INSTITUTO
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Multi-Objective Optimization of Resource Allocation in the Project Portfolio Selection Process: An Integrated FAHP-MCGP Approach

WANG Xiong

Doctor of Management

Supervisors:
PhD Fernando Ferreira, Associate Professor with Habilitation,
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Declaration

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and that to the best of my knowledge it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: Xiong wang Date: August 27, 2022

Name: WANG Xiong

作者申明

本人郑重申明：除了论文致谢中明确说明并致以谢意的部分外，所呈交的论文不包含任何他人或作者本人已用于获得任何教育机构的学位和证书而使用过的材料。同时尽我所知，除了文中特别加以标注引用的内容外，本论文不包含任何其他个人或集体已经发表或撰写的成果作品。

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Abstract

Internal audit is a function that provides independent and objective assurance and consulting services to business partners. Planning internal audit activities by selecting important audit projects and deploying appropriate resources enables audit function to use constrained resources effectively and efficiently. However, studies on internal audit planning have limited exposure in the literature. Moreover, prior research only focused on partial processes of the internal audit planning and was only concerned with risk management goal, which mainly applied ranking methods to prioritize candidate projects. To the best of our knowledge, a comprehensive and robust model has not been established to address the decision-making problems associated with the audit planning process. To fill these gaps, an integrated multi-stage framework is presented to develop a solid risk-based internal audit plan. The proposed framework begins with the risk assessment of auditable areas using FAHP, a combination of fuzzy comprehensive evaluation (FCE) and analytic hierarchy process (AHP). The next stage is to select project portfolio and allocate audit resources simultaneously through weighted multi-choice goal programming (Weighted MCGP) approach, minimizing aggregate deviations for multiple value-added objectives including risk mitigation. The third stage is to assign staff to the selected projects by balancing auditor preference and suitability of auditors for projects via MINMAX MCGP model. Finally, an audit schedule is displayed by creating a Gantt chart. A case study is performed to demonstrate the feasibility and validity of the proposed methods. The results show that the designed framework is a useful tool for internal audit planning and has promising practical application in various selection and allocation problems.

Keywords: Internal audit planning; Multiple criteria decision analysis; Risk assessment; Multi-Choice Goal Programming; Resource allocation optimization

JEL: C44; H83.

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Resumo

A auditoria interna é uma função independente que fornece serviços de consultoria para parceiros de negócio. Planear a atividade de auditoria interna, selecionando projetos importantes e implementando recursos apropriados, permite que a função de auditoria use recursos limitados de maneira mais eficaz e eficiente. No entanto, estudos anteriores sobre planeamento de auditoria interna têm vindo a revelar uma exposição limitada na literatura e concentram-se apenas no processo parcial da atividade de planeamento, preocupando-se apenas com a gestão de risco e/ou em aplicar métodos de classificação para priorizar projetos. Tanto quanto foi possível apurar, ainda não foi desenvolvido um modelo abrangente e robusto para resolver os problemas de tomada de decisão associados ao processo de planeamento de auditoria interna. Para preencher esta lacuna, uma estrutura integrada de vários estágios é apresentada para desenvolver um plano de auditoria interna baseado em risco. A estrutura proposta começa com a avaliação de risco de áreas auditáveis usando o método FAHP. Ou seja, uma combinação de *fuzzy comprehensive evaluation* (FCE) com o *analytic hierarchy process* (AHP). A etapa seguinte passa por selecionar o portfólio de projetos e alocar recursos simultaneamente por meio da abordagem de programação de metas de múltipla escolha ponderada (MCGP ponderada), minimizando os desvios agregados para vários objetivos de valor agregado, incluindo mitigação de riscos. A terceira etapa consiste em designar funcionários para os projetos selecionados, equilibrando a preferência do auditor e a adequação do auditor para o projeto por meio do modelo MINMAX MCGP. Por fim, um cronograma de auditoria é exibido criando um gráfico de Gantt. Um estudo de caso é apresentado para ilustrar a viabilidade e a validade da abordagem proposta. Os resultados indicam que a estrutura proposta é uma ferramenta útil para o planeamento de auditoria interna e tem aplicação prática substancial em vários problemas de seleção e alocação.

Palavras-chave: Planeamento de auditoria interna; Análise de decisão com múltiplos critérios; Avaliação de risco; Programação de Metas de Escolha Múltipla; Otimização de alocação de recursos

JEL: C44; H83.

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摘要

内部审计是企事业单位中具有独立性的职能部门，其为业务伙伴提供客观的确认和咨询服务。通过内部审计计划选择重要的审计项目并部署适当的资源，可以使内审部门有效地利用有限的审计资源。然而，关于内部审计计划的研究还十分有限。此外，过去的研究只关注审计计划过程中的部分阶段以及追求风险管理的单一目标。这些研究主要应用排序的方法来确定候选项目的优先级。就我们所知，目前尚未建立一个全面、稳健的模型来解决审计计划过程中的相关决策问题。为填补这些研究空白，论文提出了一个整合的多阶段框架用于制定风险导向的内部审计计划。该框架首先使用基于层次分析法的模糊综合评价模型 (FCE-AHP 或 FAHP) 对可审计领域进行风险评估。下一步则是通过加权多重选择目标规划 (Weighted MCGP) 的方法选择审计项目组合并分配资源，以最大限度的满足包括风险缓解在内的多个价值增值目标。为平衡审计人员对不同项目的偏好以及审计人员自身的技能与项目要求之间的匹配度，第三阶段通过最小最大化多重选择目标规划 (MINMAX MCGP) 模型将审计人员指派到已选定的审计项目中。最后，通过制作甘特图来展示审计计划的各个要素。论文通过一个真实案例证明了该方法的可行性和有效性。结果表明，文中所提出的整合性框架是制定内部审计计划的一个有效工具，且在解决诸多选择和分配的实际问题中具有较强的应用性。

关键词: 内部审计计划；多准则决策分析；风险评估；多重选择目标规划；资源配置优化

JEL: C44; H83。

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Acknowledgements

When my close friends thought I would pursue a Ph.D. degree as soon as I graduated from my master's in accounting program, I chose to start my career as an auditor in a global public accounting firm, and then continued my career in financial analysis and internal auditing positions in multinational companies. However, the vision I set during my undergraduate study, being a researcher with professional experience, has never been changed. By working in the industry, I also realize that there is something determinative to my personality. My curious for knowledge, my happiness from the interactions with scholars and my dream of researching and teaching distinguish myself from most of my colleagues. I always consider academia as another option of my career path. Additionally, as a part-time lecturer at Nanjing Audit University and Nanjing Xiaozhuang University, I also realize that the integration of theory and practice is the essence of learning although accounting and auditing are highly practical subjects. After working in the industry for ten years, I began to look for a doctoral program, aiming to address practical problems in audit management through research, and obtain the degree required for a faculty position. The Doctor of Management program at ISCTE-IUL and UESTC provides me the opportunity to connect the pulse of auditing practice with academic research. I am very grateful to the entrepreneurial team for initiating the program by considering the needs of professionals, as well as all the program staff for their efforts to promote the sustainable development of the program.

I sincerely thank ISCTE-IUL supervisor, Professor Fernando Ferreira, for the guidance throughout the thesis work. Besides, Dr. Fernando not only instructed me on how to select and attend international academic conferences, but also provided suggestions to properly respond to comments from journal reviewers. In the meantime, I would like to express my sincere thanks to UESTC supervisor, Professor Pengyu Yan, for taking time to discuss research ideas, as well as his guidance and advice. In addition, I would like to express my special thanks to Professor Ching-Ter Chang from Chang Gung University. A lecture given by Professor Chang inspired me to study management science and use operational research tools to solve practical problems. As a novice researcher, I was very fortunate to have the support, encouragement, and collaboration of Professor Chang. With the help of those professors, I have been able to publish papers on SCI/SSCI journals and complete my doctoral thesis.

In the journey of pursing doctoral degree, there was frustration when receiving rejection letters from the journal editor, happiness when articles were accepted by journals, and collapse when the text, which took me a few days to complete, got lost and could not be recovered. All these experiences will be treasures in my life. I am very grateful to my family for their support of my decision on further study and taking care of home so that I could focus on my research. At last, I would like to thank the internal audit department mentioned in the case study of this thesis for the support of this research.

An ancient Chinese poet by the name of Yuan Qu says in one of his famous poems, *"The way was long, and wrapped in gloom did seem. As I urged on to seek my vanished dream"*. Earning the doctoral degree does not mean the end of research work. I may become a full-time faculty/researcher at a university one day. Before my career path is switched, I will also continue conducting research and strive for producing consistent and high-quality research output.

致谢

当很多同学和朋友认为我会在会计硕士毕业后继续攻读学术博士学位的时候，我选择加入一家国际会计师事务所开始我的职业生涯。之后，又进入跨国企业从事财务分析和内部审计工作。然而，在本科时期就设定的愿景——成为既懂实务又会科研的财务专家——却一直未曾改变。工作期间，在南京审计大学和南京晓庄学院担任兼职教师的经历也让我意识到，虽然会计与审计是实践性较强的学科，理论与实践融合共进才是学习的本质。在积累了十年的业界工作经验后，我开始寻找博士项目，希望能通过学术研究来指导解决审计管理中的现实问题，同时也取得高校教职的敲门砖。电子科技大学和里斯本大学学院合作管理学博士项目给予了我在继续把握审计实践脉搏的同时进行学术研究的机会。非常感谢项目创始团队能考虑到管理者的需求并促进项目的成立，以及项目组所有工作人员为推进项目持续发展所付出的努力。

我诚挚地感谢葡方导师 Fernando Ferreira 教授对我的细心指导。不仅对我的毕业论文提出了改进建议，而且指导我如何回复期刊审稿人的意见。在我完成毕业论文之后，Fernando Ferreira 教授还继续指点我如何参加学术会议。同样，由衷感谢中方导师晏鹏宇教授的指导。晏老师亦师亦友，给与了我足够的信任，在鼓励我放手探索感兴趣的领域的同时，点拨我发表高质量学术论文的要点。此外，我还要特别感谢长庚大学张锦特教授。张教授的一场讲座叩开了我学习管理科学的大门，让我意识到运筹学具有极强的实际应用性，进而开展研究并将其运用到问题解决中。能在初入科研领域的时候得到张教授的支持并聆听教诲，是我莫大的幸运。没有以上诸位老师们的帮助，就没有我的毕业论文和已公开发表的 SCI/SSCI 论文。

回想过去，就读本项目期间发生的种种仿佛历历在目。有论文投稿后收到编辑拒信时的挫败感、有论文最终被决策科学领域主流学术期刊接受时的喜悦、亦有写了好几天的大段文字突然在文档中消失时的崩溃，这些经历都将成为我人生中的宝贵财富。非常感谢我的家人，她们对我深造的支持和在生活中的付出让我能够集中精力开展科研。最后感谢本文案例中内审部门的所有人员对本研究的支持。

“路漫漫其修远兮，吾将上下而求索”。获得博士学位并不意味着科研工作的结束。在未来的某一天，也许我会选择进入高校，成为全职的教学科研人员。在这一职业转变未发生之前，我也将继续从事研究，争取有持续的更高质量的成果产出。

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Chapter 1: Introduction

As the beginning of the main body of the thesis, chapter one mainly provides a broad overview of the research area. This research is carried out in the fields of both internal auditing, a type of project-based activity, and operational research, an analytical approach of problem-solving and decision-making. There are six components of the chapter. First, the background section clarifies the concept of internal auditing and explains its importance. Additionally, a typical internal audit cycle is presented, and then the motivation to study the risk-based internal audit planning problem is introduced. Second, the research problem is put forward. Specifically, there are four major research questions to be addressed. Third, the theoretical and practical significance of the research are discussed. The fourth section elaborates the research methods, such as the application of operational research techniques, followed by the thesis structure in the fifth section. The final section states the expected results of the study.

1.1 Research background

As an internal business department, the internal audit function (IAF) is typically perceived as a vital agent of organizational change (Kundinger, 2020; Roussy & Perron, 2018; Sarens et al., 2016). The definition of internal auditing (IA) varies among different professional bodies and governmental bodies, and the one elaborated by the Institute of Internal Auditors (IIA) is currently one of the most widely used. Founded in 1941, IIA is an authoritative international professional association that develops internal audit standards and practice guidance, as well as provides certification, research, and education. According to the definition of IA in the IIA's International Professional Practices Framework (IIA, 2017), *"internal auditing is an independent, objective assurance and consulting activity designed to add value and improve an organization's operations. It helps an organization accomplish its objectives by bringing a systematic, disciplined approach to evaluate and improve the effectiveness of risk management, control, and governance processes"* (p. 23).

Like other project-oriented organizations, such as engineering, procurement, and construction (EPC) firms, consulting firms, information technology (IT) departments, and research and development (R&D) centers, the IAF also fulfills its responsibilities by conducting various types of audit projects. Concretely speaking, an IAF carries out audit activities on different auditable units to achieve departmental goals, and every audit engagement is considered as an individual project. An auditable unit (also called as auditable area, auditable subject, or auditable entity) is the collection of elements in the organization that is exposed to risks and upon which controls to prevent, detect, and correct errors and fraud are applied. Each auditable unit can be a potential project to be worked on by internal auditors. The nature and scope of the auditable unit differ in the specific organizational context, ranging from business units (e.g., accounting, procurement, sales, and human resource department) to geographic regions (e.g., business entities or subsidiaries around the world), processes (e.g., fixed asset management, vendor payment, and contract management), risk types (e.g., anti-corruption, fraud, and data protection), and a combination of these different types of topics (Rossi et al., 2010). The work scope of the IAF in its early stages primarily focused on assets safeguarding, financial information verification and compliance examination (Turetken et al., 2019). With the development of the internal auditing profession, responsibilities of internal auditors have been expanded to conduct a variety of audits, including strategic, financial, operational, compliance and IT audits. Given the new demands from stakeholders, the IAF have even begun to act as the advisory role in recent years in addition to the traditional assurance role, enhancing its value-added potential through delivering the right insights to the business. Assurance services provided by the IAF aim at assessing investigated areas through objective examination of evidence, whereas advisory (or consulting) services intend to facilitate clients meeting their goals (Colbert, 2002; Wilkinson & Coetzee, 2015).

A variety of theories have been used to explain the development and adoption of an IAF, including agency theory (Adams, 1994), transformation theory (McNamee & McNamee, 1995), transaction cost theory (Spraakman, 1997), institutional theory (Al-Twaijry et al., 2003), new institutional theory (Arena & Azzone, 2007), Karl Marx's theory of the circuit of industrial capital (Mihret et al., 2010), and labor process theory (Mihret, 2014). Internal audit, together with the audit committee (AC) of the board of directors, the external auditor, and executive management, constitutes the cornerstones of corporate governance (Emair et al., 2021). Empirical research supports that an effective IAF plays a critical role in the detection of occupational frauds and good corporate governance and consequently in the company's survival and success (Carcello et al., 2005; Eulerich et al., 2013; Vadasi et al., 2019; Westhausen, 2017). The results of Alzeban (2021)'s analysis on global data also suggested that IAF contributed to promoting economic growth. At present, the IAF has become a mandatory department for publicly listed companies, financial institutions, and public sector (i.e., government organizations) in many countries by laws and regulations. For instance, the New York Stock

Exchange (NYSE) requires every publicly listed company to establish an IAF (Prawitt et al., 2009). Publicly listed companies in China, India, Indonesia, Malaysia, Philippines, and Thailand are also obligated by stock exchanges or governments to set up an IAF (Raiborn et al., 2017). Besides, approximately 90% of European Union (EU) member countries require or recommend the presence of an IAF in a publicly listed company (cf. Florea & Florea, 2013). The Basel Committee on Banking Supervision (BCBS) also mandates that as a highly regulated industry, banks and insurance companies must maintain an IAF (Sarens et al., 2012). Furthermore, according to an IIA's global internal audit survey, 77% of the 2,824 public sector respondents indicated that internal auditing was required in the country or area where their organizations were based, with the highest percentage from Europe-Central Asia (92%) and lowest rate in the United States and Canada (66%) (MacRae & van Gils, 2014). On the other hand, academic researchers kept calling for studies to investigate internal audit practices and processes (Behrend & Eulerich, 2019; Christ et al., 2021; Kotb et al., 2020; Lenz & Hahn, 2015; Mihret & Grant, 2017; Roussy & Perron, 2018). For example, based on the review of internal audit studies from 2005 to 2017, Roussy and Perron (2018) argued that the extant literature was far from having a comprehensive picture of how internal auditors conducted activities and every phase of the internal audit cycle deserved further investigation.

To acquire an overall understanding of IAF's daily activities, a review of the internal auditor job description is conducted. A job description, or job profile, is the textual data which characterize job postings. A total of 150 job descriptions are collected from open positions published in September 2021 on Indeed, a renowned American job search website. The reviewed positions cover internal auditor at various job levels (i.e., associate, manager, director, and vice president) in different organizations located in the United States (e.g., technology company, manufacturing company, energy company, service company, and government authority). Figure 1.1 structures internal auditor responsibilities and duties from these job descriptions by means of a simple word cloud. The description of expected qualification is excluded from the job analysis. As illustrated, IA is highly relevant to managing business risks and process controls. Working in project mode, internal auditors review documentation, perform testing, identify issues, and provide recommendations to the stakeholder. From the identified keywords (e.g., compliance, operational, financial, IT) in the job descriptions, the IAF's work scope discussed earlier also can be verified. In the meantime, a clear pattern emerges, showing that developing an annual work plan (or planning) is regarded as the key element of internal audit activities, followed by project execution and reporting.

Figure 1.1 Word cloud: internal audit work description

In addition to a high-level review of internal auditor responsibilities and duties, a deep dive into the internal audit process is taken as follows. In a typical internal audit cycle, the work begins with the development of an annual internal audit plan (or can be called as "audit plan"), which is a schedule of selected internal audit projects to be conducted in the coming year. Once the audit plan is completed and approved by the audit committee, internal auditors will carry out each project according to the planned timeline and resources (e.g., manpower and budget). Admittedly, due to the new events or challenges faced by the organization, the established audit plan might be amended throughout the year for ad-hoc requests from management. Internal audit planning is an integral part of internal audit work and a prerequisite for launching any audit project. Each audit project consists of the following four general phases of activities: (1) planning. In order to prepare for each individual project, internal auditors will send out an announcement letter to notify key contacts about the upcoming audit, prepare a planning memo which describes audit background, scope and approach, design audit procedures based on the detailed risk assessment of the auditable area, and then request related transactional data and/or supporting documents from auditees (departments being audited); (2) fieldwork. It is an execution phase and the key tasks include holding kick-off meeting, performing testing according to the designed audit steps, documenting the audit process in working papers, and holding closing meeting; (3) reporting. As the final product of the IAF, an audit report is issued to communicate the audit results. The audit report normally describes the identified issues, root cause of the problem, and the action plan and corresponding owners to fix the problem; and (4) follow-up. When the agreed action plans for addressing the audit findings are due, internal auditors will review the implementation status. Petukh et al. (2020) and Puad et al. (2020) described the implementation process of an internal audit project through case studies. According to the internal audit workflow described above, the annual internal audit plan is the source of audit work and provides the specific direction of other internal audit activities. As the saying goes, *"a good beginning is half the battle"*. A well-prepared audit plan helps to devote appropriate attention to important and valuable areas, and thus ensure the internal audit effectiveness. By aligning internal audit projects with key organizational priorities and engaging with stakeholders, an effective annual audit plan maximizes IAF's capability to render value-added services with high quality (Pitt, 2014). Therefore, annual audit planning is a crucial topic that is worth receiving greater attention from both academics and practitioners.

As required by the International Standards for the Professional Practice of Internal Auditing (or "Standards") issued by the IIA, chief audit executive (CAE) who is the head of internal audit team must establish a work plan based on a risk assessment undertaken at least annually; the plan determines the priorities of the internal audit activities, which should be consistent with the organization's goals; and CAE also must ensure that appropriate and sufficient internal audit resources are deployed effectively to accomplish the approved plan (IIA, 2017). The risk-based annual audit planning generally comprises risk assessment, project portfolio selection with resource allocation, project staffing and scheduling. In the process of developing the annual audit plan, internal audit management assess risk levels of auditable units firstly, and then estimate the needed time for performing each candidate project. Once finished, audit project portfolio can be selected considering the risk assessment result, stakeholder preferences and resource constraints. Audit staff are then assigned to the selected projects. Finally, each audit project is slotted into the available weeks and months of a year. In substance, internal audit planning is a multiple-objective optimization of resource allocation in the project portfolio selection process based on risk assessment.

A risk-based approach to internal audit planning enables the IAF to focus limited audit resources on the real threats to the organization and provides transparency to the selection of project portfolio. By comparing with non-risk-based approach, Purwanto et al. (2017) evidenced that risk-based audit planning decreased 26% working days of the planned year for a public sector. A risk-based audit planning approach is the key to adding value to the organization through internal audit. This approach continues to occupy the top position in the tools and techniques used by internal auditors (Larasati & Bernawati, 2020). An empirical survey conducted by Allegrini and D'Onza (2003) revealed that 72% of the 'Top 100' companies listed on the Italian Stock Exchange (answer rate 65%) applied a risk-based approach when preparing the annual audit plan. Castanheira et al. (2010)'s survey results indicated that out of 59 usable responses, 82% of entities whose CAEs were members of the Institute of Portuguese Internal Auditors adopted risk-based annual audit planning. According to the 47 responses of internal auditors from different Ghana's Club 100 group of companies, Ayagre (2014) observed that risk-based audit planning was widely used among them (87%), especially in financial, telecommunication and manufacturing industries. In addition, Global Internal Audit Common Body of Knowledge (CBOK) carried out a global study of the IA profession from February to April 2015, which covers 166 countries with 14,518 respondents. The survey concluded that a global average of 85% respondents followed a risk-based methodology as a resource to establish audit plan, whereas the rate is only 60% in China and South Asia (Piper, 2015; Sobel, 2015).

Typically, there are some pain points in the annual audit planning process. First, internal audit management lack clear targets and full picture of the planning work. Based on the limited information available, audit managers rely on intuition merely when choosing project portfolios and assigning audit staff to the projects. The 2015 CBOK survey reported that more than half of all respondents globally indicated that the usage of technology tools in risk assessment or audit planning is "none" or "minimal" (Cangemi, 2015). Second, a disconnection between the risk assessment result and the resource usage makes resource allocation unjustified and ineffective. This shortcoming may largely result in the neglect of important projects and complicated relationships among planning elements, and an unpersuasive and unsatisfactory audit plan might be established. Third, audit planning team also suffers from the manual distribution of available audit hours and project scheduling. Developing an annual audit plan is a time-consuming task. Gartner (2018), the world's leading research and consulting firm, conducted a professional survey on 88 organizations covering various industries, sizes and geographies. According to the survey results, the planning process took 78% of the survey participants from 4 to 12 weeks.

Motivated by the significance of the internal audit planning process, the advantages of risk-oriented approach to internal audit planning, the performance gaps, and the large gap between what academics have studied and what internal audit practitioners have valued, this research is concerned with the development of a comprehensive risk-based annual audit plan within a reasonable time period, using some straightforward and easy understanding mathematical tools. The purpose of this thesis is to apply operational research (OR) methods to determine the priority of potential audit projects, allocate internal audit resources to competing projects, match audit staff with selected projects according to the desired objectives, and finally present the plan in a visual format.

1.2 Research problem

Internal audit management face dilemmas and difficulties in making a solid annual internal audit plan. Internal audit resources (i.e., time, manpower and fund) are scarce whereas there is a broad list of candidate audit projects that can be carried out. Proper project portfolio must be chosen to ensure the value of IAF to the organization through quality service. At the same time, internal auditors have their own preference over the selected audit projects to be worked on, and vice versa. The presence of inappropriate and unfavorable personal assignment will unnecessarily hamper the harmoniousness between internal auditors' preference and project requirements/characteristics, resulting in low job satisfaction and employee motivation, poor work efficiency and quality, and potentially a project delay and even an audit failure. In other words, an imbalance between supply and demand of internal audit resources, and a mismatch between audit staff and audit project constitute the research problem.

Annual internal audit planning involves complex and challenging decision making in the process. According to the project characteristic and resource availability, the planning process must ensure an effective and efficient use of limited internal audit resources to maximize expected utility. The substance of an audit plan is to maintain organizational risk level as low as possible and to satisfy management's expectation as much as possible by selecting and scheduling appropriate assurance and consulting projects. To this end, one feasible solution to the audit planning problem is to minimize the total deviations from the desired planning goals under resource constraints, and to find a balance between the auditors' interest and the characteristics of audit projects, taking advantage of project prioritization techniques and resource allocation optimization methods.

Internal audit planning specifically handles the following decision-making problems:

- Evaluate risks of the auditable units and determine the risk appetite (or the risk acceptance level).
- Select resource-constrained internal audit projects to ensure efforts will be focused on the most valuable areas.
- Assign available audit staff to proper internal audit projects which have been selected.
- Develop work schedule of the selected internal audit projects according to the staff

assignment results.

Correspondingly, the thesis attempts to answer the following four major research questions:

- How to develop a realistic and effective risk-based internal audit plan to accomplish pre-defined goals?
  - What are the key steps, objectives, and constraints to be considered during the annual audit planning process?
- Which internal audit projects should be chosen to add value to the organization and meet expectation from senior management and audit committee?
  - Before performing any audit activity, how to evaluate the risk level that remains (i.e., residual risk) in each auditable unit after considering the existing control measures in place?
  - How to determine the amount of residual risk that can be mitigated (i.e., risk reduction value) by conducting the candidate internal audit projects (assurance or advisory engagement) in the auditable units?
- Who should be assigned to the selected audit projects?
  - Why are the assigned auditors better suited for the audit projects than others (i.e., a suitability value between each internal auditor and each audit project)?
- When should each internal audit project be initiated and completed over the year (i.e., an estimated timetable)?

By addressing the above research questions, this study contributes to the existing literature in the domain of auditing, and to the practice of data driven decision making through innovative applications of OR, as discussed in the following subchapter.

1.3 Research significance

1.3.1 Theoretical significance

Due to several triggering events, such as financial crisis, global corporate scandals (e.g., Enron, WorldCom, Toshiba, etc.) and new legislations (e.g., Sarbanes-Oxley Act of 2002 (SOX) in the United States, Bill 198 in Canada, Green Paper on the EU Corporate Governance Framework, etc.), the past two decades have witnessed fundamental changes of the internal auditing profession and a boom in the internal auditing research (Grabmann & Hofer, 2014; Roussy & Perron, 2018). However, the body of internal auditing research is still small (Christ et al., 2021; DeFond & Zhang, 2014; Hazaea et al., 2021; Pizzi et al., 2021). The plausible reasons can be:

(1) IA is a much narrower discipline in comparison with the fields of financial accounting and external auditing (Kotb et al., 2020); (2) since there are almost no regulations requiring companies to disclose information on IAF, a lack of archival data hampers research efforts (Christ et al., 2021); and (3) there is a lack of laws or regulations pertaining to the practice of internal auditing. External auditing, a type of statutory audit performed by professional service firms, is subject to mandatory standards and rules. For instance, the adoption of International Standards on Auditing is required for all statutory audits to be performed in the European Union (Elmghaamez et al., 2020). In addition, all external auditors of publicly listed companies in the United States are subject to the inspection from the Public Company Accounting Oversight Board (PCAOB) (Aobdia, 2018). By contrast, although IAF's creditability can be strengthened by implementing IIA Standards as a best practice, either the IAF's conformance to IIA Standards or a periodic external assessment of internal audit quality is a voluntary action for the organization.

Internal auditing should be considered as a worthy research topic in and of itself, therefore, it is of particular importance to discuss internal auditing topic in academic research. By reviewing internal audit research published between 2005 and 2018, Kotb et al. (2020) discovered that prior internal audit research was predominated by positivist analyses, with a prevalence of descriptive works that use surveys, questionnaires, content analysis or historical analysis. There was little interpretative research using cases, field studies, or interviews in auditing field. In this regard, using a real-world case study, this thesis extends internal auditing literature by filling the noted research gaps, especially in the field of internal audit practice at the micro level.

Among the internal audit research topics, the decision-making problem of audit planning did not receive proper attention before (Goman & Koch, 2019). This study particularly focuses on the steps of making an internal audit plan to draw scholar's attention to the beginning of the internal audit work. The research is undertaken to achieve a comprehensive and in-depth understanding of the annual audit planning process. By examining how to set up an agile, risk-based, forward-looking, and integrated audit plan, this study also echoes to one of the future research directions proposed by Kotb et al. (2020). Moreover, this research advances theoretical knowledge and offers a new point-of-view on the risk assessment, project portfolio selection and staff assignment based on a hybrid of multicriteria decision analysis and multicriteria decision-making methods. The proposed novel framework for developing a risk-based audit plan contributes to expanding the existing knowledge base in the field of auditing.

1.3.2 Practical significance

A statistical hypothesis test is generally used to infer whether a particular effect exists. However, practitioners are virtually more interested in magnitudes than existence proofs, since magnitudes are more relevant to decision making (Basu, 2012). Ziliak and McCloskey (2008) believed that the cult of statistical significance has been well established among many social scientists and expressed a concern about over-reliance on statistical significance. When accounting and auditing research was trying to become more scientific, statistics-based articles began to crowd out other forms of investigation and became the mainstream in the field (Granof & Zeff, 2008). Nevertheless, these statistics-based articles do not often consider the meaning of a regression coefficient concerning real-life decision variables and their outcomes, making the research outputs rarely have practical implications (Basu, 2012; Kotb et al., 2020). The extant internal audit research has not made significant contribution to the knowledge of the IAF and everyday realities of practice, and unfortunately the practical impact of IA are still mysterious (Kotb et al., 2020). As highlighted by Colander (2018), to enhance the practical relevance in accounting and auditing research, role model should be changed to engineering, which tries to solve a specific problem in an uncertain situation using available resources (Koen, 2003). Thus, this study conducts an internal auditing research from decision science perspective to make it readable, interesting, and, more importantly, relevant to the real world.

The IAF may serve different purposes in specific organizational context, for instance, some internal audit teams focus on providing consulting service, some mainly work on fraud examination, while others concentrate on operational process improvement. The audit practices (e.g., organizational structure, audit methodology, report format) also vary widely from one industry to another and among organizations within the same industry (Bailey et al., 2003). Nevertheless, one thing in common is that all IAFs need to select and schedule a set of projects to be executed with available audit resources. In this situation, structuring project portfolio selection and resource allocation models for annual audit planning plays a prominent part in assisting decision makers (DMs) in managing the IAF effectively.

This research seeks to shed light on the annual internal audit planning problem, update practitioners on the current status of this fundamental topic, and help them gain a detailed understanding on utilizing useful decision analysis and decision-making concepts and tools in practice. This thesis should be of interest of individuals (e.g., CAEs and audit committee members), businesses (e.g., software companies) and policy makers (e.g., the IIA). First, the IAFs face the challenge of constructing a project portfolio selection algorithm to plan resources optimally. Many studies on planning field focus on the mathematical models but neglect the real-life implication of simplification to enable practitioners to understand and implement the models (De Bruecker et al., 2015). This study offers a practical alternative that permits an efficient allocation of limited audit resources in an orderly and systematic manner, and the IAF can implement the proposed framework without rigorous mathematical manipulations. In the next place, the proposed model helps audit management prioritize audit topics and strike a balance between project requirement and audit staff preference. It also supports the IAF in making a great difference to the organization and creating a unique identity by leveraging data to make more informed decisions. In addition, internal audit software companies can also incorporate the idea and model into the audit planning module of their software and even to develop new products, providing more flexibility to users and satisfying customer needs. Furthermore, the proposed framework with a real case study can be a good reference for the IIA to improve principle and guideline for developing risk-based audit plan to inform better practice.

1.4 Research methods

This thesis is an interdisciplinary study that involves both internal auditing and operational research for addressing internal audit planning problem. Auditing research is inherently interdisciplinary since it has always been about practical problems (Hay, 2017). Meanwhile, OR as a scientific instrument is also a practice-oriented discipline that deals with the development and application of mathematical models for problem-solving and decision-making in management. Design research, or design science, is a problem-solving paradigm. It is a process to build and evaluate artefacts that transform a given situation to better standards and to promote the approximation between theory and practice (Santos et al., 2018). Hevner et al. (2004) proposed seven guidelines as the benchmark for evaluating design research, including design as an artefact, problem relevance, design evaluation, research contributions, research rigor, design as a search process, and communication of research. From the point of view of design research, the practice of OR can be regarded as academic research. This perspective of research allows OR practitioners to present their consulting work as both research and practice projects (Manson, 2006; O'Keefe, 2014). Similarly, this study is process oriented and applies advanced analytical methods to work out a solution. In this way, a “constructivist” understanding of the annual internal audit planning process is developed.

Resource allocation models have been recognized in the literature to promote an effective use of scarce resources (Vivas & Oliveira, 2017). To distribute limited internal audit resources to numerous potential audit projects, this thesis proposes a novel model called as "integrated multi-stage annual planning framework" in the context of corporate internal auditing. Specifically, a fuzzy comprehensive evaluation (FCE) based on the analytic hierarchy process (AHP) (Saaty, 1980) model (FAHP) is used to assess the risk levels of the auditable units. Besides, risk reduction value is estimated taking account of the marginal effect of internal auditing effort on decreasing the risk. Project portfolio selection with resource constraints is achieved via weighted multi-choice goal programming (Weighted MCGP) method, and audit staff are assigned to projects utilizing MINMAX MCGP method. And then an annual audit schedule is displayed by creating a Gantt Chart. To illustrate how the proposed model can be applied in practice, a case study from the real world is presented.

In addition, the thesis is a combination of qualitative and quantitative evidence. In terms of data collection in the case study, interviews are conducted with the studied internal audit team and questionnaires are completed by the survey participants. Qualitative data are converted into quantitative measures before all the collected data can be analyzed with mathematical modeling. Then commercial software is used to obtain the solutions of models.

1.5 Research structure

The structure of the thesis is depicted as Figure 1.2.

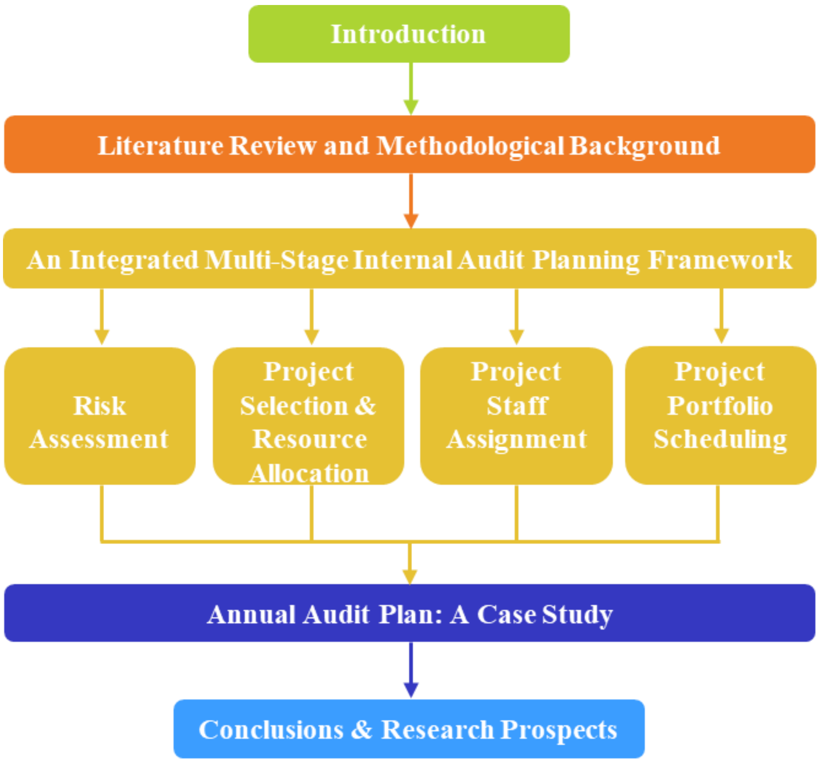

Figure 1.2 Thesis structure

According to the above layout, the thesis consists of five chapters with the following details.

Chapter 1: Introduction – This chapter describes the context of research topic, clarifies the motivation for undertaking the study, raises the major questions to be resolved, and explains the importance of the research. Finally, the research methods, thesis structure and expected research outcome are illustrated.

Chapter 2: Literature review and methodological background – This chapter includes two main components. The first one presents a literature survey to reveal the originality of the study. The review focuses on the general project portfolio planning problem and the internal audit planning problem under study. It defines relevant concepts, summarizes the characteristics of prior research, and analyzes three approaches to internal audit planning (i.e., cycle approach, cycle-risk-based approach, and risk-based approach). The other aspect is an introduction of the proposed multiple criteria decision methods that are used to solve the internal audit planning problem. The reasons, processes, and mathematical models of using the presented OR techniques (i.e., FCE, AHP, MCGP and its two variants) are elaborated.

Chapter 3: An integrated multi-stage framework for risk-based internal audit planning – To answer research questions raised in the first chapter, this chapter constructs a process-oriented framework with algorithmic solutions for developing a risk-based annual internal audit plan. This novel framework covers four phases, including risk assessment, project portfolio selection with resource allocation, audit staffing, and audit scheduling. The steps and methods of the four stages are described in detail. The model is formulated as well. In the process, scales are provided to measure risk levels of auditable units and competencies of audit staff, and exploratory research is made to calculate audit project's contribution to risk reduction and to estimate audit staff's suitability for conducting the audit project.

Chapter 4: Case application – To illustrate how the practical issue can be resolved with the proposed model, this chapter is to investigate a case study of a company in manufacturing industry. The current practice of annual audit planning process in the studied company is introduced, which mainly rely on intuitive decision and manual work. During the implementation of the designed framework, expert opinions are collected through the questionnaire, and models and data are processed by commercial software. The obtained results are analyzed and discussed. Then management feedback on the application of the proposed framework is also addressed. In addition, the sensitivity analysis is carried out to check the robustness of the solution.

Chapter 5: Conclusions and research prospects – The final chapter summarizes the conclusions of this research, discusses theoretical contributions and managerial implications, and finally pinpoints research limitations and provides recommendations for future research directions.

1.6 Expected results

By doing research into design-oriented OR, a comprehensive and integrated decision support framework is expected to be developed, which could assist the IAF in creating a risk-based annual audit plan. Specifically, the expected outcomes in each phase of the audit planning process are elaborated as follows.

- Risk assessment: a list of general types of risk for manufacturing sector should be generated, and the weights of the identified risk items will be obtained based on the AHP questionnaire completed by the experts. Then the current risk levels of auditable units can be measured by synthesizing expert ratings using FCE method. Based on the results, the contribution value of audit activities to risk reduction can be calculated.
- Audit project selection: based on DMs' objectives, a certain number of audit projects should be selected from the candidate projects and appropriate audit scopes (or audit time) should be determined for the selected projects concurrently using Weighted MCGP model.
- Audit staffing: auditor preference over projects can be firstly obtained through a questionnaire. Based on the manager's assessment of audit staff's competencies, a suitability value between auditor and project should be estimated by individual. Finally, auditors will be assigned to the selected projects to balance their preference and suitability using MINMAX MCGP model.
- Audit scheduling: an audit schedule should be developed in the form of Gantt chart.

This study is expected to enrich internal auditing literature by expanding the current knowledge about internal audit process and activity, and lead to better practice of annual audit planning. The research might also yield new insights to other research on project selection problem and multi-skill resource-constrained project scheduling problem.

Chapter 2: Literature Review and Methodological Background

The second chapter aims to conduct a review of the literature related to the research topic and introduce the methodological background for addressing the research questions as previously presented. This chapter is composed of four parts. The first part reviews prior research of project portfolio planning problem, focusing on its two critical phases (i.e., project portfolio selection and personnel assignment). The second part reviews the literature on one of the application fields of project portfolio planning – internal audit planning problem, which is a real-life problem faced by various organizations. Three types of principle of internal audit planning are presented: cycle approach, cycle-risk-based approach, and risk-based approach. The third part outlines multiple criteria decision methods for developing risk-based internal audit plan. The reasons for the use of the chosen tools, including FCE-AHP (FAHP) and two variants of MCGP, are elaborated. And then the calculation steps and mathematical models of these methods are described. A summary of chapter two is presented in the final part.

2.1 Project portfolio planning

A project is a series of interrelated tasks to be performed within a time frame in order to create a specific product, service or reach an outcome (Rosenau & Githens, 2011). A project portfolio is formed by a collection of projects that share and compete for scarce resources, such as people, time, funds, technique, assets, and materials (Tavana et al., 2015).

Project portfolio planning problem typically handles the prioritization, selection, and scheduling of candidate projects, and the appropriate personnel assignment (Gutjahr et al., 2008). As an important stage of project portfolio management, project portfolio planning is a complex and challenging decision-making problem. It aims to ensure that available resources are used efficiently and effectively. Examples include R&D project planning, new product development, employee continuing education, construction project planning, IT project planning, and internal audit planning. This thesis only focuses on the review of project portfolio selection and personnel assignment problems out of the voluminous project management literature. The resource-constrained project scheduling problem is not within the review scope due to the following reasons: (1) task-based scheduling is conducted during the detailed planning phase of each individual internal audit project, which is different from the area studied by the thesis; (2) on the contrary, annual internal audit planning aims to present a high-level schedule without using a set of formulations or algorithms; (3) internal audit scheduling is covered by the literature review on internal audit planning in subchapter 2.2; and (4) a well-known and useful scheduling tool, Gantt chart, is introduced in subchapter 3.5 for scheduling annual audit project.

2.1.1 Project portfolio selection

Project portfolio selection (PPS) is a complex decision-making process of choosing a subset of projects from available project proposals, aiming to achieve the established objectives without violating constraints and requirements (X. Zhang et al., 2020). Selecting the wrong project for a portfolio may lead to wasted efforts and failure of organization's goals.

Many scholars, especially in the past two decades, have studied PPS problem extensively considering its significance. Systematic literature reviews on PPS problem can be referred to Archer and Ghasemzadeh (1996), Danesh et al. (2018), Elbok and Berrado (2017), Iamratanakul et al. (2008), Kandakoglu et al. (2020), Mohagheghi et al. (2019), and Zorluoğlu and Kabak (2021). These authors investigated and analyzed previous research on project portfolio selection and optimization from different perspectives, such as the type of study, taxonomy of selection models and solution approaches, category of selection criteria, and classification of uncertainty modelling tools in evaluation and selection. Some other comprehensive literature surveys of PPS problem focused on specific project types, including R&D projects (Heidenberger & Stummer, 1999; Verbano & Nosella, 2010), innovation projects (Chaparro et al., 2019), digital transformation projects (Rodrigues et al., 2020), information system/technology projects (Ha & Madanian, 2020; Kundisch & Meier, 2011; Müller et al., 2015), strategic projects (Al-Sobai et al., 2020), six sigma project (Condé & Martens, 2020), and production process improvement projects (Kornfeld & Kara, 2011).

In the following text, a state-of-the-art review of PPS problem is conducted according to the selection and evaluation criteria, selection approaches and application areas. In order to avoid overlapping with the review scope covered by the above-referred literature review articles, this thesis mainly surveys relevant papers published since 2020 as presented in Table 2.1.

Table 2.1 A review of PPS research published in recent years (since 2020)

Reference	Considered Criteria	Methods	Application Area
Abbasi et al. (2020)	Outcome, risk, strategic advantages	BSC, Mixed-integer nonlinear programming	New product development
Bellahcene et al. (2020)	Benefits, cost, risk factor, user/decision-makers preferences, time	AHP, weighted additive fuzzy goal programming	Information system
Champion et al. (2020)	Cost, initial capital outlay	Stochastic programming	Energy efficient retrofit
Demircan Keskin (2020)	Organizational, financial, technical, risk, productivity	Fuzzy ANP, fuzzy nonlinear programming	Industry 4.0 implementation
Dixit and Tiwari (2020)	NPV, strategic alignment, risk	AHP, simulation optimization	Dairy firm
Harrison et al. (2020)	Delivery of capabilities	Integer linear programming	Future force design
P. Li (2020)	NPV, repayment guarantee, investment income changes with guarantee	Multi-objective chance constrained programming	Government guarantee
Ma et al. (2020)	Economic, environmental, social sustainability	Fuzzy TOPSIS	Paper manufacturing company
Panadero et al. (2020)	NPV, risk	Variable neighborhood search, Monte Carlo	General type
Raad and Shirazi (2020)	Content, structure, environment	DEMATEL-based ANP, linear programming	University transformation
RezaHoseini et al. (2020)	Economic, customer, process, environmental, social	BSC, fuzzy ANP/VIKOR/UTASTAR, ILP	General type
Song et al. (2020)	Profit, residential capacity, amount of employment	Stochastic multi-attribute acceptability analysis	Public house projects
Tansakul and Yenradee (2020)	Fuzzy NPV, fuzzy BCR, preference ratio	Linear programming, non-linear programming	Bank process improvement
Tavana et al. (2020)	Technical and execution capability, on-time delivery, organizational experience, strategies alignment	Fuzzy TOPSIS, mixed-integer linear programming	Cybersecurity industry
Yazdi et al. (2020)	Length of operation, cost, technology, location, budget, production capacity, quality, delay, logistics	Delphi method, Z-WASPAS, Z-BWM	Oil industry
Zorluoğlu and Kabak (2020)	Benefit, cost	Weighted cumulative belief degree approach	IT/business development
Farahbod and Varzandeh (2021)	Returns, risks, strategic issues	DEA, 0-1 integer programming	IT company

Ghannadpour et al. (2021)	Sustainable development	ANP, quality function deployment, UTASTAR	Automobile group
Hesarsorkh et al. (2021)	Profit, technical risk, market risk	Mixed-integer linear programming	Pharmaceutical R&D
Mavrotas and Makryvelios (2021)	Excellence, implementation, impact	Multicriteria analysis, mathematical programming, Monte Carlo	R&D
Mohammed (2021)	Time, quality, cost, safety, environmental	Fuzzy AHP, fuzzy TOPSIS	Oil company
Nowak and Trzaskalik (2021)	NPV, share of new products in sales, sales on the new market	Stochastic discrete dynamic programming	General type
F. Wang et al. (2021)	Unit water-saving cost	Cost-benefit analysis, pinch analysis, marginal cost curve diagram	Water conservation
Y. J. Wu and Chen (2021)	Efficiency, sustainability & resilience, quality of life	Delphi method, AHP, 0-1 goal programming	Smart city
L.-H. Wu et al. (2021)	Monetary and non-monetary factors	Stochastic dominance, fuzzy ranking	System development company
Kettunen and Lejeune (2022)	Time to attain a return target	Disjunctive stochastic programming	New product development
Mahmoudi et al. (2022)	Project resilience, project profitability	Elbow method with fuzzy c-means, robust ordinal priority approach	Refinery equipment manufacturer
Ranjbar et al. (2022)	Technical risk, political and social risk, strategic adaptation, competitive advantage	Fuzzy AHP, fuzzy TOPSIS	Construction and infrastructure
Tselios et al. (2022)	Financial performance	Dynamic programming	Energy project

Evaluation and selection criteria play a crucial role in the success of PPS system. In previous studies of project evaluation and selection, lots of qualitative and quantitative criteria have been applied. These criteria can be classified into three groups: financial criteria, strategic criteria, and other criteria. To begin with, financial criteria, such as net present value (NPV), benefit-cost ratio (BCR) and return on investment (ROI), measure the economic benefit and cost of the projects/organizations. Similar to the studies published before 2020, literature on PPS problem in recent years also use NPV frequently, making it one of the most popular financial criteria. To deal with the uncertainty of the project data, fuzzy NPV can be employed to improve the traditional NPV method. Next, strategic criteria are related to the strategic goals of the organization which can be achieved through the implementation of project portfolio. Some examples of the key strategic criteria applied recently are customer/employee satisfaction, social impacts, environmental condition, and business sustainability. In the third place, for special attributes that cannot be categorized into the first two groups, they belong to other criteria. For instance, Dixit and Tiwari (2020) addressed risk of severe low returns yielded from the project portfolio. Total risk of the projects (e.g., technical, managerial, personnel) was used in the work of Demircan Keskin (2020). Mavrotas and Makryvelios (2021) addressed scientific and technical excellence of the proposed project, quality, and capacity of the project implementation as well as the impact of the proposed project. Harrison et al. (2020) considered capability gain. Project interaction degrees (Wei et al., 2020), on-time delivery and organizational experience in the execution of similar projects (Tavana et al., 2020) also belong to other criteria. It can be seen from Table 2.1 that nowadays researchers usually consider multiple criteria in the PPS problem rather than a single criterion to make more informed and better decisions.

The PPS problem is a challenging and multi-dimensional problem which requires analytical methods in the process as opposed to intuitive decisions considering cognitive limitations (Schiffels et al., 2018). Numerous OR techniques have been developed in previous literature to solve this problem. Models used in the PPS problem can be grouped into three categories, i.e., optimization methods, ranking methods, and frameworks and decision support systems (DSSs) (T.-Y. Chang & Ku, 2021; Mohagheghi et al., 2020). A mind map of these three categories is shown in Figure 2.1.

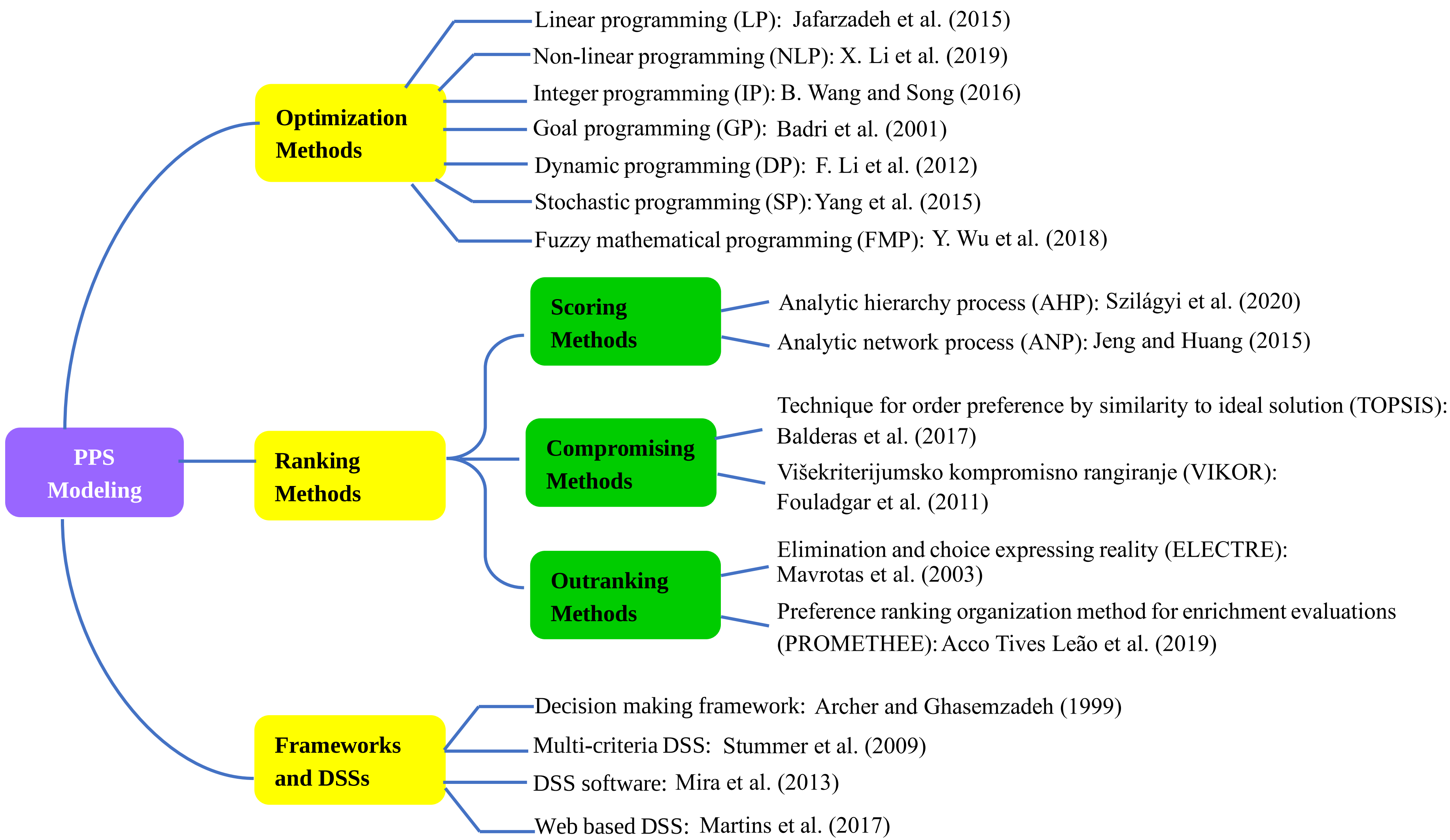

Figure 2.1 Mind map of PPS modeling approaches

In comparison with the stand-alone method that has its restrictions to deal with sophisticated PPS problem, an integrated method has been instrumental in improving the flexibility and usability of OR tools to address the complication and uncertainty of the PPS process. The integrated method also includes different fuzzy extensions. For examples, Raad and Shirazi (2020) calculated super matrix of analytic network process (ANP) using decision-making trial and evaluation laboratory (DEMATEL) communication matrix, and obtained weights of criteria and sub-criteria. And then a multi-objective programming model was proposed to create an optimal project portfolio. RezaHoseini et al. (2020) adopted sustainable balanced scorecard (BSC) framework at first to determine project selection criteria and then, the relative importance of the evaluation criteria was computed, and the projects were ranked based on the hybrid fuzzy ANP (FANP) and fuzzy VIšekriterijumsko KOmpromisno Rangiranje (FVIKOR) approach. Furthermore, according to the project ranking from the FANP-FVIKOR stage, the authors calculated the sustainability utility function of the projects using fuzzy UTilités Additives Star (F-UTASTAR) method. In their last step, a mix of projects were chosen and scheduled by using an integer linear programming (ILP) model. The objective functions in the model were to maximize the total benefits and the value of utility for projects, and to minimize the project execution interruptions. In the study of Yazdi et al. (2020), critical factors for project portfolio selection were identified using the Delphi method. Then Z-numbers were incorporated into the best-worst method (BWM) and the weighted aggregated sum–product assessment (WASPAS) methods. The hybrid approach was used for weighting selection criteria and ranking alternatives. Mohammed (2023) combined fuzzy AHP and fuzzy technique for order preference by similarity ideal solution (TOPSIS) to determine the preference weights of the evaluation criteria and to obtain the ranking of projects for selection. In summary, according to Table 2.1, majority of the recent studies (about 65.5%) used integrated method to address the PPS problem, which is in line with the conclusion made by Zorluoğlu and Kabak (2021).

In respect of the application areas, they range from IT projects, R&D projects, new product development projects, investment projects, energy and electric projects, oil and gas industry projects, mining industry projects, construction projects, research projects to municipal services projects. In a previous literature review covering 253 articles from 1972 to 2019 (Zorluoğlu & Kabak, 2021), approximately 48% of the papers investigated PPS problem in general considering universal characteristics of projects. Conversely, according to Table 2.1, the research trend nowadays indicates that most studies work on a specific type of project to make the research more practical and interesting, while the general type projects become minimal.

In a nutshell, the criteria of project evaluation and selection depend on the application environment. The criteria vary greatly among different types of projects and organizations. An obvious research trend is that scholars have paid attention to the uncertainty and incomplete information in PPS problem, and that have used fuzzy theory to resolve this concern. Another feature identified is that project portfolio scheduling was addressed concurrently in many PPS papers, while resource allocation problem was rarely addressed simultaneously. Although there are so many PPS literature with various methods, no consensus has been reached on which one is the best to be adopted. As Mohagheghi et al. (2020) and Zorluoğlu and Kabak (2021) called for, standard selection criteria and methods can be developed for specific type of projects, which can be further modified and customized by different organizations to suit their needs.

In the project portfolio planning process, once the potential projects are evaluated and selected according to the pre-defined criteria, the next step is to assign personnel to the selected project portfolio so that appropriate teams can be established for project execution.

2.1.2 Personnel assignment

In annual internal audit planning, the total available resources are known to decision makers as per the approved annual budget. Besides, based on the professional experience and historical data, audit managers can estimate the amount of resources (i.e., audit time and cost) needed for accomplishing each potential internal audit project. In other words, audit hours and costs can be allocated concurrently with the determination of project portfolio and audit work scope. On the other hand, as the greatest asset of the internal audit department and the key to success, internal audit staff who possess specialized knowledge and professional skills need to be allocated to the selected project portfolio separately. Therefore, the following literature review particularly focus on the personal assignment problem, which is also a sub-problem of project portfolio selection.

In the existing literature, personnel assignment (PA), also termed as staff assignment, personnel allocation, or human resource allocation, mostly refers to finding the right match between the available employees and the pre-scheduled jobs and tasks. OR techniques have been typically utilized to resolve the PA problem (Holness et al., 2006; Niknafs et al., 2013). A recent literature review on the PA problem was performed by Bouajaja and Dridi (2017), who summarized the major resolution approaches (e.g., exact, heuristic and metaheuristics methods) to solve the PA problem. The authors also classified the real-life applications into different business areas, including production systems, health care systems, project management and other applications (e.g., maintenance management, tourism and hotel management, education system). Arias et al. (2018) conducted a systematic mapping study to analyze existing approaches to the human resource allocation problem in business process management and process mining. Staff assignment practices in nursing homes has also attracted the interest of many researchers as per relevant literature surveys conducted by Rahman et al. (2009) and Roberts et al. (2015). The PA problem in project management field considering learning effect is another promising research area with numerous studies (Attia et al., 2014; Certa et al., 2009; R. Chen et al., 2017; R. Chen et al., 2020; Gutjahr et al., 2008; Gutjahr & Reiter, 2010; Heimerl & Kolisch, 2010a, 2010b; Hematian et al., 2020a, 2020b; Hlaoittinun et al., 2008; Q. Li et al., 2020; Stummer et al., 2012; Stummer et al., 2009; Van Peteghem & Vanhoucke, 2015). The PA problem is also covered and addressed by lots of literature on personnel/staff scheduling and rostering problem, which is more comprehensive and complex than pure staff assignment problem (Defraeye & Van Nieuwenhuyse, 2016; Erhard et al., 2018; Ernst et al., 2004; Özder et al., 2020; Van den Bergh et al., 2013; Xu & Hall, 2021).

The PA problem has various forms and application fields. In a simplified situation, the number of available individuals is the same as the tasks. That is, a person is assigned to perform only one task independently. On the other hand, a more complicated PA problem needs to deal with both the selection of multi-skill staff from candidate pool and the job assignments. This thesis discusses the project-team formation problem which is a special version of the PA problem. In a general project-team formation problem, a subset of people out of available staff is combined as a team and deployed to the projects or project tasks. The appointment of personnel to projects takes on strategic significance and can impact the ability of project-oriented organization to retain employees (Huemann et al., 2007). Project-team formation problem can be traced back to the well-known stable matching problem (Gale & Shapley, 1962). Bacon et al. (2001) summarized several types of team assignment methods, including random assignment, self-selection, facilitator assignment and computer-aided methods. A. Costa et al. (2020) identified and analyzed 51 primary studies on the software project team formation research using systematic mapping study. A taxonomy with three dimensions was proposed to synthesize relevant knowledge: criteria, solution, and team characteristics. From the perspective of the number of projects considered in the problem, prior research on project-team formation problem can be classified into the following two scenarios.

In the first case, a group of participants are selected from a pool of candidate to form one team for a single project. This type of research merely studies the assignment of individuals to the project team without the necessity of a match between the team and the project. Take a few papers published recently as examples, Rahmanniyay et al. (2019) developed a multi-objective multi-stage stochastic programming model to select high competency workforce for an aircraft maintenance project, with goals of minimizing the labor cost and maximizing the work quality. Chiang and Lin (2020) applied integer programming model to assist a real-world company in allocating developers to a software development project. Their objective was to maximize project efficiency considering the cost, communication, and skills. To select and allocate engineers to complete an international construction project, Hajarolasvadi and Shahhosseini (2022) proposed supplementary fit assessment model and complementary fit assessment model for effective team selection, which considered the preference for team members to have smooth cooperation and the complementary support in individual competencies.

In the second case, multiple teams are organized and allocated to multiple projects. Campêlo and Figueiredo (2021), Esgario et al. (2019) and Gutiérrez et al. (2016) respectively proposed integer programming, genetic algorithm, and variable neighborhood search metaheuristic to form multiple teams. Each team was associated with a general type project, and the project requirements worked as a constraint in their models. This research studies how to assign multiple auditors to the selected internal audit projects, which can be categorized as the multiple project-team formation problem. Some representative papers on similar problems in other application areas are shortly summarized as follows. A. Costa et al. (2018) presented genetic algorithm approach to allocate multiple developers to multiple software projects, aiming to maximize technical compatibility among multiple teams. In order to form the project teams for a system design course, Cavdur et al. (2019) presented a binary-goal programming model to allocate students and academic advisers to course projects in two phases, considering the preferences of the team members over the projects, student qualification and project requirements. However, a common assumption made in these two papers was that each member was only assigned to one project. Hosseini and Akhavan (2017) considered the possibility of allocating one individual to multiple projects. The authors adopted a fuzzy multi-objective 0-1 integer programming model for team formation problem of engineering projects. The non-dominated sorting genetic algorithm II (NSGA-II) algorithm was proposed to solve the model, enabling DMs to select desired project teams and assign them to projects. Their model optimized knowledge sharing among individuals, project costs and workload balance. Aiming to maximize the overall efficiency of the projects, Martinovi and Savic (2019) proposed mixed-integer programming model based on data envelopment analysis (DEA) for allocating eight consultants to three IT projects. Four consultants were required to implement each project, making it another case of multiple project-team formation problem.

2.2 Internal audit planning

As an important application field of project portfolio planning, internal audit planning has been largely unaddressed in academic research (Goman & Koch, 2019). Prior research on audit planning was mainly conducted in the context of external auditing, a statutory audit service performed by the Certified Public Accounting (CPA) firm, and the research topics centralize on audit-staff scheduling and engagement scope decision without the necessity of choosing appropriate audit projects. Although internal audit shares some similarities with external audit, such as project milestones, testing methodology, scheduling principle, they differentiate each other in terms of the principle of client/auditee determination, audit objective and audit areas. In this regard, the modeling of the planning work for internal audit should be studied separately from external audit. Despite the potential of effective internal audit planning to create value for organizations by selecting the right subset of candidate projects, there is little literature on how to support this decision making systematically (i.e., develop a formal annual internal audit plan). To the best of our knowledge, no holistic study has been performed to present the full picture of internal audit planning process (i.e., risk assessment, prioritization, selection, and scheduling of proposed projects, as well as the proper staff assignment) and to reflect the current professional practice.

A literature review of OR applications in audit planning and scheduling can be found in Mohamed (2015). The author presented survey according to three decision areas: (1) identifying the optimal audit frequency for each auditable unit, which means the optimal elapsed time or the number of transactions after which a repeated audit should be performed again. As explained in subchapter 2.2.1, such cycle approach has become an outdated practice and is only followed by a few organizations today; (2) determining the optimal allocation of audit resource among auditable units of the organization, which pertains to the core element of this research; and (3) determining the optimal assignment of a set of audit tasks in an engagement to a group of assigned auditors, although most of the papers covered in this area were related to external audit project. As this research only concentrates on planning the internal audit activities for a certain time horizon (normally one year), detailed planning and scheduling for a specific internal audit project is not within the scope of discussion. Andrade (2021) conducted a literature review of 17 papers that tackled audit staff assignment and activity scheduling decisions using mathematical programming models but did not differentiate internal audit and external audit cases either.

According to the history of the development of internal audit planning practice, the primary modes/methods for internal audit planning can be classified into three types: cycle approach, cycle-risk-based approach, and risk-based approach. These approaches represent the different eras of internal audit and illustrate the changing characteristic of internal audit work (Gartner, 2019). With the evolution of internal auditing practice, the trend is to gradually shift from cycle-based audit planning to risk-based auditing planning. The characteristics, adoption status in practice and specific techniques of the three different internal audit planning modes are reviewed as below.

2.2.1 Cycle approach

Cyclical audit plan is a traditional method to ensure that all (or significant) auditable units would be reviewed at least once within a predefined time interval (i.e., typically multiple reporting periods, such as 3 years). The main purpose of such audit planning is to determine the optimal audit frequency for various auditable units over a long-term planning horizon.

D. Wilson and Ranson (1971) formulated a model to find the optimal audit interval by minimizing the discounted present value of audit costs and expected losses in the absence of auditing, which was the pioneer in determining the audit frequency. In the model, audit costs were assumed to be incurred at a uniform rate, while losses due to fraud, waste, or error would rise exponentially to an asymptotic level. The audit costs were calculated by multiplying the number of days needed to perform the audit and the standard daily rate of the audit staff. It is also assumed that once an audit was completed, the losses would drop to zero and then started to rise again until the next audit. A major problem of the model is that it is not constrained by the availability of audit resources. In addition to this deterministic model wherein parameters are known with certainty, researchers also used stochastic model which represent randomness of a process for determining optimal audit frequency. Hughes (1977) described a sequential decision process using Markov decision model to determine the optimal internal audit timing of an internal control process. Dynamic programming was applied to minimize expected total discounted costs to maintain an effective internal control system. In order to ensure that errors in the account balance of financial statement is below a certain threshold, Morey and Dittman (1986) proposed a solution technique to identify the minimum required frequency between audits for a given individual account. Flynn and Garstka (1990) presented a dynamic programming model to optimize the frequency of inventory management audit. Bosch et al. (2008) developed an optimization model which provided information about the optimal timing of a regular internal audit of bank asset value. A common characteristic of these models is that optimal audit frequency is determined for only one specific auditable unit.

Undoubtedly, one characteristic of the cycle approach to audit planning is that it does not take relevant risks into account to guide audit resources to high-risk areas, which require priority attention. Another disadvantage of these models is their high level of mathematical complexity which may limit the applications. The current status of the adoption of cycle approach is described in the following subchapter.

2.2.2. Cycle-risk-based approach

Cycle-risk-based approach to internal audit planning is mostly the same as cycle approach, but it integrates risk concept when calculating the value of loss without auditing. It can be regarded as a branch of cycle approach.

Boritz and Broca (1986) extended the work of D. Wilson and Ranson (1971) by creating another mathematical expression to find the optimal internal audit time for an auditable unit, wherein a priority score was introduced to assess relative risk of the auditable unit. Four possible methods were discussed to perform the risk assessments of auditable units: objective direct assessment, subjective direct assessment, pairwise comparison and base rate assessment. However, this new model did not constrain the audit resources either. Given the risks and costs involved in the audit process, Knechel and Benson (1991) presented a model to determine an optimal mix of audit frequencies for the auditable units. The risk level represents the rate at which loss of each auditable unit should accrue in the absence of auditing. However, the detailed risk assessment steps were not discussed. A separable programming technique (Miller, 1963) was applied to obtain the optimal audit intervals which minimize total costs and losses for all auditable units. To ensure all departments of a hospital can be audited at least once in every three years, Tay (2017) structured a two-step risk management approach to develop a 3-year cycle plan. In step one, the risk level of the department's environment, health and safety (EHS) is determined based on the usage of hazardous materials in the workplace. Step two is to determine the readiness level of a department based on the department's level of documentation and level of measuring and monitoring of process. The audit frequency is subjectively recommended taking these two evaluation results into consideration, together with other factors such as use of new equipment, major accident, and process changes. In general, higher risk departments would be audited more frequently. Nikityuk et al. (2019) developed an internal audit planning procedure for auditing quality system of pharmaceutical companies, in which audit frequency was mapped with risk category of the auditable unit. Specifically, reduced frequency (once in two years) is planned for low-risk areas, moderate frequency (once a year) is planned for medium-risk areas, and increased frequency (at least twice a year) is planned for high-risk areas.

In a nutshell, cycle-risk-based approach considers risk of loss in the absence of auditing or risk level of an auditable area. However, unlike the full risk-based approach introduced in the subsequent subchapter, cycle-risk-based approach is still frequency oriented, and thus there is often a weak correlation between the risk assessment results and the audit resource allocation.

The practice of internal auditing is constantly evolving to cope with the dynamic environments and new challenges. With the changing business environment, it is not effective and realistic at present to make an internal audit plan with a horizon longer than one year. The IAF rarely repeats an audit project in the same year as internal auditors not only test internal controls nowadays but also conduct complex audits covering broad topics. The IIA Standards also require CAEs to conduct a risk assessment at least annually to develop the audit plan (IIA, 2017). In a global survey on IA activities in 91 countries with 9,366 usable responses, 95.6 % of the respondents indicated that they created an audit plan at least annually and 86.7% of them used risk-based techniques in audit planning (Burnaby & Hass, 2009). Therefore, an audit cycle or cycle-risk-based approach to internal audit planning has been generally viewed as an outdated approach (Koutoupis & Tsamis, 2009; Petterson, 2005). Usually, such model can be found in smaller companies (Allegrini et al., 2006). In the survey of Allegrini and D'Onza (2003), a few companies (25%) of the top 100 companies listed on the Italian Stock Exchange that had a small audit department generally followed a cycle or cycle-risk-based approach for their annual audit planning. Therefore, it can be concluded that internal auditing has basically moved from rotational/cyclical auditing era to risk-based auditing era. The risk-based approach to internal audit planning is introduced in detail in the following subchapter.

2.2.3 Risk-based approach

Committee of Sponsoring Organizations of the Treadway Commission (COSO) defines risk as *"the possibility of an event occurring that will have an impact on the achievement of objectives"* (COSO, 2013, p. 4). Balancing all risks from internal and external sources that each entity faces is imperative to the success of the IAF and the organization as a whole (Hass et al., 2006). A risk-based approach to annual internal audit planning establishes a connection between risk assessment and the selection of audit project portfolio under constrained resources. This approach emerged in 1990s and has been viewed as a best practice (Koutoupis & Tsamis, 2009). As risk-based internal auditing will enhance audit department's ability to add value to the organizations by satisfying their needs, it is expected that such practice will continue to be used by the IAF in the future (Larasati & Bernawati, 2020).

Castanheira et al. (2010) found out that the adoption of the risk-based approach to planning an annual internal audit schedule was statistically significant in international firms and publicly listed companies in Portugal. The research findings also indicated a strong but not significant association between risk-based annual audit planning and firms which were private, large, and in the finance sector. Based on the investigation at the Regional Inspectorate of Klungkung Regency in Indonesia, Oktari et al. (2020) concluded that risk-based audit planning can moderate the influence of the independence, objectivity, and competence on the quality of audit results. By examining the 117 in-house IAFs of Malaysian-list companies, Abidin (2017) revealed that audit committee review and conern as well as risk management system were positively and significantly related to the presence of risk-based auditing. However, other factors, such as intenral audit experience, IAF size, audit committee qualifications and internal control system, were not significant predicators of the implementation of risk-based auditing. This finding is consistent with the result of Lois et al. (2021)'s study which focused on the Greek context. The same conclusions may reault from the similar corporate governance systems in Malaysia and Greek as emerging economies. Meanwhile, other studies also suggested that many elements, such as the existence of risk management committee, the percentage of non-executive members of the board, company size, regulations, industry type, training, top management mindsets, internal audit characteristics and organizational culture, were crucial in promoting the adoption of risk-based auditing in annual internal audit planning and individual engagement planning (Allegrini & D'Onza, 2003; Erlina et al., 2018; Harissis et al., 2013; Koutoupis et al., 2020; Koutoupis & Tsamis, 2009; Selim & McNamee, 1999; Yunus, 2019).

Many internal audit books (P. Griffiths, 2016; Kagermann et al., 2008; Paterson, 2015; Pickett, 2010, 2013; Pitt, 2014; Rehage et al., 2008) and professional organizations (IIA, 2020; Internal Audit Community of Practice [IACOP], 2014) provided basic guidelines on developing a risk-based internal audit plan, but without operational research methods, scientific mathematical formulas, or case application. Table 2.2 presents a comprehensive summary of academic research on risk-based internal audit planning. A review of the listed papers is provided below according to the different stages of the planning activities.

Table 2.2 Summary of risk-based internal audit planning related works

Reference	Application	Auditable Unit	Methods	Risk Ass.	Project Select. / Rank	Time /Fund Alloc.	Staff Assig.	Project Sched.
Miltz et al. (1991)	Janssen Pharmaceutica	Entity by location	Pairwise comparison, Marginal analysis	X	X	X		
Hemaida (1995)	Hospital	Cost center	Multifactor evaluation process	X				
Lieb and Gillease (1996)	Du Pont Company	Financial controls	Decision support system	X	X			
Hemaida (1997)	Hospital	Cost center	Zero-one integer programming		X	X		
Ramamoorti et al. (1999)	University	Academic/Administrative department	Neural network	X				
Bradbury and Rouse (2002)	Janssen Pharmaceutica	Entity by location	DEA	X				
Zacchea (2003)	Multinational organization	Administrative office	Weighted unit risk score	X				
Davutyan and Kavut (2005)	Janssen Pharmaceutica	Entity by location	DEA (a reinterpretation)	X				
Krüger and Hattingh (2006)	Gold mining company	Process in commercial service business	AHP, GP	X	X	X		
Zacharias et al. (2007)	Greek managing authority	Information society program	AHP	X				
Sueyoshi et al. (2009)	Rental car company	Store in east region	DEA, AHP	X	X	X		
Rossi et al. (2010)	Unstated	Unstated	MILP, CP					X
Alina (2012)	Unstated	Unstated	Risk Matrix	X				
Balaniuk et al. (2012)	Government agencies	Process and program	Naive Bayes	X				
Hamid (2012)	Behshahr industrial company	Unstated	AHP	X				
R.-C. Chen et al. (2012)	Unstated	Quality system	Genetic algorithm				X	
Y.-R. Wang and Kong (2012)	Government construction department	Public construction projects	Genetic algorithm				X	

Karaöz (2016)	Turkish bank	Branch	AHP, Integer programming				X	
Serfontein and Krüger (2016)	Gold mining company	Process in commercial service business	Loss function, AHP, Lagrange multipliers	X		X		
Purwanto et al. (2017)	Indonesian government	Unstated	AHP	X	X	X		
Vivas and Oliveira (2017)	Brazilian government	Government program	MRAM		X			
Çanakoğlu et al. (2018)	Turkish bank	Branch	Integer programming				X	
Goman and Koch (2019)	Hypothetical organization	Mixed topics	Multiplicative CI	X	X			
Schneider and Nurre (2019)	Food bank	Partner agency	Multi-criteria mixed integer programming					X
Vivas and Oliveira (2019)	Brazilian government	Government program	Multicriteria PDA		X			
Zhong and Deng (2020)	Unstated	Unstated	TOPSIS, Choquet fuzzy integral	X				
Çanakoğlu and Muter (2021)	Financial institution	Branch	Integer programming				X	
X. Wang et al. (2021)	Chemical company	Mixed topics	Risk assurance map, Fuzzy AHP, MCGP	X	X	X		
Menekse and Camgoz-Akdag (2022)	University	Academic units	Spherical fuzzy ELECTRE	X	X			
This thesis	Automotive components manufacturer	Process and entity by location	FCE-AHP (FAHP), Weighted/ MINMAX MCGP, Gantt Chart	X	X	X	X	X

Among journal articles, there are a few studies that specifically focus on the risk assessment methods for risk-based internal audit planning. A variety of techniques, such as Conjoint Test Card (Lieb & Gillease, 1996), Neural Network Model (Ramamoorti et al., 1999), AHP (Hamid, 2012; Zacharias et al., 2007), Risk Probability and Impact Matrix (Alina, 2012), Naive Bayes Model (Balaniuk et al., 2012), and TOPSIS combined with Choquet fuzzy integral (Zhong & Deng, 2020) have been presented to analyze the risk of auditable units and prioritize alternatives to prepare the audit plan. Ziegenfuss (1995) reviewed five categories of IA risk assessment techniques available by that time.

The core problem of project portfolio planning is portfolio selection (Gutjahr et al., 2008). There is limited quantity of articles that utilize operational research tools to deal with project portfolio selection problem for risk-based internal audit planning, and a state-of-the-art review is presented as follows.

Taking Janssen Pharmaceutica Group as a case study, Miltz et al. (1991) focused on two aspects of risk-based internal audit planning. First, the authors assessed a risk index for each of the 57 geographically defined organizational units that might be audited. According to the Delphi approach (Spinelli, 1983), six risk factors (or can be described as selection criteria) were used in their study, such as size, internal control status, degree of change, environment (e.g., political, cultural, legal, etc.), internal and external pressure on unit management, as well as the nature of activities. A pairwise comparison was performed by five internal auditors to obtain the relative importance of each factor. However, only one internal auditor rated the six risk factors for each business unit on a five-point scale from 1 (smallest) to 5 (largest). The definition/measurement criteria for the risk scale were not provided neither. A risk index for each auditable unit was calculated using a linear additive model (Patton et al., 1983), namely, the relative importance value and the rated risk score were aggregated using addition and multiplication of the numbers (weighted sums) to a final risk score. Second, based on these risk indices, a procedure was proposed to allocate available audit time to each auditable unit to achieve the highest risk reduction, which was the only goal in the study. Management estimated the time associated with three work levels (i.e., limited review, intensive review, and complete review) for each auditable unit. The amount of risk reduction of each business unit was subjectively assessed by audit level, and finally 44 units were subject to an audit. Using the data from Miltz et al. (1991), Bradbury and Rouse (2002) and Davutyan and Kavut (2005) applied data envelopment analysis instead of pairwise comparison to address the risk quantification issue for each business unit.

In a health-care setting, Hemaida (1995) used multifactor evaluation process (MFEP) for a risk assessment during annual audit planning process. The hospital was divided into 60 auditable units by cost center. Five risk factors were taken into account to evaluate each auditable unit: revenue, resource consumption, system complexity, regulatory involvement, transactions volume, and manual versus electronic processing. Internal auditors of the hospital subjectively determined the risk factor weights. According to the nature of the risk factor, scale with respect to risk factor utilized both quantitative and qualitative criteria. Finally, all auditable units were ranked according to a composite score (weighted evaluation), which was calculated as the sum of the product of the weights and corresponding evaluation scale. Based on the risk assessment results, Hemaida (1997) presented a zero-one integer programming for allocating available internal audit time to maximize the risk coverage of auditable units. A disadvantage of this resource allocation model was that it did not consider risk reduction factor of each audit project. It is difficult to estimate risk reduction factor and thus more research is needed (Hamid, 2012; Miltz et al., 1991). Similar to the model of Miltz et al. (1991), another drawback was that the model did not consider management's risk appetite or the risk level that an organization was willing to accept.

Krüger and Hattingh (2006) presented a risk-based resource allocation framework, which was tested with five internal audit projects of an international gold mining company. The main steps in their framework include: (1) determine risk factors which impact the risk levels of pre-defined audit projects. Five frequently used risk factors were considered, including operations complexity, transaction frequency, financial implications, recent or planned changes in the area, and external impacts (legislation, reputation, morale, etc.); (2) AHP technique was applied to determine the importance weights of risk factors and the risk rating of auditable areas under each risk factor. A current risk level for each audit project was determined by combing these two variables (importance weight and risk rating). However, when there is a large number of candidate projects, it is difficult to rate different audit projects in pairwise comparison and maintain consistency itself among responses; (3) a risk-reducing factor for the project was derived with the slope of the straight line connecting vertical coordinate (first coordinate: current risk level; second coordinate: risk level after performing a complete audit) and horizonal coordinate (first coordinate: zero; second coordinate: maximum hours of a complete audit); and (4) the results were integrated with a goal programming model for allocating actual internal audit time so that risks levels of audit projects could be minimized to pre-defined goal risk levels as close as possible. However, the goal risk levels might be underestimated. With the same research background and data, Serfontein and Krüger (2016) further developed a web-based decision support system integrating loss function, AHP and method of Lagrange multipliers to aid in allocating audit resources. The main difference between the two research is that the latter study allocated resource in percentage instead of exact internal audit time.

Sueyoshi et al. (2009) proposed an integrated AHP and DEA model to assist audit managers in selecting stores of a rental car company for internal audit. In the unified framework, AHP was applied to determine the subjective risk exposure of each store. The evaluation criteria include previous control rating, customer complaints, urgency, and management proficiency. The total risk score of each store was calculated by finding the sum of product between the global weight of each criterion and the rating of the criterion. In addition to the rating of manager inputs through AHP, DEA was applied to obtain the objective efficiency score of each store. According to the nominal group technique (Delbecq et al., 1975) of various business managers, the authors determined accounting records (financial performance) and fleet information (operational performance) as the inputs and outputs used for the DEA method. Nevertheless, this method is more suitable for auditing legal entities, but cannot be generalized to auditable units without common measurement criteria, such as process-oriented auditable units which are not comparable with each other. A risk profile was then constructed by combining the AHP and DEA results in a matrix for analysis of the stores in the same city. A combined risk measure of risk characteristic (AHP score) and operational inefficiency (1−DEA score) was computed to determine the stores that should be audited with more urgency. Finally, total amount of audit time was allocated to each audited store in proportion to respective combined risk score. A prerequisite of this allocation method is that the total number of stores to be audited should be pre-defined. Also, the used allocation formula did not set minimum and maximum hour. An obvious weakness of the formulation was that the allocated time to a store might be insufficient or excessive to conduct a meaningful and efficient audit.

To support the internal audit planning of Ministry of Energy and Mineral Resources of Indonesia, Purwanto et al. (2017) also used AHP to obtain a weight/score as the risk significance ratio of 27 auditable units. The authors follow the first two steps of the framework in Krüger and Hattingh (2006), except that the considered risk factors (i.e., complexity of activities, control environment, fraud potential, degree of financial materiality, and the inherent risk) varies to some extent. The authors then defined five risk groups (i.e., very low, low, medium, high, and very high) according to the weighting range of the risk assessment results and classified all auditable units into one of the risk groups according to the corresponding score. The number of internal auditors assigned to each auditable unit, ranging from 3 to 7 auditors, was determined based on its risk group level. The higher the risk group level is, the more internal auditors will be assigned. All auditable units were further categorized into five examination types which determined the number of working days that each auditor would spend: operational audit (20 days), financial statements review (10 days), work plan and budget plan review (10 days), the performance accountability report evaluation (5 days), procurement service unit audit (10 days). In this way, total working days of each auditable unit were calculated by multiplying the number of auditors with the number of working days. The disadvantage of this approach was that it assumed the manpower needed was in proportion to the level of risk group, which was not consistent with many cases in the real world. In fact, since internal auditors might be more familiar with some auditable areas, and the audit steps are easy to be executed in certain audit projects, it is highly possible that fewer headcounts are needed to audit higher risk areas than lower risk areas.

In order to aid auditing organizations in evaluating and selecting auditable areas, Vivas and Oliveira (2017) proposed a framework at macro level to structure multicriteria resource allocation models (MRAM). There are six stages in the framework: problem identification, stakeholder identification, goals and values identification, alternatives identification, uncertainties identification and constraints identification. Techniques and tools that can be applied in the distinct framework stage were listed, such as value tree, cognitive map, risk factor analysis and focus group. Each stage was briefly described in the context of the Brazilian government auditing organization. Later on, Vivas and Oliveira (2019) explored multicriteria portfolio decision analysis (PDA) tools combined with negotiation strategies to inform a transparent selection of audit projects under divergent views. These two papers did not develop case study at micro level, and they did not test the proposed models with data either.

Goman and Koch (2019) introduced a multiplicative composite index (CI) based on weighted geometric mean to aggregate attribute values to an overall score of an alternative (auditable area). An alternative with larger CI has larger risk and thus requires more attention. In order to develop a risk-based IT annual audit plan, an example with 13 alternatives was given to illustrate the process of prioritizing auditable areas. Ten attributes of alternative area were evaluated, including expected financial and operational losses, existing control effectiveness, available audit skills, SOX compliance risk, incident rate, estimated audit complexity, changes in audit area, and total number of audit issues. Finally, top 9 auditable areas were selected considering the available working hours of two full-time auditors in a year. However, backbones of the resource allocation, such as relationship of audit efforts and risk reduction, were not mentioned and left as black boxes.

X. Wang et al. (2021) developed a structured three-phase framework for risk-based annual audit planning. A detailed case study of a global internal audit function was presented to validate the proposed framework. In the first phase, researchers proposed a numerical risk assurance map to evaluate the whole organization's risk levels in five risk areas: compliance, financial, operational, strategic, and information systems. However, only an illustrative example was introduced to explain the concept. The research mainly focused on the other two phases. In the second phase, twenty-eight potential internal audit projects were categorized into five groups according to their respective risk areas. An assumption was made that each project mitigated only one major risk area although other risk areas can also be addressed synchronously. Fuzzy AHP was applied to compute the weights of each proposed project under corresponding risk area, and the result was used as the risk reduction factor of each candidate project. It was assumed that there was a positive proportional linear relationship between the actual risk reduction by performing audit projects and the actual hours allocated to the project. Similar to Krüger and Hattingh (2006), a marginal effect was ignored in the relationship of the two elements. In the meantime, a continuous time function was assumed implicitly following the theoretical approach from Patton et al. (1983). Conversely, in most situations, there is a specified deadline/time period to complete audit projects. Unlike many other practices which assess the risks on potential auditable units, the risk assessment in their case study was conducted at overall level of the organization. Therefore, it appears that there is no connection between the current risk level and the risk reduction in terms of each auditable unit. In the last phase, the multi-choice goal programming model was utilized to allocate available audit staff time to candidate projects. The objective was to minimize the total deviations from the predefined goals concerning the goal risk level, flexibility, and project diversity in the portfolio. The results showed that two projects were not selected as no audit time was allocated to them.

Menekse and Camgoz-Akdag (2022) presented a decision support model to prioritize internal audit activities by extending the ELECTRE method with newly developed spherical fuzzy sets. In the application part, based on five components of COSO internal control framework, namely control environment, risk assessment, control activities, information and communication, and monitoring activities, internal control risk levels of four academic units in a university were evaluated and ranked using the proposed methods. According to the obtained appraisal score of alternatives, internal audit activities should be carried out in the riskiest unit. However, a deeper analysis of the five main criteria was not made to consider evaluating the sub-criteria. In addition, like many other ranking methods, ELECTRE is also subject to the rank-reversal issue (Liu & Ma, 2021). Due to this problem, ranking methods do not always generate a unique ranking for the alternatives when the set of alternatives is changed, reducing the accuracy and reliability of the proposed approach. The resource allocation problem was not considered by the authors either.

In addition, some researchers particularly studied the sub-problem of audit project portfolio selection, which is staff assignment and scheduling for a set of selected audit projects. First, in terms of staff assignment, Y.-R. Wang and Kong (2012) applied genetic algorithm approach to assign auditors to conduct monthly quality audit of public construction projects. The study aimed to assist officials of Kaohsiung County Government in Taiwan to find the optimal match between the project characteristics and auditor expertise. In their case study, three auditors chosen from the 62 registered auditors were allocated to each of the eight projects with maximum overall fitness values. R.-C. Chen et al. (2012) also utilized genetic algorithm to assign auditors to audit a quality system, optimizing the mutual choice of auditors. In order to assign five internal auditors to audit 80 branches of a Turkish banking corporation, Karaöz (2016) applied AHP method to indicate auditors' utility level with respect to location, size and type of bank branches, and then utilized integer programming model to maximize their total utility score for a year. However, the author did not consider the task requirements of branch audit for auditor experience. Also, an implicit assumption made by the author was that each branch could be audited by only one auditor without forming a team. Çanakoğlu et al. (2018) presented an integer programming model to handle the assignment of a set of internal audit teams to audit a set of branches of a financial institution. They aimed at minimizing the total duration of the audit projects. The authors presented a numerical experiment to compare two proposed heuristic methods, knapsack-based algorithm, and savings-based algorithm, in resolving the problem. In the same background, to achieve balanced workload distribution among audit teams, Çanakoğlu and Muter (2021) further proposed tabu search to improve the original solution approach to resolve the integer programming model. Internal auditor's preference over the branches was not considered in both articles. In this thesis, both auditor's preference for the planned projects and auditor qualification for performing these projects are taken into account. Second, for scheduling a set of internal audit projects, Rossi et al. (2010) proposed a generic model for finding the optimal schedule of audit activities for multiple auditable units. They considered a planning horizon consisting of multiple time periods and several units to be audited. A stochastic programming model with mixed integer linear programming (MILP) and constraint programming (CP) was proposed for determining the audit timing of each auditable unit. The objective function was to minimize the sum of the expected discounted value of the audit costs and losses over the planning horizon. The audit duration is assumed as a constant in the model whereas it varies greatly by auditable units in practice, making it an invalid assumption in many situations. Schneider and Nurre (2019) developed a multicriteria capacitated vehicle routing with multiple time windows approach to improve the efficiency of the auditing schedule for the Foodbank Inc. in Ohio state of the United States. There is only one auditor in the studied audit department to conduct on-site compliance audits at many partner agencies. Such small department is not common in most corporation context.

To sum up, prior studies were only concerned with the incomplete/partial process of the risk-based annual audit planning, and failed to consider the linkage between risk identification and risk measurement. In fact, risks cannot be measured and managed well unless they are identified first. Risk factors, conditions associated with a higher likelihood of risk consequences, are observable characteristics of risks and enable risk to be measured easily. However, most of the extant literature measure risk of the organization or auditable units directly based on risk factor without risk identification. The types of risk faced by an organization vary across industries. For example, unlike logistics companies, financial institutions are not concerned about transportation risk. Green (2015) introduced various risk types faced by organizations, including physical risks (e.g., operational, supply chain, etc.), intangible and information risks, financial risks, and strategic risks. The 2015 CBOK survey identified 13 general categories of risk that could be used to classify audit projects in the audit plan: operation, compliance/regulatory, risk management assurance/effectiveness, strategic business risk, IT, general financial, corporate governance, fraud, cost/expense reduction or containment, SOX testing or support, third party relationships, crisis management, and others (Sobel, 2015). In terms of risk factors, Colbert and Alderman (1995) provided a broad list of risk factors for measuring risk level, but in practice the number of risk factors is usually restricted to between five and ten since there might be an inverse relation between the number of factors and the ability of the auditing team to make meaningful judgments (Kanter et al., 1990). Gartner (2018) listed 14 risk factors for assessing organizational risk: business complexity, degree of change, importance to strategic objectives, last audit rating, financial impact, operational impact, regulatory impact, reputation impact, risk velocity, technologies used, time since last audit, key management turnover, control environment strength, and others. In the current study, a more thorough framework is developed to present the full picture of an annual audit planning process, measuring the level of identified risks based on the combination of quantitative and qualitative methods. Meanwhile, this study is an innovative application of operational research, in which integrated decision methods, such as FCE, AHP, Weighted MCGP and MINMAX MCGP, are utilized for the development of an annual audit plan.

2.3 Multiple criteria decision methods

It is not uncommon that real-life problems have multiple, often conflicting, decision criteria. Although many scholars use multiple criteria decision analysis (or aid) (MCDA) and multiple criteria decision making (MCDM) interchangeably, Ferreira et al. (2011) and Roy and Vanderpooten (1996, 1997) differentiated these two concepts in some features, such as the main purpose, the perception on optimum paradigm and the associated Schools of OR. MCDA, a relatively newer sub-discipline of OR to aid decision making, is a process which seeks to integrate objective measurement with value judgement and manage subjectivity (Belton & Stewart, 2002). Constructivist in nature, MCDA techniques have become valuable tools for creating something that does not fully pre-exist and understanding complex decision situations, which lead to more informed, potentially better decisions (Carayannis et al., 2018). MCDM, in turn, requires something pre-existing to determine the best alternative through a well-structured mathematical model and is greatly linked to optimization (Mateu, 2002; Munda, 2003). The distinction between MCDM and MCDA can be described as the relationship between the decision maker and the decision analyst/management scientist (C. A. B. E. Costa et al., 1997). A decision analyst is responsible for providing analytical support and aids to make the decision. MCDM is popular in North American, while MCDA was basically developed in Europe (cf. Bouyssou et al., 2000).

Bernroider and Schmöllerl (2013) conducted a survey on Austrian companies and received 114 completed questionnaires. It was observed that 71.9% of the companies were aware of the existence of MCDA and MCDM methods, yet only 33.3% used them in practice. Reasons that could lead to the difference between known and applied methods include: (1) some MCDA/MCDM methods are difficult to be adopted by practitioners without the presence of an experienced facilitator because of high complexity in calculation; (2) in many cases, decision makers are confused about selecting an appropriate approach since the obtained solution for one decision problem is not always the same by utilizing different MCDA/MCDM methods (Ishizaka & Siraj, 2018); and (3) some MCDA/MCDM methods lack of flexibility to be tailored to meet real needs.

2.3.1 Reasons for the methodological choice

MCDA and MCDM methods have shown a great potential to be an effective evaluation and/or optimization tool to handle project portfolio planning problem (Danesh et al., 2018). As stated in the first chapter, the aim of the thesis is to propose an integrated framework for internal audit planning problem based on FCE-AHP (FAHP) and MCGP (including Weighted MCGP and MINMAX MCGP) methods. Although there are lots of MCDA methods able to calculate trade-offs among criteria, the AHP is, perhaps, the most widely used MCDA method because it is intuitive and easy to use (Ghosh et al., 2022). Admittedly, there are criticisms of the AHP technique, for example, a main concern with AHP is the inconsistency of pairwise comparisons, and thus the Best-Worst Method was introduced recently to lower the inconsistency in results by reducing the number of required pairwise comparisons (Rezaei, 2015). However, AHP can check the consistency of the decision. In case of the failure of the consistency check, remedies can be made by reperforming the pairwise comparisons or excluding the inconsistent matrix. Also, some researchers have proposed particle swarm optimization (PSO) technique to repair inconsistent comparison matrix in AHP while maintaining experts' opinions (Bandichode et al., 2018; Girsang et al., 2014). In this way, even if the initial judgement is not consistent, the repaired data can be still processed by the AHP method. In addition, for practitioners, it is simpler to use AHP software that is readily available and user friendly, instead of performing calculations by themselves or using immature templates following other MCDA methods. As there are not many sub-factors under the main risk, the pairwise comparison of risk items is not cumbersome. Therefore, AHP is used to calculate criteria weight. Further, this study adopts geometric mean method, a commonly used method in AHP-group decision making, for aggregating individual judgements. Integrated with the weight of various risk types and items derived from the AHP method, FCE measures the risk levels of different risk types applicable to the auditable units. Then, the outputs of FAHP method are transferred to variables to make project portfolio selection decisions for realizing risk mitigation and other value-added goals using Weighted MCGP model. Finally, audit staff are assigned to the selected projects utilizing MINMAX MCGP model taking account of preferences of both auditors and audit projects.

Risk-based internal audit planning is a multiple-stage problem concerned with qualitative and quantitative data. Therefore, it is more practical to establish a framework with integrated methods to satisfy the needs of different stages, overcoming the limitation of a stand-alone method (Mohagheghi et al., 2020; Zorluoğlu & Kabak, 2021). There are four stages in the proposed internal audit planning framework and the reasons for the methodological choice in each stage are elaborated as follows: (1) risk assessment. Risks of each auditable area need to be evaluated firstly in the risk-based internal audit planning process. Then audit managers shall estimate the level of risks that can be mitigated by conducting an internal audit project in the auditable area. In project portfolio management, it is necessary to properly address the vagueness that exists in the project evaluation (Mavrotas & Makryvelios, 2021). Various risks are the primary evaluation criteria to select internal audit projects. Nevertheless, according to the utilized techniques listed in Table 2.2, almost all the prior literature on the risk assessment phase of internal audit planning has not considered the uncertainty. Risk assessment is a complex multi-level problem with vagueness and qualitative linguistic terms are inevitable (Y. Wu et al., 2019). Practitioners have found that it is easier to use linguistic variables such as low, moderate, high, and significant, to assess risks (Ameyaw & Chan, 2015). Although these fuzzy variables cannot be expressed meaningfully with a single value, FCE provides a way to model and quantify the fuzzy variables for the risk level. AHP method is embraced in the FCE process to estimate the weighting vector of the evaluation factor. As the model is simple and can be solved easily using a commercial software or even with a Microsoft Excel spreadsheet, the method is easy to be understood and used by DMs who are not experts in the OR field. Therefore, FCE-AHP method is well suited for the risk assessment in the annual audit planning process; (2) project portfolio selection. Majority of previous research on PPS problem used pure and hybrid mathematical programming methods (Zorluoğlu & Kabak, 2021). However, the projects ranked the highest are not necessarily the best alternatives to be chosen (Raad & Shirazi, 2020). In addition to maximizing risk mitigation, the IAF should also consider other critical factors such as budget constraints, flexibility, and stakeholder interest. Therefore, Weighted MCGP model is proposed to generate an optimal portfolio of internal audit projects considering multiple factors. Compared to other programming models, MCGP is simple but comprehensive to handle the insufficiency of available information. MCGP method also considers multiple objectives and multi-aspiration levels of a decision-making problem simultaneously. Tabrizi et al. (2016) applied MCGP model to PPS problem and assisted a large pharmaceutical company in selecting a set of medicines, proving the applicability and validity of the method in a real case study. Weighted MCGP model further improved MCGP model without increasing the mathematical complexity. In Weighted MCGP model, DMs can emphasize the goals which they consider more valuable and obtain the solution with the minimum aggregate deviation or maximum aggregate achievement for all multiple goals, which fits for the PPS problem; (3) auditor assignment. This is also a multi-objective problem and a straightforward MINMAX MCGP model is proposed to solve the problem. The model provides a solution that gives the maximum importance to the goal that most displaced with respect to its target. With MINMAX MCGP method, DMs can get the most balanced solution between all multiple goals in multiple aspiration levels setting, and thus fits the purpose of this study to balance the auditor preference and the auditor's fitness to the project; and (4) project scheduling. In this stage, a classic and user-friendly tool – Gantt chart is proposed, which is a type of bar chart that provides a visual view of project schedule. As it has been a well-known concept and commonly used in project management, relevant literature review is not performed in this chapter.

The proposed integrated method is compared with other popular MCDA and MCDM methods in Table 2.3. It is more reliable than stand-alone approach in the planning process.

Table 2.3 Comparison of the proposed method with other popular methods

Nature	ELECTRE	AHP	BWM	TOPSIS	ANP	VIKOR	GP	Proposed method
Is pairwise comparison needed?	N	Y	Y	N	Y	N	N	Y
Is fuzzy concept solved?	N	N	N	N	N	N	N	Y
Is criteria weight obtained?	N	Y	Y	N	Y	N	N	Y
Is it subject to rank reversal?	Y	Y	N	Y	Y	Y	N	N
Are multiple objectives considered?	N	N	N	N	N	N	Y	Y
Are multiple aspirations considered?	N	N	N	N	N	N	N	Y

In the following text, the methods used in the proposed framework are described.

2.3.2 The FCE-AHP (FAHP) method

The integrated FCE and AHP method has been adopted in numerous assessment processes in uncertain situations, such as customer satisfaction evaluation (Liang et al., 2021), evaluation of safety production management (J. Zhang et al., 2019), safety assessment of metro construction projects (Z. Z. Wang & Chen, 2017), risk analysis of seismic hazards in hydraulic fracturing areas (Hu et al., 2018), assessment of regional ecological carrying capacity (X. Wu & Hu, 2020), evaluation of the operational level of energy intensive equipment (Y. Li et al., 2017), assessment of the degree of rock joint surface roughness (Zhao et al., 2021), performance evaluation of job candidates (X. Wang et al., 2022), operation performance evaluation of public buildings (Zhou et al., 2021), risk assessment of sustainable mining (Jiskani et al., 2020), and performance evaluation of microfinance lending process (Alaoui & Tkiouat, 2017). However, many of the prior application studies lack of sensitivity analysis and, to the best of our knowledge, the method has not been applied to the risk assessment of an auditable unit in a corporate context, which is comprehensive and complex and requires practical and reliable evaluation results. The general idea of this technique is introduced in the following parts.

2.3.2.1 Construction of FCE model

FCE is also known as fuzzy synthetic evaluation (Aghimien et al., 2020). Based on fuzzy set theory developed by Zadeh (1965), FCE is a process to carry out a synthetic assessment of an object that is impacted by multiple factors concerning ambiguity, imprecision, and uncertainty. In fuzzy set theory, membership values generally lie in the interval [0, 1], representing the degree to which an element belongs to a particular fuzzy set. FCE uses fuzzy mathematics, namely membership degree or membership function, to convert unclear data (qualitative assessment) into clear result (quantitative assessment) and calculate the comprehensive evaluation grade with fuzzy operators (Kuo & Chen, 2006). The detailed FCE procedures are introduced below (Hsiao & Ko, 2013; Y. Zhang et al., 2020).

Step 1: Establishment of evaluation factor set. In FCE, factors or attributes used to assess the objects should be identified in the very beginning. Domain $U = \{u_1, u_2, \cdots, u_m\}$ is defined as the first-level evaluation factor set; u_i (i =1, 2,···, m) represents the main factors relevant to the assessment and each main factor can be further divided into j sub-factors. Therefore, the second-level evaluation factor set can be expressed as $u_i = \{u_{i1}, u_{i2}, \cdots, u_{in}\}$, and u_{ij} (i =1, 2,···, m; j =1, 2,···, n) are the j th sub-factor of a main factor u_i.

Step 2: Determination of judgement set $V = \{v_1, v_2, \cdots, v_t\}$. The element of judgement set v_k (k =1, 2, ···, t) denotes all the possible evaluation grades or results given by evaluators in terms of the evaluation objects.

Step 3: Setup of the membership matrix for the first-level factors. When the evaluation object is measured as v_k considering one second-level factor u_{ij}, a single sub-factor evaluation set can be constructed as Equation (2.1).

$$r_{ij} = (r_{ij1},\ r_{ij2},\ r_{ij3},\ \cdots,\ r_{ijt}) \tag{2.1}$$

where r_{ij} represents the membership function of a specific second-level factor; r_{ijk} (i =1, 2,···, m; j =1, 2,···, n; k =1, 2,···, t) denotes the percentage of the evaluators who rated k th grade for a second-level factor, which means the membership degree. In other words, Equation (2.2) can be obtained in which x_{ijk} is the number of experts who determine sub-factor u_{ij} as the

k th grade, while N is the total number of experts involved in the evaluation. Therefore, for each second-level factor, the total amount of r_{ij} equals to unity as Equation (2.3). The membership function is used to describe the fuzziness of the evaluation factors by assigning each evaluation factor a grade of membership ranging between 0 and 1 (Du et al., 2019).

$$r_{ijk} = x_{ijk} / N \tag{2.2}$$

$$\sum_{k=1}^{t} r_{ijk} = 1. \tag{2.3}$$

The membership matrix of a first-level factor u_i is composed of memberships of each single sub-factor evaluation set, as shown in Equation (2.4). R_i is a fuzzy relationship matrix, also called fuzzy transformation.

$$R_i = (r_{ijk})_{in \times t} = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1t} \\ r_{i21} & r_{i22} & \cdots & r_{i2t} \\ \vdots & \vdots & \vdots & \vdots \\ r_{in1} & r_{in2} & \cdots & r_{int} \end{bmatrix} \tag{2.4}$$

Step 4: Determination of weighting vector of the evaluation factor. Corresponding to different levels of evaluation factors in the first step, the weighting vector $W = \{w_1, w_2, \cdots, w_m\}$ represents the relative importance of the first-level evaluation factors, and $\sum_{i=1}^{m} w_i = 1$ ($i = 1, 2, \cdots, m$). The weighting vector $w_i = \{w_{i1}, w_{i2}, \cdots, w_{in}\}$ refers to various weights of the second-level factors with respect to their upper level factor, and $\sum_{j=1}^{n} w_{ij} = 1$ ($i = 1, 2, \cdots, m$; $j = 1, 2, \cdots, n$). The weight of each factor can be decided through AHP method, which is introduced later.

Step 5: Selection of composition operator. In order to calculate the final evaluation result for the object, a fuzzy composite operation is needed. Four types of frequently used composition operator are summarized as Table 2.4 (Hsiao, 1998). In these models, d_{ik} represents the membership degree result of the alternative v_k concerning a given main factor u_i. The symbols $\wedge$ and $\vee$ mean choosing the maximum and the minimum values, respectively, while symbols • and + stand for multiplication and addition, respectively. Out of these models, model 4 has the advantage of considering the impact of all attributes and retaining the information of single sub-factor evaluation. It has been proved effective and widely adopted in fuzzy comprehensive evaluation research.

Table 2.4 Summary of composition operators

Characteristics	Algorithm			
	Model 1: $M\ (\wedge, \vee)$	Model 2: $M\ (\bullet, \vee)$	Model 3: $M\ (\wedge, +)$	Model 4: $M\ (\bullet, +)$
Formula	$d_{ik} = \bigvee_{j=1}^{n}(w_{ij} \wedge r_{ijk})$	$d_{ik} = \bigvee_{j=1}^{n}(w_{ij} r_{ijk})$	$d_{ik} = \min\left\{1, \sum_{j=1}^{n} w_{ij} \wedge r_{ijk}\right\}$	$d_{ik} = \sum_{j=1}^{n} w_{ij} r_{ijk}$
Weighting effect	Not obvious	Obvious	Not obvious	Obvious
Degree of comprehensiveness	Low	Low	High	High
Use of information in the fuzzy relationship matrix	Insufficient	Insufficient	Relatively sufficient	Sufficient
Type	Principal factor prominence	Principal factor prominence	Weighted average	Weighted average

Step 6: Conduct a multi-criteria and multi-level fuzzy comprehensive evaluation. By applying the fuzzy composite operation between the weighting vector and the fuzzy relationship matrix, both the lower-level fuzzy comprehensive evaluation matrix D_i ($i=1, 2, \cdots, m$) and the overall level matrix D are established as follows.

$$D_i = w_i \circ R_i = \left[d_{i1}, d_{i2}, \cdots, d_{it}\right] \tag{2.5}$$

$$D = W \circ R = W \circ \left[D_1, D_2, \cdots, D_m\right]^T \tag{2.6}$$

where $\circ$ denotes all kinds of composition operators and this study will use model 4 from the prior step. Based on the formula described in step 3 and step 4, Equations (2.5) and (2.6) can be easily calculated and a fuzzy output is obtained. To make it more convenient for decision making, the fuzzy output is then converted into a crisp number in the final assessment through a process of defuzzification (J.-F. Chen et al., 2015). Out of various defuzzification techniques, weighted average method is one of the simplest and widely used approaches, and will be utilized in this study.

2.3.2.2 Determination of weighting vectors using AHP

In multi-objective decision-making contexts, there are always complicated systems with plenty of variables, complex structure, and uncertainty. It is necessary to make an appropriate evaluation of the relative importance (or weight) of each factor in complex problems for reaching the objective. AHP, which was firstly introduced by Saaty (1980), is a classic MCDA technique and an intuitively simple method. DMs can estimate weights or set priorities of influencing factors in the decision-making process by utilizing this method. AHP is an effective method that combines quantitative analysis with qualitative analysis and its applications have proliferated. Comprehensive state-of-the-art surveys on AHP method and/or its applications can be found in Emrouznejad and Marra (2017), W. Ho (2008), W. Ho and Ma (2018), Ishizaka and Labib (2011), Khaira and Dwivedi (2018), Podvezko (2009), Sipahi and Timor (2010), and Vaidya and Kumar (2006). Remarkable AHP application fields include medical and healthcare (Liberatore & Nydick, 2008), construction industry (Darko et al., 2019), transportation industry (Wolnowska & Konicki, 2019), banking sector (Pekkaya & Erol, 2019), sustainable development (Dos Santos et al., 2019), operations management (Subramanian & Ramanathan, 2012), project management (Al-Harbi, 2001), and supply chain management (Mastrocinque et al., 2020). A general AHP process can be divided into the following five steps (Jozaghi et al., 2018).

Step 1: Formulation of a hierarchical structure model. AHP method disaggregates a decision problem into multiple levels from top to bottom. Decision goal is the only factor in the top layer of the hierarchy, and the subsequent lower layers refer to the progressive breakdown of the main criteria, sub criteria and the alternatives. A typical multi-level multi-criteria decision analysis framework can be seen in Figure 2.2.

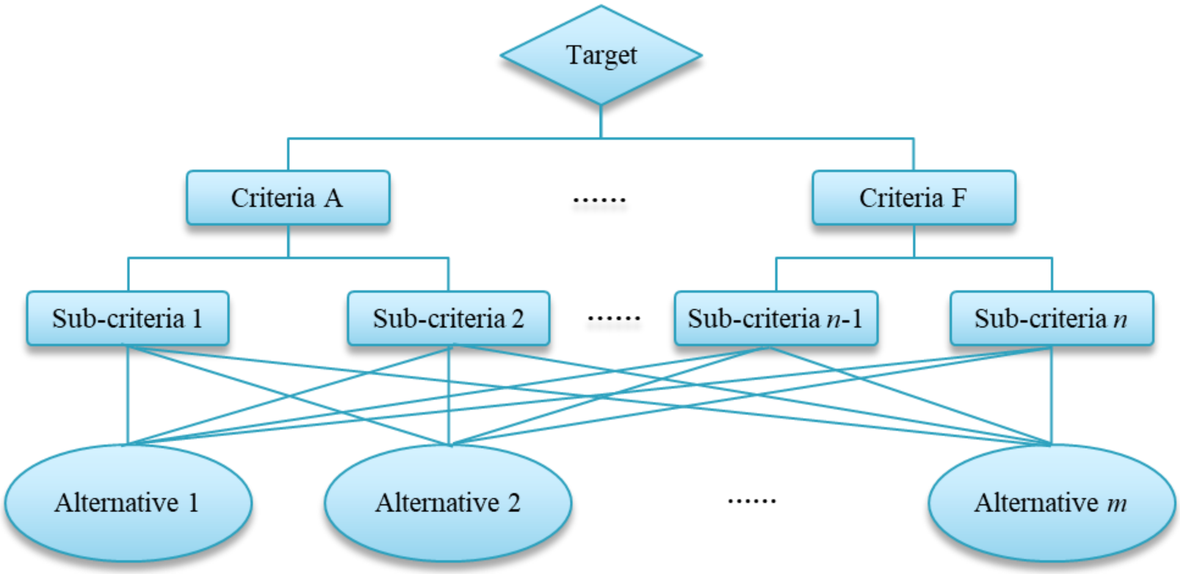

Figure 2.2 Typical hierarchy of multi-level multi-criteria decision problem

Step 2: Construction of pairwise comparison judgment matrix. To generate the weight (or relative importance) of each factor at the same level in the hierarchy, any two factors are compared with each other in terms of their importance to a relevant element in the immediate upper level. The resulting weights of factors can be named as local weights. Hence, for n factors, a pairwise comparison matrix A can be created as Equation (2.7).

$$A=(a_{ij})_{n\times n}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2.7}$$

where a_{ij} represents the relative importance of factor a_i to factor a_j (i, $j = 1, 2, \cdots, n$). The measurement is usually completed by domain experts according to the scale given in Table 2.5.

Table 2.5 Scales of AHP pairwise comparison

Scale	Definition	Explanation
1	Equal importance or preference	a_i and a_j are equally important
3	Slight importance or preference	a_i is slightly more important than a_j
5	Obvious importance or preference	a_i is obviously more important than a_j
7	Strong importance or preference	a_i is strongly more important than a_j
9	Extreme importance or preference	a_i is extremely more important than a_j
2, 4, 6, 8	Median value	The intermediate level of adjacent judgments
Reciprocal	Anti-comparison	$a_{ji}=1/a_{ij}$

Step 3: Determination of local weights. The most commonly-used method to calculate weight vector is the characteristic root method. The calculation process is as follows:

(1) Normalize each column vector in A and obtain the normalized judgement matrix A'.

$$A' = (a_{ij}^{'})_{n\times n} = \left(a_{ij} \Big/ \sum_{i=1}^{n} a_{ij} \right)_{n \times n} \tag{2.8}$$

(2) Calculate geometric mean of rows in matrix A' and normalize the results, which can be represented in the following equations.

$$M_i = \left[\prod_{j=1}^{n} a_{ij}^{'} \right]^{1/n} \tag{2.9}$$

$$w_i = M_i \Big/ \sum_{i=1}^{n} M_i \tag{2.10}$$

Then $W = \{w_1, w_2, \cdots, w_n\}$ is the weighting vector.

Step 4: Consistency check. In order to ensure the reliability of subjective judgments made by decision makers, consistency verification should be carried out.

(1) Calculate the maximum eigenvalue of the pairwise comparison matrix A as $\lambda_{\max}$, and $(AW)_i$ is the i th component of the multiplication between a matrix A and a vector W.

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(AW)_i}{nw_i} \tag{2.11}$$

(2) Calculate consistency index (CI) and consistency ratio (CR) as below equations. RI is the average random consistency index and its value can be found in Table 2.6 (Liu & Zhang, 2013).

$$CI = (\lambda_{\max} - n)/(n-1) \tag{2.12}$$

$$CR = CI/RI \tag{2.13}$$

If $CR < 0.1$, the consistency of judgement matrix is satisfactory and the weight obtained in step

3 can be used. Otherwise, for matrices with a $CR > 0.1$, initial values of judgement matrix elements should be revised to decrease the inconsistency until it satisfies $CR < 0.1$.

Table 2.6 *RI* value for corresponding *n*

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Step 5: Determination of combined weights. The combined weight calculates the relative importance of the factors in a layer to the target layer. For instance, in Figure 2.2, combined weight of a sub-criteria can be computed by multiplying its local weight with the weight of immediate upper-level criteria. With respect to the combined weights of alternatives, all the local weights of each path in the hierarchy are multiplied and then the resulting products are summed by the paths involving the alternative to be calculated (Sueyoshi et al., 2009).

2.3.3 The MCGP method

2.3.3.1 Goal programming model

Among the various MCDM methods, goal programming (GP) model, which originated from the work of Charnes and Cooper (1961), is widely used to solve decision problems involving multiple but normally competing goals. As an extension of linear programming, GP enables DMs to find a solution that represents the best compromise satisfying a set of objectives as better as possible by minimizing the total deviations between the achievement and aspiration levels of goals as set forth by the DMs (Aouni et al., 2017). A recent literature review on the broad applications of GP model in engineering, management and social sciences can be referred to Colapinto et al. (2017). The GP model is a distance-based method and its conceptual expression is described below.

$$\text{Minimize } \sum_{i=1}^{n}(d_i^+ + d_i^-) \quad (2.14)$$

Subject to

$$f_i(x) - d_i^+ + d_i^- = g_i, \; i = 1, 2, ..., n \quad (2.15)$$

$$d_i^+, d_i^- \geq 0, \; i = 1, 2, ..., n \quad (2.16)$$

$$x \in F \;\; (F \text{ is a feasible set}) \quad (2.17)$$

where $f_i(x)$ is the objective function of the i th goal. d_i^+ and d_i^- are the over-achievements and under-achievements of the i th goal, respectively. g_i is the aspiration level (target value) of the i th goal.

2.3.3.2 MCGP model and its variants

Decision makers can only map one aspiration level to each goal under standard GP model, and such restriction impairs the usefulness of GP in many real situations due to uncertainty in decision problems or lack of available information. For instance, when making a 3-year strategic plan for the company, Chief Executive Officer (CEO) desires to increase revenue by 10% annually. However, this can be a conservative aspiration level in order to accomplish personnel performance and to earn bonus more easily. In fact, if multiple aspiration levels can be mapped to one goal, the company may realize higher growth rate by conducting proper business activities. To assist DMs to avoid underestimating the aspiration level setting when formulating the decision problem, C.-T. Chang (2007, 2008) proposed MCGP approach which allows DMs to consider multiple aspiration levels for a goal. MCGP model resolves a major downside of the standard GP model. There are two types of aspiration levels in the MCGP model: ‘the more the better’ and ‘the less the better’ (Alizadeh & Yousefi, 2019). MCGP is easy understanding, and it has been applied to address a variety of real-life problems since its introduction. For example, project portfolio selection (Tabrizi et al., 2016), supplier selection (Bera et al., 2019; Fu, 2019), location selection of logistics centers (K.-H. Chen et al., 2014), topology design problem of remote patient monitoring systems (Zheng & Chang, 2021), vehicle routing problem (Yousefi et al., 2017), and product portfolio design (S.-Y. Wang et al., 2021). Singh and Sonia (2017) performed a state-of-the-art review of the development and application of MCGP model. MCGP model is formulated as follows.

$$\text{Minimize } \sum_{i=1}^{n}[(\alpha_i d_i^+ + \beta_i d_i^-) + \delta_i (e_i^+ + e_i^-)] \tag{2.18}$$

Subject to

$$f_i(x) - d_i^+ + d_i^- = y_i, \ i = 1, 2, \ldots, n \tag{2.19}$$

$$y_i - e_i^+ + e_i^- = g_{i,\max} \text{ or } g_{i,\min}, \ i = 1, 2, \ldots, n \tag{2.20}$$

$$g_{i,\min} \le y_i \le g_{i,\max}, \ i = 1, 2, \ldots, n \tag{2.21}$$

$$d_i^+, d_i^-, e_i^+, e_i^- \ge 0, \ i = 1, 2, \ldots, n \tag{2.22}$$

$$x \in F \ \ (F \text{ is a feasible set}) \tag{2.23}$$

where α_i, β_i and δ_i are the penalty weights attached to the deviational values d_i^+, d_i^- and sum of deviational values of e_i^+ and e_i^-, respectively. e_i^+ and e_i^- are positive and negative deviations of $|y_i - g_{i,\max}|$ or $|y_i - g_{i,\min}|$. y_i is a continuous variable between interval values $g_{i,\min}$ and $g_{i,\max}$, which are the lower and upper bounds of y_i respectively. In Equation (2.20), use $g_{i,\max}$ for the case of the more the better while $g_{i,\min}$ is used for the less the better scenario. Definition of other variables is referred to GP model.

The popularity of MCGP method has aroused scholars' interests to extend the model in different ways, such as fuzzy multi-choice goal programming (FMCGP) (Bankian-Tabrizi et al., 2012) and weighted-additive FMCGP (WA-FMCGP) (Hocine et al., 2020). Besides, H.-P. Ho (2019) recently presented Weighted MCGP and MINMAX MCGP to further improve the practical utility of MCGP method. These two variants of MCGP are relatively new. At below, the formulations of Weighted MCGP and MINMAX MCGP are stated in Equation (2.24) and Equation (2.25) - (2.27), respectively.

$$\text{Minimize } \sum_{i=1}^{n} w_i(\alpha_i d_i^+ + \beta_i d_i^- + e_i^+ + e_i^-) \tag{2.24}$$

Subject to

constraints (2.19) - (2.23)

where w_i is the relative importance on the i th decision goal, and $\sum_{i=1}^{n} w_i = 1$. Other variables are the same as those in MCGP model.

$$\text{Mininize } D \tag{2.25}$$

Subject to

$$D \geq \alpha_i d_i^+ + \beta_i d_i^-, \quad i = 1, 2, ..., n \tag{2.26}$$

$$D \geq \delta_i (e_i^+ + e_i^-), \quad i = 1, 2, ..., n \tag{2.27}$$

constraints (2.19) - (2.23)

where D is an additional variable that measures the maximum deviation between goals. Other variables are the same as those in MCGP model.

This study uses the above two MCGP-based approaches for project portfolio selection, resource allocation, and staff assignment.

2.4 Summary

This chapter introduces prior studies relevant to the research topic – risk-based internal audit planning, and then presents the background of the proposed methods to resolve the decision-making problems in the audit planning process.

As internal audit planning is one of the application fields of project portfolio planning problem, this chapter starts from the concept of project portfolio planning. Then two main activities of project portfolio planning are reviewed. Firstly, PPS problem is the core component of project portfolio planning. A state-of-the-art review on PPS problem is conducted according to the selection and evaluation criteria, selection approaches and application areas. Secondly, as a successive step and a sub-problem of PPS process, personnel assignment problem are reviewed. A special version of PA problem, the project-team formation, is specifically discussed. According to the number of projects considered in the problem, prior research on project-team formation problem can be classified into two categories: one team for a single project and multiple teams for multiple projects. Regarding the project portfolio scheduling, it is not within the review scope. A high-level schedule will be presented using a simple but well-known and commonly used project scheduling tool, Gantt chart. This tool will be introduced in the next chapter.

After conducting the literature survey on project portfolio planning, a comprehensive literature review of internal audit planning is presented. Internal audit planning is an important real-life problem which could add value to the organization. However, it has been largely unaddressed in the research (Goman & Koch, 2019), and scholars called for more research on this problem (Kotb et al., 2020). The review and analysis are organized according to the three methods for developing an internal audit plan: cycle approach, cycle-risk-based approach, and risk-based approach. Internal auditing practice has basically shifted from cycle-based audit planning to risk-based audit planning, and majority of the organizations have adopted risk-based techniques in audit planning based on the global and regional surveys (Allegrini & D'Onza, 2003; Sobel, 2015). Therefore, this study concentrates on describing risk-based approach to internal audit planning and conduct the review according to the four successive stages in the risk-based internal audit planning framework: risk assessment, project portfolio selection, staff assignment and scheduling.

Finally, this chapter outlines the calculation steps and mathematical models of the proposed multiple criteria decision methods for resolving the internal audit planning problem, including

FCE-AHP (FAHP), Weighted MCGP and MINMAX MCGP. The reasons for the methodological choice in each of the above-mentioned audit planning stage are elaborated as well. Internal audit planning is virtually a multiple-stage and multiple-objective problem to optimize the resource allocation in the project portfolio selection process based on the risk assessment. The designed framework and the proposed integrated methods fit for this purpose. In addition, the methods can be implemented without rigorous mathematical manipulations and can be solved with the typical software.

In the following chapter, the proposed integrated multi-stage framework for audit planning will be depicted and the processual steps of each stage will be described in detail.

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Chapter 3: An Integrated Multi-Stage Framework for Risk-Based Internal Audit Planning

The main purpose of chapter three is to provide a systematic scheme with algorithmic solutions for the annual audit planning problem. This chapter consists of six sections. At the beginning of the chapter, an integrated multi-stage framework in the form of a flowchart is proposed for developing a risk-based internal audit plan. An overview of the flowchart and a list of notations to be used in the proposed integrated methods are also provided. The following four components respectively elaborate the working steps and methods of the four successive stages in the risk-based internal audit planning process. In this way, the process of creating a comprehensive and effective annual audit plan is explained in detail. A synthesis of the chapter is given in the end.

3.1 An overview of the proposed framework

3.1.1 A flowchart of the internal audit planning process

Effective internal audit planning enables the IAF to provide insight to stakeholders, and safeguard and enhance organizational value by initiating meaningful audit projects. While the details of the planning process and the format of the annual audit plan may vary from organization to organization, there are some elements in common for developing an internal audit plan (Anindyajati & Rachman, 2020; Begma et al., 2019). To be specific, firstly the general project portfolio planning phases, including project prioritization and selection, personal assignment, and project scheduling, are applicable to the annual audit planning. In addition to these generic phases, risk assessment is another key characteristic and step in the context of risk-based internal audit planning. In a word, risk-based internal audit planning is a process that identifies all the risk types within the organization, lists all the auditable units (or potential audit projects), assesses the risk level of each auditable unit, selects the areas to be audited, assigns audit staff to every selected project, and finally creates an audit schedule. In this way, a comprehensive and effective internal audit plan is generated. In order to assist audit management in making more informed decisions during the annual planning process, a multi-stage framework with integrated methods is proposed as Figure 3.1.

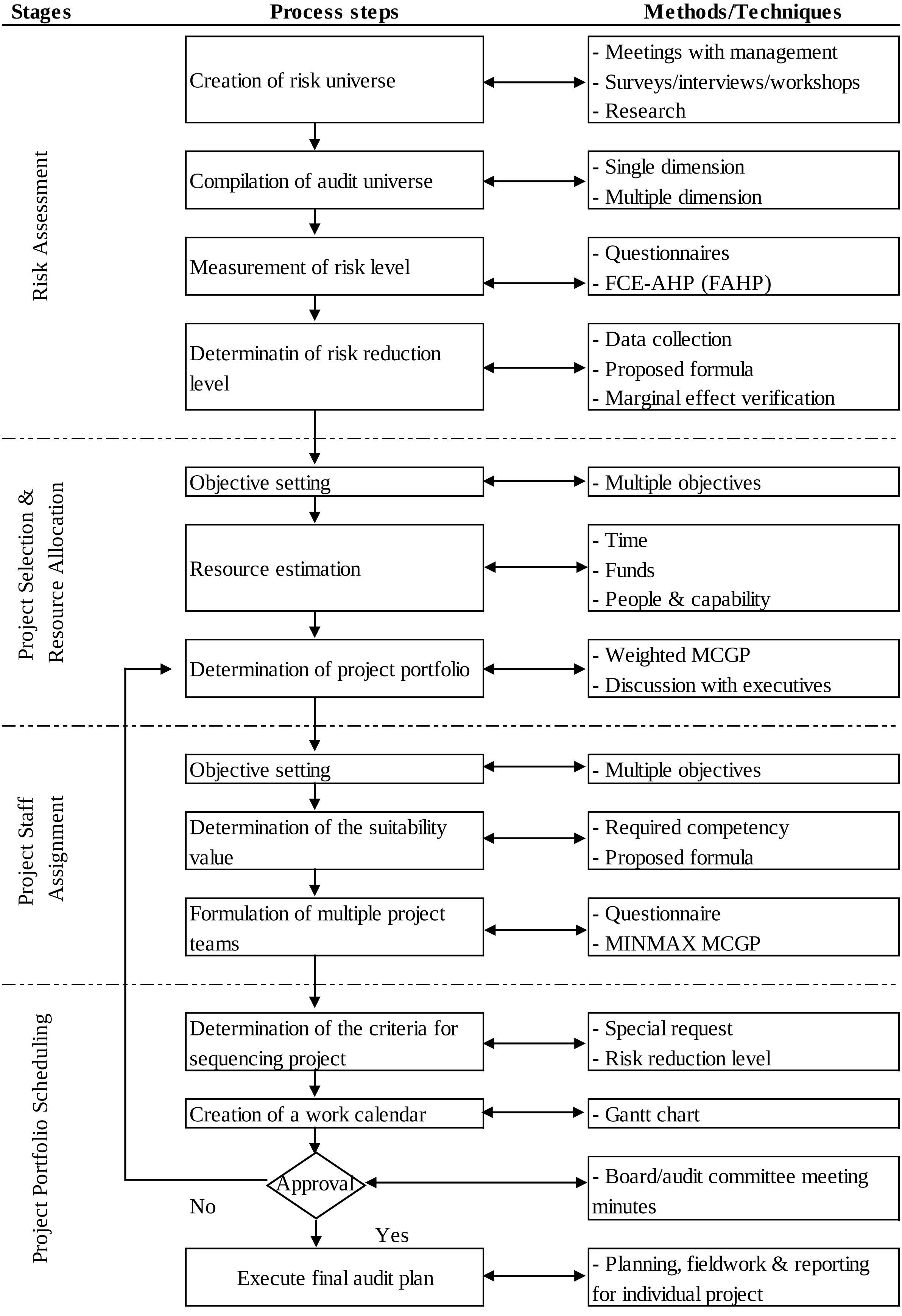

Figure 3.1 The proposed framework for risk-based internal audit planning

In the proposed framework, there are four main stages to prepare the annual internal audit plan, namely: (1) risk assessment; (2) project selection and resource allocation; (3) project staff assignment; and (4) project portfolio scheduling. The illustrated framework is briefly introduced to provide a general understanding of the risk-based internal audit planning process.

In the first stage, a risk universe, also known as risk register or risk inventory, should be established. The risk universe identifies all the key risks that the organization faces or might face (P. Griffiths, 2016). Inputs on organizational risks can be obtained through meetings, surveys, interviews and workshops with management, and independent research. In parallel, an audit universe needs to be developed. The audit universe is a list of all the auditable units/areas that can be audited within an organization, and each auditable unit can be viewed as a potential internal audit project (Balkaran, 2022). The components of an audit universe can be all the subsidiaries of the organization, all the business processes, all the organizational functions, or a mix of them. The audit planning team compares the importance of the identified risk types and assesses the current risk level of each auditable unit. Experts' opinions on the relative importance of various risks and the risk rating can be obtained through questionnaires. Based on the collected data, the risk levels of the auditable units can be calculated using FCE-AHP (FAHP) approach. To measure the contribution of each candidate project to the mitigation of existing risk in respective auditable unit, the data on the efforts needed for different audit scopes are provided by managers and then a risk reduction value of each project is estimated. The result implies that the spent audit time has decreasing marginal effect on risk reduction.

In the second stage, multiple objectives are defined for audit project selection problem. Also, available audit resources (e.g., working hours, capability, and funds) are estimated. According to the pre-defined objectives, risk reduction results, and various constraints, internal audit projects to be conducted in the year can be selected from the audit universe utilizing Weighted MCGP method. The CAE, the head of internal audit department, shall also solicit feedback from executives on the selected project portfolio (draft plan). Based on the given opinions, audit planning team determines whether any adjustments to the selection results should be made before proceeding to the next step.

The third stage is to assign internal audit staff to the selected project portfolio, using MINMAX MCGP method to satisfy multiple goals. Based on auditors' competency level and project characteristics, a suitability value between auditor and audit project is computed.

The last stage is audit scheduling, which comprises the determination of the sequence of conducting the projects (e.g., designated period, decreasing order of risk reduction value) and creation of a Gantt chart to display the work schedule. Finally, the CAE will present the developed annual work plan to the audit committee or the board. Once the proposal is approved, the internal audit plan can be executed. In the meantime, it is noteworthy that obtaining the approval for the proposed audit plan is not the end of the planning work. The approved annual internal audit plan can be further updated as necessary to respond to the changes of internal and external environments during the year.

When implementing the framework in the annual planning process, mathematical notations to be used in the proposed integrated methods are summarized in the next section.

3.1.2 Mathematical notations

Table 3.1 defines all the parameters and decision variables used in the model formulation.

Table 3.1 Definition of mathematical notations of the study

Notation	Definition
R_i	i th main risk, $i = 1, 2, \cdots, I$
r_{ij}	j th secondary risk in i th main risk, $i = 1, 2, \cdots, I$, $j = 1, 2, \cdots, J$
AU_m	m th auditable unit in the audit universe, $m = 1, 2, \cdots, M$
W	Weighting vectors for main risks
w_i	Weighting vectors for secondary risks, $i = 1, 2, \cdots, I$
Z_{mi}	Score of i th main risk for m th auditable unit, $i = 1, 2, \cdots, I$, $m = 1, 2, \cdots, M$
Z_m	Pre-audit overall risk score of m th auditable unit, $m = 1, 2, \cdots, M$
H_{mi}	Fuzz comprehensive evaluation set of i th main risk for m th auditable unit, $i = 1, 2, \cdots, I$, $m = 1, 2, \cdots, M$
H_m	Fuzz comprehensive evaluation set of the overall risk for m th auditable unit, $m = 1, 2, \cdots, M$
S	Evaluation grade set
RP_n	Risk reduction percentage under n th level of audit effort, $n = 1, 2, \cdots, N$
T_{mn}	Working hours spent on m th auditable unit at n th work scope level, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
RR_{mn}	Risk reduction value of m th auditable unit by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
ΔT_{mn}	Additional time to conduct audit work in auditable unit m at work scope which is one level higher than n, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
ΔRR_{mn}	Additional risk reduction achieved by making audit effort at one level higher than n when working on auditable unit m, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{int})}$	Amount of time that in-house audit staff spend on m th auditable unit by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{ext})}$	Amount of time that external services spend on m th auditable unit by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{erm})}$	Amount of time spent on m th auditable unit linked to ERM by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{mgt})}$	Amount of time spent on m th auditable unit linked to management request by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$

$T_{mn(\text{hot})}$	Amount of time spent on m th auditable unit linked to industry audit hot spot by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{stgy})}$	Amount of time spent on m th auditable unit linked to organizational strategy focus by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{ac})}$	Amount of time spent on m th auditable unit linked to audit committee interest by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
$T_{mn(\text{adv})}$	The amount of time spent on m th auditable unit in advisory service by devoting n th level of audit effort, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
T	Available audit time in total
F	Total budget
p	Hourly rate of 3rd party professional service
w_k	Relative importance on k th decision goal, $k = 1, 2, \cdots, K$
α_k	Penalty weights attached to the deviational values d_k^+, $k = 1, 2, \cdots, K$
β_k	Penalty weights attached to the deviational values d_k^-, $k = 1, 2, \cdots, K$
d_k^+ (d_k^-)	Underachievement (overachievement) of k th goal, $k = 1, 2, \cdots, K$
e_k^+ (e_k^-)	Positive (negative) deviation between aspiration value of k th goal and lower or upper bound of corresponding aspiration value, $k = 1, 2, \cdots, K$
y_k	A continuous variable which is aspiration value of k th goal, $k = 1, 2, \cdots, K$
$g_{k,\max}$	Upper bounds of y_k, $k = 1, 2, \cdots, K$
$g_{k,\min}$	Lower bounds of y_k, $k = 1, 2, \cdots, K$
X_{mn}	Binary decision variable used to decide whether to select m th auditable unit at n th work scope level, $m = 1, 2, \cdots, M$, $n = 1, 2, \cdots, N$
C_l	l th competency, $l = 1, 2, \cdots, L$
A_u	u th internal auditor, $u = 1, 2, \cdots, U$
P_v	v th internal audit project, $v = 1, 2, \cdots, V$
w_{lv}	Weight of l th competency for v th audit project, $l = 1, 2, \cdots, L$, $v = 1, 2, \cdots, V$
w_{lv}^o	Weight corrector of l th competency for v th project, $l = 1, 2, \cdots, L$, $v = 1, 2, \cdots, V$
O_{luv}	Decision matrix of v th project, $l = 1, 2, \cdots, L$, $u = 1, 2, \cdots, U$, $v = 1, 2, \cdots, V$
Q_{luv}	Weighted and corrected decision matrix for v th internal audit project, $l = 1, 2, \cdots, L$, $u = 1, 2, \cdots, U$, $v = 1, 2, \cdots, V$
E_{uv}	Suitability value of u th auditor for v th project, $u = 1, 2, \cdots, U$, $v = 1, 2, \cdots, V$
D	An extra continuous variable that measures the maximum deviation between goals
δ_k	Penalty weights of the sum of deviational values of e_k^+ and e_k^-, $k = 1, 2, \cdots, K$
G_{uv}	Preference value of u th auditor for v th project, $u = 1, 2, \cdots, U$, $v = 1, 2, \cdots, V$
X_{uv}	A binary decision variable used to decide whether u th audit staff is assigned to v th internal audit project, $u = 1, 2, \cdots, U$, $v = 1, 2, \cdots, V$
s_v	Total number of team members for v th internal audit project, $v = 1, 2, \cdots, V$
t_v	Duration of v th internal audit project, $v = 1, 2, \cdots, V$
a	Difference between total working days of each auditor
b	Difference between total preference values of each auditor

In the following sections, both steps and methods of each annual audit planning stage in the proposed framework are explained in detail.

3.2 Stage I: risk assessment

The internal audit function conducts a risk assessment to identify and prioritize areas on which the audit work should concentrate due to limited resources (Bailey et al., 2003). A prerequisite of risk assessment for risk-based audit planning is to link auditable areas with risk types. To this end, it is necessary to firstly identify the organizational risks and break down the organization into auditable sections. Risk universe and audit universe are the recommended and widely used tools to achieve this purpose. According to a professional survey conducted by Gartner (2018), 90% of the 88 surveyed organizations considered both the audit universe and risk universe when creating the annual audit plan, and 6% and 3% of the organizations respectively used risk universe only and audit universe only, while neither of them was adopted by the rest 1% survey participants. Detailed steps for establishing the risk universe and/or audit universe can be referred to D. M. Griffiths (2020), O'Har et al. (2017) and Zacchea (2003). The high-level introduction of the methods for developing risk universe and audit universe is provided as follows.

3.2.1 Creation of risk universe

Risks impact the achievement of organizational objectives (Jovanović et al., 2020). Responding to the four categories of entity objectives defined by the COSO Enterprise Risk Management (ERM) framework (COSO, 2017), the following four main categories of risk are identified to be broadly used by most organizations (Alawattegama, 2018; Amankwah-Amoah & Wang, 2019; Callahan & Soileau, 2017; Deloitte, 2013; Gutterman, 2020; Herbane et al., 2004; IIA, 2020): (1) strategic risk, which refers to the risks that affect or are created by an organization's overall strategy or long-term goals; (2) financial risk, which is associated with financial activities and the potential financial loss; (3) operational risk, which is related to the failure of the organization's day-to-day operations to execute its strategic plan; and (4) compliance risk, which involves the violations of laws, rules, regulations, internal policies and procedures, and ethical standards. Each of these main risk categories can be decomposed into several secondary risks. Let R_i denotes the i th main risk and r_{ij} denotes the j th secondary risk under the i th main risk (i = 1, 2, ⋯, I ; j = 1, 2, ⋯, J). Certainly, more risk levels may be further expanded from the upper-level risks as necessary.

In fact, specific risk types depend on the organization's real situation, such as industry nature, company size, and transaction type. There is no 'one size fits all'. According to the Financial Stability Board's guidance on the supervision of risk culture, Arnaboldi and Vasciaveo (2017) presented risk indicators for financial institutions, including 4 macro-category risks (i.e., tone from the top, accountability, communication and challenges, incentives), 12 sub-category risks (e.g., leading by example, ownership of risk, openness to alternative views, and succession planning) and 92 quantitative components (e.g., number of critical issues self-disclosed by business managers versus critical issues raised by control functions, correlation rate between number of compliance breaches and number of internal sanctions, and trend analysis of cases of law breaches not linked to fraud and causing sanctions for the company). Etges et al. (2018) developed a risk inventory for healthcare organizations based on the interviews and surveys, which covered 28 risks with specific risk scenarios (e.g., clinical batch claim, non-compliance with laws and regulations, supply chain, unethical conduct, union strike, talent retention, etc.). Using a professional report from a consulting firm, Aditya et al. (2018) structured a modernization IT risk universe framework with 10 key risk aspects (e.g., security and privacy risk, applications and databases risk, and infrastructure risk) for developing an IT audit plan.

Manufacturing sector continues to be a critical force in both advanced economies and emerging market and developing economies (EMDEs) (Bryson et al., 2015). It is a foundation of a country and determines a country's comprehensive strength and international competitiveness. A strong manufacturing sector creates a sustainable economic ecosystem and attracts investment. A manufacturing company will also be applied to validate the feasibility of the proposed framework in the next chapter. As a result of literature review on risk management, as well as referring to the risk universe applied in practice (i.e., the real-world internal documents shared by 7 companies such as Eaton Corporation, Cisco, AMD, Hayes Lemmerz, Celanese Corporation, Dow Chemical, and ASP studied in the case application), a generic risk universe for manufacturing industry is developed and displayed in Table 3.2. It can be used as a starting point for organizations in various industries to create a unique risk universe. By understanding specific business objectives, the audit planning team can further customize a risk universe that fits for their organizational needs.

Table 3.2 A generic risk universe applicable to manufacturing sector

Main Category	Sub-Category	Risk Description	Examples	Reference
Strategic risk (R_1)	Corporate governance (r_{11})	- Board performance - Tone at the top - Control environment	Lack of guidelines and Board oversight may lead to regulatory violations, litigation exposure, business interruption and financial loss.	Birkel et al. (2019), COSO (2018), ElKelish (2018), Portman (2013), Gartner (2020c)
	Key relationship management (r_{12})	- Strategic suppliers - Government relations	Inability to effectively manage government relations may negatively impact the organization.	Gartner (2020c), Gutterman (2020), Leopizzi et al. (2020)
	Major initiatives (r_{13})	- Planning and execution - Measurement & monitoring - Mergers & acquisitions	Poor execution and integration of mergers, acquisitions & divestitures may result in operational disruptions or inefficiencies.	COSO (2018), Y. B. Chang and Cho (2017), Portman (2013), Gartner (2020c), Gutterman (2020)
	Market dynamics (r_{14})	- Competition - Macro-economic factors - Lifestyle/business trends - Socio-political	Deterioration or changes in economic conditions impact the Company's ability to grow the business.	Birkel et al. (2019), COSO (2018), Portman (2013), Gartner (2020c), Ignat et al. (2020), Leopizzi et al. (2020)
	Planning & resource allocation (r_{15})	- Organization structure - Strategic planning - Annual budgeting/forecasting	Budget/forecast based on unreasonable assumptions or information, resulting in wrong decisions, and resource misallocation.	Birkel et al. (2019), COSO (2018), Portman (2013), Gartner (2020c), Ignat et al. (2020)
	Reputation, brand & communication (r_{16})	- Investor/media relations - Crisis communication - Sustainability - Employee satisfaction	Failure to develop, implement and communicate sustainability programs may have a negative impact on the organization's reputation.	COSO (2018), Portman (2013), Gartner (2020c), Gutterman (2020), Ignat et al. (2020), Leopizzi et al. (2020)
Financial risk (R_2)	Accounting & reporting (r_{21})	- Internal control structure - Statutory/internal reporting - Master data & data integrity	Deficiencies in internal control structure may result in misstated financials, fraudulent activities, financial loss, and reputation damage.	COSO (2018), Portman (2013), Gartner (2020c), Ignat et al. (2020), Scarlat et al. (2012)
	Treasury (r_{22})	- Cash management - Credit & collection - Insurance	Inaccurate information regarding cash inflows/outflows may have a negative impact	COSO (2018), Portman (2013), Gartner (2020c),

		- Debt	on cash forecasting and management of funds.	Gutterman (2020), Scarlat et al. (2012)
	Tax (r_{23})	- Income tax provision/return - Tax strategy & planning - Value added taxes (VAT)	Untimely claim of VAT or inaccurate reconciliation may result in penalties and/or a misstatement of financials.	COSO (2018), Portman (2013), Gartner (2020c), Scarlat et al. (2012), Stoel et al. (2017)
Operational risk (R_3)	Sales & marketing (r_{31})	- Service/product development - Price & revenue management - Customer satisfaction - Product availability/quality	Poor customer service and/or inability to meet customer requirements may lead to loss of business and damage reputation.	COSO (2018), Portman (2013), Gartner (2020c), Gutterman (2020), Leopizzi et al. (2020), Scarlat et al. (2012)
	Purchasing & supply chain (r_{32})	- Procurement strategy - Vendor selection - Loading & logistics - Inventory planning	Ineffective vendor selection, negotiation, or bidding processes result in lack of availability, higher costs or impaired quality and potential liability exposures.	COSO (2018), Portman (2013), Gartner (2020c), Gutterman (2020), Leopizzi et al. (2020), Scarlat et al. (2012)
	People/human resources (r_{33})	- Culture/change management - Recruiting & retention - Development & performance - Succession planning - Compensation & benefits	Inability to recruit and retain appropriate talent could result in a lack of business integrity and non-achievement of organization goals. Failure to identify and manage key personnel result in unplanned loss of key knowledge/skills.	COSO (2018), Portman (2013), Gartner (2020c), Gutterman (2020), Leopizzi et al. (2020), Scarlat et al. (2012)
	Information technology (r_{34})	- Information security - IT operations - IT system resiliency - IT strategy & planning - Data management	IT operational procedure related to applications and network monitoring, and the handling of system incidents is not sufficient to support business objectives resulting in unplanned service interruptions.	Birkel et al. (2019), COSO (2018), Portman (2013), Gartner (2020c), Leopizzi et al. (2020), Scarlat et al. (2012), Subriadi and Najwa (2020)
	Physical assets (r_{35})	- Property and equipment - Capital project management	Inappropriate management of capital projects may result in project delay and budget overruns.	COSO (2018), Portman (2013), Gartner (2020c)
	Production/manufacturing (r_{36})	- Environment, health & safety - Production capability - Business continuity planning	Poor production reliability may lead to operations disruption, rework, loss of customers and inability to capture market opportunities.	COSO (2018), Gartner (2020c), Ignat et al. (2020), Scarlat et al. (2012), Sun et al. (2020)

Compliance risk (R_4)	Legal (r_{41})	- Contract/records management - IP infringement - Litigation	Trademarks, copy rights, patents and related documentation are not appropriately managed resulting in loss of competitive advantage.	Birkel et al. (2019), COSO (2018), Portman (2013), Gartner (2020c), Leopizzi et al. (2020)
	Regulatory (r_{42})	- Anti-trust/anti-corruption - Trade & customs - Data protection & privacy	Failure to comply with domestic/international data protection and privacy laws could have litigation exposure and reputational damage.	COSO (2018), Portman (2013), Gartner (2020c), Leopizzi et al. (2020)
	Standards of business conduct (r_{43})	- Ethics - Fraud - Company policy	Fraudulent may remain undiscovered if management does not properly encourage 'free from retaliation' reporting of such acts.	COSO (2018), Portman (2013), Gartner (2020c), Ignat et al. (2020), Leopizzi et al. (2020)

3.2.2 Compilation of audit universe

An audit universe simplifies the assessment of risks throughout the organization (IIA, 2020). The auditable units or areas (AU_m, $m = 1, 2, \cdots, M$) in the audit universe are treated as the evaluation object, and various risks are used as the evaluation criteria.

There are different ways to develop audit universe. Categorizations of the auditable unit include function, entity, process, department, project, subject, or topic that could justify an internal audit project (IIA, 2020). Organizations need to determine appropriate perspective and approach, either single dimension or multiple dimensions, for creating their own audit universe. Heldifanny and Tobing (2019) analyzed the risk-based internal audit plan at a university whose audit universe is a mix of process (e.g., procurement, recruitment, student admission, waste management, IT integration, information system, budgeting, fixed asset management, etc.), program (e.g., study program, infrastructure construction) and entity (e.g., library, laboratory, hospital, faculties/schools, etc.). Based on the Control Objectives for Information and Related Technology (COBIT) framework, Senft and Gallegos (2008) provided an example of IT audit universe through the lens of critical IT processes (e.g., operations management, service desk and problem management, software development and implementation, application controls and maintenance, change management, security and service continuity, system management, virtual security, enterprise resource planning, etc.). Gartner (2018)'s survey revealed that most organizations defined audit universes based on business units (73%) and processes (72%), followed by risk type (42%), geographic area (31%) and others (7%). That survey also indicated that majority of audit universes (54%) comprise fewer than 149 entities, while 30% organizations have more than 250 units, and the rest 16% are between 150 and 249.

Each auditable unit is considered as a potential internal audit project. It is preferable to create a comprehensive audit universe which lists all the auditable units within the organization. Nevertheless, except for some organizations such as financial service industry that are mandatory to maintain an audit universe to meet regulatory requirements (Chartered IIA, 2020), the IAF in other organizations may choose not to develop a complete audit universe. In that case, based on various inputs and professional judgement, audit planning team still needs to propose a population of candidate projects to be conducted in the planned year, which can be viewed as a partial or an incomplete audit universe.

According to the nature of the audit project, there are two types of audit services for the identified auditable unit: assurance and advisory services. Assurance service makes independent evaluation on the effectiveness and efficiency of the controls, processes, and activities of the reviewed areas, while advisory service supports management on their tasks or actions as supplementary resources. According to a recent professional survey conducted by Gartner (2020b), the most common advisory activities are pre-implementation reviews (78%) and post-implementation reviews (74%), followed by control design support (71%), governance reviews (55%), risk assessment workshops (31%), other (16%) and contingency and scenario plan design (11%).

It is worth highlighting that both risk universe and audit universe are not stagnant. Internal audit team should update and maintain them periodically (e.g., at least once a year during the annual planning or whenever changes are applicable). According to the internal surveys, discussions or interviews, and external literature (e.g., news event, research report), outdated items can be removed from the risk universe and audit universe, and new items should be added to the lists to ascertain their accuracy.

3.2.3 Measurement of risk level

As the object of a potential audit activity, an auditable unit is a collection of organizational elements that is exposed to risks and implemented with controls to handle risks. A risk level that remains in the auditable unit (usually termed as 'residual risk') prior to any audit activity should be assessed considering the existing control measures taken by the management.

A specific-risk approach is adopted for risk assessment in this research. Other frequently used risk assessment methodology includes risk-by-process approach and risk-factor approach. Under specific-risk approach, the risks associated with every auditable unit in the audit universe are specified (Heldifanny & Tobing, 2019). Using a matrix with each auditable unit in a row and each risk in a column, the connection between the risk types and the auditable units is created. Then the total risk score of each auditable unit can be calculated by means of FCE-AHP (FAHP) method. The measurement process can be divided into three phases as follows.

First, according to Table 3.2, the 4 main risks are the first-level evaluation factor set, and the 18 subcategory risks are the second-level evaluation factor set. Risk rating scale is the judgement set. Due to the difficulty of measuring risks precisely, qualitative measures (e.g., low, medium, and high) are more likely to be used by organizations than quantitative ranges or point estimates (Stoel et al., 2017). Table 3.3 shows different risk levels revised from Joshi and Singh (2017). Then Table 3.4 presents one illustrative example of specific-risk approach using the proposed generic risk universe.

Table 3.3 Risk level description

Scale	Description
Significant	Risk is totally intolerable and thus requires prompt action to address the risk.
High	Risk is unacceptable and should implement remediation plan as early as possible.
Medium	Risk may be acceptable in a short period of time but action to reduce risk is necessary.
Low	Risk is acceptable and the situation is not a concern but there are opportunities for further improvement or reduction of risk should be implemented in future.
Very low	Risk is slight or even negligible.

Table 3.4 An example of specific-risk approach

AU	Strategic				Financial			Operational				Compliance		
	r_{11}	r_{12}	…	r_{16}	r_{21}	r_{22}	r_{23}	r_{31}	r_{32}	…	r_{36}	r_{41}	r_{42}	r_{43}
AU_1	Low	Medium	…	Significant	High	Medium	Medium	Low	High	…	Medium	Very Low	Low	Medium
AU_2	High	Low	…	Medium	High	Medium	High	High	Medium	…	Significant	Significant	Medium	Medium
AU_3	Medium	High	…	Very low	Medium	High	Very low	Medium	Low	…	Very low	Medium	High	Medium
AU_4	Low	Medium	…	High	High	Medium	Medium	Low	High	…	Very low	Low	Low	Medium
AU_5	High	Medium	…	High	Low	Low	Medium	High	Medium	…	Very low	Medium	High	High
AU_6	Medium	High	…	Medium	Medium	Medium	High	Medium	Medium	…	High	Medium	Medium	Low
AU_7	High	Low	…	Significant	Medium	Medium	Medium	Low	Medium	…	Medium	Low	Medium	Medium
...		...				...			...				...	
AU_M	Medium	Low		Very low	Medium	Low	Medium	Low	Medium		Very low	Medium	High	Low

Second, a hierarchical taxonomy of risk can be structured based on Table 3.2. To prioritize various risk types according to their importance to the organizational performance, an AHP questionnaire is designed and distributed to those who are involved in the organization's annual audit planning process. Saaty (1980)'s nine-point scale of pairwise comparison is used for AHP application. Once the experts' opinions on the relative importance of risks are collected and a consensus is reached, a commercial software for AHP problem is used to obtain the weighting vector W for main risks and weighting vector w_i for secondary risks. Specifically, $W = \{w_1, w_2, \cdots, w_i\}$ means the relative importance of each main risk, and $\sum_{i=1}^{I} w_i = 1$; $w_i = \{w_{i1}, w_{i2}, \cdots, w_{ij}\}$ is the aggregation of the weight of the secondary risk under each main risk, and $\sum_{j=1}^{J} w_{ij} = 1$.

Third, another questionnaire, which is for rating the qualitative risk level of each auditable unit (or proposed potential internal audit activity), needs to be filled out by the invited survey participants. Combining with the calculated importance weights of different risks from the previous phase (W and w_i), the collected data can be processed by a FCE software (or simply use Excel spreadsheet if there are not too many evaluation objects) to obtain the multi-level fuzzy comprehensive evaluation matrix. Defuzzification is then applied to calculate the crisp value of the fuzzy concept, which converts the uncertainty into an applicable action when solving real-life problems (Kuo & Chen, 2006). In the defuzzification process, let $Z_{mi} = H_{mi} \circ S$ and $Z_m = H_m \circ S$, where Z_{mi} and Z_m respectively represent the defuzzification score of the i th main risk and overall risk for the m th auditable unit; H_{mi} and H_m represent the fuzz comprehensive evaluation matrix of the m th auditable unit in terms of the i th main risk and overall risk, respectively; and S is the evaluation grade set which depicts qualitative risk level as mathematical numbers. In terms of the operation symbol $\circ$, the comprehensive evaluation matrix can be defuzzied by applying the weighted average method, which is one of the most commonly used defuzzification methods (Loh et al., 2017). Finally, all the M auditable units can be ranked by the computed score of the overall risk level.

Many previous studies and practical guidelines of internal audit planning prioritized and selected internal audit projects merely depending on the rank of total risk score of the auditable unit, but this method ignores non-risk related goals as well as the difference of the risk reduction degree by devoting different levels of internal audit effort. The major return of internal audit activities is the risk reduction for the audited area. A direct method to internal audit project portfolio selection covers auditable units with higher risk. On the other side, an indirect method considers multiple objectives and calculates the risk reduction level on top of the existing/pre-audit risk. The proposed indirect method could further enhance the effectiveness of the internal audit planning process. The indirect method is introduced in the following sections.

3.2.4 Determination of risk reduction level

Conducting an internal audit project contributes to the risk management of the audited area (Sobel, 2016). Before proceeding to the project portfolio selection, risk reduction values of the auditable units should be estimated according to the devoted audit time. However, it is difficult to predict the exact relation between internal audit effort and risk reduction (Hamid, 2012). The research on exploring such relation is also quite limited, and further investigation into this area will be beneficial.

Inspired by Miltz et al. (1991) and X. Wang et al. (2021), a maximum amount of risk reduction is firstly set. For instance, since it is impossible to fully eliminate any risk, it is assumed that 90% of the existing risk can be reduced at the most through completing an internal audit project. And then audit work scope and corresponding risk reduction percentage (RP_n , $n = 1, 2, \cdots, N$) are classified into the following four grades. Audit time (T_{mn}) is the hours spent on auditable unit m at audit level (or work scope level) n . (1) Small scope review or low audit effort. Internal audit team only performs interview, walkthrough, and high-level review of the auditable unit without deep investigation or testing. Alternatively, among the multiple processes within the auditable unit, internal auditors only focused on the limited urgent subjects. In this case, the risk reduction level is judgmentally set as 40% of the maximum risk reduction amount. (2) Moderate scope review or medium audit effort. Audit testing covers all the key processes. Risk reduction level is determined to be 60% of the maximum risk reduction amount. (3) Large scope review or high audit effort. Internal auditors perform detailed testing on majority of the applicable processes, including some cycles that are less important. The risk reduction level equals to 80% of the maximum risk reduction amount. (4) Full scope review or significant audit effort. Auditors conduct a complete and extensive review of the whole auditable unit. In other words, auditors take a deeper dive into the subject. Correspondingly, maximum risk reduction amount is achieved. To express the quantitative relation, the subjectively assessed formulas created by Miltz et al. (1991) is simplified and modified as

Equation (3.1), and Equation (3.2) is used to examine the diminishing marginal returns of audit time.

$$RR_{mn} = RP_n \times 0.9\,Z_m \tag{3.1}$$

$$\frac{\Delta RR_{mn}}{\Delta T_{mn}} > \frac{\Delta RR_{m(n+1)}}{\Delta T_{m(n+1)}} \tag{3.2}$$

where RR_{mn} denotes the risk reduction value of the m th auditable unit by devoting the n th level of audit effort; RP_n means the risk reduction percentage under the n th level of audit effort, thereby RP_1, RP_2, RP_3, and RP_4 equals to 40%, 60%, 80%, and 100%, respectively; Z_m is the pre-audit risk score (existing risk level) of the m th auditable unit as assessed earlier; ΔT_{mn} (or $\Delta T_{m(n+1)}$) indicates the additional time to conduct audit work in auditable unit m at one level higher than level n (or n +1); ΔRR_{mn} (or $\Delta RR_{m(n+1)}$) indicates the additional risk reduction achieved by making audit effort at one level higher than level n (or n +1) when working on auditable unit m .

The second equation reflects a decreasing marginal risk reduction to additional audit effort. In other words, for each auditable unit, the higher the audit effort level is devoted, the more the risk reduction is realized. However, risk reduction per unit of time decreases (Miltz et al., 1991). Compared with the linear relationship between audit time and risk reduction adopted by Krüger and Hattingh (2006), and X. Wang et al. (2021), diminishing marginal returns makes more sense according to the internal audit practice. Audit time at the four different work degrees for each auditable unit can be obtained from audit management based on their professional judgements (e.g., complexity and nature of each project) and/or historical data (e.g., timesheet which records actual audit time spent on previous comparable projects).

Once the audit time for different work scopes is collected, the risk reduction value can be calculated and the marginal analysis can be performed. With hypothetical numbers, Table 3.5 shows a numerical example of risk reduction level using the above two equations. The next step is to proceed to project portfolio selection and resource allocation according to decision makers' multiple objectives.

Table 3.5 A template of the risk reduction level

Auditable Unit	Pre-audit Risk	Small Audit		Moderate Audit		Large Audit		Full Audit	
		RR_{m1}	T_{m1}	RR_{m2}	T_{m2}	RR_{m3}	T_{m3}	RR_{m4}	T_{m4}
AU_1	3	1.08	300	1.62	500	2.16	750	2.7	1100
AU_2	4	1.44	360	2.16	410	2.88	480	3.6	600
AU_3	2.8	1.008	200	1.512	260	2.016	330	2.52	410
AU_4	4.5	1.62	500	2.43	580	3.24	670	4.05	800
AU_5	3.7	1.332	420	1.998	500	2.664	600	3.33	720
AU_6	3	1.08	320	1.62	380	2.16	450	2.7	530
AU_7	2.5	0.9	300	1.35	410	1.8	550	2.25	700
...	...	...		...		...		...	
AU_M	3.5	1.26	100	1.89	150	2.52	220	3.15	350

3.3 Stage II: project selection and resource allocation

Project selection and resource allocation are the core decision problems during annual internal audit planning. In this stage, audit project portfolio selection is solved together with the allocation of internal audit resources (i.e., time, fund). In this regard, the thesis has some similarity to Zaraket et al. (2014)'s research, which considered software project selection and resource allocation as two interdependent problems. The audit projects are selected when they are allocated with audit hours or budgeted funds. Otherwise, if audit time or budgeted funds is not allocated to the candidate projects, the audit projects are not included in the annual work plan. Human resource allocation (or auditor assignment) will be addressed separately in the next stage.

3.3.1 Objective Setting

In the prior literature of audit project selection and resource allocation, as reviewed in the subchapter 2.2.3, majority of the previous studies only considered one single risk-related objective, but neglected other value-added planning objectives. Excessive focus on risks restricts IAF's ability to consider organizational strategy, impairing IAF's professional behavior and reputation (Pitt, 2014). Although broad coverage of high-risk areas and risk reduction maximization are critical in risk-oriented auditing, valuable internal audit activities can be conducted in low-risk areas as well. For example, unlike assurance type projects, advisory services may be requested by senior management and/or the board in areas that are not identified as top priorities in the risk assessment (IIA, 2020). The head of internal audit should accommodate these requests too. The average audit department spends 10% of total audit productive hours on advisory services in 2019, which was only 5% in 2016. This percentage is expected to continue to rise (Gartner, 2020b). In addition to the risk minimization, X. Wang et al. (2021) took two other objectives into account, such as the desired utilization rate of the available audit hours and the desired proportion of advisory projects.

To add value to the organization, internal audit function should focus its limited audit resources on the organization's most pressing issues. Therefore, internal audit priorities should align with the organization's objectives and address the risks that rate among the most significant (IIA, 2020). In addition, empirical evidence shows that ERM implementation has an impact on internal audit's activities, such as altering internal audit's focus and workload (Beasley et al., 2008; Tsai et al., 2017). Furthermore, Aditya et al. (2018) pointed out that the audit plan should be insightful, proactive, relevant, future-focused, and risk-focused. This requires internal audit function to discuss with leaders of other functional departments and to understand their major initiatives planned for the following year. Kotb et al. (2020) also mentioned that internal audit plan should be agile, forward-looking, integrated, risk-based and aligned with business strategy. Many professional services organizations like Gartner publish annual report of audit plan hot spots, which sheds light on the risk trends for the year ahead across all industries, geographic locations, and different sizes of organizations. These research reports may give IAF food for thought.

Based on the aforementioned characteristics of an ideal annual internal audit plan, seven audit project selection goals are proposed as follows: (1) risk level should be reduced as much as possible; (2) linkage to ERM should be established and the more the better; (3) management request should be accommodated and the more the better; (4) industry audit hot spots should be covered as many as possible; (5) company's strategic focus should be covered as many as possible; (6) potential interest of audit committee/board should be considered and the more the better; and (7) spend as much time as possible on advisory projects. To certain extent, ERM list, management request, audit hot spots and interest of audit committee/board also represent stakeholders' views on the organizational risk. As discussed with four audit leaders who participate in the annual planning activities in their organizations, including the company under study in the next chapter, these goals are sufficient to satisfy their needs. Of course, excessive goals can be excluded if they are not applicable to some smaller organizations. With the development of the internal auditing profession, additional goals that audit management would like to achieve in future also can be added as necessary.

3.3.2 Resource estimation

Scarce audit resources which are needed to implement the audit plan include people (e.g., labor hours and capability), technology (e.g., computer assisted audit technique), timing/schedule (availability of resources) and funding (IIA, 2020). These resource limitations all become the constraints for audit management to achieve desired goals.

When estimating available audit time in total (T), the planning group should deduct administrative hours (e.g., public holidays and paid time off), training hours and committed/fixed hours for mandatory projects (e.g., SOX assurance services, direct assistance to the external auditor) from the total working hours of the internal audit team. The amount of time that in-house audit staff spend on the selected projects ($T_{mn(\text{int})}$) should be within the total available audit time. Considering the travel restriction (e.g., the COVID-19 pandemic), language barrier and skill issue (e.g., lack of expertise in certain areas such as fraud and IT, or lack of tools/technique), professional third-party vendors (e.g., consulting firms) can be hired to perform some projects that cannot be completed by the internal team (i.e., outsourcing service and co-sourcing service). The funds used for professional external services (hourly rate p and external service hours $T_{mn(\text{ext})}$) should be within the budget (F). These constraints might be adjusted according to each organization's practice if needed.

3.3.3 Determination of project portfolio

To assist the decision making in the internal audit planning process, the audit project portfolio selection problem is formulated as Equation (3.3) to Equation (3.17). Weighted MCGP model is utilized to minimize the aggregate deviation from all the seven goals.

$$\text{Minimize} \quad \sum_{k=1}^{K} w_k(\alpha_k d_k^+ + \beta_k d_k^- + e_k^+ + e_k^-) \tag{3.3}$$

Subject to

$$\sum_{m=1}^{M}\sum_{n=1}^{N} RR_{mn} \times X_{mn} - d_1^+ + d_1^- = y_1, \quad m = 1,2,\dots,M\ ; \quad n = 1,2,\dots,N \tag{3.4}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{erm})} \times X_{mn} - d_2^+ + d_2^- = y_2, \quad m = 1,2,\dots,M\ ; \quad n = 1,2,\dots,N \tag{3.5}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{mgt})} \times X_{mn} - d_3^+ + d_3^- = y_3, \quad m = 1,2,\dots,M\ ; \quad n = 1,2,\dots,N \tag{3.6}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{hot})} \times X_{mn} - d_4^+ + d_4^- = y_4,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.7}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{stgy})} \times X_{mn} - d_5^+ + d_5^- = y_5,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.8}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{ac})} \times X_{mn} - d_6^+ + d_6^- = y_6,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.9}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{adv})} \times X_{mn} - d_7^+ + d_7^- = y_7,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.10}$$

$$y_k - e_k^+ + e_k^- = g_{k,\max},\ \ k = 1, 2, ..., 7 \tag{3.11}$$

$$g_{k,\min} \le y_k \le g_{k,\max},\ \ k = 1, 2, ..., 7 \tag{3.12}$$

$$d_k^+, d_k^-, e_k^+, e_k^- \ge 0,\ \ k = 1, 2, ..., 7 \tag{3.13}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{int})} \times X_{mn} \le T,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.14}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} T_{mn(\text{ext})} \times X_{mn} \times p \le F,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.15}$$

$$\sum_{n=1}^{N} X_{mn} \le 1,\ \ m = 1, 2, ..., M \tag{3.16}$$

$$X_{mn} = 0 \text{ or } 1,\ \ m = 1, 2, ..., M;\ \ n = 1, 2, ..., N \tag{3.17}$$

In the above model, Equation (3.3) represents the objective to minimize the aggregate deviation based on audit leader's preference on different goals. Equation (3.4) to Equation (3.10) correspond to the seven proposed goals and the deviations between the realized results and the desired results. In these equations, $T_{mn(\text{erm})}$, $T_{mn(\text{mgt})}$, $T_{mn(\text{hot})}$, $T_{mn(\text{stgy})}$, $T_{mn(\text{ac})}$, $T_{mn(\text{adv})}$ are the amount of time under the n th level of audit effort for the m th auditable unit with relevance to ERM, management request, industry audit hot spot, organizational strategy focus, interest of audit committee/board, and advisory type respectively. Equation (3.11) to Equation (3.13) determine the rang of aspirational levels and drive the target value to get closer to the upper bound. Equation (3.14) ensures that the time spent on the projects which are fully conducted by in-house internal audit team is within the total available audit time. Equation (3.15) ensures that the funds used for hiring external consultants are within the budget. Equation (3.16) ensures that an audit project cannot be conducted under multiple level of work scope. In Equation (3.17), X_{mn} is the binary decision variable used to decide whether to select the m th auditable unit at the n th work scope level. If the project is selected, it should be 1; otherwise, it equals to 0. Other variables are defined in the standard MCGP model in chapter two, which is Equation (2.18) to Equation (2.23).

The proposed model is flexible to adapt to the specific conditions of different organizations. In case goals and constraints need to be updated, the analysts can make the changes easily. A commercial software is used to process the collected data (e.g., DM’s preference on the goals, the possible time to complete a project and the risk levels of the candidate audit areas). As a result, a list of selected auditable units and corresponding audit effort level can be presented. To avoid overlooking critical information, CAE shall discuss the selection results with executives to seek for their feedbacks. If no changes are proposed, audit planning team can proceed to the next stage.

3.4 Stage III: project staff assignment

In the previous stage, the project portfolio and allocated audit time are determined. An internal audit project is typically required to be completed within a reasonable time period (e.g., no longer than two months). Based on the range of the allocated audit hours, internal audit manager defines a rule to determine the number of team members and working days for each selected audit project. For instance, there will be 4 auditors for projects with estimated audit time greater than 750 hours. Normally, each auditor works 8 hours per working day. Assume that 800 hours are allocated to the audit project, it would take 25 working days for the team to complete the internal audit project. The defined number of auditors is selected from the whole internal audit department. Then a key problem to be resolved in this stage is the assignment of the team members to each project.

An appropriate assignment of auditors is crucial to the success of audit activities, and an effective approach is needed to support this complex decision-making activity (R.-C. Chen et al., 2012). The staff assignment during the planning of an individual project deals with the allocation of auditors to specific internal audit tasks, which is different from the staff assignment problem in the annual audit planning. To ensure the appropriate assignment of internal auditors to the planned projects and the balance of the average workload among the auditors over the planned year, auditor assignment in the annual planning focuses on the team formulation for the projects.

3.4.1 Objective setting

In the project-team formation problem, preferences of the potential team members and the personnel qualification for the projects are the most common goals considered in the literature. In the context of internal audit, audit managers also take both goals into account. Empirical research indicated that both auditor motivation and auditor qualification had a significant positive effect on audit quality (Gamayuni, 2018; Haryana et al., 2019; Kadous & Zhou, 2019; Kuntari et al., 2017; Nurdiono & Gamayuni, 2018).

Whereas the audit process and methodology are similar for all internal audit projects, each project covers a specific topic and has its unique features (e.g., performing the audit of subsidiaries which are located at different places and have different sizes, or performing the audit for different functions and processes). In the meantime, audit staff have their own preference on the specific audit projects. For example, some auditors would like to participate in the audit project requiring domestic or international travels while others may not be willing to travel due to family reason; some auditors prefer advisory projects while others prefer assurance projects; some auditors prefer projects with relevance to new areas while others prefer routine and repetitive projects. Internal auditors are generally more satisfied and motived when they work in the projects in which they are interested. Nevertheless, sometimes internal auditors may not be the ideal fit for the projects they prefer. Every audit project has its preference on auditor's experience and competency as well. The suitability between project characteristics and auditor expertise is another important factor to be considered and evaluated. Assigning the most qualified auditors to the project can save the audit time and shorten the planned project duration. On the contrary, assigning an auditor to an inappropriate project will impair work quality, or create extra work for other team members in order to complete the project within the deadline.

As reviewed in subchapter 2.2.3, the prior literature on auditor assignment only considered one objective — either maximization of the auditor preference or maximization of the suitability. In fact, internal audit managers struggle with giving priority to auditor preference or the suitability, which is a challenging problem. Motivated by the dilemma surroundings such settings, this research aims to optimize the assignment of internal auditors to projects considering both goals. The objective is to achieve a balanced solution to satisfy both auditor preference and auditor's fitness to the project as much as possible.

3.4.2 Determination of the suitability value

Whereas the preferences of internal auditors for the projects can be collected from audit staff questionnaires (e.g., indicate a number from 1 to 5 according to the degree of preference), a suitability value between the auditor and the project is better to be obtained through formulated calculation. The suitability value is calculated by matching the auditor qualification and project characteristic weighting in the following steps.

Step 1: Identify the competency (C_l, $l = 1, 2, \cdots, L$) to characterize both internal auditors (A_u, $u = 1, 2, \cdots, U$) and projects (P_v, $v = 1, 2, \cdots, V$). Key critical competencies required to perform internal audit project are listed in Table 3.6. These six competencies are selected as the key criteria to evaluate auditors' qualification.

Table 3.6 Internal audit competency

Competency	Description	Source
Communication skill (C_1)	Express thoughts and ideas clearly and effectively in oral (e.g., inquiry, interview, presentation) and in writing (e.g., documentation of internal audit work, report writing).	Coetzee et al. (2015), Gartner (2020a), Petridis et al. (2021), X. Wang et al. (2022)
Risk and control knowledge (C_2)	Understand risk concepts and be able to recognize common risks to organizations including fraud risk; understand control types to handle risks, internal control design and implementation, and know about internal control/IT control framework.	Coetzee et al. (2015), Gartner (2020a), Petridis et al. (2021), X. Wang et al. (2022)
Business process analysis (C_3)	Identify audit findings or improvement opportunities for the business based on understanding and analysis of the process flows for business operations.	Coetzee et al. (2015), Gartner (2020a), Petridis et al. (2021), X. Wang et al. (2022)
Familiarity with the auditable unit (C_4)	Internal auditors have previous experience in the same or similar audit area. They are familiar with the specific audit topic, understand how to review the area, or have a good relationship with the stakeholders relevant to this audit.	Nusran (2021), Sarens et al. (2009), Yazdaniyan and Dastgir (2019)
Insight generation (C_5)	Consider all available information to identify problem, form meaningful opinions, make decisions, and provide recommendations/solutions (including critical, conceptual, and analytical thinking skills).	Coetzee et al. (2015), Gartner (2020a), Petridis et al. (2021), X. Wang et al. (2022)
Data analysis (C_6)	Evaluate and analyze commercial and financial data using appropriate data analytics methods; interpret the results and make valid observations that explain the data and support decision making (e.g., sample selection).	Coetzee et al. (2015), Gartner (2020a), Petridis et al. (2021), X. Wang et al. (2022)

Step 2: Map the competency scale to the discrete fuzzy score. The calculation of suitability value is a kind of ranking problem to rank auditor's qualification for the project. T.-Y. Chang and Ku (2021) have demonstrated that a 5-point Likert scale (Likert, 1932) seems to be the best

choice for the scale of filtering according to their numerous random ranking experiments. The authors proposed a scale that is used to categorize all the criteria values of the alternatives into 5 types, and each category is mapped to a discrete fuzzy score [0, 1]: (1) strongly significant criterion mapped to fuzzy score 1; (2) significant criterion mapped to fuzzy score 0.75; (3) normal criterion mapped to fuzzy score 0.5; (4) non-significant criterion mapped to fuzzy score 0.25; and (5) strongly non-significant criterion mapped to fuzzy score 0. Table 3.7 shows an application of the discrete fuzzy score to auditor's competency scale, which is adopted and modified from Gartner (2020a).

Table 3.7 A 5-point Likert scale of competency

Category	Description	Discrete Fuzzy Score
Very good	Demonstrate constant excellence in the independent application of this knowledge/skill area. Can answer challenging questions within the department and provide perspectives on process or practice improvement in this knowledge area/skill.	1
Good	Have extensive experience in this knowledge area/skill; there is no need for assistance; staff are confident to provide guidance to others.	0.75
Fair	Can apply knowledge and skill successfully to complete assigned tasks independently with necessary assistance from an expert from time to time.	0.5
Poor	Have introductory-level knowledge/skill but still focus on learning; have little practical experience in the area and thus need significant assistance from peers, supervisors, and other resources during the whole audit process.	0.25
Very Poor	A novice like a new intern who lacks of relevant knowledge/skill or experience in the area.	0

Step 3: For the v th audit project, experts generate the weight of the l th competency (w_{lv}), which represents the distinguishing characteristics of an audit project. For example, compared with assurance type projects, advisory type projects emphasize more on insight generation and thus higher weight will be assigned to this competency; audit projects related to vendor payment and employee expense report usually get more weight on data analysis as the core task for such audits is to identify abnormalities by processing a large number of transactional records. Also, the total competency weights for each project equals to one, or $\sum_{l=1}^{L} w_{lv} = 1$.

Step 4: Based on the fuzzy filtering ranking (FFR) method which is a simple and flexible method to solve practical ranking issues (T.-Y. Chang & Ku, 2021), a decision matrix (O_{luv}) is created and the weight corrector (w_{lv}^{o}) is calculated. For each audit project, experts rate the competency of the auditors according to step 2. This reflects the discontinuous perception of the DM for most MCDM issues (T.-Y. Chang & Ku, 2021). Therefore, a decision matrix can be generated for each project. In fact, auditors' competencies don't change among the projects except for competency C4. However, for each competency, the total value of the audit team is not necessarily equal, which affects the weight deviation of the competency. Therefore, a weight corrector is used to ensure that the total value of each competency equals to 1, which can be expressed as $\sum_{u=1}^{U} O_{luv} \times w_{lv}^{o} = 1$. For example, in an internal audit department with three auditors, assume that the familiarity with the auditable unit (competency C4) of the team members for the v th audit project are evaluated as 0.75, 1, and 0.25, then the weight corrector is 0.5.

Step 5: Generate the weighted and corrected decision matrix (Q_{luv}). Q_{luv} is obtained by multiplying the weight with the weight corrector, and decision matrix, denoted as $Q_{luv} = w_{lv} \times w_{lv}^{o} \times O_{luv}$. Assume that the weight of competency C4 for the v th audit project is 0.2, taking the same example from the previous step, the weighted and corrected value of the team members for competency C4 can be obtained as 0.075, 0.1, and 0.025.

Step 6: Determine the suitability value of the u th auditor for the v th audit project (E_{uv}) based on the sum of Q_{luv} in each internal auditor. From the above example, if the weighted and corrected value of the first auditor for other competencies are 0.0857, 0.03, 0.08, 0.0375, and 0.0333, the suitability value of this auditor for the select project is 0.3415. The total amount of the suitability value of all the available auditors should be 1.

The proposed method is simple to apply. The whole calculation process to determine the suitability value can be completed using Microsoft Excel. The rational for the approach taken here is that the suitability value is derived by considering both the current competency level of every available audit staff in the internal audit department and the characteristics of each selected project. Additionally, the suitability value measures the individual fitness to the given audit projects. The given projects only refer to the projects which will be completed by internal team rather than outsourced projects. In other words, the internal audit department is qualified for the project overall. Therefore, the value indicates the relative fitness to a project among the available auditors. If E_{uv} is higher, then the u th internal auditor fits better for the v th audit project. Moreover, the results are comparable among the audit projects since the total value in every project is normalized to one.

3.4.3 Formulation of multiple project teams

To assist the project team formation in the annual planning process, the problem is formulated as Equation (3.18) to Equation (3.29). MINMAX MCGP model is utilized to obtain the solution, which represents a balanced allocation between the achievement of the two goals: satisfy auditor preference and improve suitability as much as possible.

$$\text{Minimize } D \tag{3.18}$$

Subject to

$$D \geq \alpha_k d_k^+ + \beta_k d_k^- \text{ , } k = 1, 2 \tag{3.19}$$

$$D \geq \delta_k (e_k^+ + e_k^-) \text{ , } k = 1, 2 \tag{3.20}$$

$$\sum_{u=1}^{U}\sum_{v=1}^{V} G_{uv} \times X_{uv} - d_1^+ + d_1^- = y_1 \text{ , } u = 1, 2, ..., U \text{ ; } v = 1, 2, ..., V \tag{3.21}$$

$$\sum_{u=1}^{U}\sum_{v=1}^{V} E_{uv} \times X_{uv} - d_2^+ + d_2^- = y_2 \text{ , } u = 1, 2, ..., U \text{ ; } v = 1, 2, ..., V \tag{3.22}$$

$$y_k - e_k^+ + e_k^- = g_{k,\max} \text{ , } k = 1, 2 \tag{3.23}$$

$$g_{k,\min} \leq y_k \leq g_{k,\max} \text{ , } k = 1, 2 \tag{3.24}$$

$$d_k^+, d_k^-, e_k^+, e_k^- \geq 0 \text{ , } k = 1, 2 \tag{3.25}$$

$$\sum_{u=1}^{U} X_{uv} = s_v \text{ , } v = 1, 2, ..., V \tag{3.26}$$

$$-a \leq \sum_{v=1}^{V} t_v \times X_{u_1 v} - \sum_{v=1}^{V} t_v \times X_{u_2 v} \leq a \text{ , } u_1, u_2 = 1, 2, ..., U \text{ ; } v = 1, 2, ..., V \tag{3.27}$$

$$-b \leq \sum_{v=1}^{V} G_{u_1 v} \times X_{u_1 v} - \sum_{v=1}^{V} G_{u_2 v} \times X_{u_2 v} \leq b \text{ , } u_1, u_2 = 1, 2, ..., U \text{ ; } v = 1, 2, ..., V \tag{3.28}$$

$$X_{uv} = 0 \text{ or } 1, \ u = 1, 2, ..., U \text{ ; } v = 1, 2, ..., V \tag{3.29}$$

In the above model, Equation (3.18) is the objective function to minimize an extra continuous variable D. This variable measures the maximum deviation between goals as expressed in Equation (3.19) and (3.20). In Equation (3.21), G_{uv} refers to a specific preference index of the u th auditor for the v th audit project. The function denotes the deviations between the realized preference results and the desired preference results. Equation (3.22) denotes the deviations between the realized suitability results and the desired suitability results. Equation (3.23) to Equation (3.25) determine the range of aspirational levels and drive the target value to get closer to the upper bound. Equation (3.26) makes sure the number of the auditors assigned to the v th audit project is the same as the pre-defined number of team members s_v . In Equation (3.27), t_v refers to the pre-defined duration of the v th audit project. The function means that the difference in the total working days of each auditor is controlled within ± a days. Equation (3.28) makes sure that the difference between auditors' total preference value does not exceed ± b . In Equation (3.29), X_{uv} is the binary decision variable used to decide whether the u th auditor is assigned to the v th audit project. If yes, it is 1; otherwise, it is 0. Other variables are defined in the standard MCGP model in chapter two, which is Equation (2.18) to Equation (2.23).

In case adjustments to the goals and constraints are requested, the proposed auditor assignment model is also flexible to adapt to the specific needs. The data of auditor assignment problem include DM's preference on each goal, a list of selected projects with the number of team members and the duration, auditor preference for each project, and calculated fitness level between the auditor and the project. A commercial software is used to solve the problem to obtain the optimal solutions. As a result, all the available internal auditors can be appropriately allocated to the selected project portfolio.

3.5 Stage IV: project portfolio scheduling

At this moment, the project portfolio and auditor assignment are all determined. The last stage is to schedule the internal audit projects. In this stage, a method is proposed to prepare an audit work timetable within the planning horizon, which shows the project sequence, the assigned auditors, and the project duration. This is the final product of annual audit planning process, which presents the results of the previous planning stages.

3.5.1 Determination of the criteria for sequencing project

When planning the time frame of the internal audit projects, the days for public holiday and staff vacation plan should be blocked firstly. Then the audit managers start from the special projects with specific known schedule. For example, the time periods are usually fixed for the SOX assurance tests in American companies in order to meet the publication requirement of the financial statements. The timing of the direct assistance to external auditors are also fixed according to the schedule of external auditors. Furthermore, if the purpose of the advisory projects is to support the project of business departments, the timing of the advisory work should align with the progress of the business project.

For other audit projects without designated time period, they can be ranked by the decreasing order of the risk reduction value. As internal audit plays a significant role in risk management, the risk reduction level can be used as the criterion to determine the sequence of the audit projects. The risk reduction value is obtained from Equation (3.1) and measures the contribution of each project. In general, the more risk that the project can reduce, the more important the project is, and thus the earlier the project should be scheduled and performed. In the meantime, the availability of the audit staff should be considered to avoid excessive idle time. For example, according to the project ranking based on the risk reduction value, the project ranked the first and the second are assigned to the same two auditors. If the third project is assigned to other auditors, the third project can be performed in parallel with the first project. Another factor to be considered is the business readiness for the audit. Sometimes the business is in the process of changing the current process, and it would be meaningless to audit a process which will be updated soon. In case the business is not ready to be audited at the planned time, the project sequence can be adjusted to the periods after the new process is rolled out.

3.5.2 Creation of a work calendar

Based on the available information, a table including three elements can be created: project name, team member, and period of time (start date, working days, end date). Then a Gantt chart (Gantt, 1903) can be used to present the developed annual audit plan. Gantt Chart has been applied extensively in project management and planning work. It is a useful tool to display a schedule. It provides a powerful method for implementing interactive approaches to scheduling (J. M. Wilson, 2003). It also supports the effective communication of the work plan. The Gantt chart can be created using Microsoft Excel. Figure 3.2 displays a simplified annual audit plan in a Gantt chart. In Figure 3.2, the table lists the scheduled projects with assigned auditors and the Gantt chart converts the information from the table into a bar chart. The Gantt chart is also helpful in determining the start date of each project by showing relevant elements for analysis.

Project	Start Date	Working Days	End Date	Auditor
P1	4-Jan	30	15-Feb	A1, A2
P2	22-Feb	25	29-Mar	A1, A2
P3	5-Apr	15	26-Apr	A1
P4	1-May	20	29-May	A1, A2
P5	3-Jun	30	14-Jul	A1, A2
P6	20-Jul	20	17-Aug	A1, A2
P7	5-Apr	15	26-Apr	A2
P8	25-Aug	25	29-Sep	A1, A2
P9	10-Oct	20	7-Nov	A1, A2
P10	12-Nov	20	8-Dec	A1, A2

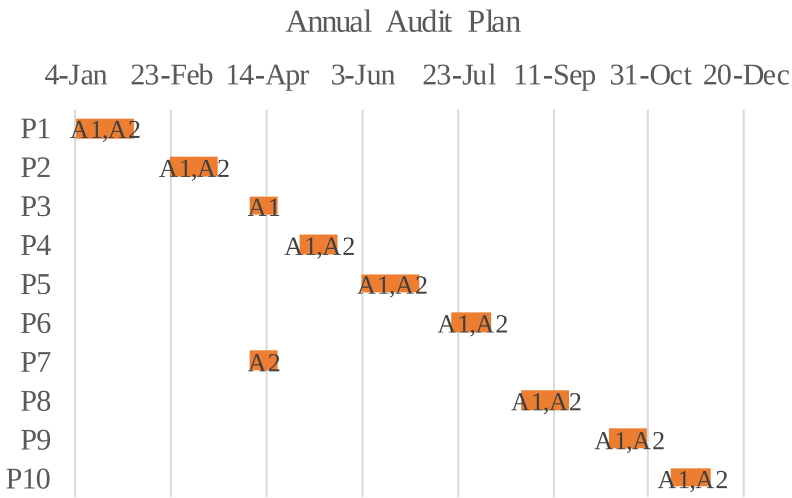

Figure 3.2 A simplified annual audit plan using Gantt chart

The head of internal audit communicates the finalized audit plan to audit committee or other similar supervision authority organization (e.g., board of director) for approval. Then the internal audit function can execute the annual audit plan according to the work calendar. Of course, it is not the end. Due to the dynamic and uncertain business environments such as emerging risks and priorities, the annual audit plan needs to be adaptable and flexible to deal with the new events or challenges that the organizations face (Eulerich et al., 2020). Therefore, there can be adjustments to the audit plan during the year (e.g., replacement of a planned project with a more urgent request, or conduct additional audit). The ongoing communication regarding any changes to the original plan can be made in the quarterly audit committee meeting. Nevertheless, it is also possible that no changes to the annual plan are needed during the year for most organizations.

3.6 Summary

This chapter designs a multi-stage framework with integrated methods for developing risk-based internal audit plan. The proposed model combines both quantitative and qualitative criteria, and provides a comprehensive and detailed study. With the power of multi-criteria decision analysis methods, audit planning team can make deeper and more scientific analysis on the candidate internal audit projects. In order to use scarce resources efficiently, internal audit function also makes better decision in project portfolio selection and staff assignment by utilizing multi-objective decision making methods.

Starting from the overview of the constructed framework, chapter three explains the four stages of risk-based internal audit planning process. The first stage focuses on the risk assessment. The internal audit function identifies a list of organizational risks and develops a list of auditable units. By mapping the risk types to the auditable units, the audit planning team determines an overall risk score for each auditable unit based on FCE-AHP (FAHP) method. Then a risk reduction value of each audit project is estimated to measure the risk level that can be reduced through an audit activity. In the second stage, the chapter introduces seven competing goals that audit management would like to achieve in the annual planning process. The number of projects that can be conducted in the planned year is subject to the limited audit resources. To minimize the aggregate deviation from all the seven goals, internal audit project portfolio is selected using Weighted MCGP method. The third stage is to assign internal audit staff to the selected project portfolio using MINMAX MCGP method. The solutions can balance auditor's preference for the projects and auditor's suitability to the projects. A suitability value is introduced to determine the fitness level between internal auditors and audit projects. The last stage concentrates on scheduling audit projects. Several criteria, such as risk reduction value, business readiness and availability of audit staff, are considered to determine the sequence of conducting the internal audit projects. And Gantt chart is used as a tool to display the work schedule.

Overall, the proposed integrated multi-stage audit planning framework is thorough and flexible, which shows great potential for project portfolio selection and resource allocation. To illustrate its validity, the designed framework is applied to a real-life case study of audit planning in the next chapter.

Chapter 4: Case Application

As discussed in the previous chapter, the integrated multi-stage framework is a practical and useful tool for risk-based internal audit planning. This chapter further illustrates the validity and feasibility of the proposed framework through a case study in a real manufacturing company. The first section introduces the basic information of the company and its internal audit function. The current annual audit planning process and the encountered problems are described as well. The second section presents the process of applying the proposed model to the studied company stage by stage, which is the main component of the chapter. The obtained results are analyzed and discussed as well. The sensitivity analysis is carried out in the third section. Then the following section describes management views regarding the utilization of the designed framework and methods. Finally, the last section presents a summary of the chapter.

4.1 Background

A case is presented to illuminate how the proposed integrated multi-stage framework can be used to assist DMs in developing an annual risk-based audit plan in the real world. The case study is conducted at a multinational automobile parts manufacturing company, which is a public company listed in Shanghai Stock Exchange. For the sake of confidentiality, the company is given a new name as AutoSpareParts (ASP). With its global headquarter located in China, ASP has 19 manufacturing facilities, 8 sales centers, 8 technical support centers, 5 R&D centers and 4 warehouse centers across Asia, Europe, and the Americas. ASP employs more than 10,000 people all over the world. Currently there are 10 employees in the internal audit department of the company, including a chief audit executive who reports functionally to the audit committee and administratively to the chief financial officer (CFO), one senior audit manager, two audit managers, four senior auditors and two audit associates. They all work in the corporate headquarter in China. Meanwhile, ASP in-house internal audit department enters a secondment/loan staff agreement with a global business consulting firm. The purpose of the agreement is to use external staff or teams with specialized skills, capabilities, and experiences to undertake some projects if needed. Internal audit co-sourcing model permits a company to receive maximum value from the internal audit function in a more cost-effective way.

Currently, annual audit planning process at ASP starts from every September and ends in December of the year. The following steps describe how an annual audit plan is developed at ASP now.

First, coming up with a potential listing of audit activities or topics for the following year. The potential audit topics for the next year are collected through various inputs, including routine audit projects conducted every year, interviews with business management to learn their audit request and understand issues or challenges faced by the company, auditable areas raised by audit managers and staff, findings from past audits for deeper dive, and interviews with audit committee members. In addition to these sources, a detailed risk assessment on the entire company is performed to ensure that potential topics have been proposed to cover certain risks with higher scores. Specifically, the CAE and audit managers discuss and assess 67 third-level risks of the risk universe. According to the historical practice, the audit leadership team rates risk impact and risk likelihood respectively for each risk item on a 4-point scale ranging from 1 (low) to 4 (significant) with 2 and 3 as intermediate values. A total score of risk item is obtained by multiplying risk impact by risk likelihood. Finally, there are three categories of risk level. Risk items with a total score less than or equal to 4 are low risk, items with a score greater than or equal to 9 are high risk, and items with a score between 5 and 8 are medium risk. Then the audit leadership team maps the 67 risk items with the potential audit activities identified earlier and the audit projects completed in the past, which is called as risk coverage map. Performing risk assessment of risk universe allows the IAF to determine risk levels of different risk items at the organizational level and recognize whether there is sufficient audit coverage over risks. In case that high risks are not covered by potential audit activities or a risk has never been covered by any previous audit projects, additional auditable areas should be proposed accordingly to address the concerns on risk exposure. Out of the above inputs, senior audit manager identifies feasible audit topics as the potential audit activities for the following year.

Second, preliminary selection of audit topics for the audit plan. On a spreadsheet listing the potential audit activities, senior audit manager independently performs risk assessment of these auditable units. Each potential audit topic is simply rated as “low”, “medium” or “high” based on professional judgement. In terms of the decision on audit project portfolio selection, senior audit manager judgmentally classifies the potential audit activities as “yes”, “maybe”, or “no”. When making the selection decision, priorities are given to those areas that have high risk or requested by management and audit committee frequently. Repetitive audits (e.g., continuous auditing of employee expense report and vendor payment, mandatory internal audit by local regulation) are always selected. CAE reviews the selection file and confirms the conclusion.

Third, preparation of a draft audit plan. For audit activities determined to be selected according to the previous step (i.e., topics marked as "yes" in the selection file), the audit leadership team proposes high-level scope of the audit and defines co-source requirements. By referring to the actual hours used by the same or similar audits in the past, senior audit manager estimates hours including external support hours needed to carry out each selected audit project. If the total hours of the proposed activities exceed available hours, some audit topics will be removed from the draft plan. In contrast, if the total hours are less than the available hours, a few potential audit topics categorized as "maybe" in the selection file will be judgmentally added to the audit plan. Once the audit topics are finalized, each audit project is scheduled by quarter considering the urgency of the audit and the balanced workload in each quarter.

Finally, obtaining the approval of the final proposed audit plan and assigning audit team. To make sure that there are no conflicts with company strategy and major initiatives, the CAE organizes an output meeting to go through the draft audit plan with executive leadership team (e.g., CEO, CFO, chief human resource officer, chief operating officer, chief legal officer, chief information officer, etc.) for obtaining buy-in for the selected audit activities and schedule. Sometimes minor changes on the draft plan need to be made based on the feedback from executives. The CAE then presents final proposed audit plan to the audit committee and obtains approval. Normally no modifications are requested from audit committee. In the meantime, in line with the scheduled quarter, audit managers discuss a more detailed schedule and fill out an annual calendar by slotting individual audit project into specific weeks as they deem fit. An audit manager is nominated to lead and supervise the audit project. Audit staff will be manually assigned to the project considering their qualification and availability when the project is about to be kicked off.

From ASP's experience, the current annual audit planning process which has been implemented since late 2018 appears to be effective and can meet internal audit requirements. However, as both internal and external environments become more uncertain and complex, and ASP business is expanding through merger and acquisition (M&A), there are increasing management requests on internal audits and higher expectation on the value adding services from internal audit professionals. In the era of big data, the company is also looking to fully leverage data to make more informed decisions. ASP internal audit team continuously looks for ways to improve its operations and quality to get prepared for the future challenges.

Based on the analysis of the above annual audit planning process adopted by ASP, some issues and improvement opportunities are identified as follows. First, the current risk assessment model seems to be redundant, resulting in inefficient efforts. The risk assessment on risk universe is only provided at organizational level to help identify overlooked auditable units. The risk scale currently used is also not precise enough. In addition to the organizational level risk assessment, another risk assessment is conducted on the identified potential audit activities, but the evaluation is only performed by one audit leader and is imprecise without analyzing principal risks. There is also a lack of alignment among the two risk assessments. In fact, it can be one-time effort to break down the entire organization into auditable units. Every year, inputs collected from various channels can be used to update the audit universe and risk universe as well as support auditors' risk rating. In this way, internal auditors do not need to worry about audit coverage, and a detailed annual risk assessment only needs to be performed on all the auditable units. Second, the selection of potential auditable areas is highly manual, affecting the reliability and accuracy of the conclusion. The selection process becomes more complex when there is overwhelming information, such as too many evaluation objects and criteria. However, human judgment is subject to cognitive limitations (Kalakoski et al., 2019). The professional judgement might not be consistently applied without the assistance of mathematical model, and thus a different selection result might be obtained if the manual selection process is reperformed. Third, resource allocation is not optimum and sustainable without considering multiple scenarios. Audit hours are not utilized sufficiently by simply estimating an average time needed for a project. In fact, audit hours are greatly impacted by the audit scope. Additionally, auditor assignment ignores employee motivation as employee preference is not taken into account. Last, the calendar does not reflect budgeted hours allocated to each audit project. Audit hours are not converted into equivalent weeks before drawing the schedule manually. A few projects with large difference in allocated audit hours even occupy the same number of weeks, which could mislead the project progress monitoring.

To prepare for the expanding business, improve the effectiveness and efficiency of annual audit planning, better utilize audit resources, and attract and retain internal auditors, audit leadership team realizes that it is necessary to establish a more standardized and sophisticated procedure of annual planning. Instead of relying on intuition and excessive manual work, audit management desire to develop a more systematic and automated annual planning process without investing in expensive internal audit software. The proposed multi-stage framework can synthesize different opinions on assessing risks and can consider various goals and requirements in selecting value-added audit projects and allocating reasonable resources. By doing so, audit leaders can make transparent and wise decisions during the annual planning process. The application of the comprehensive framework and managers' views on the process and results are introduced in the following subchapters.

4.2 Implementation of the proposed framework

The implementation of the proposed framework into the studied company is organized by the following four stages as elaborated in chapter three.

4.2.1 Risk assessment on auditable units

The risk assessment establishes a link between the key risks of the organization and all the major auditable units (Pitt, 2014). Because ASP has not developed a formal audit universe, the lists of potential audit activities (partial audit universe) developed in the past 3 years' annual planning are obtained. The lists are combined while removing duplicates, which could capture majority of the critical audits across the enterprise as per the senior audit manager. The consolidated list is used as the audit universe of ASP for illustration purpose. There are 45 auditable units on the created audit universe, which are defined from multiple dimensions, such as entity, function, and process.

Under specific-risk approach, various risk types, which are included in the generic risk universe of manufacturing sector, are used as the criteria for evaluating each auditable unit of ASP. AHP meetings are conducted with five internal audit experts, including three (senior) audit managers and two senior auditors, to obtain relative weights of risk types in the decision. All participants marked their comparison judgments on the distributed questionnaires (Appendix A). These responses were aggregated manually using the geometric mean and then processed by the AHP software, Super Decisions Software V3.2 (Mu & Pereyra-Rojas, 2018). In this group decision-making, the DMs are all qualified professionals and thus have equal weights. The AHP results are given in Table 4.1, which is also the weighting vector of the evaluation factor in the fuzzy comprehensive evaluation model. According to the ranking of the weight, operational risk (R_3) is regarded as the most important main risk to the organization, and the top five secondary risks to the company are accounting and reporting (r_{21}), sales and marketing (r_{31}), corporate governance (r_{11}), regulatory (r_{42}), and production/manufacturing (r_{36}).

In the meantime, the risk score can be obtained with FCE method. The decision maker panel is requested to evaluate risk level of each auditable unit by risk type. The given questionnaire is referred to Appendix B. To comply with the confidentiality agreement entered with the company, some of the audit project names are modified from the original questionnaire used. Table 4.2 provides an example of DM panel's risk rating on the first auditable unit (AU_1), manufacturing plant A, which is a newly set-up plant in an emerging industrial city in China.

Table 4.1 Risk type weights (Overall matrix *CR*=0.0053)

Main risk	Area weight	Secondary risk	Item weight	Combined weight	Rank
R_1	0.2716	r_{11}	0.3534	0.0960	3
		r_{12}	0.2761	0.0750	7
		r_{13}	0.1097	0.0298	14
		r_{14}	0.0593	0.0161	18
		r_{15}	0.0922	0.0250	16
		r_{16}	0.1093	0.0297	15
R_2	0.2256	r_{21}	0.5156	0.1163	1
		r_{22}	0.1655	0.0373	10
		r_{23}	0.3189	0.0719	8
R_3	0.3509	r_{31}	0.3274	0.1149	2
		r_{32}	0.0902	0.0317	11
		r_{33}	0.0858	0.0301	13
		r_{34}	0.2141	0.0751	6
		r_{35}	0.0504	0.0177	17
		r_{36}	0.2321	0.0815	5
R_4	0.1519	r_{41}	0.2066	0.0314	12
		r_{42}	0.5402	0.0821	4
		r_{43}	0.2532	0.0385	9

Table 4.2 Experts' judgments of risk level for manufacturing plant A

Main risk	Secondary risk	Number of DMs in each risk grading					Total
		Very low	Low	Medium	High	Significant	
R_1	r_{11}	0	0	0	3	2	5
	r_{12}	0	0	4	1	0	5
	r_{13}	0	0	2	3	0	5
	r_{14}	3	2	0	0	0	5
	r_{15}	0	0	1	3	1	5
	r_{16}	0	0	1	3	1	5
R_2	r_{21}	0	0	0	2	3	5
	r_{22}	0	1	0	4	0	5
	r_{23}	0	3	2	0	0	5
R_3	r_{31}	0	1	2	2	0	5
	r_{32}	0	0	0	3	2	5
	r_{33}	0	0	0	1	4	5
	r_{34}	0	1	2	2	0	5
	r_{35}	0	0	4	1	0	5
	r_{36}	0	0	2	1	2	5
R_4	r_{41}	0	0	3	2	0	5
	r_{42}	0	0	0	1	4	5
	r_{43}	0	0	0	2	3	5

According to the data in Table 4.2, three experts (60% of survey participants) vote "high" in terms of corporate governance risk (r_{11}) at manufacturing plant A, while the other two experts (40% of survey participants) believe that this risk is significant at the plant. Similarly, four experts (80% of survey participants) select "medium" for key relationship management risk (r_{12}) at the plant and only one expert (20% of survey participants) believe that the risk should be high. By normalizing the data, the fuzzy relationship matrix can be obtained. Combing weighting vector from Table 4.1 and the obtained fuzzy relationship matrix, the fuzzy comprehensive evaluation matrix by the main risk type, H_{mi} (m =1, i = 1, 2, 3, 4), are presented as Equation (4.1) to Equation (4.4). Each expert's rating has equal weight in the computation.

$$H_{11}=\begin{bmatrix}0.3534\\0.2761\\0.1097\\0.0593\\0.0922\\0.1093\end{bmatrix}^{T}\circ\begin{bmatrix}0&0&0&0.6&0.4\\0&0&0.8&0.2&0\\0&0&0.4&0.6&0\\0.6&0.4&0&0&0\\0&0&0.2&0.6&0.2\\0&0&0.2&0.6&0.2\end{bmatrix}=\begin{bmatrix}0.0356\\0.0237\\0.3051\\0.454\\0.1817\end{bmatrix}^{T} \tag{4.1}$$

$$H_{12}=\begin{bmatrix}0.5156\\0.1655\\0.3189\end{bmatrix}^{T}\circ\begin{bmatrix}0&0&0&0.4&0.6\\0&0.2&0&0.8&0\\0&0.6&0.4&0&0\end{bmatrix}=\begin{bmatrix}0\\0.2244\\0.1276\\0.3386\\0.3094\end{bmatrix}^{T} \tag{4.2}$$

$$H_{13}=\begin{bmatrix}0.3274\\0.0902\\0.0858\\0.2141\\0.0504\\0.2321\end{bmatrix}^{T}\circ\begin{bmatrix}0&0.2&0.4&0.4&0\\0&0&0&0.6&0.4\\0&0&0&0.2&0.8\\0&0.2&0.4&0.4&0\\0&0&0.8&0.2&0\\0&0&0.4&0.2&0.4\end{bmatrix}=\begin{bmatrix}0\\0.1083\\0.3498\\0.3444\\0.1976\end{bmatrix}^{T} \tag{4.3}$$

$$H_{14}=\begin{bmatrix}0.2066\\0.5402\\0.2532\end{bmatrix}^{T}\circ\begin{bmatrix}0&0&0.6&0.4&0\\0&0&0&0.2&0.8\\0&0&0&0.4&0.6\end{bmatrix}=\begin{bmatrix}0\\0\\0.124\\0.292\\0.5841\end{bmatrix}^{T} \tag{4.4}$$

Take Equation (4.1) as an example, the first matrix is the importance weight of the six risks under the strategic risk, the second matrix is the fuzzy relationship matrix, and the results mean that the degree of membership (or probability) of strategic risk at manufacturing plant A to be "very low", "low", "medium", "high", and "significant" are respectively 0.0356, 0.0237, 0.3051, 0.454 and 0.1817. In this study, let risk appraisal set S = { very low, low, medium, high, significant } = { 1, 2, 3, 4, 5 } (Loh et al., 2017). By applying the weighted average algorithm for defuzzification, the fuzzy comprehensive evaluation results are converted into scores, and the value of strategic risk is 3.7224. In other words, the strategic risk of manufacturing plant A ranges between medium and high.

Combining the weight set of the main risks with the decision-making sets H_{mi} (m =1, i = 1, 2, 3, 4), the comprehensive evaluation result of manufacturing plant A based on all risks is obtained as Equation (4.5).

$$H_1 = \begin{bmatrix} 0.2716 \\ 0.2256 \\ 0.3509 \\ 0.1519 \end{bmatrix}^{\mathrm{T}} \circ \begin{bmatrix} 0.0356 & 0.0237 & 0.3051 & 0.454 & 0.1817 \\ 0 & 0.2244 & 0.1276 & 0.3386 & 0.3094 \\ 0 & 0.1083 & 0.3498 & 0.3444 & 0.1976 \\ 0 & 0 & 0.124 & 0.292 & 0.5841 \end{bmatrix} = \begin{bmatrix} 0.0097 \\ 0.0951 \\ 0.2532 \\ 0.3649 \\ 0.2772 \end{bmatrix}^{\mathrm{T}} \quad (4.5)$$

By defuzzification, the overall risk level is calculated to be 3.805. According to the appraisal set S, the result falls in the interval [3, 4], which indicates that the overall risk level of manufacturing plant A is between medium and high. Following the same steps, the pre-audit risk score of all other auditable units can be obtained.

Implementing an audit project could mitigate the existing risks in the areas being audited. Once the current risk level of each auditable unit is measured through FAHP approach, risk reduction value can be estimated by applying Formulas (3.1) and (3.2). Table 4.3 provides an overview of the potential audit projects, including the calculated pre-audit risk level and risk reduction value. According to the current risk level, the top five auditable units are AU_{23}, AU_9, AU_{27}, AU_{35}, and AU_{19}. These five auditable units are all rated as high risk. Working hours and other project information for making decisions are given by the senior audit manager. When estimating the time needed to conduct each potential audit project, managers' workings hours are not considered because their major responsibility is to supervise and review the work prepared by the audit staff, as well as improve and optimize the current audit process and team members' knowledge and skills.

Table 4.3 A summary of ASP auditable units

AU	Pre-Audit Risk	Small Audit		Moderate Audit		Large Audit		Full Audit		External Hour	ERM	Mgt Request	Hot Spot	Strategic Focus	AC Interest	Adv-isory
		RR_{m1}	T_{m1}	RR_{m2}	T_{m2}	RR_{m3}	T_{m3}	RR_{m4}	T_{m4}							
1	3.8050	1.3698	320	2.0547	480	2.7396	760	3.4245	1200	0%	No	Yes	No	No	No	No
2	3.6653	1.3195	320	1.9793	480	2.6390	760	3.2988	1200	0%	Yes	Yes	No	No	No	No
3	3.1268	1.1256	200	1.6885	320	2.2513	500	2.8141	800	0%	Yes	Yes	No	Yes	Yes	No
4	3.4528	1.2430	400	1.8645	520	2.4860	800	3.1075	1280	50%	No	Yes	No	No	Yes	No
5	2.6900	0.9684	320	1.4526	480	1.9368	760	2.4210	1200	0%	No	No	No	No	No	No
6	3.3584	1.2090	280	1.8135	400	2.4180	600	3.0226	880	0%	No	Yes	No	No	No	No
7	2.9621	1.0664	400	1.5995	520	2.1327	800	2.6659	1280	0%	No	No	No	No	No	No
8	3.4050	1.2258	200	1.8387	320	2.4516	500	3.0645	800	0%	No	No	No	No	No	No
9	4.0721	1.4660	360	2.1989	520	2.9319	800	3.6649	1200	30%	No	No	No	No	No	No
10	3.5520	1.2787	360	1.9181	520	2.5574	800	3.1968	1200	30%	No	No	No	No	No	No
11	3.4663	1.2479	400	1.8718	520	2.4957	800	3.1197	1240	30%	No	Yes	No	Yes	No	No
12	2.6958	0.9705	320	1.4557	440	1.9410	720	2.4262	1120	30%	No	No	No	No	No	No
13	2.8077	1.0108	200	1.5162	320	2.0215	500	2.5269	800	0%	No	Yes	No	No	No	No
14	2.5358	0.9129	120	1.3693	240	1.8258	440	2.2822	760	30%	No	Yes	No	No	No	No
15	3.3275	1.1979	120	1.7969	240	2.3958	440	2.9948	760	30%	Yes	No	No	No	No	No
16	3.2534	1.1712	200	1.7568	320	2.3424	480	2.9281	800	30%	No	Yes	No	No	No	No
17	3.1492	1.1337	200	1.7006	280	2.2674	400	2.8343	600	0%	Yes	Yes	No	No	Yes	No
18	3.0012	1.0804	200	1.6206	240	2.1609	360	2.7011	560	0%	Yes	Yes	No	No	Yes	No
19	4.0015	1.4405	240	2.1608	300	2.8811	400	3.6014	600	0%	Yes	Yes	No	Yes	Yes	No
20	3.2488	1.1696	240	1.7544	300	2.3391	400	2.9239	600	30%	Yes	No	No	No	No	No
21	3.2064	1.1543	200	1.7315	240	2.3086	400	2.8858	600	30%	No	No	No	No	No	No
22	3.3097	1.1915	200	1.7872	300	2.3830	480	2.9787	700	0%	Yes	Yes	No	Yes	No	No
23	4.1198	1.4831	600	2.2247	720	2.9663	1000	3.7078	1500	0%	Yes	Yes	No	Yes	Yes	Yes
24	3.0305	1.0910	280	1.6365	360	2.1820	520	2.7275	720	100%	No	Yes	No	Yes	No	Yes
25	2.5607	0.9219	360	1.3828	420	1.8437	600	2.3046	800	100%	Yes	Yes	No	No	Yes	No
26	3.4342	1.2363	400	1.8545	500	2.4726	640	3.0908	800	30%	Yes	Yes	No	Yes	No	Yes
27	4.0549	1.4598	360	2.1896	440	2.9195	600	3.6494	800	100%	Yes	Yes	Yes	No	Yes	No
28	2.7853	1.0027	80	1.5041	160	2.0054	400	2.5068	700	0%	No	Yes	No	No	No	Yes
29	3.0266	1.0896	160	1.6344	240	2.1792	400	2.7239	600	0%	No	No	Yes	No	No	No
30	3.3786	1.2163	400	1.8244	500	2.4326	640	3.0407	800	0%	No	Yes	No	No	No	No
31	3.2497	1.1699	240	1.7548	400	2.3398	600	2.9247	1000	0%	Yes	Yes	No	No	No	No

32	3.2020	1.1527	320	1.7291	400	2.3054	520	2.8818	660	0%	Yes	Yes	Yes	No	No	Yes
33	3.3896	1.2203	280	1.8304	400	2.4405	600	3.0506	880	0%	No	Yes	Yes	Yes	No	No
34	2.6792	0.9645	80	1.4468	120	1.9290	200	2.4113	400	0%	No	Yes	No	No	Yes	Yes
35	4.0209	1.4475	100	2.1713	200	2.8950	400	3.6188	720	0%	Yes	Yes	No	Yes	Yes	Yes
36	3.4882	1.2558	680	1.8836	880	2.5115	1160	3.1394	1600	0%	No	Yes	Yes	Yes	Yes	No
37	3.4142	1.2291	300	1.8437	400	2.4582	600	3.0728	900	0%	No	No	No	No	No	No
38	3.3006	1.1882	160	1.7823	280	2.3764	520	2.9705	880	0%	No	No	No	Yes	Yes	No
39	3.2391	1.1661	400	1.7491	520	2.3322	720	2.9152	960	30%	Yes	No	No	Yes	No	No
40	3.5333	1.2720	200	1.9080	320	2.5440	560	3.1800	920	0%	Yes	No	Yes	Yes	Yes	Yes
41	3.4904	1.2565	120	1.8848	200	2.5131	300	3.1414	500	0%	No	Yes	No	No	No	No
42	3.1093	1.1193	300	1.6790	400	2.2387	520	2.7984	700	0%	Yes	No	No	Yes	Yes	No
43	3.7986	1.3675	360	2.0512	500	2.7350	700	3.4187	1000	0%	Yes	Yes	Yes	No	Yes	No
44	3.3049	1.1898	320	1.7846	480	2.3795	700	2.9744	1000	0%	No	Yes	No	No	No	No
45	2.8118	1.0122	400	1.5184	600	2.0245	900	2.5306	1300	0%	No	No	Yes	No	Yes	No

For example, the existing risk at manufacturing plant A (AU_1) is 3.805. Performing a small-scope audit at this plant could take the audit team 320 hours and thereby reduce the risk by 1.3698. Correspondingly, carrying out a moderate (large or full) audit takes 480 (760 or 1200) hours and reduce the risk by 2.0574 (2.7396 or 3.425). This audit is an assurance service and can be completed by the ASP internal audit team without assistance from the external consultants (i.e., external hour accounts for 0% of the total work time). Management used to request audit team to conduct the audit of manufacturing plant A. However, this audit topic is not related to enterprise risk management, does not belong to the industry hot spot, is not corporate strategic focus, nor within the potential scope of audit committee's interest. On the other hand, giving consideration to the restriction of international travel due to COVID-19 pandemic, external resources can provide local audit support of overseas entities such as manufacturing plant I (AU_9), which could account for 30% of total work time. That is to say, the in-house internal audit team would concurrently complete the other 70% of the audit tasks in a remote mode. IT audit projects, such as vulnerability management (AU_{27}) will be fully (100%) completed by consultants due to lack of proficient IT auditors at ASP.

4.2.2 Resource allocation in audit project portfolio selection

The next stage is to select potential audit projects and allocate employee time by considering stakeholders' preferences. At ASP, the standard hours of work for employees are 8 hours a day (40 hours a week). In light of public holidays and the time reserved for administrative work, training, and urgent request to enhance flexibility, every audit staff can spend 1,600 hours in average on the audit work in a year and thus 9,600 hours are available by six internal auditors. The approved 2022 annual budget for hiring external consultants is RMB 2 million (~USD 312,500). For audit service provided by a senior consultant, the consulting firm charges ASP a global discount rate of USD 160 per hour. In other words, IAF can hire external resource up to 1,950 hours. Consequently, 11,550 hours in total can be used for conducting audit work.

In terms of the seven goals proposed in subchapter 3.3.1, the importance on each goal, detailed aspirations, penalty weights for below each goal, and penalty weights for above each goal are given by the senior audit manager, as shown in Table 4.4. Below the goal means that the result value of the goal is smaller than the lower bound, and above the goal means that the result value of the goal is larger than the upper bound. While the weights on each goal can be generated by a MCDA method, to simplify the process for illustration purpose, the data are judgmentally given by the senior audit manager based on her professional experience.

Table 4.4 Weights, aspirations, and penalty weights of each goal

Goals	Weights	Lower Bound	Upper Bound	Penalty weights for below the goal	Penalty weights for above the goal
G1: Risk reduction	0.2	38	66	5	
G2: Linkage with ERM	0.2	5,775	11,550	5	
G3: Management request	0.15	5,775	11,550	3	
G4: Audit hot spots	0.07	600	7,760	2	
G5: Strategic focus	0.12	2,310	11,550	2	
G6: Interest of audit committee	0.16	3,465	11,550	3	
G7: Advisory project	0.1	1,155	3,465	2	3

According to the above dataset, ASP's goals can be expressed as follows.

(G1) The total risk reduction value should be over 38, the larger the better. Because risk reduction is the most important issue in risk-based auditing problem, the senior audit manager of ASP assigns the penalty weight of 5 for below the goal to avoid getting the result value less than the lower bound and make the result value the larger the better.

(G2) The time spent on the audit projects related to ERM must be over 5,775 hours (50% of total available time, or upper bound), the larger the better. It is essential for audit projects to address ERM, thereby a penalty weight of 5 is assigned to this goal.

(G3) The time spent on audit topics requested by management must be over 5,775 hours (50% of total available time), the larger the better. Management concerns are a key component that should be considered in the audit project selection problem. Hence, a penalty weight of 3 is assigned for below the goal.

(G4) The time spent on hot spots audits must be over 600 hours (about 5% of total available time), the larger the better. Covering audit plan hot spots helps to keep aligned with the industrial trend. Hence, senior audit manager of ASP assigns penalty weight of 2 for below the goal of hot spots.

(G5) The time spent on audit topics concerning company's strategy must be over 2,310 hours (20% of total available time), the larger the better. Internal audit projects need to address the organization's current strategy, so that senior audit manager of ASP assigns penalty weight of 3 for below the goal.

(G6) The time spent on audit topics which would be the interest of audit committee must be over 3,465 hours (30% of total available time), the larger the better. Audit committee's interest should be paid attention to by the IAF and thus a penalty weight of 3 is assigned for below this goal.

(G7) The time spent on advisory service must be over 1,155 hours (10% of total available time), the larger the better. It is not acceptable for IAF to provide assurance service only. Therefore, senior audit manager of ASP assigns penalty weight of 2 for below the advisory project goal. However, as assurance service is still the major work area of the IAF, senior audit manager sets 3,465 hours (30% of total available time) as the upper bound. Also, to avoid too many hours spent on the advisory service, a penalty weight of 3 is assigned for exceeding the advisory project goal.

Formulation of the audit project portfolio selection problem at ASP can be expressed as follows.

$$\begin{aligned}\text{Minimize } & 0.2\times(d_1^+ + 5d_1^- + e_1^+ + e_1^-) + 0.2\times(d_2^+ + 5d_2^- + e_2^+ + e_2^-) + 0.15\times(d_3^+ + 3d_3^- + e_3^+ + e_3^-) \\ & + 0.07\times(d_4^+ + 2d_4^- + e_4^+ + e_4^-) + 0.12\times(d_5^+ + 2d_5^- + e_5^+ + e_5^-) + 0.16\times(d_6^+ + 3d_6^- + e_6^+ + e_6^-) \\ & + 0.1\times(3d_7^+ + 2d_7^- + e_7^+ + e_7^-)\end{aligned} \quad (4.6)$$

Subject to

$$\sum_{m=1}^{45}\sum_{n=1}^{4} RR_{mn}\times X_{mn} - d_1^+ + d_1^- = y_1,\quad m=1,2,...,45;\ n=1,2,3,4 \quad (4.7)$$

$$y_1 - e_1^+ + e_1^- = 66 \quad (4.8)$$

$$38 \le y_1 \le 66 \quad (4.9)$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{erm})}\times X_{mn} - d_2^+ + d_2^- = y_2,\quad m=1,2,...,45;\ n=1,2,3,4 \quad (4.10)$$

$$y_2 - e_2^+ + e_2^- = 11,550 \quad (4.11)$$

$$5,775 \le y_2 \le 11,550 \quad (4.12)$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{mgt})}\times X_{mn} - d_3^+ + d_3^- = y_3,\quad m=1,2,...,45;\ n=1,2,3,4 \quad (4.13)$$

$$y_3 - e_3^+ + e_3^- = 11,550 \quad (4.14)$$

$$5,775 \le y_3 \le 11,550 \quad (4.15)$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{hot})}\times X_{mn} - d_4^+ + d_4^- = y_4,\quad m=1,2,...,45;\ n=1,2,3,4 \quad (4.16)$$

$$y_4 - e_4^+ + e_4^- = 7,760 \quad (4.17)$$

$$600 \le y_4 \le 7,760 \quad (4.18)$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{stgy})}\times X_{mn} - d_5^+ + d_5^- = y_5,\quad m=1,2,...,45;\ n=1,2,3,4 \quad (4.19)$$

$$y_5 - e_5^+ + e_5^- = 11,550 \quad (4.20)$$

$$2,310 \le y_5 \le 11,550 \quad (4.21)$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{ac})}\times X_{mn} - d_6^+ + d_6^- = y_6,\quad m=1,2,...,45;\ n=1,2,3,4 \quad (4.22)$$

$$y_6 - e_6^+ + e_6^- = 11,550 \quad (4.23)$$

$$3,465 \le y_6 \le 11,550 \quad (4.24)$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{adv})} \times X_{mn} - d_7^+ + d_7^- = y_7\,,\quad m = 1, 2, \ldots, 45;\;\; n = 1, 2, 3, 4 \tag{4.25}$$

$$y_7 - e_7^+ + e_7^- = 3{,}465 \tag{4.26}$$

$$1{,}155 \le y_7 \le 3{,}465 \tag{4.27}$$

$$d_k^+, d_k^-, e_k^+, e_k^- \ge 0\,,\quad k = 1, 2, \ldots, 7 \tag{4.28}$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{int})} \times X_{mn} \le 9{,}600\,,\quad m = 1, 2, \ldots, 45;\;\; n = 1, 2, 3, 4 \tag{4.29}$$

$$\sum_{m=1}^{45}\sum_{n=1}^{4} T_{mn(\text{ext})} \times X_{mn} \times 160 \le 312{,}500\,,\quad m = 1, 2, \ldots, 45;\;\; n = 1, 2, 3, 4 \tag{4.30}$$

$$\sum_{n=1}^{4} X_{mn} \le 1\,,\quad m = 1, 2, \ldots, 45 \tag{4.31}$$

$$X_{mn} = 0 \text{ or } 1\,,\quad m = 1, 2, \ldots, 45;\;\; n = 1, 2, 3, 4 \tag{4.32}$$

$$12 \le \sum_{m=1}^{45}\sum_{n=1}^{4} X_{mn} \le 18 \tag{4.33}$$

$$\sum_{n=1}^{4} X_{4n} = 1\,,\quad \sum_{n=1}^{4} X_{17n} = 1\,,\quad \sum_{n=1}^{4} X_{18n} = 1 \tag{4.34}$$

Definition of Equation (4.6) to Equation (4.32) can be referred to the model in subchapter 3.3. To control the total number of audit projects to be performed in a year, the required number of audit projects at ASP should be between 12 and 18, as expressed in Equation (4.33). In terms of Equation (4.34), it can be explained that the 4th auditable unit is mandatory to be audited to comply with local regulation, and the 17th and 18th auditable units must be selected as continuous audits (CA).

Based on the data in Table 4.3, the problem is resolved using LINGO 17.0 software (Lindo Systems, 1415 North Dayton Street, Chicago, IL, USA). Figure 4.1 shows the results of project portfolio selection, corresponding working time and risk reduction value. As a result, out of 45 auditable units, 15 are selected for an audit, including 11 assurance projects and 4 advisory projects (AU_{23}, AU_{26}, AU_{35} and AU_{40}). Among these selected projects, small audits (level 1 scope or low audit effort) should be undertaken for 2 auditable units (AU_4 and AU_{26}), only 1 auditable unit (AU_{22}) is required for a moderate audit (level 2 scope or medium audit effort) and 1 auditable unit (AU_{42}) is required for a review of large scope (level 3 scope or high audit effort), and the other 11 auditable units (AU_3, AU_{17}, AU_{18}, AU_{19}, AU_{23}, AU_{25}, AU_{27} AU_{35}, AU_{36}, AU_{40} and AU_{43}) are subject to full audits (level 4 scope or significant audit effort). The results are in line with the methodology of ASP IAF that calls for deeper and wider audits. Under the proposed allocation plan, the planned audit projects would cost 11,520 hours in total. All the available internal time (9,600 hours) are fully utilized, and 98.5% of external consultant time (1,920 hours) are expected to be used.

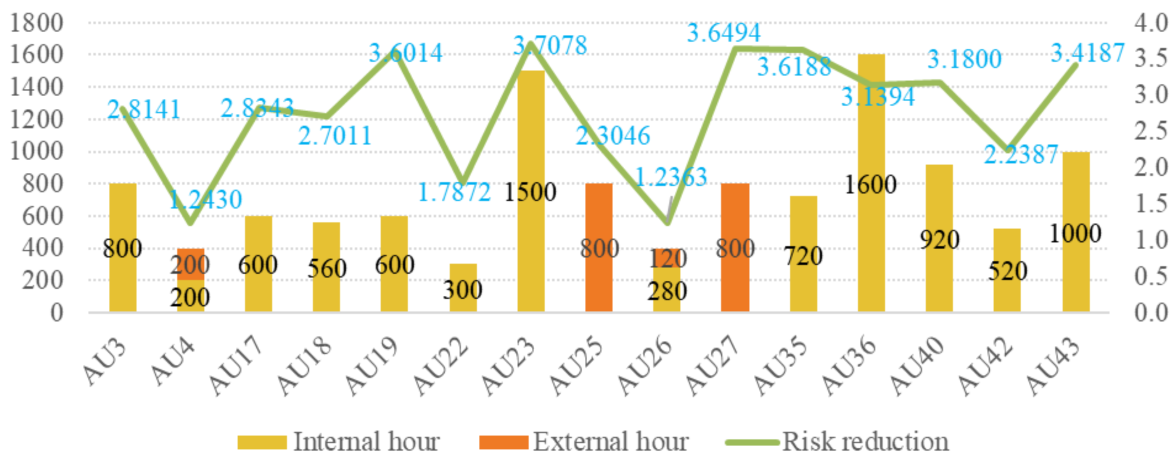

Figure 4.1 The selected project portfolio, allocated hours, and risk reduction

In addition, Figure 4.2 depicts the realized goals. All the goals can be achieved as follows according to the optimal solution.

(G1) A total risk reduction of 41.5 is obtained, which is 9.14% higher than the desired risk reduction level.

(G2) There are 13 audit projects relevant with ERM and the time spent on these projects are 9,520 hours, which accounts for 82.64% of the total time for the planned projects and is 65% higher than the expectation.

(G3) The time spent on the 13 projects related to management request are 10,080 hours, which takes up 87.5% of the planned time and is 75% higher than the expectation.

(G4) It would take 4,320 hours to complete 4 audit projects which cover audit plan hot spots, accounting for 37.5% of the planned time. The achieved result is six times more than the expectation.

(G5) There are 9 audit projects that cover company's strategy and the time spent on these projects are 7,360 hours, taking up 63.89% of the total planned time. The achieved result is more than three times as many as the desired hours.

(G6) The time spent on the 13 projects related to the interest of audit committee are 10,820 hours, which accounts for 93.92% of the planned time and is twice higher than the expectation.

(G7) The time spent on the 4 advisory service are 3,540 hours, which is 30.73% of the time needed to complete the select audits. It is slightly (75 hours) above the upper bound and is three times as many as the pre-defined requirement.

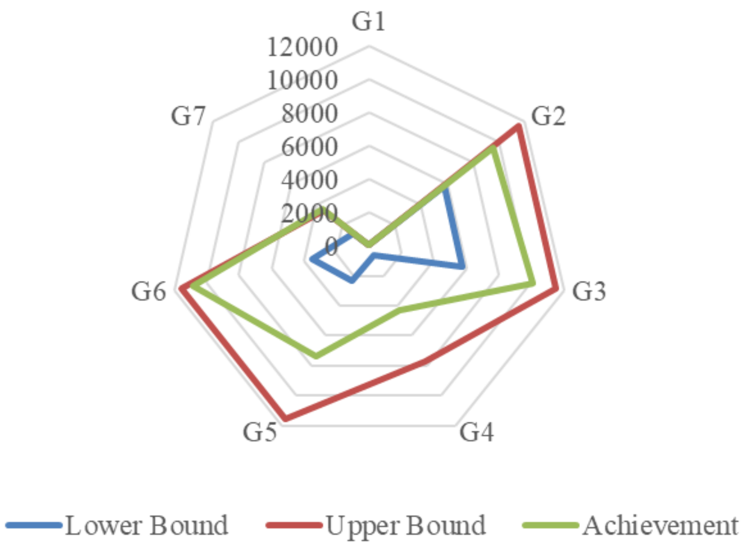

Figure 4.2 Comparison between achieved result and target

4.2.3 Audit staff assignments

Once project portfolio and audit time allocation are determined, internal auditors need to be assigned to the selected projects considering auditors' preference and their suitability for performing different projects. Because projects for auditing AU_{25} and AU_{27} are fully outsourced to the designated consulting firm, the staff assignment problem does not need to be considered for these two audit projects. Therefore, this study aims to assign 6 internal auditors to 13 internal audit projects.

In general, the higher the planned project time is, the greater number of team members is in need. The senior audit manager determines the number of auditors needed for the selected audit projects according to the following rules: (1) there will be 1 internal auditor for project with estimated audit time less than 300 hours; (2) there will be 2 internal auditors for project with estimated audit time between 300 hours and 600 hours; (3) there will be 3 internal auditors for project with estimated audit time between 600 hours and 800 hours; (4) if the amount of the project hours are within the range of 800 – 1,000 hours, 4 auditors will be assigned; (5) for project requiring audit time from 1,000 to 1,200 hours, 5 internal auditors are needed; and (6) all the 6 internal auditors will be assigned to the project if more than 1,200 internal hours are needed by the project. Accordingly, Table 4.5 shows the high-level auditor assignment plan based on the above rules. The project duration is calculated based on the planned project time (as shown in Figure 4.1) and the number of assigned auditors. An assumption made here is that the audit work is distributed among the team members evenly and all participants work in parallel. When both internal resource and external resource are assigned to the project, but the working hours planned for the two resources are not equal (e.g., project P_8), the longer period of time that either team spends working on projects should be taken as the duration.

Table 4.5 Number of auditors and project duration

Project #	AU #	Project name	Number of auditors		Duration (working days)
			ASP	Consulting Firm	
P_1	AU_3	Manufacturing plant C	4		25
P_2	AU_4	Manufacturing plant D	1	1	25
P_3	AU_{17}	CA - travel and expense	3		25
P_4	AU_{18}	CA - vendor payment	2		35
P_5	AU_{19}	Capital project - Asia	3		25
P_6	AU_{22}	Procurement strategy and supplier processes	2		18.75
P_7	AU_{23}	New acquisition integration	6		31.25
P_8	AU_{26}	Entity restructuring	1	1	35
P_9	AU_{35}	Product quality	3		30
P_{10}	AU_{36}	Inventory processes and management	6		33.33
P_{11}	AU_{40}	Crisis management	4		28.75
P_{12}	AU_{42}	Reliability / Maintenance Process	2		32.5
P_{13}	AU_{43}	Order fulfillment	5		25
P_{14}	AU_{25}	WAN redesign and implementation review		4	25
P_{15}	AU_{27}	Vulnerability management		4	25

In this study, the suitability of audit staff for the project is obtained through the following steps.

First, audit managers describe the characteristic of audit project by generating the weight of competency required to complete the project (w_{lv}). Because internal auditing is a competency-based activity, each competency plays a part in carrying out audit project and the weight means the importance of different competencies to the overall project performance. The nature and complexity vary among audit projects. As shown in Table 4.6, for project P_1, risk and control knowledge (C_2) and business process analysis (C_3) are more important than other knowledge and skills, and thereby higher weights are assigned to these two competencies. In addition, projects P_3 and P_4 involve more data analytics work and this skill is critical to ensure the project quality. Therefore, corresponding weight (w_{63} and w_{64}) are higher than that of other projects. However, projects P_{14} and P_{15} do not need to be evaluated as the resources will be assigned by the consulting firm based on ASP's requirement.

Table 4.6 Audit project characteristics (w_{lv})

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
C_1	0.2	0.1	0.05	0.05	0.15	0.05	0.25	0.2	0.1	0.3	0.14	0.15	0.1
C_2	0.25	0.25	0.1	0.1	0.2	0.2	0.15	0.08	0.07	0.2	0.1	0.15	0.2
C_3	0.25	0.25	0.02	0.1	0.33	0.4	0.15	0.1	0.15	0.3	0.15	0.23	0.3
C_4	0.1	0.2	0.3	0.25	0.07	0.15	0.05	0.3	0.4	0.1	0.35	0.3	0.1
C_5	0.1	0.1	0.15	0.1	0.05	0.1	0.3	0.3	0.27	0.05	0.25	0.16	0.1
C_6	0.1	0.1	0.38	0.4	0.2	0.1	0.1	0.02	0.01	0.05	0.01	0.01	0.2

Second, audit managers evaluate the qualification of audit staff according to the criteria and scale defined in the subchapter 3.4.2. To obtain the auditor-competency matrix (O_{luv}), audit managers need to perform evaluation of audit staff on the familiarity with the auditable unit (C_4) by project, while the level of other competencies remain the same across the projects. Then the weight corrector (w_{lv}^o) can be calculated based on the output value of the auditor-competency matrix. The correction value makes the output value equal for each competency. Table 4.7 shows the given auditor-competency matrix and computed weight corrector. The assessment results show that senior auditors (denoted as A_1, A_2, A_3 and A_4) are more skilled than audit associates (denoted as A_5 and A_6) in general, although audit associates have advantages in certain competencies.

Third, obtain the weighted and corrected auditor-competency matrix (Q_{luv}) by multiplying weight (w_{lv}) with weight corrector (w_{lv}^o), and auditor-competency matrix (O_{luv}). The sum of the weighted and corrected discrete fuzzy scores Q_{luv} in each audit staff is the suitability value of the internal auditor for the project (E_{uv}). The results are shown in Table 4.8. If the suitability value is higher, then the auditor can conduct the project more effectively and efficiently than the other colleagues. The audit staff can be ranked by this total score accordingly. For instance, for project P_1, senior auditor A_4 is the most qualified auditor among the team members. The obtained ranking of internal auditors in all audit projects is in line with audit managers' impressions on auditor's suitability for the project.

Table 4.7 Auditor-competency matrix (O_{luv}) and weight corrector (w_{lv}^{o})

	C_1	C_2	C_3	C_5	C_6
	$P_1 \sim P_{13}$	$P_1 \sim P_{13}$	$P_1 \sim P_{13}$	$P_1 \sim P_{13}$	$P_1 \sim P_{13}$
A_1	0.75	0.5	0.5	0.75	0.25
A_2	0.5	0.5	0.5	0.5	0.75
A_3	0.75	0.5	0.75	0.5	0.5
A_4	0.5	0.75	0.75	0.75	0.5
A_5	0.75	0.25	0.5	0.5	0.25
A_6	0.5	0.25	0.25	0.25	0.5
w_{lv}^{o}	0.2667	0.3636	0.3077	0.3077	0.3636

	C_4												
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
A_1	1	0.75	0.25	0.25	0.5	0.75	0.5	0.5	0.5	1	0.75	0.25	0.75
A_2	0.5	0.5	0.75	0.5	0.5	0.75	0.25	0.5	0.25	0.75	0.25	0.25	0.75
A_3	0.75	0.75	0.25	0.25	0.75	0.5	0.25	0.75	0.5	0.5	0.75	0.5	0.5
A_4	0.5	0.5	0.5	0.5	1	0.5	0.5	0.75	0.5	0.75	0.25	0.25	0.5
A_5	0.75	0.5	0.25	0.25	0.5	0.25	0.25	0.5	0.25	0.5	0.5	0.25	0.75
A_6	0.25	0.5	0.5	0.5	0.75	0.5	0.25	0.5	0.25	0.5	0.25	0.5	0.25
w_{lv}^{o}	0.2667	0.2857	0.4	0.4444	0.25	0.3077	0.5	0.2857	0.4444	0.25	0.3636	0.5	0.2857

Table 4.8 The weighted and corrected decision matrix (Q_{luv}) and auditor's suitability (E_{uv})

		C_1	C_2	C_3	C_4	C_5	C_6	SUM	Order
P_1	A_1	0.0400	0.0455	0.0385	0.0267	0.0231	0.0091	0.1828	3
	A_2	0.0267	0.0455	0.0385	0.0133	0.0154	0.0273	0.1666	4
	A_3	0.0400	0.0455	0.0577	0.0200	0.0154	0.0182	0.1967	2
	A_4	0.0267	0.0682	0.0577	0.0133	0.0231	0.0182	0.2071	1
	A_5	0.0400	0.0227	0.0385	0.0200	0.0154	0.0091	0.1457	5
	A_6	0.0267	0.0227	0.0192	0.0067	0.0077	0.0182	0.1012	6
P_2	A_1	0.0200	0.0455	0.0385	0.0429	0.0231	0.0091	0.1789	3
	A_2	0.0133	0.0455	0.0385	0.0286	0.0154	0.0273	0.1685	4
	A_3	0.0200	0.0455	0.0577	0.0429	0.0154	0.0182	0.1996	2
	A_4	0.0133	0.0682	0.0577	0.0286	0.0231	0.0182	0.2090	1
	A_5	0.0200	0.0227	0.0385	0.0286	0.0154	0.0091	0.1342	5
	A_6	0.0133	0.0227	0.0192	0.0286	0.0077	0.0182	0.1097	6
P_3	A_1	0.0100	0.0182	0.0031	0.0300	0.0346	0.0345	0.1304	5
	A_2	0.0067	0.0182	0.0031	0.0900	0.0231	0.1036	0.2446	1
	A_3	0.0100	0.0182	0.0046	0.0300	0.0231	0.0691	0.1550	4
	A_4	0.0067	0.0273	0.0046	0.0600	0.0346	0.0691	0.2023	2
	A_5	0.0100	0.0091	0.0031	0.0300	0.0231	0.0345	0.1098	6
	A_6	0.0067	0.0091	0.0015	0.0600	0.0115	0.0691	0.1579	3
P_4	A_1	0.0100	0.0182	0.0154	0.0278	0.0231	0.0364	0.1308	5
	A_2	0.0067	0.0182	0.0154	0.0556	0.0154	0.1091	0.2203	1
	A_3	0.0100	0.0182	0.0231	0.0278	0.0154	0.0727	0.1671	3
	A_4	0.0067	0.0273	0.0231	0.0556	0.0231	0.0727	0.2084	2
	A_5	0.0100	0.0091	0.0154	0.0278	0.0154	0.0364	0.1140	6
	A_6	0.0067	0.0091	0.0077	0.0556	0.0077	0.0727	0.1594	4
P_5	A_1	0.0300	0.0364	0.0508	0.0088	0.0115	0.0182	0.1556	4
	A_2	0.0200	0.0364	0.0508	0.0088	0.0077	0.0545	0.1781	3
	A_3	0.0300	0.0364	0.0762	0.0131	0.0077	0.0364	0.1997	2
	A_4	0.0200	0.0545	0.0762	0.0175	0.0115	0.0364	0.2161	1
	A_5	0.0300	0.0182	0.0508	0.0088	0.0077	0.0182	0.1336	5
	A_6	0.0200	0.0182	0.0254	0.0131	0.0038	0.0364	0.1169	6
P_6	A_1	0.0100	0.0364	0.0615	0.0346	0.0231	0.0091	0.1747	4
	A_2	0.0067	0.0364	0.0615	0.0346	0.0154	0.0273	0.1818	3
	A_3	0.0100	0.0364	0.0923	0.0231	0.0154	0.0182	0.1953	2
	A_4	0.0067	0.0545	0.0923	0.0231	0.0231	0.0182	0.2179	1
	A_5	0.0100	0.0182	0.0615	0.0115	0.0154	0.0091	0.1257	5
	A_6	0.0067	0.0182	0.0308	0.0231	0.0077	0.0182	0.1046	6
P_7	A_1	0.0500	0.0273	0.0231	0.0125	0.0692	0.0091	0.1912	2
	A_2	0.0333	0.0273	0.0231	0.0063	0.0462	0.0273	0.1634	4
	A_3	0.0500	0.0273	0.0346	0.0063	0.0462	0.0182	0.1825	3
	A_4	0.0333	0.0409	0.0346	0.0125	0.0692	0.0182	0.2088	1
	A_5	0.0500	0.0136	0.0231	0.0063	0.0462	0.0091	0.1482	5
	A_6	0.0333	0.0136	0.0115	0.0063	0.0231	0.0182	0.1060	6
P_8	A_1	0.0400	0.0145	0.0154	0.0429	0.0692	0.0018	0.1838	3
	A_2	0.0267	0.0145	0.0154	0.0429	0.0462	0.0055	0.1511	5
	A_3	0.0400	0.0145	0.0231	0.0643	0.0462	0.0036	0.1917	2
	A_4	0.0267	0.0218	0.0231	0.0643	0.0692	0.0036	0.2087	1
	A_5	0.0400	0.0073	0.0154	0.0429	0.0462	0.0018	0.1535	4
	A_6	0.0267	0.0073	0.0077	0.0429	0.0231	0.0036	0.1112	6
P_9	A_1	0.0200	0.0127	0.0231	0.0889	0.0623	0.0009	0.2079	2
	A_2	0.0133	0.0127	0.0231	0.0444	0.0415	0.0027	0.1378	4
	A_3	0.0200	0.0127	0.0346	0.0889	0.0415	0.0018	0.1996	3

	A_4	0.0133	0.0191	0.0346	0.0889	0.0623	0.0018	0.2201	1
	A_5	0.0200	0.0064	0.0231	0.0444	0.0415	0.0009	0.1363	5
	A_6	0.0133	0.0064	0.0115	0.0444	0.0208	0.0018	0.0983	6
P_{10}	A_1	0.0600	0.0364	0.0462	0.0250	0.0115	0.0045	0.1836	3
	A_2	0.0400	0.0364	0.0462	0.0188	0.0077	0.0136	0.1626	4
	A_3	0.0600	0.0364	0.0692	0.0125	0.0077	0.0091	0.1949	2
	A_4	0.0400	0.0545	0.0692	0.0188	0.0115	0.0091	0.2032	1
	A_5	0.0600	0.0182	0.0462	0.0125	0.0077	0.0045	0.1491	5
	A_6	0.0400	0.0182	0.0231	0.0125	0.0038	0.0091	0.1067	6
P_{11}	A_1	0.0280	0.0182	0.0231	0.0955	0.0577	0.0009	0.2233	1
	A_2	0.0187	0.0182	0.0231	0.0318	0.0385	0.0027	0.1329	5
	A_3	0.0280	0.0182	0.0346	0.0955	0.0385	0.0018	0.2165	2
	A_4	0.0187	0.0273	0.0346	0.0318	0.0577	0.0018	0.1719	3
	A_5	0.0280	0.0091	0.0231	0.0636	0.0385	0.0009	0.1632	4
	A_6	0.0187	0.0091	0.0115	0.0318	0.0192	0.0018	0.0922	6
P_{12}	A_1	0.0300	0.0273	0.0354	0.0375	0.0369	0.0009	0.1680	3
	A_2	0.0200	0.0273	0.0354	0.0375	0.0246	0.0027	0.1475	4
	A_3	0.0300	0.0273	0.0531	0.0750	0.0246	0.0018	0.2118	1
	A_4	0.0200	0.0409	0.0531	0.0375	0.0369	0.0018	0.1902	2
	A_5	0.0300	0.0136	0.0354	0.0375	0.0246	0.0009	0.1420	5
	A_6	0.0200	0.0136	0.0177	0.0750	0.0123	0.0018	0.1405	6
P_{13}	A_1	0.0200	0.0364	0.0462	0.0214	0.0231	0.0182	0.1652	4
	A_2	0.0133	0.0364	0.0462	0.0214	0.0154	0.0545	0.1872	3
	A_3	0.0200	0.0364	0.0692	0.0143	0.0154	0.0364	0.1916	2
	A_4	0.0133	0.0545	0.0692	0.0143	0.0231	0.0364	0.2108	1
	A_5	0.0200	0.0182	0.0462	0.0214	0.0154	0.0182	0.1393	5
	A_6	0.0133	0.0182	0.0231	0.0071	0.0077	0.0364	0.1058	6

In the meantime, internal auditors are asked to indicate a particular number of preferences, from 1 to 5, over the available projects (G_{uv}). The questionnaire is given in Appendix C. As indicated in Table 4.9, project P_{10} seems to be more popular than other projects among the internal audit team.

Table 4.9 Auditor’s preference (G_{uv})

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
A1	1	4	3	3	1	4	5	3	5	2	4	4	4
A2	3	1	4	4	4	3	4	1	3	5	3	2	5
A3	3	4	1	3	2	4	2	3	5	4	5	4	3
A4	2	3	1	2	3	3	5	5	2	5	4	4	2
A5	4	4	3	4	5	2	2	3	3	5	2	5	3
A6	5	5	4	5	5	3	1	2	1	5	3	5	5

When internal auditors are assigned to the audit project, the following two objectives are proposed.

(G1) The total value of auditor preference should be over 122, the larger the better. In an ideal scenario, all internal auditors should have the opportunity to participate in the project they prefer. According to the number of team members defined for each project and the indicated preference number, an upper bound of 171 is set for this objective. In the light of the importance of employee satisfaction in the job motivation and enthusiasm, senior audit manager assigns a penalty weight of 3 for below the preference goal.

(G2) The total suitability value should be over 6.5, the larger the better. In the most ideal scenario, only the top internal auditors for each project are assigned. According to the number of team members defined for each project and the calculated suitability value, an upper bound of 12 is set for this objective. Because suitability is very important to ensure the smooth implementation of the audit project and the completion of internal audit mission, senior audit manager assigns a penalty weight of 5 for below this goal.

Assume that ASP audit staff is fixed during the planning year. In other words, the audit department does not increase team size, and there are no terminations occurred in the year. To balance the workload, the senior audit manager wants to avoid the large gap in the total working days among the audit staff and thus sets a variance range of 10 days. In addition, to ensure the fairness when considering each auditor's preference, the difference of total preference value among the audit staff should not exceed 12. Based on the MINMAX MCGP model, auditor assignment problem at ASP is formulated as follows to obtain a balanced solution to satisfy both auditor preference and auditor's fitness to the project.

$$\text{Minimize } D \tag{4.35}$$

Subject to

$$D \geq d_1^+ + 3d_1^-, \quad D \geq e_1^+ + e_1^- \tag{4.36}$$

$$D \geq d_2^+ + 5d_2^-, \quad D \geq e_2^+ + e_2^- \tag{4.37}$$

$$\sum_{u=1}^{6}\sum_{v=1}^{13} G_{uv} \times X_{uv} - d_1^+ + d_1^- = y_1, \quad u = 1,2,\ldots,6; \quad v = 1,2,\ldots,13 \tag{4.38}$$

$$y_1 - e_1^+ + e_1^- = 171 \tag{4.39}$$

$$122 \leq y_1 \leq 171 \tag{4.40}$$

$$\sum_{u=1}^{6}\sum_{v=1}^{13} E_{uv} \times X_{uv} - d_2^+ + d_2^- = y_2, \quad u = 1,2,\ldots,6; \quad v = 1,2,\ldots,13 \tag{4.41}$$

$$y_2 - e_2^+ + e_2^- = 12 \tag{4.42}$$

$$6.5 \leq y_2 \leq 12 \tag{4.43}$$

$$d_k^+, d_k^-, e_k^+, e_k^- \geq 0, \quad k = 1,2 \tag{4.44}$$

$$\sum_{u=1}^{6} X_{uv} = s_v \ , \quad v = 1, 2, ..., 13 \tag{4.45}$$

$$-10 \leq \sum_{v=1}^{13} t_v \times X_{u_1 v} - \sum_{v=1}^{13} t_v \times X_{u_2 v} \leq 10 \ , \quad u_1, u_2 = 1, 2, ..., 6 \ ; \quad v = 1, 2, ..., 13 \tag{4.46}$$

$$-12 \leq \sum_{v=1}^{13} G_{u_1 v} \times X_{u_1 v} - \sum_{v=1}^{13} G_{u_2 v} \times X_{u_2 v} \leq 12 \ , \quad u_1, u_2 = 1, 2, ..., 6 \ ; \quad v = 1, 2, ..., 13 \tag{4.47}$$

$$X_{uv} = 0 \text{ or } 1, \quad u = 1, 2, ..., 6 \ ; \quad v = 1, 2, ..., 13 \tag{4.48}$$

Definition of Equation (4.35) to Equation (4.48) can be referred to the model in subchapter 3.4. Based on the obtained dataset, the above model is resolved using LINGO 17.0 software (Lindo Systems, 1415 North Dayton Street, Chicago, IL, USA). As a result, each of the 6 auditors will participate in 7 internal audit projects. The total preference value of the team is 166 and the total suitability value of the team is 7.2436. Thus, the two objectives are both achieved. In the meantime, the total number of working days for each audit staff ranges between 197.08 days to 202.08 days, indicating a balanced work allocation among the team members. By working in the assigned projects, the preference value of each audit staff is respectively 28, 29, 26, 26, 27, 30. Therefore, the assignment is fair by considering all employees' preference. Let FI represents consultants from the consulting firm. Figure 4.3 presents the solution to the assignment problem. For instance, a team composed of internal auditors A_2, A_5 and A_6 will conduct both project P_3 and project P_5.

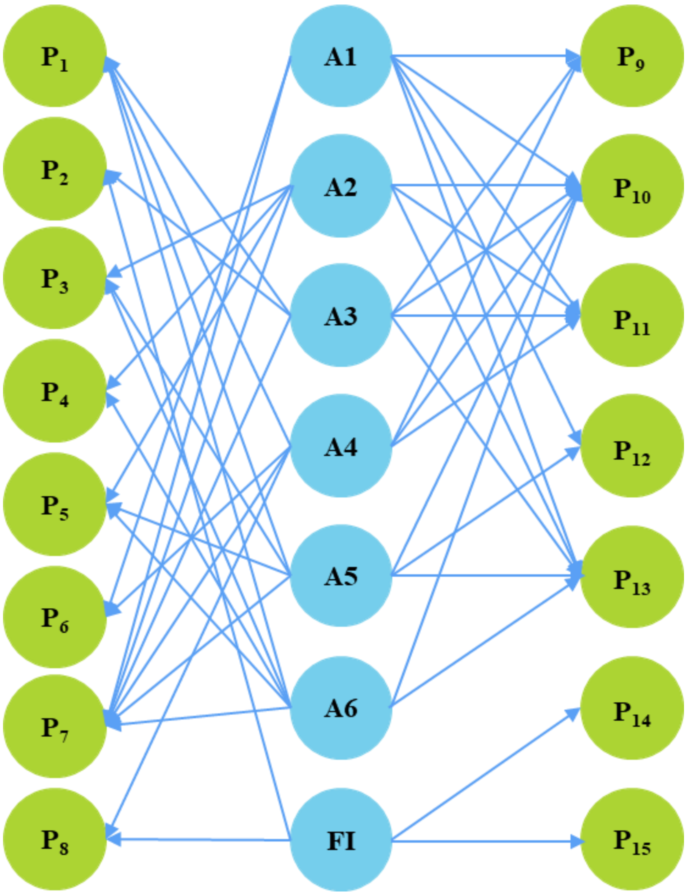

Figure 4.3 Auditor assignment to the selected projects

4.2.4 An annual internal audit schedule

As the final stage, the selected project portfolio should be scheduled. The planned audit work timetable and corresponding schedule in Gantt chart is shown as Figure 4.4. In the figure, FI (1) denotes one consultant assigned by the firm and FI (4) means that four consultants are needed from the consulting firm.

In principle, projects are scheduled according to the decreasing order of the risk reduction value and the availability of the audit staff. The start date of each project is determined based on the end date of the previous project. When calculating the finish date of each project, Chinese public holiday of the year 2022 has been considered. To better utilize the resource and enable the audit team to complete all projects within the planning horizon, multiple projects should be carried out in parallel as long as the auditor does not work for more than one project concurrently.

Project	Start Date	Working Days	End Date	Auditor	Risk Reduction
P_1	28-Sep	25	9-Nov	A_3, A_4, A_5, A_6	2.8141
P_2	7-Jul	25	11-Aug	A_3, FI (1)	1.2430
P_3	7-Jul	25	11-Aug	A_2, A_5, A_6	2.8343
P_4	10-Nov	35	29-Dec	A_2, A_6	2.7011
P_5	23-Feb	25	30-Mar	A_2, A_5, A_6	3.6014
P_6	21-Jul	18.75	16-Aug	A_1, A_4	1.7872
P_7	1-Jan	31.25	22-Feb	A_1, A_2, A_3, A_4, A_5, A_6	3.7078
P_8	31-May	35	20-Jul	A_4, FI (1)	1.2363
P_9	23-Feb	30	8-Apr	A_1, A_3, A_4	3.6188
P_{10}	9-Apr	33.33	30-May	A_1, A_2, A_3, A_4, A_5, A_6	3.1394
P_{11}	17-Aug	28.75	27-Sep	A_1, A_2, A_3, A_4	3.1800
P_{12}	10-Nov	32.5	26-Dec	A_1, A_5	2.2387
P_{13}	31-May	25	6-Jul	A_1, A_2, A_3, A_5, A_6	3.4187
P_{14}	28-Sep	25	9-Nov	FI (4)	2.3046
P_{15}	1-Jan	25	14-Feb	FI (4)	3.6494

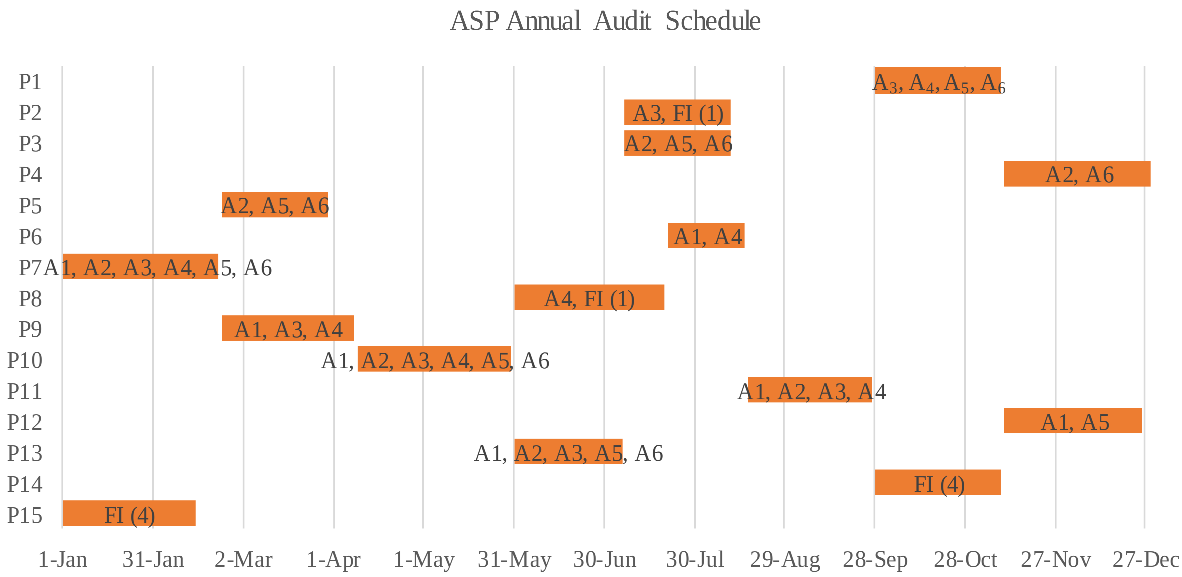

Figure 4.4 ASP annual audit schedule

To illustrate the process, because project P_7 has the highest risk reduction value and requires all the audit staff to participate in the activities, it should be conducted as the first audit project of the year. While the risk reduction value of project P_{15} ranks the second, only external consultants are assigned to this project and thus it can be performed at the same period of project P_7. The risk reduction values of project P_9 and project P_5 come next. By coincidence, audit team for the two projects consist of different internal auditors. Therefore, both projects can be run at the same time. However, if audit managers continue to schedule the project by following the order of the risk reduction value only, the end date of the last project would exceed the planning horizon. The advantages of Gantt chart are to visually show the overall progress of all the planned audit projects and allow DMs to adjust the start date of the project as necessary. Although the risk reduction value of project P_8 ranks the last, as auditor A_4 is the only internal resource for the project, it can be conducted along with project P_{13} to which only auditor A_4 is not assigned. Also, to better use the team capacity, project P_2 and project P_3 are scheduled right after project P_{13} while project P_8 is still in the progress. Considering that there is no conflict of assigned auditors, project P_6 can be scheduled after the completion of project P_8 while project P_2 and project P_3 are ongoing. In most cases, two audit projects are operated simultaneously and can be supervised by the two audit managers. Overall, the annual calendar seems to be reasonable and manageable.

4.3 Sensitivity analysis

When assessing the risk levels of auditable units through FCE-AHP (FAHP) method, only one specific set of weights is considered in the above case study. To examine the risk ranking of each auditable unit in respect of different weight representation, sensitivity analysis is carried out.

In the illustrative case, namely Case I, W = (0.2716, 0.2256, 0.3509, 0.1519), in which operational risk is viewed as the most critical risk to the organization, followed by strategic risk, financial risk, and compliance risk. By exchanging the order of strategic risk and operational risk in the weight vector and keeping the weights of other two risks unchanged, Case II makes strategic risk the most important one, thereby W = (0.3509, 0.2256, 0.2716, 0.1519). Similarly, financial risk becomes the most important one in Case III by exchanging the order of financial risk and operational risk in the weight vector, and W = (0.2716, 0.3509, 0.2256, 0.1519). Case IV exchanges the order of compliance risk and operational risk in the weight vector, and W = (0.2716, 0.2256, 0.1519, 0.3509). In addition to changing the weights on the top-level criteria, Case V assumes that the importance of each main criterion and sub criterion are equal, i.e., $W = [1]_{4*4}$, $w_1 = [1]_{6*6}$, $w_2 = [1]_{3*3}$, $w_3 = [1]_{6*6}$, $w_4 = [1]_{3*3}$. The comparison of final evaluation results by top 10 risky auditable units is shown in Figure 4.5.

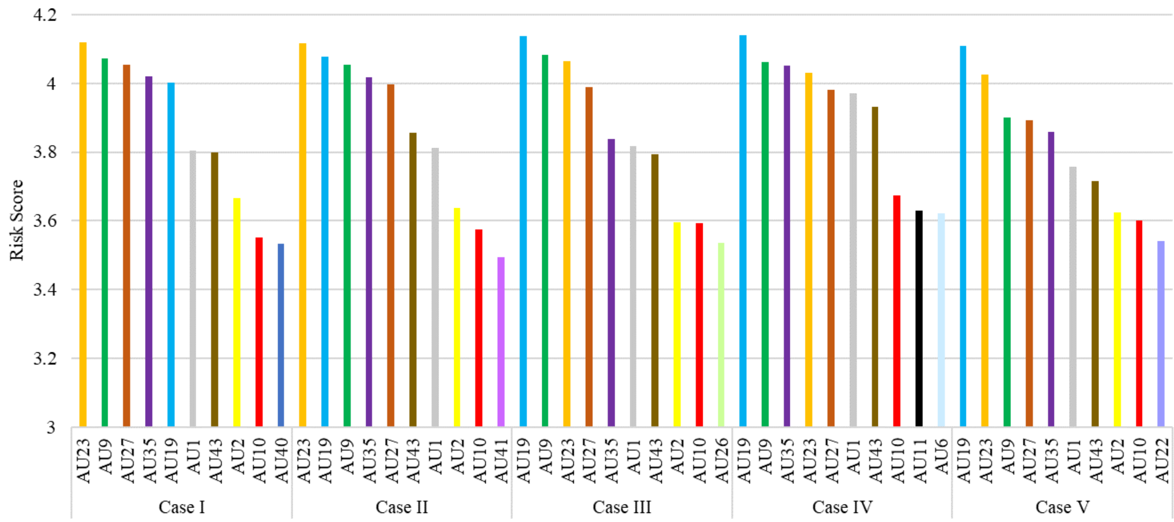

Figure 4.5 Top 10 risky areas by different weights

As seen from the above results, new acquisition integration (AU_{23}) has the highest risk score in both Case I and Case II but not in other cases. Therefore, this auditable area is not sensitive to strategic risk but is sensitive to financial and compliance risks. Also, capital project - Asia (AU_{19}) ranks fifth in the illustrative case, but ranks either the first or the second in other cases. Therefore, it is sensitive to other risks. An interesting phenomenon that can be found from the results is that new acquisition integration (AU_{23}), manufacturing plant I (AU_9), vulnerability management (AU_{27}), product quality (AU_{35}), capital project - Asia (AU_{19}), manufacturing plant A (AU_1), and order fulfillment (AU_{43}) are the top 7 risky auditable units in all the cases, although the specific rankings are different in each case. Manufacturing plant J (AU_{10}) either ranks 8th or 9th in these cases. In general, these auditable units are deemed as high-risk areas and the impact of weights on the result is not obvious. On the other hand, crisis management (AU_{40}) becomes top 10 risky area only in the illustrative case when the operational risk is more important to the organization, and manufacturing plant B (AU_2) is not ranked as top 10 risky area only in Case IV when the compliance risk has the higher weight. To summarize, how DMs view the importance of various risks could impact the final risk evaluation results to a certain extent. However, the difference of the risk score of each auditable unit is not significant among the cases, ranging from 0.062 to 0.4321, or from 2% to 14%.

In fact, the ranking of candidate projects by risk score is not the only criterion to select the audit project. Sometimes, it can be misleading by simply using the risk score. Conducting an audit of the area with higher risk score may not be the best choice. It is necessary to consider in a comprehensive way to add more value to the organization. In determining the multi-objective selection of audit projects to be performed and the allocation of audit time, the weights on multiple objectives might impact the selection results. As shown in Table 4.10, this study sets different weights for each goal under four scenarios of selection strategy. The first scenario is from the illustrated case study. The other three strategies emphasize other objectives except risk reduction.

Table 4.10 Weights of different selection strategies

Goals	Weights of the goals			
	Scenario I	Scenario II	Scenario III	Scenario IV
G1: Risk reduction	0.2	0.1	0.1	0.1
G2: Linkage with ERM	0.2	0.1	0.1	0.3
G3: Management request	0.15	0.3	0.05	0.1
G4: Audit hot spots	0.07	0.05	0.3	0.05
G5: Strategic focus	0.12	0.1	0.1	0.3
G6: Interest of audit committee	0.16	0.3	0.05	0.1
G7: Advisory project	0.1	0.05	0.3	0.05
Solution	15 projects	16 projects	17 projects	16 projects
Utilized audit time (hours)	11,520	11,540	11,540	11,540

Assume that other conditions are the same as those in the illustrated case study, the solutions to project selection and resource allocation are presented as Figure 4.6 by different scenarios.

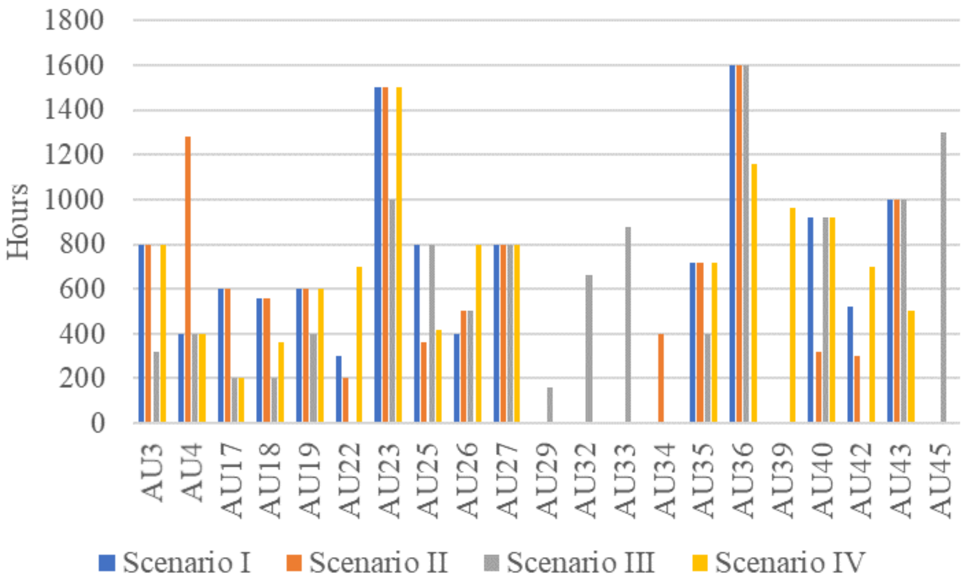

Figure 4.6 Comparison of selection results

As illustrated in the case study, scenario I emphasizes on risks. In this scenario, risk reduction (G1) and linkage with ERM (G2) are considered as the most important goals and have relatively higher weights while balancing other goals. Finally, 15 projects are selected. Scenario II focuses on the needs of stakeholders. Under this strategy, management request (G3) and AC interest (G6) are emphasized and given higher weights. As a result, 16 projects are selected. Scenario III considers more about the nature of the project and assigns higher weights to hot topics (G4) and advisory project (G7), and it ends up with 17 selected projects to be performed.

In scenario IV, DMs think of the organization as a whole and view enterprise risk management (G2) and company strategy (G5) as critical factors. As a result, 16 projects are selected. In all the scenarios, the available audit time are almost fully utilized. According to the presented results, there are 13 projects in common under all scenarios although the determined work scope varies among the strategies. For example, comparing with scenario I, scenario II selects one additional project — vulnerability management (AU_{27}). To compensate the time spent on the audit of vulnerability management, the audit efforts are different for 6 out of the 15 projects in common.

Additionally, in order to test the impact of penalty weights on the auditor assignment, two other preference strategies are adopted: (1) assume that the preference for below the two goals are equal, let $\beta_1 = \beta_2 = 1$, the assignment plan would the same as the illustrated case. However, if higher penalty weight is assigned to both goals, for example, $\beta_1 = \beta_2 = 5$, in comparison with the illustrated case, there is only one change of the project for internal auditor A_1 (from P_{12} to P_4), A_2 (from P_4 to P_9), and A_4 (from P_9 to P_{12}) respectively, while the other assignment plans remain the same. (2) In contrast to the illustrated case, assign higher penalty weights for below the preference goal (e.g., $\beta_1 = 5$ and $\beta_2 = 3$), the only difference from the illustrated assignment plan is that internal auditor A_4 will be assigned to P_{13} instead of P_9, while A5 will be assigned to P_9 instead of P_{13}.

4.4 Management feedback on the framework

The proposed method is designed to provide an integrated framework combining management judgments from the multiple stages of the annual audit planning process. The audit project portfolio selection decision is previously carried out based on the existing risk levels of the auditable units. In the new framework, the use of risk reduction concept further enhances and reflects the value of the audit work that brings to the organization. In practice, when multiple decision makers are involved, it is also difficult to achieve consensus on the risk level. However, the proposed FAHP approach synthesizes opinions of various DMs in performing risk assessment and thus resolves the issue of disagreement. In addition, both Weighted MCGP and MINMAX MCGP model allows DMs to consider multiple aspiration levels and thereby there will be no concern on underestimating the goal. At last, the use of Gantt chart assists audit managers in tracking the project status visually.

Since the case study used management information and data that were not considered in the real-life audit planning performed manually, a direct comparison between the solution of the implemented methodology and the actual audit plan was not possible. However, the proposed process is reasonable and the results are satisfactory.

With regards to the process, from the point of view of audit managers, the proposed framework offers a transparent and systematic procedure for developing a formal risk-based internal audit plan. On the one hand, the proposed framework not only selects more critical projects, but also sets up the effort level to reduce low value work. The project portfolio selection problem is not solved through ranking and prioritization. Instead, the new framework incorporates all relevant elements of both project portfolio selection and resource allocation problems in a model, allowing DMs to determine how much effort will be put into the candidate projects. On the other hand, the proposed framework not only assign qualified internal auditors to the audit project, but also allows them to participate in projects that they enjoy as much as possible. In that case, IA management believe that employee engagement can be increased and project quality can be ensured as well. Moreover, with the increasing number of candidate projects and team members, the manual planning work becomes more challenging but the proposed process will not become more complicated. *"Unlike the look back approach we are using now, the proposal is a proactive approach. This is the mindset we need to implement to show how people can make decision. The proposal makes much more sense in the data driven audit planning, and we will need it when it becomes hard for us to reduce potential audits and pick more meaningful projects at one point. We are not data driven audit team as current leadership is not at this appetite, but this could change next day. In order to implement the proposed model one day, we hope to operate a readily-available software so that general auditors without programming skills can use it step by step by entering the inputs only"* [in the senior audit manager's own words].

In terms of the results, as discussed in the subchapter 4.2, the models achieve predefined objectives of each stage. The audit projects that have been chosen and conducted by ASP before are basically covered by the selection results using the proposed framework and the Gantt chart is simpler than a full annual calendar that the audit team draws today. Internal audit leaders are satisfied with the generated audit plan using the proposed framework. The illustrated example proves that the framework is pragmatic, and the integrated approach is superior to manual process and stand-alone method in terms of the outcomes and applicability.

While the proposed framework is easy to be understood and the steps are easy to be followed, if it is put into use, audit managers hope to simplify the application process so that the planning can be completed by the internal audit team without proficient modeling and programming skills, as opposed to relying on the assistance of decision analysts.

As per the CAE, *"The framework is a good way to track and explain the decisions. You also bring up a good point to start resource plan upfront selection. How we operate now is that we work backward to manage the numbers at the last minute. However, it is not necessary to use your approach at this moment because we do not have a large population to make the selection now. Our candidate topics are mainly from management input meetings. We pretty much know what we are going to select as we kind of understand which area would executives like us to check. The obtained assignment results would be good for the employees, but the personal turnover is also relatively high last year so that it is too early to assign the audit team except for determining audit project leaders. With that said, I'm not denying the benefits of the approach and the promising results. This is the way to future. This will be useful as we grow up and become more complex considering the ongoing and future M&A. I'm also thinking of applying the approach to individual audit engagements, we can figure out where else we can apply this approach best, and a potential area might be the audit sampling"*.

4.5 Summary

Chapter four of this thesis uses a real-life case to illustrate the effectiveness of the proposed model. This chapter opens with the background of the case study, describing the current annual internal audit planning process of the studied company as well as the drawbacks and pain points of the process. Then, the four-stage framework is applied to develop a risk-based annual audit plan for the company. In the first stage, a combined FCE and AHP model is presented to provide a comprehensive risk appraisal of each auditable unit identified by the company. This is followed by selecting a portfolio consisting of candidate projects using Weighted MCGP method. In order to satisfy DMs' multiple objectives, such as risk reduction, linkage to ERM, stakeholders' interest and request, and alignment with strategic objectives, it tourns out that 15 out of 45 candidate projects can be selected considering the available resources. In the meantime, based on the given four types of audit scope, the particular level of audit effort is determined for each selected project. The solution optimizes the resource allocation of the internal audit department, directing audit resource to more valuable areas. In the third stage, employee suitability for the internal audit project is calculated according to manager's evaluation on employee competency and project characteristics. With MINMAX MCGP method, an audit team is then formed and assigned to each project to maintain a balance between employee preference and employee suitability. As a result, every internal auditor will participate in 7 internal audit projects. In the last stage, a Gantt chart is used to depict an annual audit schedule, showing that multiple internal audit projects can be carried out simultaneously so that all projects can be completed within the planning year. Finally, the chapter concludes with the management response to the framework. In general, internal audit leaders are positive about the results, and they are interested in innovating the annual audit planning process with effective and user-friendly decision-making tools that allow for the consideration of multiple criteria and multiple objectives.

In a word, the proposed integrated approach shows great promise for developing a risk-based annual internal audit plan. The novel framework not only allows the internal audit department to use limited resource more efficiently and effectively but also helps to create a harmonious and stable team. Although the presented case study seems to represent a particular scenario of a manufacturing company, it can be easily modified for a more general implementation, because similar problems with minor differences are quite common in most companies with internal audit function. To some extent, the integrated approach would be of great practical value in the applications of various planning and scheduling problems.

Chapter 5: Conclusion and Research Prospects

The final chapter of this thesis makes conclusion of the research and discusses theoretical contribution and practical implications. The research limitations and directions for future research are addressed as well.

5.1 Research conclusions

There are lots of benefits to create and follow a plan in an organization. Planning can direct employee actions by providing guidelines and decision goals, it can assist DMs in preparing for the emergencies and controlling the situation by considering and foreseeing possible events and scenarios, and it also helps allocate scarce resources such as people, materials, and time in a systematic and organized manner.

Internal audit is an indispensable part of effective corporate governance. Internal audit enhances and safeguards organizational value by providing independent, risk-based, and objective assurance, advice, and insight to the stakeholders. It is a project-based assurance and consulting activity. As the first phase of internal audit cycle, internal audit planning defines topic, scope, schedule, and resources of the audit activity that will be conducted in the planning period. Candidate projects compete for resources with each other, and a structured and optimized approach becomes necessary to assist with the decision. Therefore, internal audit planning is a methodical process of project portfolio selection with resource allocation, which enables IAF to concentrate on reviewing important areas. IAF most often creates an audit plan each year and thus the process is called as annual audit planning. While the plan might be adjusted to accommodate new priorities during the year in the light of changes in the internal and external conditions, it is still necessary to prepare an internal audit plan at the very beginning to guide audit activities.

Nowadays, risk-based approach to audit planning is regarded as a basic characteristic of modern internal auditing (Eulerich et al., 2020). Effective and thorough internal audit planning enables IAF to use constrained resources effectively and efficiently, reducing organizational risks with enhanced extent of audit coverage (Menekse & Camgoz-Akdag, 2022). Decision making is the core of administrative action (Simon, 1947). Risk-based audit planning is a challenging decision-making practice on resource allocation, which not only involves multiple criteria and multiple objectives but also requires strong analytical skills (Hass et al., 2006). As an analytical approach of problem-solving and decision-making, OR techniques can be applied to a variety of real-world use cases, including selection of alternatives, production/service planning, project management, resource allocation, personnel management. This thesis presents a novel decision support model, named as an integrated multi-stage framework for risk-based internal audit planning, based on the OR methods.

Internal audit planning problem comprises multiple stages. The proposed framework starts from risk assessment of each potential auditable area. Due to the mismatch between the limited internal audit resources and a broad list of candidate projects which address organizational risks, it is critical to conduct risk assessment for proper resource deployment. A risk assessment model is developed using the FCE-AHP (FAHP) approach. When conducting risk assessment, practitioners normally use qualitative terms, such as low, moderate, high, and significant. As an application of the fuzzy set theory, FCE provides a way to model and quantify ambiguous and subjective judgments in the assessment process. Meanwhile, AHP method is an effective weight estimation technique and can be embraced in the FCE process to estimate the weights of different risk items. In this way, FAHP method has particular application in group decision analysis and works well in assessing the overall risk level of an auditable unit. Then the risk reduction value is calculated based on the obtained risk levels and possible audit scopes. The next stage is to select candidate project portfolios and allocate resources (e.g., audit time, budgeted funds) to the audit project simultaneously through Weighted MCGP approach. There are multiple objectives in determining the audit projects to be performed and appropriate level of audit efforts. In addition to higher risk reduction value, other factors such as management request, audit hot spot and audit committee’s interest, which represent stakeholders’ evaluation of organizational risks, are also considered to ensure audit efforts could focus on more valuable areas. Weighted MCGP model allows DMs to set multiple aspiration levels (e.g., the more the better, the less the better) for each predefined goal to avoid underestimation/overestimation of decision making, emphasize the goals which DMs consider more important and obtain the solution with the minimum aggregate deviation or maximum aggregate achievement for all multiple goals. The third stage is to assign staff to the selected projects by balancing auditor preference and auditor’s fitness to the project via MINMAX MCGP model. In this phase, the suitability value of the auditor for each audit project is calculated based on manager’s evaluation on auditors’ competency. Under the MINMAX MCGP method, DMs can get the most balanced solution between all multiple goals in multiple aspiration levels setting. The last stage is project scheduling based on the urgency of project, balanced workload among auditors and the assignment plan. A classic and user-friendly tool, Gantt chart, is used to provide a visual view of project schedule. Then a formal approval of the audit plan should be obtained from the audit committee.

In this study, a real-world case is used to illustrate how the proposed integrated framework could be applied in practice. An annual audit plan is developed for the company following the designed steps with survey data collected from the internal audit team. This research shows that the proposed approach can optimally select audit projects, allocate audit time, and assign internal auditors. As a result, the proposed integrated approach is superior to stand-alone approach or other mathematical models that are too complicated to be used by non-experts. On the one hand, the results on the risk assessment not only reveal that the risk of the evaluated auditable units ranges from low level to high level, but also verify that FAHP can handle complicated evaluation with multiple criteria and levels. On the other hand, the research findings on the feasible achievements of the multiple objectives model through Weighted MCGP and MINMAX MCGP verify that the IAF can focus on risky areas while meeting the needs of stakeholders, and the IAF can also perform quality audit without undermining auditor preference. The analysis criteria and objective function with changing weights also yielded new solutions for developing the internal audit planning. The CAE and senior manager responsible for annual audit planning are also basically satisfied with the process and results.

5.2 Research contribution

Although this thesis does not create new theory, it is not only an example of the practice project of OR but also design research as measured against the seven guidelines defined by Hevner et al. (2004): (1) design as an artefact. This research developed a new artefact — an integrated multi-stage framework for risk-based internal audit planning; (2) problem relevance. As a multi-criteria and multi-objective problem, internal audit planning is a vital step in the whole audit cycle and is the source of all other audit activities. This research is carried out to assist audit leaders with the decisions they needed to make in the work; (3) design evaluation. The effectiveness of the proposed framework is evaluated through a case study, using the comments of the management of the studied IAF; (4) research contribution. Theoretical and practical contributions are elaborated in the below section in detail; (5) research rigor. The proposed framework applies existing theory of fuzzy set, AHP, GP and Gantt chart; (6) design as a search process. The designed process is based on a large body of literature covering project portfolio planning, risk assessment, internal audit, as well as multi-objective, multi-criteria approach.

Then the framework is developed by integrating useful tools to meet the needs of each stage of the process; and (7) communication. Sufficient details of the framework and models are presented so that practitioners can implement the solution and researchers can build on this work as well.

5.2.1 Theoretical contribution

This research offers a new decision support framework integrating FCE, AHP, Weighted MCGP, MINMAX MCGP and Gantt chart to develop a feasible annual audit plan. Compared with traditional approach, the proposed combined model incorporates a broader range of criteria and objectives. A more detailed and thorough study on audit planning at micro level is provided. The proposed planning framework is comprehensive and flexible, which shows great potential for project selection, resource allocation and scheduling. The main theoretical contributions are summarized as follows:

First, it expands the knowledge base in internal auditing. Internal audit planning is an important but under-researched area (Goman & Koch, 2019). By introducing a comprehensive multi-stage framework for risk-based internal audit plan and applying the framework to a real-life case, this thesis contributes to better understanding of a critical stage of the internal audit process and filling research gaps noted by Hazaea et al. (2021), Kotb et al. (2020), and Roussy and Perron (2018). The models, methods, and exemplification, which have been appropriately evaluated, improve the existing foundations in the internal audit knowledge. The exploration of the relationship between risk mitigation and audit time also contributes to the body of knowledge in risk assessment.

Second, this thesis applies extant knowledge in new and creative ways. The objective of the research is to address an important and relevant business problem by developing and implementing technology-based solutions. To the best of our knowledge, no researcher has been undertaken to solve internal audit problems using an integrated approach of FCE, AHP, and MCGP variants. The proposed framework not only allows DMs to consider quantitative and qualitative criteria but also assists DMs in setting objectives in the manner of “the more the better” for benefit-type criteria and “the lower the better” for cost-type criteria in internal audit planning problem. Furthermore, this study is also the first time to apply a new compromising method, fuzzy filtering ranking method, to employee suitability assessment.

Third, this study resolves heretofore unsolved problems. Compared with previous research on internal audit planning, which adopt prioritization and ranking method to select audit projects or only focus on a single goal of risk mitigation, this study enables simultaneous consideration of resource allocation and project selection to achieve multiple objectives for developing value-added audit plan. Moreover, a new risk model for manufacturing industry and a competency model of internal auditor are proposed that researchers can use for future studies. The models are based on the existing literature and their empirical validity are tested, aiming to overcome the theoretical and empirical limitations of the current models proposed by the IIA.

Fourth, it promotes interdisciplinary study in auditing. This research is an interdisciplinary study that combines internal auditing and operational research, providing the means to explore new directions in auditing research in an interdisciplinary context. The main advantage of the study is to apply simple and effective quantitative methods to assist organizations in planning and scheduling annual audit projects. By illustrating the implementation of OR techniques in practice through a real-world case, this study presents new insights on developing risk-based audit plan and for future auditing research.

5.2.2 Managerial implications

Planning is a classic decision-making problem in management. In risk-based internal audit planning, proper connection between risk assessment and audit planning has not been established and a recognized general model to select potential auditable areas methodologically has not been created. Filling these gaps can contribute to audit practice (Goman & Koch, 2021). While the thesis represents a case of annual audit planning in manufacturing sector, the implications of this study are not limited to the studied company because the proposed framework can also be applied to any organization for risk-based audit planning. Moreover, the proposed model is flexible and would be of great practical value for many other decision-making problems, especially for selection, allocation, and evaluation in various scenarios.

There is an urgent need for the IAF to be a qualified change agent of the organization by making solid audit plan that could connect with the pulse of the organization, rather than just being the organizational policeman and watchdog. The proposed integrated multi-stage framework involves every aspect of the audit planning work and presents a detailed implementation process for developing an effective risk-based internal audit plan. With the proposed framework, internal audit planning can be conducted in a justified, scientific, transparent, and systematic way, which enhances the reliability of internal audit activity. Starting from the creation of audit universe and risk universe, the risk level of auditable unit should be assessed at first according to the risk indicators, followed by the estimation of risk reduction value contributed by performing audit project within a certain range of audit time. Second, the most valuable audit project portfolios are selected and limited audit resource are allocated optimally according to the defined multiple objectives. Third, although project can be carried out more efficiently when assigning auditors to projects that they are familiar with, managers should also be aware that doing so could result in job burnout and a lack of employee development. A satisfied and motivated employee is normally more engaged and loyal and thus is more likely to make significant contributions to the organization. Therefore, auditor preference and auditor qualification should be balanced when assigning auditors to the selected projects. Fourth, a calendar can be generated according to the obtained selection results and allocation plan. Based on the above process, IAF can apply simple but useful OR tools to develop a feasible audit plan within a reasonable time.

This study also provides a reference for practitioners, the IIA, consulting firms, and audit software companies. Scarce resource should be planned sufficiently to ensure proper achievement of targets. In practice, project selection and auditor assignment are mostly carried out manually, which relies heavily on personal judgment, and oftentimes some valuable projects are neglected and the auditor expertise does not match the project characteristics very well. The research results show that the proposed model can support the CAE in developing annual audit plan according to department strategy. Which audit projects should be performed and how much effort should be devoted can vary from company to company due to different visions and strategies. With the assistance of the designed framework, audit planning team can not only avoid cumbersome manual work and excessive subjectivity, but also synthesize expert opinions, improve the accuracy of the audit scope and flexibility of the plan, and enable better auditor satisfaction. The proposed approach can also be applied to the detailed risk assessment and selection of audit samples from population when carrying out the individual audit project. It can also be used during fieldwork testing of an individual project where decision analysis is needed, such as evaluation of selected suppliers during the audit of supplier diversity program. As the thesis presents new insights on the value of audit plan (e.g., emphasize on value added audit plan instead of risky areas only) and identifies several factors contributing to elevate the risk assessment model and auditor competency model, it is also useful for the IIA and consulting firms to further improve guidelines associated with the risk-based audit planning. In addition, internal audit software company can also upgrade the relevant functions of the software to improve user satisfaction.

5.3 Research limitations and future research

5.3.1 Research limitations

Although the research questions are addressed and research objectives are achieved, there are some limitations in this study.

First, like other OR research, the resulting solution is always subject to the completeness of the model and the reasonableness of assumption in representing the real case. When applying the proposed framework to other organizations, modification to the model might be needed to improve its usefulness. The inclusion of additional criteria (e.g., risk items, auditor competency), objectives and constraints as well as the subtraction of some of them can be considered. In addition, in the proposed framework, the relationship between risk reduction and audit time is subjectively assessed as it is difficult to conduct empirical investigation.

Second, a major component of data in the study are purely dependent on subjective evaluations or estimation provided by DMs (e.g., risk indicator, audit time by different audit scopes, auditor expertise, and project characteristic). Only few data are available in the organization (e.g., nature of candidate projects), which can be considered as a limitation. Due to the cutting-edge mindset in audit activity and the involvement of required technology, the process is also more likely to be adopted by larger and more mature IAFs which pay attention to audit quality and desire to build a best-in-class audit team.

Third, another issue may arise is that the amount of effort for audit planning work tend to increase. If the population of candidate projects and the size of audit team are small, it might not be efficient to apply the proposed framework and managers can easily make decision based on experience. Moreover, without a user-friendly software of the proposed approach for entrance of the required data and the reporting of the results, a decision analyst might be needed. However, with repeated use of the model, the effort level can be reduced.

5.3.2 Future research

There are some suggestions regarding future directions of research related to this work. Future studies could apply the proposed framework to various types of organizations (e.g., state owned enterprise, private corporations, foreign invested company) in different countries and engage more practitioners and industry experts in the data collection. When working on AHP group decision making problems, other consensus models, such as Bayesian approach and Delphi technique can be applied to further extend the classical AHP method. When determining the membership degree using FCE method, other improved membership functions, such as linear membership functions (e.g., trapezoidal function and triangular function) and nonlinear functions can be selected. In future, nonlinear relationship between risk reduction value and audit time can be explored as well. When assigning the auditors to the selected projects, especially for a large audit project to be conducted by multiple auditors, researchers may also take additional element, such as preference over team members into consideration to maintain harmonious collaboration.

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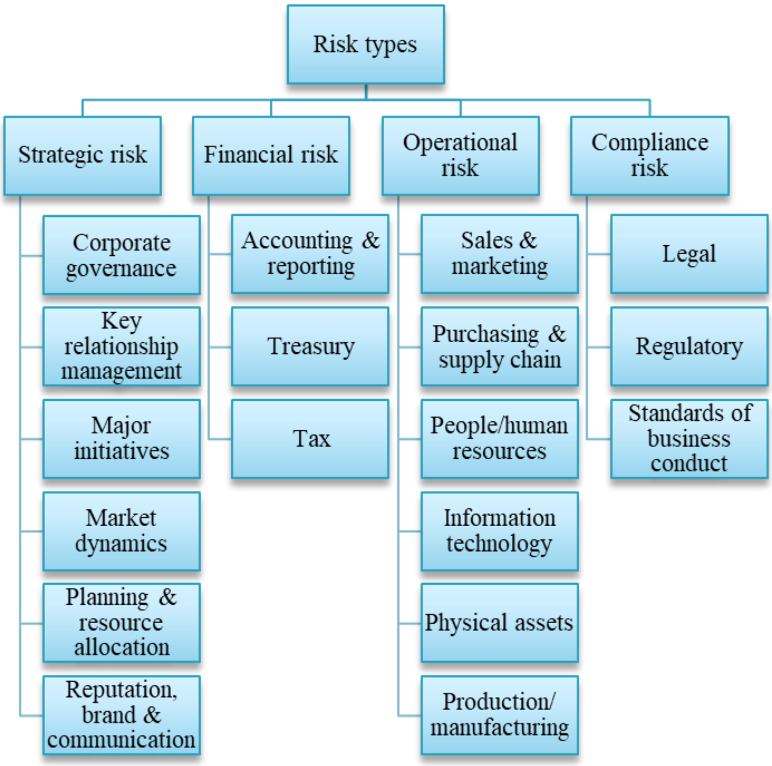
Appendix A: AHP Questionnaire

Dear Experts,

The purpose of this questionnaire is to determine the weights of the identified risk types in your enterprise. Please refer to the risk breakdown structure in the chart below.



For each pair of risks listed in the questionnaire, please conduct the pairwise comparison and select the relative importance degree based on your experience. Judgment scale of relative importance for pairwise comparison (Saaty's 1-9 scale) is explained as follows.

Numeric value	Verbal judgement
1	Both criteria are equally important
3	One criterion is moderately more important than the other
5	One criterion is strongly more important than the other
7	One criterion is very strongly more important than the other
9	One criterion is extremely more important than the other
2, 4, 6, 8	The intermediate level of adjacent judgments

Thank you very much for your support!

A. Main risk pairwise comparison

1.	Strategic risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial risk
2.	Strategic risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operational risk
3.	Strategic risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compliance risk
4.	Financial risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operational risk
5.	Financial risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compliance risk
6.	Operational risk	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compliance risk

B. Pairwise comparison of secondary risk under strategic risk

1.	Corporate governance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Key relationship management
2.	Corporate governance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Major initiatives
3.	Corporate governance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Market dynamics
4.	Corporate governance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Planning & resource allocation
5.	Corporate governance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation, brand & communication
6.	Key relationship management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Major initiatives
7.	Key relationship management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Market dynamics
8.	Key relationship management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Planning & resource allocation
9.	Key relationship management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation, brand & communication
10.	Major initiatives	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Market dynamics
11.	Major initiatives	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Planning & resource allocation
12.	Major initiatives	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation, brand & communication
13.	Market dynamics	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Planning & resource allocation
14.	Market dynamics	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation, brand & communication
15.	Planning & resource allocation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation, brand & communication

C. Pairwise comparison of secondary risk under financial risk

1.	Accounting & reporting	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Treasury
2.	Accounting & reporting	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Tax
3.	Treasury	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Tax

D. Pairwise comparison of secondary risk under operational risk

1.	Sales & marketing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Purchasing & supply chain
2.	Sales & marketing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	People/human resources
3.	Sales & marketing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Information technology
4.	Sales & marketing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical assets
5.	Sales & marketing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Production/manufacturing
6.	Purchasing & supply chain	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	People/human resources
7.	Purchasing & supply chain	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Information technology
8.	Purchasing & supply chain	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical assets
9.	Purchasing & supply chain	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Production/manufacturing
10.	People/human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Information technology
11.	People/human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical assets
12.	People/human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Production/manufacturing
13.	Information technology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical assets
14.	Information technology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Production/manufacturing
15.	Physical assets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Production/manufacturing

E. Pairwise comparison of secondary risk under compliance risk

1.	Legal	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Regulatory
2.	Legal	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Standards of business conduct
3.	Regulatory	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Standards of business conduct

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Appendix B: FCE Questionnaire

Dear Experts,

The purpose of this questionnaire is to determine the overall risk levels of the auditable units prior to conducting audit activities. For each listed auditable unit, please rate the risk level by detailed risk type (as shown on the risk breakdown structure in the previous questionnaire). The risk rating is provided as follows. Please use the drop-down menu and select corresponding risk rating based on your best estimation.

Scale	Description
Significant	Risk is totally intolerable and thus requires prompt action to address the risk.
High	Risk is unacceptable and should implement remediation plan as early as possible.
Medium	Risk may be acceptable in a short period of time but action to reduce risk is necessary.
Low	Risk is acceptable and the situation is not a concern but there are opportunities for further improvement or reduction of risk should be implemented in future.
Very low	Risk is slight or even negligible.

Thank you very much for your support!

#	Auditable Unit / Risk Type*	Strategic risk						Financial risk			Operational risk						Compliance risk		
		r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}	r_{21}	r_{22}	r_{23}	r_{31}	r_{32}	r_{33}	r_{34}	r_{35}	r_{36}	r_{41}	r_{42}	r_{43}
1	Manufacturing plant A																		
2	Manufacturing plant B																		
3	Manufacturing plant C																		
4	Manufacturing plant D																		
5	Manufacturing plant E																		
6	Manufacturing plant F																		
7	Manufacturing plant G																		
8	Manufacturing plant H																		
9	Manufacturing plant I																		
10	Manufacturing plant J																		
11	Manufacturing plant K																		
12	Manufacturing plant L																		
13	Sales office and lab A																		
14	Sales office and warehouse B																		
15	Sales office and warehouse C																		
16	Sales office and warehouse D																		
17	CA - travel and expense																		
18	CA - vendor payment																		
19	Capital project - Asia																		
20	Capital project - Europe																		
21	Capital project - Americas																		
22	Procurement strategy and supplier processes																		
23	New acquisition integration																		

24	IT cloud governance																		
25	Wide Area Network (WAN) redesign and implementation review																		
26	Entity restructuring																		
27	Vulnerability management																		
28	Factoring automation																		
29	Productivity validation																		
30	Contract management																		
31	Trade compliance																		
32	Master data set up and change process																		
33	Digitization																		
34	Manual JE process review																		
35	Product quality																		
36	Inventory processes and management																		
37	Records management																		
38	Working capital management																		
39	ERP Access / GRC																		
40	Crisis management																		
41	Tolling arrangement and processes																		
42	Reliability / Maintenance Process																		
43	Order fulfillment																		
44	BOM Management and operating permits																		
45	HR Processes																		

* Note: The specific name of the secondary risk is shown on the original questionnaire. Instead, a risk code is used here to represent respective risk name due to space limitation).

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Appendix C: Auditor Preference Questionnaire

Dear audit professionals,

Thank you for taking time to help us complete this academic questionnaire. The purpose of this questionnaire is to understand your preference over different internal audit projects. The numbers from 1 (not preferred) to 5 (preferred) indicate the degree of the preference. In the below table, please select the appropriate number for each project according to your own preference.

Thank you very much for your support!

#	Audit project	Degrees of preference				
		1	2	3	4	5
1	Manufacturing plant C					
2	Manufacturing plant D					
3	CA - travel and expense					
4	CA - vendor payment					
5	Capital project - Asia					
6	Procurement strategy and supplier processes					
7	New acquisition integration					
8	Entity restructuring					
9	Product quality					
10	Inventory processes and management					
11	Crisis management					
12	Reliability / Maintenance Process					
13	Order fulfillment					
14	WAN redesign and implementation review					
15	Vulnerability management					