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Risk-based internal audit planning in banking: A multi-period assignment model

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ABSTRACT

Risk-based internal audit planning has become increasingly important for banking institutions seeking to improve audit effectiveness and resource allocation. This study develops a deterministic mathematical model for risk-based internal auditor assignment in a large-scale banking network. The proposed framework models the assignment of 133 internal auditors with heterogeneous seniority and experience levels to 1,754 branches classified by risk level over a medium-term planning horizon of 20 periods. An efficiency function is incorporated into the objective function to evaluate each auditor-branch-period assignment. In addition to strengthening audit effectiveness and establishing a more systematic planning process, the model explicitly integrates fair workload distribution constraints alongside risk-based assignment requirements. Results from the real data application show that the baseline policy setting, where the minimum workload requirement is fixed at 5 periods, generates an efficient and balanced assignment schedule. Sensitivity analysis further indicates that RHS = 8 yields the highest objective value as an alternative scenario under the tested conditions. Overall, the findings suggest that combining risk prioritization with workload fairness can significantly improve the effectiveness, transparency, and consistency of internal audit planning in banking institutions.

1. Introduction

Banks are indispensable, building blocks of the economic system, and the importance attached to auditing activities has been maintained over the years. At this point, it can be argued that the banking sector requires effective auditing due to its inherently risky structure. Mishkin (2022) emphasizes that the banking sector constituted a fundamental component of the financial system and played a pivotal role in sustaining continuous economic growth. Similarly, in a study conducted by Saunders and Cornett (2014), it was stated that the inherently high levels of risk-taking by banks can have consequences that affect not only their own balance sheets but also the entire economic system. This perspective also explains why management and supervisory activities hold critical importance in the banking sector. Arens et al. (2017), in their study, assessed the compliance of banks' activities with legal regulations, international standards, and internal risk policies; they also contributed to the prevention of operational vulnerabilities, irregularities, and potential crisis factors. Ineffective internal auditing can increase systemic vulnerabilities. Another key contribution of their study is the emphasis on auditing as a critical function not only for regulatory compliance but also for safeguarding corporate sustainability. They further argue that audit activities enable the early detection of operational errors, irregularities, and risky practices, thereby contributing to the financial stability of banks.

In this context, one of the most critical factors for the success of audit activities is the process of assigning internal auditors to branches. An examination of current practices in the banking sector reveals that this assignment process is typically carried out at the discretion of a single decision-maker. However, in large-scale banks, such as Bank X, operating extensive branch networks, the planning of which branch is to be audited by which auditor and in which period directly affects the effectiveness of risk management and the overall quality of the audit process.

Inappropriate or delayed assignment decisions may lead to insufficient auditing of high-risk branches, thereby increasing the bank's exposure to operational and financial risks. For this reason, bank auditing and

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the detailed planning of audit activities require substantially greater attention and rigor compared to other assignment problems. However, there are insufficient studies in the literature addressing auditor assignment problems, and a clear gap remains with respect to adequately capturing the diverse dynamics introduced by risk. Moreover, existing studies on auditor assignment have predominantly focused on allocating externally sourced auditors to audit contracts, whereas in practice banks most commonly assign audits using their own internal auditors. Similarly, the existing literature reveals that the balance between internal auditor assignment and the consideration of fair workload distribution has not been adequately addressed in prior studies.

In response to this gap, the present study is based on the premise that the internal auditor assignment problem cannot be considered independently of constraints related to fair workload distribution. Accordingly, it aims not only to address the identified gaps in the existing literature but also to develop a systematic assignment mechanism for Bank X, where manual assignment practices are still employed despite the critical importance of effective audit planning. In the main implementation of the model, the minimum workload requirement is defined under the baseline policy setting (RHS = 5). The principal contributions of this study are summarized as follows: such as:

- The establishment of a structured risk-based compatibility and experience-matching framework that systematically aligns branch risk classifications with internal auditor's seniority levels within a multiperiod planning horizon,
- The development of a rigorously constructed efficiency maximizing scoring function that models the multiplicative interaction between internal auditor experience and branch criticality,
- The explicit integration of workload equity and regulated rest constraints through a sliding window formulation designed to preserve audit quality and organizational sustainability,
- The empirical validation of the proposed deterministic integer programming model through a large-scale-real world application comprising 1754 branches and 133 internal auditors,
- The robustness of the proposed model is further examined through sensitivity analysis using alternative RHS scenarios,
- The derivation of analytically grounded policy implications through systematic RHS sensitivity analysis, identifying parameter intervals that optimize the trade-off between operational efficiency and equitable workload distribution.

The remainder of this paper is organized as follows: Section 2 reviews the literature on internal auditor assignment, audit scheduling, and risk-based auditing in banking. Section 3 presents the proposed deterministic integer programming model, including the objective function and operational constraints. Section 4 reports the case study results under the baseline policy setting (RHS = 5), while Section 5 examines alternative RHS values through sensitivity analysis. Finally, Section 6 concludes the study with key findings, managerial implications, and future research directions.

2. Literature review

Classical assignment problems have attracted substantial attention in the literature since the 1950s and have generally focused on establishing one-to-one matching relationships between m tasks and n agents. While assignment problems have been applied across a wide range of domains, they have also been utilized in the context of assigning internal auditor. In this regard, one of the earliest studies in the literature was conducted by Summers (1972). Conducted within an audit firm, the study emphasizes the presence of both monetary and non-monetary benefits in auditing activities and proposes a utility structure that enables the joint measurement of these two types of benefits. Based on the developed composite utility coefficient Summers (1972) argues that the balance between public interest and economic benefit is more accurately reflected. The results of the study indicate that Internal Auditor 3 provides the highest overall contribution, while Activity 1 yields the greatest utility. Accordingly, the study concludes that Internal Auditor 3 should benefit more from promotion and compensation-related incentives and be assigned to a greater number of tasks.

Balachandran and Thompson (1975) developed an interactive decision support system for audit-staff scheduling by formulating the auditor–task assignment problem as a 0–1 generalized assignment model.

The proposed integer programming model minimizes total mismatch between auditor capability and task difficulty, while incorporating workload bounds and various policy constraints to ensure implementable schedules. Unlike earlier linear and goal programming approaches, the model prevents fractional or concurrent assignments and allows the inclusion of conditional staffing rules.

Subsequently, Gardner et al. (1990) conducted a multi-period, multi-objective assignment study within an independent audit firm, arguing that internal auditor assignment models should not be restricted to profit maximization alone, as multiple objectives better reflect real-world practice. They considered four-quarters with the final quarter as a high-demand season; six internal auditor levels and 40 audits and proposed using overtime during the peak period while shifting training activities to less intensive seasons. Within their multi-objective framework, they employed weight ranges to express the relative importance of each objective and identified clear trade-offs, showing in particular that maximizing profit led to the greatest deterioration in maximum job completion delay. By adopting a perspective distinct from Summers' profit-focused model, they contributed to the literature by clarifying which objective must be sacrificed most when optimizing a given goal.

Lee and Jeong (1995) formulated the auditor assignment problem as a multi-agent, multi-objective decision process integrating firm profitability, audit risk, and individual auditor preferences with firm profit maximized through a linear programming objective function. They developed an Intelligent Audit Planning System (IAPS) that combined a profit-maximizing linear programming model with a rule-based audit risk evaluation through a Post-Model Analysis (PMA) framework. When conflicts between profitability and audit risk emerged, rule-based goals were transformed into additional linear constraints, and the model was iteratively re-optimized. An intelligent coordinating agent further supported negotiation among auditors to accommodate individual preferences and resolve conflicts within the assignment process.

In subsequent years, the scheduling plan developed by Dodin and Elimam (1997) involving four internal auditors, two audit contracts, and a 12-week planning horizon took its place in the literature. Contrary to most existing approaches, the authors argued that the initiation of an activity does not necessarily require the completion of all its predecessors. In addition, they introduced a setup cost parameter by incorporating the travel time incurred when switching between different contracts into the cost structure. The proposed model consisted of two scenarios. In the first scenario, an environment with no setup cost and no allowance for task overlap is considered, whereas in the second scenario, setup costs are incorporated and overlapping activities are permitted. As a result of their study, Dodin and Elimam (1997) demonstrated that the second scenario outperformed the first and for medium and large-scale organizations, the second scenario constitutes a low-cost solution approach that can be obtained within a relatively short computational time. Specifically, when task overlap was allowed within the model, fewer transitions between contracts were required, delays were reduced, and a lower overall scheduling cost was achieved. In this respect, the study offered an alternative perspective by challenging the traditional assumption that activity overlap is inherently undesirable, thereby proposing a more effective approach to minimizing total costs.

Dodin et al. (1998) addressed the scheduling problem of an audit firm by employing a tabu search-based metaheuristic approach. In the initial phase of the study, a feasible schedule satisfying the model's capacity and precedence constraints was generated; in subsequent phases, this schedule was iteratively improved using the tabu search algorithm, yielding performance gains ranging from 10% to 40% compared to the initial feasible solution.

In their study Chan et al. (1998) developed a multinational and multilocation internal auditor assignment model, in which cost components such as travel expenses and per diem allowances were explicitly incorporated into the objective function. By emphasizing that most existing studies in the literature are confined to single country settings, they adopted a different perspective and addressed a more complex multinational assignment problem by conducting their analysis within the context of an international internal audit firm. Particular emphasis was placed on travel costs through the introduction of a travel cost limit for each audit, and travel costs were further modeled as sequence-dependent setup costs. In this respect, the study has been recognized as a distinctive contribution that extends the scope of internal auditor assignment models to multinational environments.

Brucker and Schumacher (1999) formulated an integrated auditor assignment and scheduling problem under time-window constraints, precedence relations, and lower and upper workload bounds. The objective function minimized mismatching costs and weighted job tardiness while incorporating penalty terms for workload violations and overtime beyond regular availability periods. Acknowledging the strong NP-hardness of the problem, they proposed a two-stage tabu search framework that separated assignment decisions from sequencing improvements guided by critical-block structures. Their computational results showed that the approach was capable of producing feasible and high-quality schedules across different instance sizes.

Rossi et al. (2010) assumed the existence of an internal audit team and restrict team members from being assigned to multiple audits simultaneously. Unlike previous studies, they further assumed that under uncertainty and in the presence of multiple auditable units, the monetary loss associated with each unit increased over time if audits were postponed. The objective of their model was to minimize both fixed auditing costs and the losses incurred due to audit delays. The initial constraints of the model were formulated using stochastic programming; subsequently, the model was further developed through mixed integer linear programming and constraint programming techniques. The results showed that mixed-integer linear programming yielded superior performance when the assignment horizon was short, whereas constraint programming provided more computationally efficient solutions as the horizon length increased.

Uyar and Yelgen (2015) developed a linear programming–based task planning model for audit firms to minimize labor costs under structured activity and workload constraints. The model assigned auditors with different hierarchical statuses to nine audit activities while incorporating hourly wage differentials, minimum total working time, and activity-specific time requirements. Formulated as a cost minimization problem with 36 decision variables and 48 constraints, the empirical results demonstrated that optimal auditor allocation significantly reduced total audit cost while satisfying operational constraints, highlighting the applicability of linear programming techniques in structured audit workforce planning contexts.

Karaoz (2016) developed an internal auditor assignment within a framework comprising 80 branches operating in Turkiye and five internal auditors. The branches were divided into two distinct classes based on their location and size. Specifically, branches located in the same city as the bank's head office or situated near high-traffic areas such as shopping malls were categorized as more critical, and it was argued that auditing these branches is of greater importance. The study aimed to maximize the objective function by constructing an impact value for each branch and determining interior auditor–branch assignments accordingly.

In their study, Canakoglu et al. (2018) assumed that internal audits would be conducted by teams and, unlike most internal auditor assignments in the literature that are formulated on an annual basis, proposed a six-month internal auditor assignment horizon and developed the corresponding internal audit plan accordingly. In their work, which aimed to maximize the number of audited branches, they argued that the internal auditors assigned to a branch must possess at least the minimum level of audit competency required by that branch.

In addition to the mathematical model, they developed two heuristic solution approaches to address the increase in problem size as the number of auditors and branches grew. The results demonstrated that these heuristics yielded higher-quality solutions within shorter computational times for large-scale problem instances.

Yildirim et al. (2018) developed the internal audit scheduling problem as a time indexed Mixed Integer Linear Programming model in the context of management system standards. The objective function minimizes the overall project make-span subject to precedence, resource, and auditor-specific constraints. The proposed MILP model was implemented and solved to optimality using CPLEX, demonstrating its practical applicability to real-world audit scheduling instances

Motl and Kordík (2021) argued that each internal auditor should be assigned exclusively to a single audit until its completion, noting that deviations from this principle had led to inefficiencies in prior practices. They further emphasized that an audit engagement may require multiple internal auditors at the same competency level and accordingly formulated an objective function composed of various cost components to be minimized. The results demonstrated that the proposed method outperformed the manually constructed baseline schedule. Specifically, the schedule preparation time was reduced from 3 days to 45 min, and the number of internal auditors required for staffing decreased from three to two.

Wang et al. (2022) developed a multi-objective, competency-based scheduling and staff assignment model for internal audit projects that jointly minimized project delay and maximized auditor competency development. The framework combined a work breakdown structure, a weighted auditor–task compatibility matrix, a log-linear learning curve to capture competency evolution, CPM/PERT-based network planning, and a multi-choice goal programming formulation to balance conflicting objectives under precedence and workload constraints. A real case application demonstrated that the model achieved on-time completion while improving cumulative auditor competencies, thereby extending the audit scheduling literature by explicitly incorporating learning-driven human capital development into the optimization process.

Wang et al. (2024) conducted their analysis within the internal audit unit of a manufacturing firm. Their two-stage approach began with the computation of an auditor–project compatibility index, followed by a second stage in which auditor assignments were determined based on the calculated compatibility scores and individual auditor preferences. The proposed model explicitly incorporated auditor–project compatibility and, unlike most existing studies, also considered auditor-specific preferences such as willingness to travel. The results showed that the proposed assignment framework generated more balanced and fair outcomes with higher compatibility levels compared to manually prepared schedules.

A review of the literature reveals that prior studies predominantly focus either on cost minimization or on maximizing the number of assigned internal auditors. However, the view that these models do not fully align with today's realistic auditing perspective becomes prominent at this point. Moreover, most studies in the literature are built around the assignment of internal auditors in independent audit firms to audit contracts, which naturally results in a primary objective focused on maximizing the number of assigned internal auditors. Studies that focus on assigning a bank's own internal auditors to its own branches within a single banking institution remain limited. Given that, in such assignment problems, the objective entails a broader mission than merely maximizing the number of assigned internal auditors, it becomes evident that the existing literature does not sufficiently reflect real-world auditing practices in this respect, thereby revealing a clear research gap.

At the same time, the number of studies in the literature that explicitly consider fair workload distribution among assigned internal auditors remains very limited. However, the fact that audit performance is a holistic outcome and that internal auditor motivation constitutes a major component of this performance has largely been overlooked. Similarly, the fact that large-scale banks are exposed to higher levels of risk and, correspondingly, to greater potential losses has largely been overlooked, and the scarcity of specialized modeling studies addressing this issue further accentuates this limitation. In response to these gaps in the literature, the present study proposes a risk-based assignment model that maximizes the efficiency generated by auditor–branch matching while explicitly incorporating fair workload distribution among internal auditors.

3. Proposed methodology

The fundamental premise of this study is that internal auditor assignment in banking should not be treated as a homogeneous assignment problem, as bank branches exhibit heterogeneous risk levels and internal auditors possess differing levels of experience. Accordingly, the core objective of the proposed methodology is to enable risk-based assignments by ensuring that high-risk branches are inspected by more experienced internal auditors, while lower risk branches are allocated to less experienced internal auditors. The problem is formulated over a multiperiod planning horizon for Bank X, where auditor–branch–period assignments are determined by jointly considering branch risk profiles and internal auditor experience levels.

In addition to risk-based matching, the proposed methodology explicitly incorporates fairness considerations among internal auditors by integrating workload balancing constraints into the model. The assignment problem is formulated as a deterministic integer linear programming model with the objective of maximizing overall assignment efficiency, defined as a function of branch risk levels and internal auditor experience. The constraint set ensures compliance with risk-based eligibility requirements, internal auditor capacity limits, and equitable workload distribution. Through this integrated formulation, the proposed model provides a systematic and transparent decision support mechanism that replaces manual assignment practices and reflects the practical requirements of risk-based internal auditor assignment.

3.1. Sets and indices

K: Index of internal auditors k = 1.,133
J: Index of branches j = 1.,1754
T: Index of periods $t = 1.,20$

3.2. Parameters

$$y_k : Experience\ (inyears)\ of\ internal\ auditor\ k$$

$$risk_j : \begin{cases} 1, if\ branch\ jis\ classified\ as\ high\ risk \\ 0, otherwise \end{cases}$$

$$d_j : Audit\ duration\ of\ branch\ j(in\ days)$$

$$y_k \geq 2 \rightarrow S_k : \begin{cases} 1, experienced\ internal\ auditor \\ 0, inexperienced\ internal\ auditor \end{cases}$$

$$V_{kj} : Productivity\ coefficient\ of\ internal\ auditor\ k\ when\ assigned\ to\ branch\ j$$

H: Minimum number of periods assigned to internal auditor k over the planning horizon (baseline setting: H = 5

3.3. Decision variables

$$X_{kjt} : \begin{cases} 1, if\ internal\ auditor\ k\ is\ assigned\ to\ branch\ jin\ period\ t \\ 0, otherwise \end{cases}$$

$$Z_{jt} : \begin{cases} 1, if\ branch\ jis\ audited\ in\ period\ t \\ 0, otherwise \end{cases}$$

3.4. Objective function

$$max \sum_{k \in K} \sum_{j \in J} \sum_{t \in T} V_{kj} X_{kjt} \tag{1}$$

3.5. Subject to

$$V_{kj} = \frac{(1 + y_k)(1 + risk_j)}{d_j} \tag{2}$$

$$\sum_{j \in J} X_{kjt} \leq 1 \forall k, \forall t \tag{3}$$

$$\sum_{t \in T} Z_{jt} = 1 \forall j \tag{4}$$

$$\sum_{k \in K} X_{kjt} = Z_{jt} \forall j, \forall t \tag{5}$$

$$X_{kjt} \leq 1 - risk_j(1 - S_k)\ \forall k, \forall j, \forall t \tag{6}$$

$$\sum\nolimits_{t\in T}\sum\nolimits_{j\in J}X_{kjt}\geq H\forall k \tag{7}$$

$$\sum\nolimits_{t=t}^{t+3}\sum\nolimits_{j\in J}X_{kj\,t}\leq 3\forall k \tag{8}$$

$$X_{kjt},Z_{jt}\in\{0,1\} \tag{9}$$

The efficiency formulation is defined in Equation (2). The efficiency formulation was constructed based on expert judgment obtained from senior internal audit managers. During model development, structured consultations were conducted to determine how internal auditor's experience and branch risk should interact within the assignment mechanism. Experts emphasized that productivity increases jointly with internal auditor's experience and branch criticality; therefore, a multiplicative structure was adopted to reflect this interaction effect. The addition of the constant term (+1) was also recommended from experts, to ensure that neither low-risk branches nor less experienced internal auditors would generate zero productivity values. This scaling approach guarantees strict positivity, preserves proportional differences, and prevents distortions in the objective function. Thus, the proposed efficiency formulation ensures that all parameters contribute to the computed efficiency value. The objective function of the model, given in Equation (1), aims to maximize the total efficiency obtained from all auditor–branch–period assignments. Constraint (3) ensures that an internal auditor is assigned to at most one branch in each period. Constraint (4) guarantees that each branch is inspected exactly once within the five year (20-period) planning horizon. Constraint (5) ensures that an internal auditor is assigned to a branch if and only if that branch is inspected; otherwise, no internal auditor assignment is allowed. Constraint (6) guarantees that only senior internal auditors are assigned to high-risk branches ($risk_j = 1, S_k = 1$). Constraint (7) ensures that each internal auditor is assigned in at least a minimum number of periods over the planning horizon, represented by parameter H. In the baseline policy setting, H is set to 5. Finally, Constraint (8) imposes a sliding-window workload regulation by ensuring that, within any four consecutive periods, an internal auditor can be assigned in at most three periods. This guarantees at least one rest period in every four-period window. In other words, Constraint (8) is formulated as a sliding window workload regulation. Specifically, in any four consecutive periods, an internal auditor may be assigned to inspections in at most three periods. This guarantees that at least one period within every four-period window remains free, allowing time for reporting, training, and recovery activities, thereby preserving audit quality.

Constraints (7) and (8) are designed to ensure a fair distribution of workload among internal auditors. In real-world practice, it is not efficient for an internal auditors to be continuously engaged in branch inspections, as breaks are required for activities such as rest, reporting, and training. Therefore, constraint (8) aims to maintain the quality of the inspection process by ensuring that internal auditors have a "scheduled break" period between internal auditor assignments.

4. Case study

The proposed deterministic integer linear programming model was applied to a real-world case study conducted at Bank X, a large commercial bank operating in Turkiye with 1,754 branches and 133 internal auditors. The planning horizon was divided into 20 discrete periods, consistent with the bank's inspection policy. All case study results reported in this section are based on the baseline policy setting, where the minimum workload requirement parameter in Constraint (7) is fixed at 5 (RHS = 5). In the case study, branch-level risk classifications, internal audit durations, and auditor experience levels were used as model inputs.

The developed mathematical model was solved using IBM ILOG CPLEX Optimization Studio. The period-based assignment results are presented in Table 1, and the objective function value obtained under the baseline policy setting (RHS = 5) is 482.84. The total number of assignments equals 1,754, which is fully consistent with Constraint (4), since each branch is required to be inspected exactly once over the 20-period planning horizon.

Table 2 provides clear evidence regarding the fairness of workload distribution among internal auditors. As observed, all 133 auditors are assigned to inspection activities, with the number of inspected branches per auditor ranging from 5 to 15. Notably, no auditor is assigned an excessively

Table 1. Period-based assignment results.

Period	Number of Assignments	Period	Number of Assignments
1	105	**11**	85
2	96	**12**	95
3	97	**13**	63
4	49	**14**	90
5	87	**15**	97
6	91	**16**	100
7	86	**17**	52
8	79	**18**	93
9	79	**19**	103
10	87	**20**	120
		Total	**1754**

Table 2. Number of branches inspected per auditor.

Number of internal auditors	Number of inspected branches
18	5
2	6
1	10
2	11
1	12
7	13
13	14
89	15
Total: 133	

low or disproportionately high number of inspections. The majority of internal auditors (89 out of 133) are assigned to inspect 15 branches, while the remaining internal auditors are distributed across nearby workload levels, indicating a balanced and equitable allocation of inspection tasks. Because the model enforces at least one break within every four consecutive periods, the maximum feasible number of inspection periods over a 20-period horizon is structurally limited to 15. The concentration of most auditors around 15 assignments in the solution therefore reflects the intended effect of Constraint (8), rather than a coincidental outcome. Hence, the assignment patterns observed in the results validate the effectiveness of the proposed sliding window workload constraint, confirming that the model simultaneously maintains high productivity levels and safeguards audit quality through enforced rest intervals.

One of the key objectives addressed by the developed mathematical model is to examine whether qualified internal auditors are assigned to high-risk branches; accordingly, Table 3 has been constructed for this purpose.

Table 3 indicates that Constraint (6) is satisfied by the model, as high-risk branches are consistently assigned to the most experienced internal auditors (9–10 years of seniority). In the early periods, the model generates a relatively high number of high-risk inspections; however, the distribution of assignments across periods is shaped by the combined effect of the workload regulation in Constraint (8) and the exact-once inspection requirement in Constraint (4). Similarly, the absence of high-risk branch inspections in the first quarter of 2030 reflects the inter-period scheduling structure imposed by the model, followed by a recovery in the remaining periods to satisfy the planning horizon requirements.

As a result, it is observed that all 74 high-risk branches were inspected by qualified internal auditors. To enable a clearer analysis of the model's assignment decisions, the annual assignment results generated by the model and the number of high-risk branch inspections are presented in Table 4. To enable a clearer analysis of the model's assignment decisions, annual assignment results, and the annual number of high-risk branch inspections are presented in Table 4 under the baseline policy setting (RHS = 5).

As shown in Table 4, despite period-based fluctuations in the number of inspected branches reported in Table 1, the model exhibits interannual stability in total inspections under the baseline policy setting. Moreover, as presented in Table 4, the annual number of inspected high-risk branches ranges between 14 and 15, indicating a stable pattern and reinforcing the model's interannual consistency.

Table 3. Assignment of senior internal auditors to high-risk branches in 2026.

Year	2026	2026	2026	2026
Quarter	Q1	Q2	Q3	Q4
Number of Inspected High-Risk Branches	5	5	4	1
Experience Level of Assigned Internal Auditors (Years)	9,10,9,9,10	9,10,9,9,10	10,9,9,10	9
Year	2027	2027	2027	2027
Quarter	Q1	Q2	Q3	Q4
Number of Inspected High-Risk Branches	4	3	4	3
Experience Level of Assigned Internal Auditors (Years)	9,10,9,10	9,10,9	10,9,9,10	9,9,10
Year	2028	2028	2028	2028
Quarter	Q1	Q2	Q3	Q4
Number of Inspected High-Risk Branches	3	3	5	4
Experience Level of Assigned Internal Auditors (Years)	9,10,10	10,9,9	9,10,9,9,10	9,9,9,10
Year	2029	2029	2029	2029
Quarter	Q1	Q2	Q3	Q4
Number of Inspected High-Risk Branches	1	4	5	5
Experience Level of Assigned Internal Auditors (Years)	10	9,10,9,9	9,10,9,9,10	9,10,9,9,10
Year	2030	2030	2030	2030
Quarter	Q1	Q2	Q3	Q4
Number of Inspected High-Risk Branches	0	5	5	5
Experience Level of Assigned Internal Auditors (Years)	–	9,10,9,9,10	9,10,9,9,10	9,10,9,9,10

Table 4. Annual inspection results under the baseline policy setting (RHS = 5).

	2026	2027	2028	2029	2030	Total
Total Number of Inspected Branches	347	343	346	350	368	1754
Total Number of Inspected High Risk Branches	15	14	15	15	15	74

5. Sensitivity analysis

Sensitivity analyses were conducted to evaluate the robustness of the proposed model and to examine the impact of the minimum workload requirement imposed by Constraint (7). Since the right-hand side (RHS) value of Constraint (7) is assumption based, the model was re solved in IBM ILOG CPLEX Optimization Studio by varying the RHS value from 1 to 20 over the 20 period planning horizon. The resulting solutions were then analyzed in terms of objective function performance, temporal assignment stability, and workload consistency across periods.

To first assess the local behavior of the model around the baseline scenario, separate assignment schedules were generated for RHS values within plus or minus two units of the baseline value (RHS = 5). Figure 1 presents the period-based branch assignments for RHS values of 3, 4, 5, 6, and 7.

As shown in Figure 1, the assignment patterns across periods remain broadly similar under ±2 RHS variations, indicating that the model preserves its overall scheduling structure around the baseline scenario. However, noticeable differences emerge in several periods, particularly in low assignment periods, where the RHS parameter has a stronger effect on the number of assigned branches. This result suggests that the baseline solution is relatively stable, while still being sensitive to parameter changes in constrained periods.

To complement this comparison, Figure 2 presents the deviations of period-based branch assignments from the baseline scenario (RHS = 5). This figure makes it easier to identify periods in which the model is relatively stable and periods in which small RHS changes produce larger scheduling differences. The deviation patterns confirm that the baseline solution is robust in most periods, while a limited number of constrained periods exhibit stronger sensitivity.

In addition to the baseline-centered analysis, the global effect of the RHS parameter on solution quality was evaluated across the full RHS range from 1 to 20. Figure 3 shows the variation in the objective function value with respect to the RHS value. As shown in Figure 3, the objective function reaches its maximum at RHS = 8 (486.05) and then begins to decline. This result indicates that increasing the minimum workload requirement up to a certain level improves overall assignment efficiency but further increases force the model to use less efficient auditor branch pairings. After RHS = 13, the objective function remains constant up to RHS = 20, indicating a saturation region in which additional increases in the minimum workload requirement no longer change the feasible assignment structure.

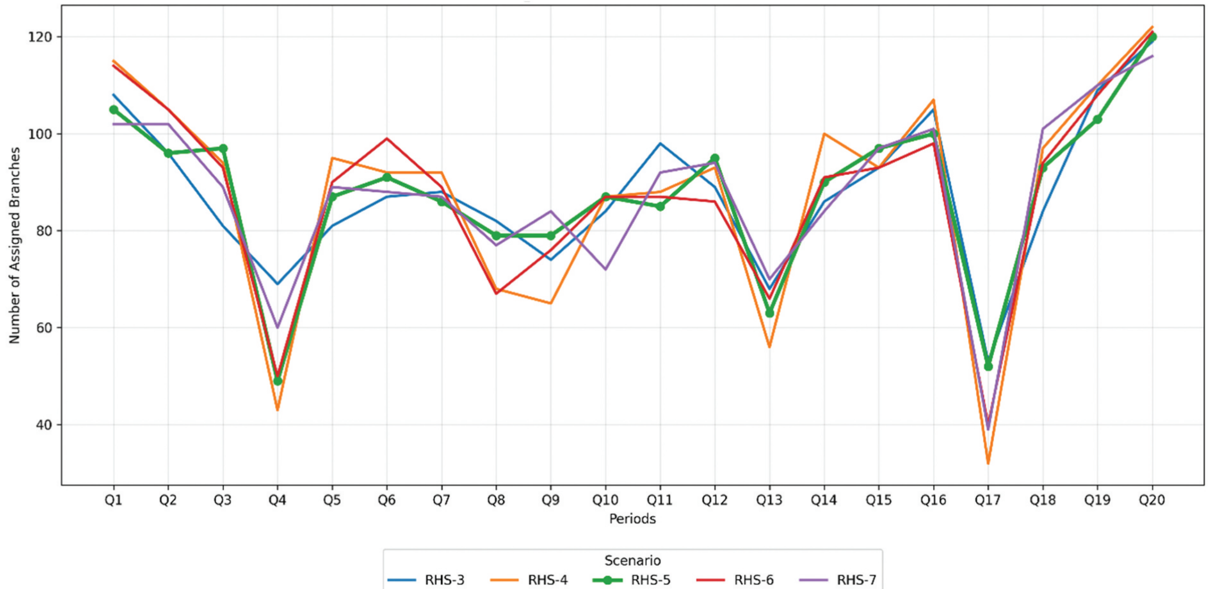

Figure 1. Period based distribution of branch assignments for RHS values within ±2 of the baseline.

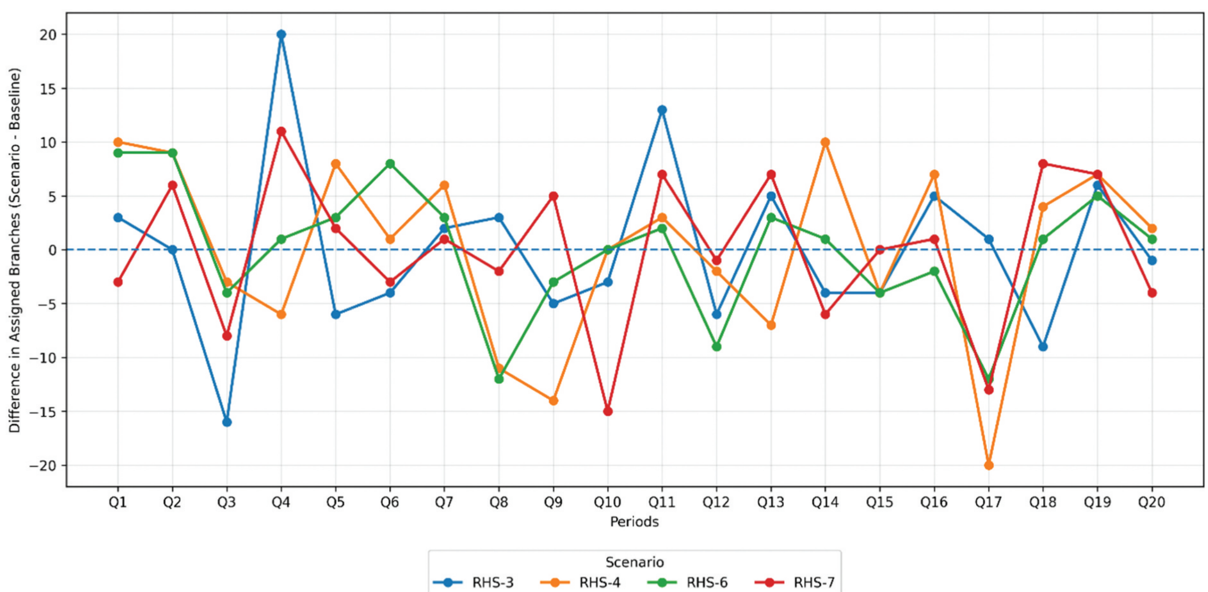

Figure 2. Deviations from baseline branch assignment across periods.

To evaluate the temporal stability more explicitly, Figure 4 reports the interperiod fluctuation metric across RHS values. The temporal fluctuation metric is defined as the average absolute interperiod change in the number of assigned branches, where lower values indicate smoother and more stable assignment schedules across consecutive periods. Let A_t denote the total number of assigned branches in period t. The fluctuation metric is computed as the average absolute inter-period change.

$$\text{TFM} = \frac{1}{19}\sum_{t=2}^{20} |A_t - A_{t-1}| \tag{10}$$

As shown in Figure 4, fluctuation levels remain relatively close across the tested RHS values, indicating that changes in the minimum workload requirement do not materially disrupt the temporal smoothness of the assignment schedule. This analysis provides an additional managerial perspective by quantifying schedule smoothness rather than relying only on the objective function value.

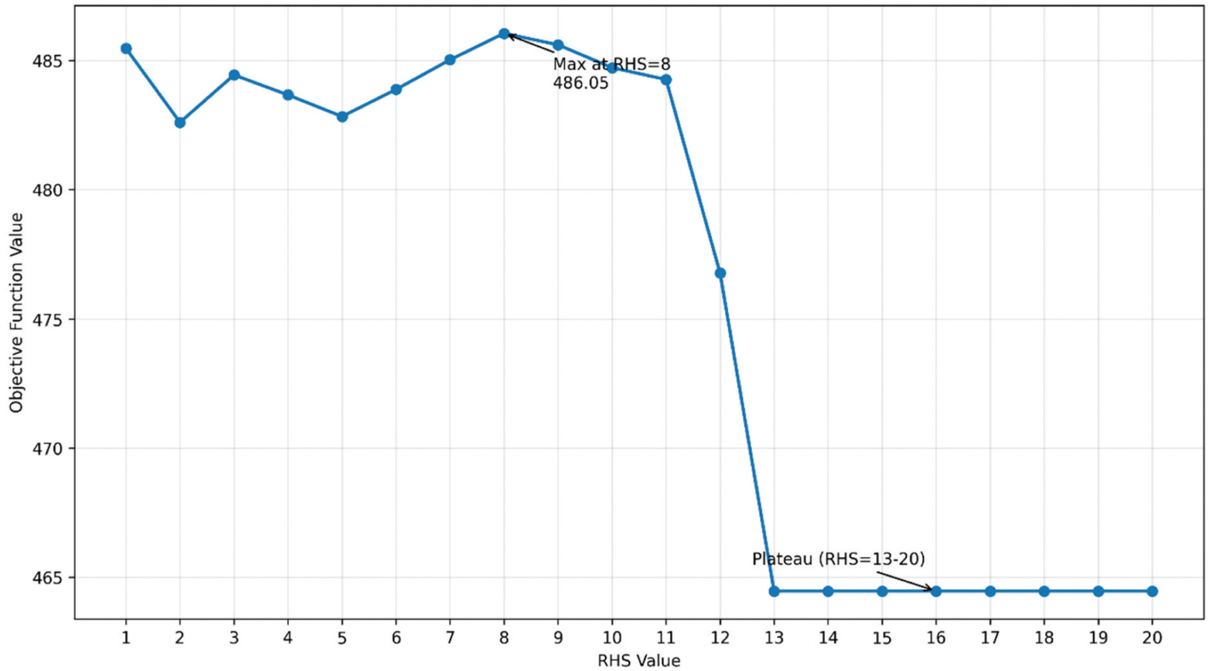

Figure 3. Objective function value by RHS.

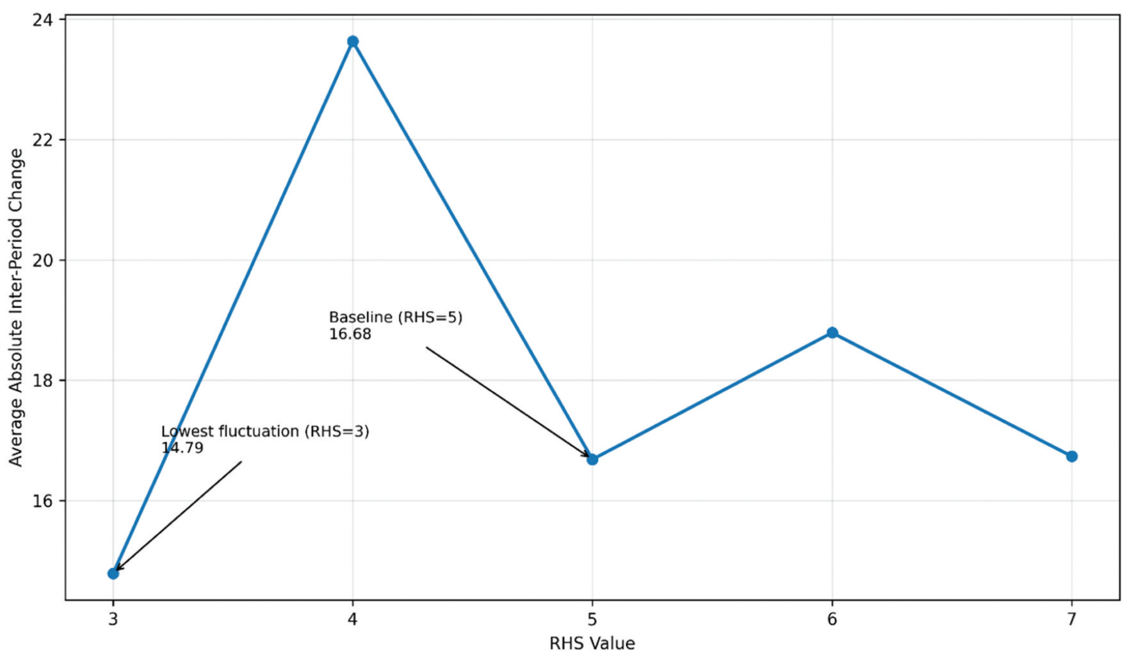

Figure 4. Inter-period fluctuation metrics by RHS.

Based on the combined evidence from Figures 1 to 4, RHS = 8 can be interpreted as the best-performing alternative scenario in terms of objective function value. However, the baseline parameter setting (RHS = 5) is retained in the main case study results to ensure consistency with the managerial policy assumption and the case study framework. To illustrate the behavior of the model under this alternative setting, Table 5 presents the detailed period-based results for the RHS = 8 sensitivity scenario, including total branch assignments, high-risk branch assignments, and the corresponding high-risk share.

As shown in Table 5, the model assigns a total of 1,754 branches over the planning horizon, of which 74 are high-risk branches, corresponding to an overall high-risk share of 4.2%. The temporal pattern remains

Table 5. Period-based total and high-risk branch assignments for RHS = 8.

Period	Year-Quarter	Total Branch Assignments	High-Risk Branch Assignments	High-Risk Share (%)
1	2026-Q1	106	4	3.8
2	2026-Q2	101	4	4
3	2026-Q3	81	4	4.9
4	2026-Q4	62	3	4.8
5	2027-Q1	72	3	4.2
6	2027-Q2	92	4	4.3
7	2027-Q3	94	5	5.3
8	2027-Q4	80	3	3.8
9	2028-Q1	70	3	4.3
10	2028-Q2	88	4	4.5
11	2028-Q3	95	4	4.2
12	2028-Q4	95	4	4.2
13	2029-Q1	57	3	5.3
14	2029-Q2	91	3	3.3
15	2029-Q3	103	5	4.9
16	2029-Q4	105	4	3.8
17	2030-Q1	40	1	2.5
18	2030-Q2	100	4	4
19	2030-Q3	104	5	4.8
20	2030-Q4	118	4	3.4
Total		**1754**	**74**	**4.2**

consistent with the operational structure observed in the baseline scenario. In particular, a noticeable decline is observed in Period 17, followed by a recovery in the subsequent periods. This pattern is consistent with the interperiod workload regulation and feasibility conditions embedded in the model. Therefore, the RHS = 8 sensitivity scenario remains compatible with the workload balancing and rest period structure defined by the constraints.

Figure 5 further visualizes the RHS = 8 solution by presenting the total number of assigned branches and the number of high-risk branch assignments across all periods. Although the baseline RHS = 5 already yields a stable schedule, RHS = 8 provides a higher objective value without materially degrading temporal smoothness.

Figure 5 shows that high-risk branch assignments remain relatively stable across periods, while total assignments exhibit controlled fluctuations driven by feasibility conditions and interperiod workload constraints. Together, Table 5 and Figure 5 demonstrates that the RHS = 8 sensitivity scenario provides a strong balance between efficiency, temporal stability, and risk-based inspection coverage.

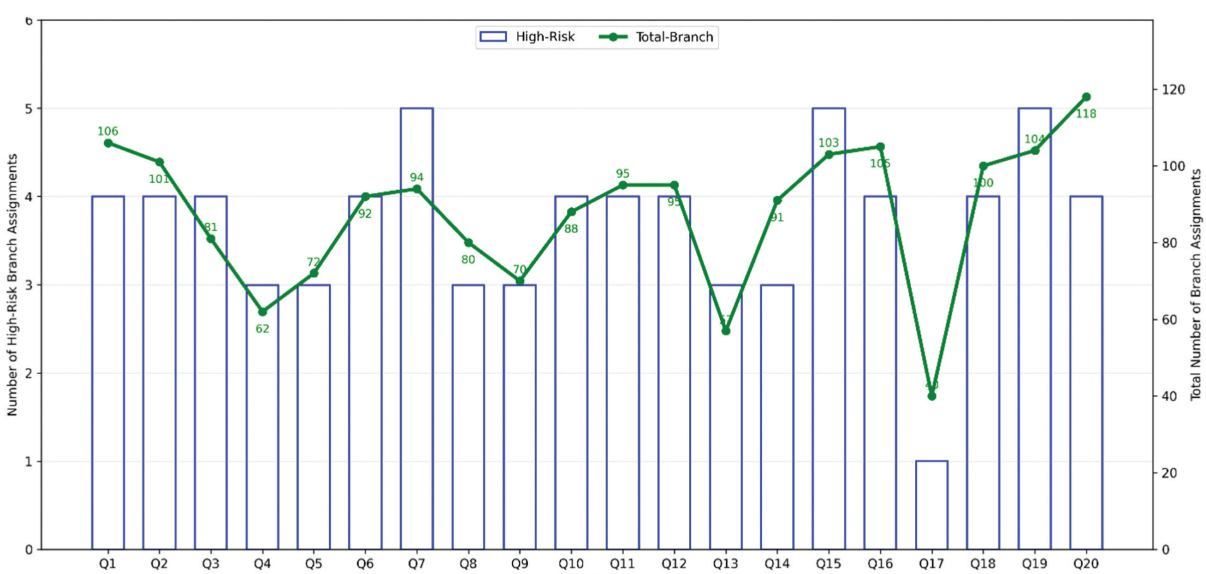

Figure 5. RHS = 8 total vs high-risk branch assignments by period.

Although the sensitivity analysis shows that the objective function reaches its maximum at RHS = 8, the final model specification in this study is retained at RHS = 5. This choice is intentional and is made to preserve consistency with the baseline policy assumption introduced in the mathematical model and used throughout the case study analyses. In other words, RHS = 5 represents the managerial minimum workload requirement adopted by the bank, whereas RHS = 8 is reported as a comparative sensitivity scenario that improves the objective value under the tested conditions. Therefore, the sensitivity analysis is used here to evaluate model behavior and robustness under alternative RHS settings, rather than to replace the baseline parameters used in the main implementation.

6. Conclusion

This study proposes a deterministic integer linear programming model for the risk-based assignment of internal auditors within a multi-period planning horizon. The model integrates internal auditor experience, branch risk classification, and audit duration into a unified productivity-based objective function, while simultaneously incorporating practical operational constraints such as mandatory branch coverage, minimum workload requirements, eligibility restrictions for high-risk branches, and rest-period regulations.

The case study conducted at Bank X, consisting of 1,754 branches and 133 internal auditors over 20 periods, demonstrates the practical applicability of the proposed model. Under the baseline policy setting (RHS = 5) used in the main implementation, the results show that all internal auditors are actively utilized, high-risk branches are consistently assigned to qualified auditors, and workload distribution is maintained within a balanced range. Period-level fluctuations observed in certain intervals are structurally driven by the inter-period workload regulation rather than model instability. In addition, the period-based planning structure provides operational flexibility by allowing internal auditors to determine the specific timing of inspections within each quarter, which is expected to support time management for reporting, training, and administrative tasks.

The sensitivity analysis on the RHS value of Constraint (7) indicates that the model preserves a stable assignment structure when the parameter is varied across alternative settings. The highest objective function value is obtained at RHS = 8, which should be interpreted as the best-performing alternative sensitivity scenario under the tested conditions, rather than as a replacement for the baseline policy setting. After a certain point, further increases in the RHS value no longer affect the results significantly, indicating a saturation region shaped by the structural limits of the assignment framework. These findings reinforce the robustness and reliability of the proposed model.

Overall, the proposed model provides a systematic and data-driven decision support tool for internal auditor assignment. By simultaneously ensuring fairness, risk prioritization, and operational feasibility, the model contributes to both the assignment optimization literature and practical risk-based internal audit management in large-scale banking institutions.

A further point to note is that the proposed model is developed under several simplifying assumptions. In particular, the model is deterministic, branch risk classifications and audit durations are assumed to remain fixed over the planning horizon, and travel time or travel cost considerations are not explicitly incorporated into the assignment structure. In addition, the empirical validation is based on a single large-scale banking case, which supports practical relevance but may limit direct generalization to other institutional contexts without adaptation. These limitations do not reduce the value of the proposed framework, but they indicate important directions for model extension.

Future research may extend the proposed framework in several directions. First, stochastic or robust optimization versions can be developed to account for uncertainty in audit duration, branch risk evolution, and operational disruptions. Second, a multiobjective formulation can be considered to jointly optimize assignment efficiency, workload fairness, and travel-related costs. Third, internal auditor preferences, specialization profiles, and branch-specific competency requirements can be integrated into the decision structure to improve practical realism. Finally, comparative applications across different banks or financial institutions may help evaluate the transferability and scalability of the proposed model under different regulatory and operational settings.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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