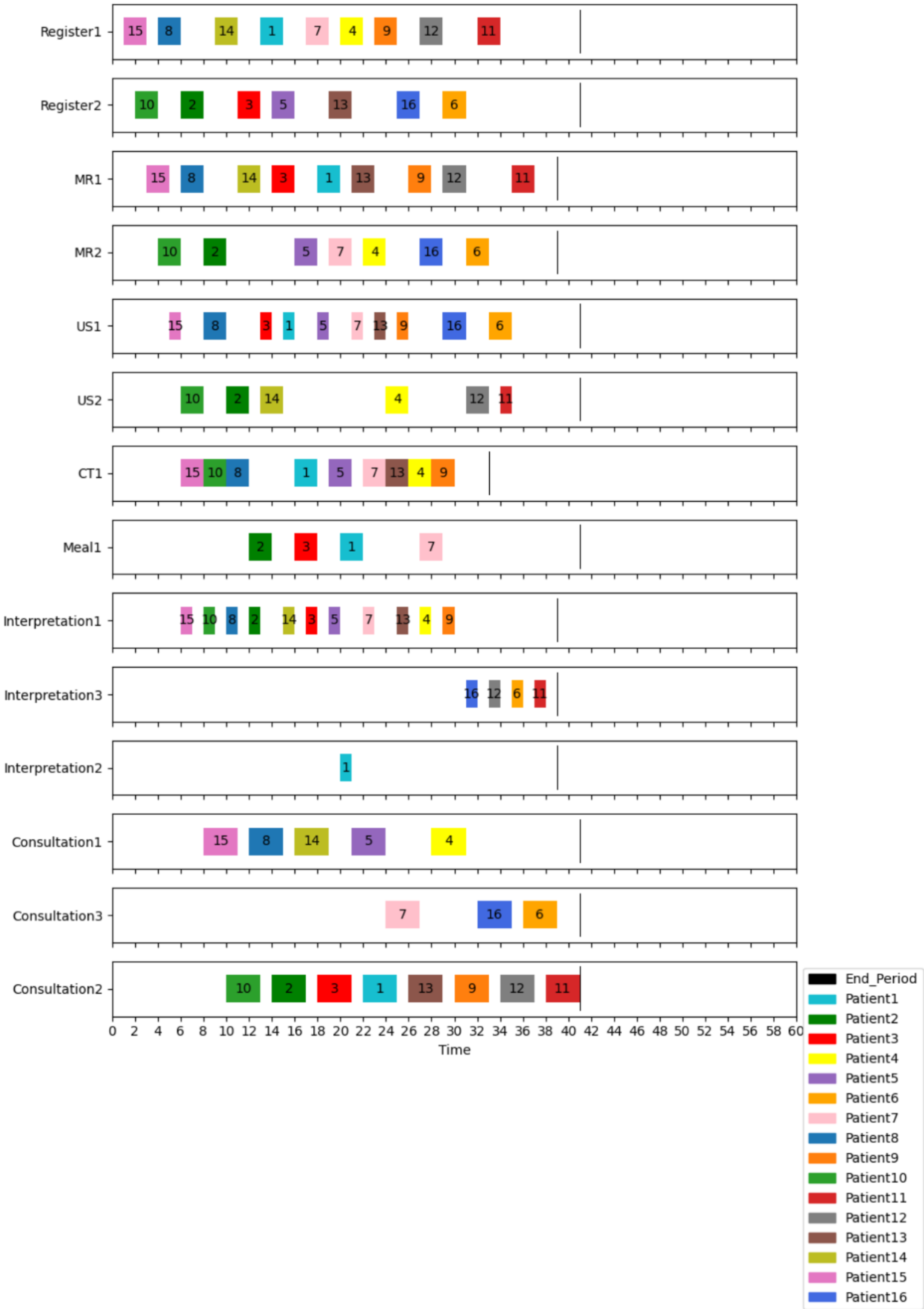

Figure 4-12 Resource utilization timeline with patient allocation in scenario 6

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The horizontal axis delineates the chronological utilization of each resource throughout the scheduling period. Colored blocks represent the allocated times for different customers, with each color corresponding to a specific customer. Idle periods are indicated by gaps between consecutive blocks along the resource's timeline. 1period =15 minutes.

Table 4-13 Comparison of performance of manual and IP method in scenario 6

Performance	object	Idle time								Delay time
		Customers			MR1	MR2	MD1	MD2	MD3	
		Minimum	Maximum	Total						
Manual	0	0	0	0	22	21	5	5	0	0
IP	5	0	1	5	18	21	5	7	5	0

the Integral Programming method results in a slight increase in customer idle time and MD idle time. On the other hand, the Manual method exhibits a marginal rise in MR idle time. Both methods are efficient in terms of over time, with neither resulting in extended waiting times for customers, MR, or MD. Given these nuances, the choice between methods might hinge on whether it's more crucial to minimize customer waiting times or resource idle times.

doi:10.6342/NTU202400044

Summary of Result

In assessing scheduling efficiency, the manual method was used as a benchmark against the IP method across varied scenarios. Key metrics included idle time (customer inactivity periods), delay time (duration for machine and MD task completion), and an objective value penalizing customer overtime. These scenarios, reflecting real-world conditions, helped evaluate the algorithms' effectiveness.

In Table 4-14, we summarize the important findings across scenarios for comparisons: The IP method tended to increase customer idle times compared to the manual method across scenarios. Its performance was mixed in managing resource overtime - it was less effective in some cases, yet equal or slightly better in some scenario (scenario 4). The IP method consistently led to greater MR idle times, indicating suboptimal resource use, although both methods were similar in MR overtime. The IP method usually increased MD idle times, except in scenario 3, where the manual method had higher idle times. In scenario 4, the IP method better managed MD overtime. In high-volume service scenarios, both methods struggled with efficiency. However, in a novel scenario, they performed equally. However, it is noteworthy that the manual scheduling method typically requires approximately 120 minutes to complete, which is six times longer than the duration needed for the IP method.

These findings highlight a nuanced interplay between the two methods, with the IP method excelling in certain areas but showing less efficiency in resource utilization, particularly for idle time. Occasionally, its reduction of overtime outperformed the manual method, indicating a possible trade-off. Choosing the appropriate method hinges on the specific scenario and operational goals.

doi:10.6342/NTU202400044

Table 4-14 Summary of performances and implications of scenarios

Scenario	Performance	Implications
Scenario2: 12 Random Packages with Insufficient MDs	Idle time: M <IP Overtime: M=IP	Successful implementation of IP; IP provided suboptimal solution with shorter time
Scenario 3:12 Random Packages with Adequate MDs	Idle time: M < IP No overtime	Increased MD avoid overtime; more idle times of MD
Scenario 4: 10 Big Packages + 2 Small Packages	Idle time: M < IP Overtime: M>IP	Increased workload did not exceed the capacity of current resource. IP occasionally defeat M
Scenario 5: 12 Big Packages + 2 Small Packages (Overload)	Idle time: M < IP Overtime: M<IP	Longer customer idle times, inefficiencies with increased service demand
Scenario 6: 16 Small Packages (Novel Scenario)	Idle time: M < IP Overtime: M<IP	IP adapt to new scenario easily with similar performance

IP= integral programming; M: manual method

doi:10.6342/NTU202400044

Chapter 5 Conclusion and suggestions

5.1 Summary of Key findings

The decision to set a 20-minute time limit was informed by a pilot study of the IP approach and our clinical practice observations. We operate on a modest scale, catering to 12-16 customers with 6 workshops. It was presumed that IP would outperform manual scheduling techniques; however, our findings indicated otherwise. We observed that even slight variations in the number or types of packages and customers led to considerable disruptions in the scheduling order. Two possible reasons were identified in the scheduling process. Firstly, the interpretation task by the MD is scheduled to begin after the start of the MR scan for the patient. This sequencing introduces a significant level of complexity into the scheduling algorithm, necessitating the IP method to handle a higher computational load, even for our relatively small-scale operations. Secondly, the potential for flexibility in the schedule, such as the possibility to reduce the time allocated for MD interpretations from 40 minutes to 30 minutes, has not been effectively captured in the current IP model.

Precise definition of problems and constraints is critical for the effective performance of IP. However, translating domain-specific service knowledge into a programmable format can lead to information loss or distortion. For instance, our objectives include minimizing customer idle time and reducing overtime for medical doctors (MDs) and medical representatives (MRs). These subgoals are comparable in performance when using both IP and manual methods. Yet, in terms of resource utilization, the manual method generally outperforms IP. This is because the manual

doi:10.6342/NTU202400044

approach tends to consider the scheduling task more holistically, while IP focuses primarily on achieving the main objective.

Regarding adaptability, both IP and manual methods can adjust to new scenarios with similar outcomes. However, they differ in the time required to complete a scenario: the manual method typically takes 2 hours, whereas IP can provide a solution in approximately 20 minutes. The discrepancy between the solutions and the optimal outcome is roughly 20%. The choice between manual and IP methods should be based on the permissible time frame and the complexity of the scenario. For situations involving fewer than 10 customers with standardized packages, the manual method appears to be more robust. Conversely, for more complex cases, the IP method may be preferable.

Moreover, the dynamism of the situation profoundly influences IP's effectiveness. In static environments, where variables remain consistent, IP can meticulously calibrate its models for optimal outcomes. However, in volatile conditions that undergo frequent shifts, the continuous recalibration required for IP can become a bottleneck, potentially making manual or heuristic approaches more viable. Furthermore, the complexity and size of the problem can either be a strength or a challenge for IP. While it's adept at managing large datasets and multivariate problems, the intricate interrelationships between variables in highly complex scenarios might stretch the computational and time capacities of IP, potentially leading to suboptimal solutions or extended processing times. Practical challenges like dynamic changes, model complexity, and real-world nuances pose challenges for IP. As the model grows in complexity, advanced techniques become essential. Also, in real-world settings, where changes are frequent and unpredictable, IP models might need regular updates.

doi:10.6342/NTU202400044

The manual method, with its inherent flexibility, can swiftly adapt to such changes without the need for extensive recalibrations.

Trade-offs: Optimization often brings along trade-offs. For instance, while IP might optimize for reduced wait times, it might inadvertently increase resource idle times. Recognizing and navigating these trade-offs is crucial. The manual method, with its intuitive approach, might be more adept at balancing such trade-offs, ensuring a more harmonized scheduling outcome.

Summary of IP in imaging health check-up scheduling：in the intricate domain of scheduling, both IP and manual methods offer valuable insights and solutions. While IP provides a structured, algorithmic approach, the manual method brings in the irreplaceable value of human touch and adaptability. The choice between these methods should be guided by the specific objectives, challenges, and nuances of the operational environment. Adopting a combined approach, which capitalizes on the strengths of both methods, might offer the most holistic and effective scheduling solution.

Table 5-1 Comparisons of manual and IP in difference scenarios

Scenario	Manual Method	Integral Algorithm (IP)
12 Random Packages with Insufficient MDs	Adaptable, quick solutions, satisfactory under resource constraints	Aims for optimal solutions, longer processing, efficient in the long run
12 Random Packages with Adequate Doctors	No overtime noted, unused potential in MD utilization	Equivalent

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10 Big Packages + 2 Small Packages	Efficiently allocates larger tasks first, satisfactory outcomes	Equivalent
12 Big Packages + 2 Small Packages (Overload)	Superior in managing overtimes, more efficient resource utilization	Longer customer idle times, inefficiencies with increased service demand
16 Small Packages (Novel Scenario)	Quick allocations, may not find the most optimal solution	Methodical evaluation, likely more efficient but takes longer

doi:10.6342/NTU202400044

5.2 Strategies in Imaging Health Check-up Scheduling

Adaptation to Variability: In the fast-paced setting of health imaging checkup scheduling, the ability to adapt to the variability of patient numbers and service packages is of the utmost importance. Robust scheduling systems are imperative, designed to be flexible enough to handle the ebb and flow of demand. This adaptability is key to maintaining continuous service and managing unexpected changes in patient influx. Manual scheduling methods, with their nuanced resource utilization, exemplify the significant role of human expertise in this adaptive process, standing in contrast to a trend towards automation. Such personalized approaches enable the kind of refined decision-making required in healthcare's multifaceted landscape.

Balancing Time Efficiency and Computational Power: The balancing act between time efficiency and computational power is a central theme in health checkup scheduling. While IP methods offer computational rigor, they may also inadvertently lengthen customer wait times, highlighting the need for a delicate balance between swift service and quality care. To this end, manual methods, despite their greater time investment, often emerge as the preferred option due to their meticulous attention to detail. However, the urgency of healthcare demands that time-efficient methods, such as heuristic algorithms, be employed to deliver quick solutions that align with the dynamic nature of medical services.

Nurse scheduling algorithms, while precise for managing shifts, may fall short in health checkup contexts where the scheduling requires the agility to cater to diverse

doi:10.6342/NTU202400044

service packages, adapt quickly to changes, and prioritize reducing customer wait times and enhancing their overall experience. Heuristic Algorithms: Heuristic algorithms prioritize speed and practical solutions, leveraging domain knowledge to guide the search process towards effective outcomes without exhaustive computation. While they streamline decision-making to improve service efficiency, they may not always capture the nuances required for the optimal service experience, a characteristic inherent to heuristic approaches. Genetic Algorithms: Genetic algorithms excel due to their robust nature and capacity to navigate complex, multi-layered problems to locate superior solutions. This strength is paralleled by the manual scheduling method's ability to handle scenarios with limited variables effectively. In the context of our imaging health checkups, it is posited that both heuristic and genetic algorithms could theoretically yield positive results.

Operating perspective: From an operating system's standpoint, overhead and complexity are critical considerations. IP brings algorithmic intricacy, potentially adding computational overhead, especially in large or complex models. Every IP deployment requires system resources for its intricate mathematical processes. Conversely, the manual method, rooted in human decision-making, might minimize computational overhead but introduces administrative challenges, necessitating human intervention for oversight and adjustments. Complexity in IP is inherent, demanding robust computational resources to manage its detailed models. While it ensures consistency, the system might sometimes be strained by its demands. The manual method, however, transfers this complexity onto human operators, demanding expertise to effectively navigate scheduling challenges.

doi:10.6342/NTU202400044

Customer Perspective: From a customer's or patient's perspective, their journey through any service system is punctuated by two primary touchpoints: waiting times and the quality of service received. IP, with its mathematical prowess, is designed to streamline this journey, aiming to systematically reduce wait times by optimizing schedules. The promise of IP lies in its ability to dissect vast amounts of data to predict and position resources where they're most needed, theoretically ensuring that customers spend the least amount of time waiting. However, the algorithmic nature of IP can sometimes be a double-edged sword. While it seeks optimization, in certain scenarios, it may inadvertently increase idle times or waiting periods for customers, especially if the model isn't finely tuned to real-world dynamics or if there are unforeseen disruptions in service. This could lead to customer dissatisfaction, even if the system is operating at what it perceives to be 'optimal' efficiency.

On the other hand, the manual method, enriched by human expertise and intuition, often brings a more holistic approach to the table. Human operators can read the room, so to speak, adjusting to the immediate needs and preferences of customers. They can make on-the-fly decisions to accommodate urgent requests or to mitigate unforeseen challenges, ensuring a smoother and more responsive customer experience. Moreover, the human touch embedded in manual methods often translates to more empathetic interactions, fostering a sense of personalization. In scenarios where a personal touch, understanding, and immediate adaptability are essential, the manual approach might offer a more gratifying and tailored service experience for customers.

Resource Utilization: In the realm of resource utilization, especially concerning equipment and staff, IP presents a structured methodology for task allocation. Its

doi:10.6342/NTU202400044

primary objective is to drive down idle times while amplifying resource utilization. The manual method, enriched by hands-on knowledge, offers the advantage of agility, swiftly adapting to changes and ensuring that resources are optimally used, especially when situations are fluid. Transitioning to Resource Management, it's an essential facet, especially when resources are limited or carry a significant cost. Proper management ensures that resources are neither sitting idle nor being overburdened, the latter of which could culminate in wear and potential malfunctions. Economically, every moment a resource is not efficiently used equates to incurred costs without equivalent value generation. Additionally, efficient resource management dovetails with sustainability initiatives; for example, reducing machine downtime can curtail energy use. As operations expand, the intricacies of managing resources intensify, underscoring the importance of honing effective strategies at initial stages for seamless future expansion and flexibility."

Automation: IP represents a pinnacle of automation in operational systems, harnessing algorithmic strength to process complex scheduling problems. This automated method excels where manual computations may be insufficient, particularly in large-scale, complex scenarios. By applying a systematic, algorithm-driven approach, IP provides a solution framework that navigates through the complexities of voluminous data, optimizing the scheduling process with precision and reliability. Automation through IP diminishes the potential for human error and streamlines tasks that would otherwise require extensive manual effort and resources.

Human Intuition: While IP boasts computational prowess, it lacks the human element. The manual method leverages human intuition, experiential knowledge, and the ability

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to consider qualitative factors. In scenarios where context, nuance, and adaptability are vital, the manual approach, with its human-driven processes, can potentially outshine algorithmic methods.

Scenario Specificity: The performance of Integer Programming (IP) is intrinsically linked to the specific conditions and intricacies of the scenario it's applied to. A primary consideration is the modeling limitations of IP. While IP excels in mathematically defining problems with clear, quantifiable data, real-world scenarios often come with qualitative factors and subjective elements that can't be easily encapsulated in mathematical terms. For instance, while IP might effectively optimize a manufacturing process with distinct variables, it might grapple with the nuanced preferences in a customer service setting where human emotions and subjective judgments play significant roles.

doi:10.6342/NTU202400044

5.3 Factors not considered

Service quality & customer experience, is not considered in our analysis for several reasons. Firstly, metrics within this category, such as customer satisfaction, are inherently subjective. They can display broad variability based on individual preferences, making them challenging to quantify in a consistent manner. Additionally, the data provided does not include specific metrics related to service quality or customer experience. This absence underscores the potential for vast external influences on these metrics, which might not be directly tied to the operational methods being compared. Such externalities can introduce confounding factors, detracting from the clarity and specificity of our analysis.

Financial & environmental Impact extends beyond the immediate scope of our current analysis, which is centered on operational and resource metrics. Delving into financial and environmental implications requires a comprehensive understanding of various intricate factors. For instance, accurately gauging environmental impact demands insights into aspects like energy consumption, waste generation, and more. Given that the provided data does not encompass detailed financial or environmental metrics, our capacity to offer informed comparisons in these domains is limited. Thus, to maintain the precision and relevance of our analysis, we've opted to center our attention on the operational efficiency and resource management aspects of the methods.

This study, while offering insightful comparisons between the Manual and Integral Programming methods, has certain limitations. Primarily, our analysis was

doi:10.6342/NTU202400044

constrained by the specific metrics provided in the dataset, focusing predominantly on operational efficiency and resource management. As such, potentially crucial dimensions like service quality, customer experience, financial implications, and environmental impact were not incorporated. These unexplored dimensions could offer a more comprehensive perspective, influencing the comparative assessment of the two methods.

Additionally, the study's findings are inherently scenario-dependent, meaning the results and conclusions drawn might not generalize across all possible operational contexts. The absence of real-world qualitative insights and the reliance on quantitative data alone could potentially oversimplify complex logistical challenges. Without a deeper understanding of the specific operational environment, externalities, and potential confounding factors, the applicability of the study's conclusions to broader or different contexts remains uncertain.

doi:10.6342/NTU202400044

5.4 Future direction

Customizability and Flexibility (Low Difficulty): Ensuring that operational methods can be tailored to specific needs is foundational for their success. This research direction, relatively more straightforward, would emphasize iterative testing and refinement of the Manual and Integral Programming methods across varied scenarios. The primary challenge is to retain the core strengths of each method while allowing for adaptability. With continuous feedback and refinement cycles, these methods can be honed to cater to diverse operational requirements, ensuring their broad applicability.

Real-world Implementation (Moderate Difficulty): Moving from controlled studies to real-world settings introduces a myriad of variables. Practical environments come with their set of challenges, from human behavioral factors to unpredictable disruptions. Conducting such studies would necessitate collaborations with entities willing to test these methods in live environments. While the insights derived would be invaluable, researchers would need to establish rigorous data collection protocols and ensure that the learnings from real-world feedback are looped back into refining the operational methods.

Scalability Analysis (Moderate Difficulty)**:** As operations expand, understanding the adaptability and performance of the Manual and Integral Programming methods becomes vital. While the foundational principles might remain consistent, the dynamics of large-scale operations can differ significantly from smaller ones. This direction would involve progressively scaling up the operational contexts in

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which these methods are tested, closely observing performance dynamics, and preemptively addressing potential challenges that arise with growth.

Interdisciplinary Insights (Moderate Difficulty): Integrating operational research with insights from fields such as psychology or behavioral economics can offer a multifaceted understanding of logistical challenges. This research direction, while conceptually enriching, involves the complexities of merging quantitative data with qualitative insights. The integration of additional diagnostic procedures, such as endoscopy, into the scheduling framework presents a more intricate challenge. It necessitates the acquisition of more detailed data to accurately determine resource requirements. Despite these complexities, we are confident in the adaptability of our algorithm. Its effective management of CT scheduling serves as a testament to its capability to accommodate activities beyond the scope of the department. By establishing collaborative studies and synthesizing diverse perspectives, the aim would be to bridge the gap between operational metrics and human experiences, offering a more holistic view of the operational landscape.

Algorithmic Enhancements (High Difficulty): Deep-diving into the Integral Programming method to innovate or refine algorithms is a challenging yet rewarding endeavor. This direction demands expertise in computational research, not just in tweaking existing algorithms but potentially in pioneering new approaches. The dual challenge here is ensuring that these enhancements are both theoretically robust and practically applicable, calling for a blend of academic rigor and practical insights.

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Artificial Intelligence Integration (High Difficulty): The realm of AI integration in operational methods is at the forefront of technological innovation. AI, with its predictive capabilities and decision-optimization potential, can revolutionize operational systems. The challenges, however, are manifold. From ensuring that AI models are trained ethically and accurately to their seamless integration with existing systems, this direction requires deep AI expertise, extensive testing, and a visionary approach to harnessing technology for operational excellence.

doi:10.6342/NTU202400044

5.5 Conclusion

Our research compared the traditional manual scheduling approach with the IP method for addressing challenges in scheduling imaging health checkups. The IP algorithm creates an automated pipeline to dynamically schedule the daily workflow of customers undergoing multiple procedures. Although it is commonly believed that IP algorithms require significant computational power and time, our findings suggest otherwise. Contrastingly, the manual method, which relies on human expertise, may be time-consuming but has the potential to consistently produce optimal or near-optimal results. Remarkably, the outcomes generated by our IP solution were found to be similar or nearly as effective as manual scheduling within a preset time limit of 20 minutes. However, it is important to note that our current model does not account for unpredictable variables such as staff absences, equipment malfunctions, or unexpected extensions in examination times. To be truly effective in clinical settings, it is essential to integrate complex mathematical models that can quantify and accommodate these uncertainties.

Our comparative analysis of the manual and IP methods across various scenarios revealed nuanced insights into their respective performances. When it comes to resource management, the manual method often presents a more balanced approach, ensuring resources are utilized optimally and minimizing both idle and over times. The IP method, while rigorous, sometimes leans towards specific optimizations, which can lead to trade-offs in resource utilization. While the current analysis was focused on operational and resource metrics, it's essential to acknowledge that a more comprehensive comparison, incorporating aspects like service quality and financial implications, could further enrich our understanding. Such dimensions could introduce

doi:10.6342/NTU202400044

additional factors that might sway the preference towards one method over the other, especially when considering long-term strategic goals and broader stakeholder implications.

In sum, it is evident that both the manual approach and IP have their respective strengths and limitations, and there is no universally superior method. The decision to utilize one over the other must be informed by the unique demands of the operational context, the specifics of the scenario in question, and a comprehensive assessment of the benefits and compromises each method presents. Incorporating IP into our daily operations has the potential to significantly refine the scheduling process and bolster overall efficiency.

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