# What is the most optimal allocation of bankers in a bank's branch network?

University of Melbourne
MAST90014 Optimisation for Industry

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## Abstract

In this project, we demonstrate the application of linear programming with Gurobi for the purpose of optimization in the banking industry. In our effort to simulate the problem, we utilized as much real-world data available to us and generated additional data based on statistics.

We developed a model that would output the optimal allocation of bankers in a network of branches in Victoria, as well as the corresponding total profit. Using said model, we performed analysis to answer questions that can occur in the real world.

The source code to the project can be found at
https://github.com/TinaL9703/oi_group_assignment

# 1 Introduction

Everyone at some point in their lives will require a mortgage from a bank. As the digital age unfolds around us, no doubt many would prefer face-to-face interactions to be fully informed about mortgages. Therefore, it is crucial to provide high quality service to ensure customer satisfaction whilst minimizing costs to compete with both online-only mortgage lenders and other banks in the market. Labour costs are one of the largest costs to a business, it can range anywhere between 18% - 52% of the operating budget. Therefore it is critical to allocate resources in the most optimal way to meet targets and generate profit.

National Australia Bank has about 350 home lending specialists working in 825 physical branches all over Australia. A branch is defined as a physical store where you can enquire about anything banking related with a specialised customer service representative known as a banker.

The bank wants to grow their mortgage business as the industry has been booming for the last 20 years and is expected to continue growing over the foreseeable future. This is largely due to the increasing population. In addition, the expansion of online home lending services has skyrocketed over the last few years providing cheaper mortgage rates due to not having physical branches to operate and maintain. As a result, NAB also wants to capitalize on this opportunity to cut costs where they can.

In this project, we will demonstrate the application of linear programming in the domain of banking. Optimisation modeling has been adopted by many use cases such as staff and workflow scheduling, resource allocation, etc. We will apply linear programming and assess the efficacy of our models using sensible metrics to simulate questions that occur in the real world.

# 2 Literature

Before creating our model, we conducted research on associate literature about banking cost efficiency and relevant optimisation cases related to staff allocation. Although few papers were the domain of banking, we were able to locate many research papers on the optimisation of operating cost in the public services industry.

From the paper posted by Ferrier and Lovell, 1990, they discussed the combined application of linear programming and econometric techniques for measuring cost efficiencies in the domain of banking. The paper introduces an efficient production frontier that describes the relationship of costs (such as labour, capital, etc) at different levels of outputs (such as profit and bank services). Linear programming has been used in this scenario to find the allocative efficiency management can use for decision-making to optimise for different performance targets such as profit maximisation and cost reduction. The paper also highlights the gaps and inefficiencies in less optimal resource allocations from the over-utilization of labor and the under-utilization of capital.

Human resource allocation has always been a challenging task in the servicing industry. From the literature by Sasanfar et al., 2021, they utilised linear optimisation methods to improve customer services satisfaction and enquiry handling time. For example, same as branches of a bank, hospitals face challenges such as high demand for services, exceeding expenses, and limited staff resources. Although the patients' flow in the emergency department of the hospital was predefined, the results still demonstrated an improvement in patient wait times by 23.18% and an overall process utilization increase of 6.3%.

To remove the initial assumption of fixed patient inflow, both Sinreich and Jabali, 2007 and Brenner et al., 2010 incorporated population flow into their linear optimisation model specific to the emergency department at the University of Kentucky Chandler Hospital. This ensured that the model reflects the true activities in the hospital's daily operation of their emergency department. The research team stated that, optimization modeling was critical in finding the optimal configuration of the staff not only for the emergency department but also extending to various other departments in the hospital.

These ideas can easily be applied to our problem of optimally allocating staff to branches of the bank and guide us in variable identification and model formulation. It also confirms that linear programming is a suitable method for solving the problem at hand.

## 3 Problem Definition

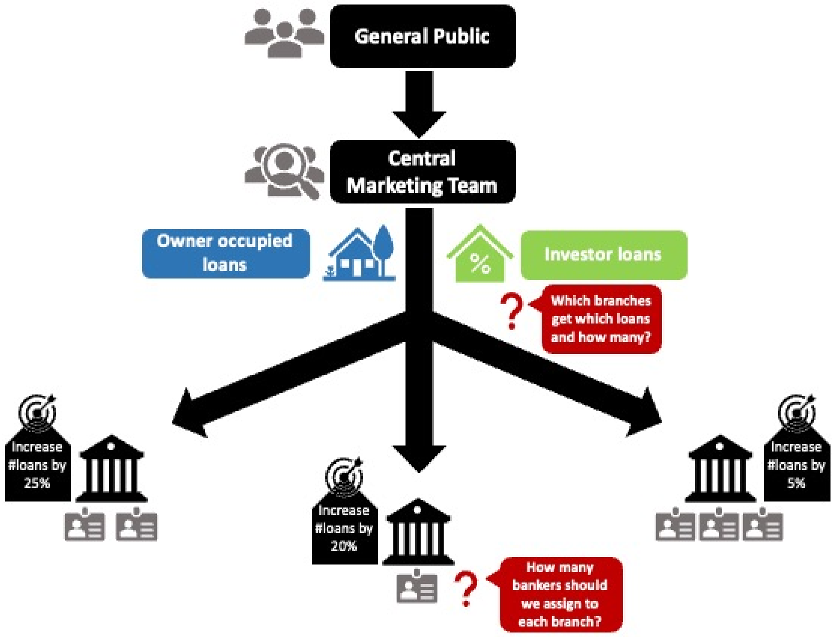


Figure 1: Problem Visualisation

Our problem is illustrated in Figure 1. We are responsible for workforce planning at a bank, and have been given the task of optimally allocating bankers in the branch network for the next financial year.

- NAB's operations consist of a central marketing team who source potential new mortgage loans (L) from the general public and allocate them to branches (B) to process. The assignment is based on how close the branch is to meeting their financial year targets, meaning branches that are further from hitting their sales target will be allocated more loans to ensure targets are met.

- Mortgages can be of types owner-occupied or investor. Australian Prudential Regulatory Authority (APRA) requires banks to have no more than 50% of new mortgages to be of type investor to ensure financial stability of the bank's lending risks sourced from Reserve Bank of Australia article[1].

[1] https://www.rba.gov.au/publications/rdp/2021/2021-07/

- There is a total of 350 bankers (P) to allocate to branches to process these loans. Each banker has a capacity and has a preference for which branch they want to work at based on their distance to all the branches given by `dist`.
- Each loan can only be processed by one banker.

Based on the above constraints, we are to report on the below questions to assist senior management in deciding the adequate banker allocation:

1. What is the best performance target to set and the corresponding allocation bankers?
2. What is the allocation of bankers that will achieve the greatest possible profit for the bank and the corresponding profit margin to choose?
3. What is the most efficient allocation of bankers and the corresponding profit margin that will achieve this? Here, efficiency is defined as the greatest utilization of a banker's capacity (i.e. the least unused banker capacity).

# 4 Data

Most data sources have been gathered from publicly available sources while others have been generated and approximated using rules we believe are most sensible. Although we did not end up using much of the gathered data due to it's large size, it assisted us in creating our reduced dataset. Below we outline the process we undertook to obtain the relevant data sources.

## 4.1 Loan data

1. We referred to the Victorian Property Sales Report[2] as our main source of housing data. It was published in September 2022 by the Victoria Government and contained the median house price and number of sales in 802 suburbs in Victoria from the first quarter of 2021 to the first quarter of 2022. For our project, we chose the latest data and used the median house price and number of sales to generate the loan data.
2. Our generated loan data contains 21,095 records with two variables, `loan_amount`, and `loan_type`. `loan_amount` is the dollar value of a loan, while `loan_type` takes on the values {`0: owner-occupied, 1: investment`}.
3. The 21,095 loans were generated based on the number of sales in each suburb. The `loan_amount` of each loan is randomly generated according to a normal distribution of $\mu$ = median house prices in that suburb and $\sigma = 100$ (chosen to align with the units of house prices). The number of loans we generate for that suburb equals to the number of respective sales.
4. The `loan_type` is randomly assigned from the set {`0, 1`}. The reason for including this variable is to capture the different profits obtainable from these types of loans in the real world. In general, investment loans are twice as profitable as owner-occupied loans, however, they generally also have lower loan amounts in comparison.

## 4.2 Branch data

1. The branch locations were obtained from web scraping NAB bank locations map[3], to collect the longitude and latitudes of each branch in Victoria.

[2] https://discover.data.vic.gov.au/dataset/victorian-property-sales-report-median-house-by-suburb
[3] https://nab.banklocationmaps.com.au/en/branches/aus

2. We then matched the locations of branches with the suburbs from the property data to get the median house price around the branch. Our assumption is that a bank located in an area with a higher house price should have a higher capacity. For the suburbs of banks not in the property data, we used the house price from Real Estate Institute of Victoria[4] or replaced it with the median house prices from nearby suburbs.

3. Finally, we generated the capacity using the following formula: `total_values_of_loans` $\times$ `weight` $\times\alpha$, `total_values_of_loans` is the sum of the loans we generated as part of loans data. The `weight` is the proportion of the house price in the bank's location compared to the sum of house prices in all bank locations (weight = house price/sum(house price)). $\alpha$ is a random number generated between 0.95 to 1, its' purpose was to add more variation to the data without altering the capacities too much as well as as to ensure the combined capacity of all branches is less than the total value of loans.

### 4.3 Banker data

The banker data contains the variables, data types and values as shown in Table 1.

| Variable | Data type | Range |
|---|---|---|
| Banker_ID | int | 1-350 |
| Longitude | float | Victoria, Australia |
| Latitude | float | Victoria, Australia |
| Tenure | float | [0.5 years, 10 years] |
| Salary | int | [65k,95k] |
| Capacity | int | [250m, 1000m] |

Table 1: Variables in the banker data.

1. We randomly generated, based on a uniform distribution, the salaries for 350 bankers in the range of 65k to 95k. This range was obtained from human resourcing platform Seek[5]. This was to ensure a diverse and realistic distribution of salaries.

2. We assumed a linear relationship between tenure and salary and mapped tenure (in years) for each banker based on the equation below:

$$\begin{aligned} \text{Salary} &= \text{Tenure} \times a + b \\ 65 &= 0.5 \times a + b \\ 95 &= 10 \times a + b \\ \Rightarrow 30 &= 9.5 \times a \\ a &= 3.16 \\ b &= 63.42 \end{aligned} \iff \begin{aligned} \text{Salary} &= \text{Tenure} \times 3.16 + 63.42 \\ \text{Tenure} &= \frac{\text{Salary} - 63.42}{3.16} \end{aligned}$$

3. To obtain the loan capacity of each banker, for simplicity we applied another linear mapping illustrated in Table 2.

4. To generate the location for each banker, we conducted research on Victoria's population density. According to the data published by the Department of Transport and Planning

[4]https://reiv.com.au
[5]https://www.seek.com.au/career-advice/role/lending-specialist/salary

| Capacity | Tenure |
|---|---|
| 250m | [0.5,2.5) |
| 500m | [2.5,5) |
| 750m | [5,7.5 |
| 1000m | [7.5,10] |

Table 2: The distribution of banker's capacity.

| Place | Average approximated population by 2021 (in 10k) | Population % | No. of banker |
|---|---|---|---|
| Melbourne city | 17 | 12% | 43 |
| Greater Geelong | 27 | 19% | 68 |
| Wyndham | 29 | 21% | 73 |
| Casey | 36 | 26% | 91 |
| Greater Bendigo (C) (LGA) | 12 | 9% | 30 |
| Ballarat | 12 | 9% | 30 |
| Shepparton | 6 | 4% | 15 |
| **Total** | **139** | **100%** | **350** |

Table 3: Summary of bankers' locations.

Victoria[6], the population is mainly concentrated in the Greater Melbourne area. We assume that all bankers live in Local Government Areas (LGA) with high population density (as marked in Figure 2). Based on this assumption, the locations of all 350 bankers' are summarised in Table 3.

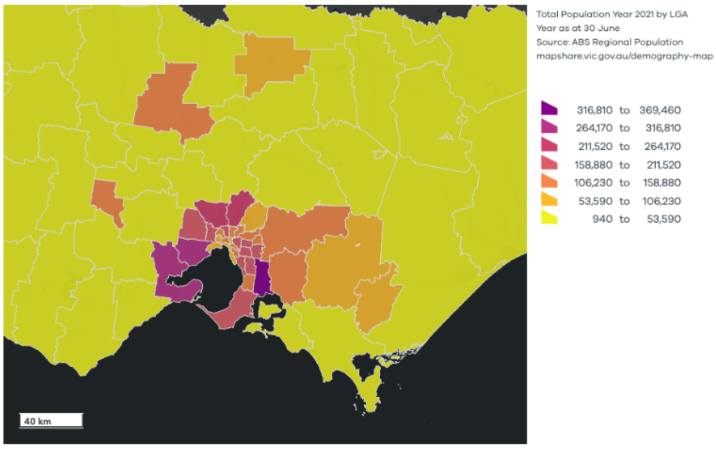


Figure 2: Population Density Map

# 5 Solution Strategy

We initially created one model that would answer all three questions, however upon running the model with the full dataset, we have found that the model cannot obtain a result due to the sheer number of the binary variables and limited computational power.

Since we formulated the variables in the model as binary variables, we suspect that Gurobi

[6]https://www.planning.vic.gov.au/land-use-and-population-research/insights/population-map

is permuting over all possible solutions and therefore consuming a lot of time and computing power to find the optimal solution. Therefore, we created a smaller dummy dataset to simulate real-world data to conduct our analysis on. Specifically, we ran the model based on the reduced dataset containing: $\{$*6 bankers, 3 branches, 15 loans*$\}$.

We then quickly realized that the model was still too complicated for Gurobi to find an optimal solution within a reasonable runtime, and so we decided to speed up the runtime by decomposing the problem into 3 models where each model attempts to answer one of the three analyses questions we proposed.

Here we have laid out the aim of each model:

- **M1:** To find the optimal staff allocation given a range of performance targets.
- **M2:** To find the optimal profit margin and allocation that maximizes total profit for the entire bank.
- **M3:** To find the optimal profit margin that utilizes the banker's full capacity as much as possible.

To make models 2 and 3 work, we incorporated a function into our objective to calculate the profit based on different profit margins and their logical relationship with demand. The function we used to estimate the relationship between profit margin and demand is a monotonically decreasing function (in our case we have kept it as a linear function for simplicity). The rationale is that the bank will sell higher volumes of loans for lower profit margins while for higher margins they will have fewer sales. We expect that an optimal exists somewhere in-between since the bank will make money either way, but whether lower or high margins make more money is difficult to say and is mostly determined by economic conditions, which we will attempt to simulate.

In Figure 3, we illustrate the dummy data we created to run our models on:

```
bank
    capacity
0    1000.0
1    5000.0
2    3500.0
loan
     loan_amount  loan_type
0          300.0          1
1          200.0          0
2          400.0          0
3          100.0          0
4          300.0          1
5          200.0          0
6          400.0          0
7          100.0          0
8          400.0          0
9          100.0          0
10         150.0          1
11         200.0          0
12         600.0          0
13         100.0          1
14         300.0          0
banker
    salary (in k)  capacity
0       89.280451       750
1       89.283944       250
2       83.659089       500
3       78.007058       250
4       92.503595       750
5       87.615097      1000
```

Figure 3: Dummy Data

# 6 Model Formulation

## 6.1 Model 1

**Variables:**

$x_{tlb}$ : binary variable, 1 if type $t \in T$ loan $l \in L$ is assigned to branch $b \in B$, 0 otherwise.

$y_{pb}$ : binary variable, 1 if banker $p \in P$ is assigned to branch $b \in B$, 0 otherwise.

$z_{tlp}$ : binary variable, 1 if type $t \in T$ loan $l \in L$ is assigned to banker $p \in P$, 0 otherwise.

**Model:**

$$\min \quad \sum_{b \in B} \sum_{p \in P} dist_{pb} \cdot y_{pb} + \sum_{b \in B} \sum_{p \in P} y_{pb} \cdot banker_{p'salary'} \tag{1}$$

s.t.

$$\sum_{b \in B} x_{tlb} \leq 1 \qquad \forall t \in T, l \in L, \tag{2}$$

$$\sum_{p \in P} z_{tlp} \leq 1 \qquad \forall t \in T, l \in L, \tag{3}$$

$$\sum_{b \in B} y_{pb} \leq 1 \qquad \forall p \in P, \tag{4}$$

$$\sum_{t \in T} \sum_{l \in L} z_{tlp} \cdot loan_{tl} \leq banker_{p'capacity'} \qquad \forall p \in P, \tag{5}$$

$$\sum_{t \in T} \sum_{l \in L} x_{tlb} \cdot loan_{tl} \leq branch_{b'capacity'} \qquad \forall b \in B, \tag{6}$$

$$\sum_{t \in T} \sum_{l \in L} x_{tlb} \cdot loan_{tl} \geq 0.1 \cdot branch_{b'capacity'} \qquad \forall b \in B, \tag{7}$$

$$\sum_{b \in B} x_{tlb} = \sum_{p \in P} z_{tlp} \qquad \forall t \in T, l \in L, \tag{8}$$

$$x_{tlb} + z_{tlp} \leq 1.5 + y_{pb} \qquad \forall t \in T, l \in L, p \in P, b \in B, \tag{9}$$

$$\sum_{l \in L} x_{'investment'lp} \cdot loan_{'investment'l} \leq \sum_{t \in T} \sum_{l \in L} x_{tlb} \cdot loan_{tl} \qquad \forall b \in B. \tag{10}$$

**Explanations:**

(1): The objective function minimizes the total travel cost for all banker $p \in P$ who has been assigned to some branch $b \in B$ and the salary paid for all banker $p \in P$ who has been assigned to some branch $b \in B$.

(2): Each loan can only be assigned to at most one branch.

(3): Each loan can only be assigned to at most one banker.

(4): Each banker can only work for one branch.

(5): The value of loans assigned to the banker cannot exceed their capacity.

(6): The value of loans assigned to each branch cannot exceed their capacity.

(7): Each branch has to meet their target of 10% of its total capacity on loans.

(8): If a loan has been assigned to a branch, it has to be assigned to one banker.

(9): If a loan has been assigned to a branch and a banker, then this banker is working for this branch.

(10): The value of the investment loan in each branch cannot exceed 50% of the total value of the loan assigned.

## 6.2 Model 2

**Variables:**

$x_{tlb}$ : binary variable, 1 if type $t \in T$ loan $l \in L$ is assigned to branch $b \in B$, 0 otherwise.

$y_{pb}$ : binary variable, 1 if banker $p \in P$ is assigned to branch $b \in B$, 0 otherwise.

$z_{tlp}$ : binary variable, 1 if type $t \in T$ loan $l \in L$ is assigned to banker $p \in P$, 0 otherwise.

$r$: continuous variable, the rate a branch can profit from the loan, presented without % (i.e. r = 20 $\iff$ rate = 20% ).

**Constant:**

$R(r) = -r/24 + 1$: The division by 24 is to account for the range we are considering for our analysis which is set between $[0, 24]$. We chose this range as historically, interest rates on loan have not exceeded 25%. This function is used to describe the relationship between the present value of the loans and its' nominal value accounting for defaults. The logic is that when the profit margins are high, the expected return on the loan decreases as customers may struggle to pay off the full life of the loan.

**Model:**

$$\max \quad \sum_{t\in T}\sum_{l\in L} x_{tlb} \cdot loan_{tl} \cdot R \cdot r/100 - \sum_{b\in B}\sum_{p\in P} dist_{pb} \cdot y_{pb} - \sum_{b\in B}\sum_{p\in P} y_{pb} \cdot banker_{p'salary'} \tag{1}$$

s.t.

$$\sum_{b\in B} x_{tlb} \leq 1 \qquad \forall t \in T, l \in L, \tag{2}$$

$$\sum_{p\in P} z_{tlp} \leq 1 \qquad \forall t \in T, l \in L, \tag{3}$$

$$\sum_{b\in B} y_{pb} \leq 1 \qquad \forall p \in P, \tag{4}$$

$$\sum_{t\in T}\sum_{l\in L} z_{tlp} \cdot loan_{tl} \leq banker_{p'capacity'} \qquad \forall p \in P, \tag{5}$$

$$\sum_{t\in T}\sum_{l\in L} x_{tlb} \cdot loan_{tl} \leq branch_{b'capacity'} \qquad \forall b \in B, \tag{6}$$

$$\sum_{t\in T}\sum_{l\in L} x_{tlb} \cdot loan_{tl} \geq 0.11 \cdot branch_{b'capacity'} \qquad \forall b \in B, \tag{7}$$

$$\sum_{b\in B} x_{tlb} = \sum_{p\in P} z_{tlp} \qquad \forall t \in T, l \in L, \tag{8}$$

$$x_{tlb} + z_{tlp} \leq 1.5 + y_{pb} \qquad \forall t \in T, l \in L, p \in P, b \in B, \tag{9}$$

$$\sum_{l\in L} x_{'investment'lb} \cdot loan_{'investment'l} \leq \sum_{t\in T}\sum_{l\in L} x_{tlb} \cdot loan_{tl} \qquad \forall b \in B, \tag{10}$$

$$0 \leq r \leq 24. \tag{11}$$

**Explanations:**

(1): The objective function maximizes the total profit for all branches, where the first summation refers to the profit made from loans, the second summation refers to the total travel cost for all banker $p \in P$ who has been assigned to some branch $b \in B$ and the third summation refers to the salary paid for all banker $p \in P$ who has been assigned to some branch $b \in B$.

(2): Each loan can only be assigned to at most one branch.

(3): Each loan can only be assigned to at most one banker.

(4): Each banker can only work for one branch.

(5): The value of loans assigned to the banker cannot exceed their capacity.

(6): The value of loans assigned to each branch cannot exceed their capacity.

(7): Each branch has to meet their target of 11% of its total capacity on loans.

(8): If a loan has been assigned to a branch, it has to be assigned to one banker.

(9): If a loan has been assigned to a branch and a banker, then this banker is working for this branch.

(10): The value of the investment loan in each branch cannot exceed 50% of the total value of the loan assigned.

(11): The rate is in $[0, 24\%]$.

## 6.3 Model 3

**Variables:**

$x_{tlb}$ : binary variable, 1 if type $t \in T$ loan $l \in L$ is assigned to branch $b \in B$, 0 otherwise.

$y_{pb}$ : binary variable, 1 if banker $p \in P$ is assigned to branch $b \in B$, 0 otherwise.

$z_{tlp}$ : binary variable, 1 if type $t \in T$ loan $l \in L$ is assigned to banker $p \in P$, 0 otherwise.

**Constants:**

$r \in \{0, 1, \ldots, 24\}$: the rate presented without %.

$R(r) = -r/24 + 1$: The division by 24 is to account for the range we are considering for our analysis which is set between $[0, 24]$. We chose this range as historically, interest rates on loan have not exceeded 25%. This function is used to describe the relationship between the present value of the loans and its' nominal value accounting for defaults. The logic is that when the profit margins are high, the expected return on the loan decreases as customers may struggle to pay off the full life of the loan.

**Model:**

$$\max \quad \frac{\sum_{t\in T}\sum_{l\in L} x_{tlb}\cdot loan_{tl}\cdot R\cdot r/100 - \sum_{b\in B}\sum_{p\in P} dist_{pb}\cdot y_{pb} - \sum_{b\in B}\sum_{p\in P} y_{pb}\cdot banker_{p'salary'}}{\sum_{b\in B}\sum_{p\in P} y_{pb}} \tag{1}$$

s.t.

$$\sum_{b\in B} x_{tlb} \le 1 \qquad \forall t\in T, l\in L, \tag{2}$$

$$\sum_{p\in P} z_{tlp} \le 1 \qquad \forall t\in T, l\in L, \tag{3}$$

$$\sum_{b\in B} y_{pb} \le 1 \qquad \forall p\in P, \tag{4}$$

$$\sum_{t\in T}\sum_{l\in L} z_{tlp}\cdot loan_{tl} \le banker_{p'capacity'} \qquad \forall p\in P, \tag{5}$$

$$\sum_{t\in T}\sum_{l\in L} x_{tlb}\cdot loan_{tl} \le branch_{b'capacity'} \qquad \forall b\in B, \tag{6}$$

$$\sum_{t\in T}\sum_{l\in L} x_{tlb}\cdot loan_{tl} \ge 0.11\cdot branch_{b'capacity'} \qquad \forall b\in B, \tag{7}$$

$$\sum_{b\in B} x_{tlb} = \sum_{p\in P} z_{tlp} \qquad \forall t\in T, l\in L, \tag{8}$$

$$x_{tlb} + z_{tlp} \le 1.5 + y_{pb} \qquad \forall t\in T, l\in L, p\in P, b\in B, \tag{9}$$

$$\sum_{l\in L} x_{'investment'lb}\cdot loan_{'investment'l} \le \sum_{t\in T}\sum_{l\in L} x_{tlb}\cdot loan_{tl} \qquad \forall b\in B. \tag{10}$$

**Explanation:**

(1): The objective function maximizes the average profit made by an individual banker, where the numerator is the same as in model 2 and the denominator is the total number of bankers assigned.

(2): Each loan can only be assigned to at most one branch.

(3): Each loan can only be assigned to at most one banker.

(4): Each banker can only work for one branch.

(5): The value of loans assigned to the banker cannot exceed their capacity.

(6): The value of loans assigned to each branch cannot exceed their capacity.

(7): Each branch has to meet their target of 11% of its total capacity on loans.

(8): If a loan has been assigned to a branch, it has to be assigned to one banker.

(9): If a loan has been assigned to a branch and a banker, then this banker is working for this branch.

(10): The value of the investment loan in each branch cannot exceed 50% of the total value of the loan assigned.

# 7 Model implementation and solution

We would like to preface our analysis with the fact that the solution we found may not be the optimal as the original problem has been broken down into 3 models, however we do still believe we have found optimal results for the 3 questions individually.

## 7.1 Model 1 Results

We present the solution of our model 1 results in Figure 4 and Figure 5.

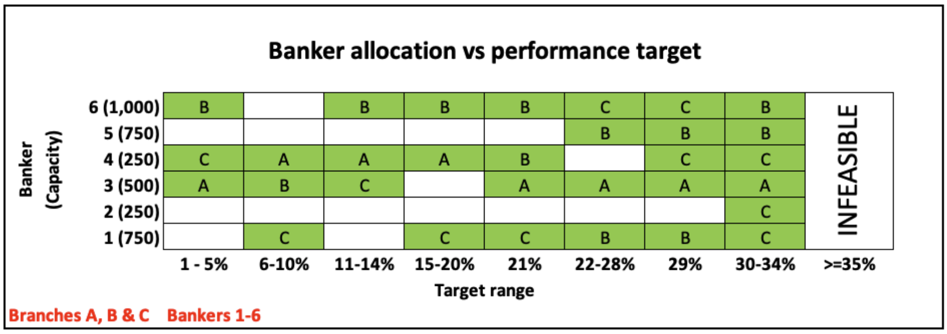


Figure 4: Model 1 Allocation

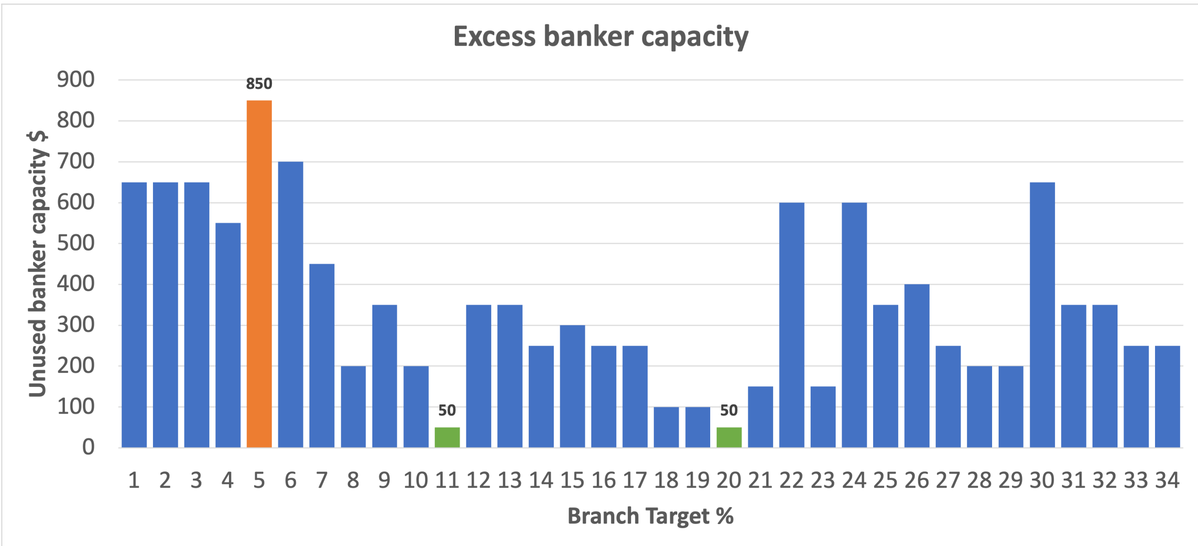


Figure 5: Model 1 Excess Banker Capacity vs Target levels

In Figure 4, we visualized the banker allocations for each branch (A, B, and C) against branch targets between 1% and 35%. The green coloured cells represent the branch the banker has been assigned to. This output has been generated by running model 1 repeatedly, changing only the target multiplier in constraint (7) in the range 1% to 35%. The targets have been binned in such a way that the changes in allocation can easily be seen. It is also worthwhile to note that differences in allocation generally occur for every 5% increase in target. This is consistent with our intuition as we hypothesized allocations should not change until the banker's capacities are maxed out before the model shuffles the bankers around to reach a new optimum. However, the exceptions occur at 21% and 29% where the allocations preceding and proceeding are quite different. Despite the fact that banker 2 and 4 have the same capacity, banker 4 almost always has a job while banker 2 only obtain a role when targets are high. This is due to banker 4 living closer to the branches and has a lower salary than banker 2.

Based on the number of bankers in the system, when the target reaches 35%, the model can no longer find an optimal solution as there is just not enough resources to allocate despite still having enough loans to distribute. In this scenario, the bank would need to hire more employees if they want to set a target above 35%.

In Figure 5, we plot the excess banker capacities (i.e. unused banker capacity) for each target percentage. At 5%, the allocation is at its least efficient since the sum of the excess capacities reaches 850 units, which can almost service another loan. At 11% and 20%, the banker allocation is at its most efficient since only 50 units of capacity is left unused.

Now that an optimal target is found, we chose to set the target at 11% (the smaller amount as we have limited loans in our data) for models 2 and 3 when conducting our profitability analysis.

## 7.2 Model 2 & 3 Results

| **Model 2:** Allocation for greatest profit | | | | | **Model 3:** Allocation that utilizes banker capacity the most | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Banker | Branch | Banker Capacity | Utilised | Unused Capacity | Banker | Branch | Banker Capacity | Utilised | Unused Capacity |
| 1 | C | 750 | 700 | 50 | 1 | C | 750 | 750 | 0 |
| 2 | C | 250 | 200 | 50 | 5 | A | 750 | 700 | 50 |
| 3 | A | 500 | 500 | 0 | 6 | B | 1000 | 1000 | 0 |
| 4 | A | 250 | 200 | 50 | | | | | |
| 5 | B | 750 | 750 | 0 | | | | | |
| 6 | B | 1000 | 1000 | 0 | | | | | |
| | | Total Unused Banker Capacity | | 150 | | | Total Unused Banker Capacity | | 50 |
| | | Total Profit from Model | | 139 | | | Total Profit from Model | | 114 |

Figure 6: Model 2 vs Model 3 Allocation

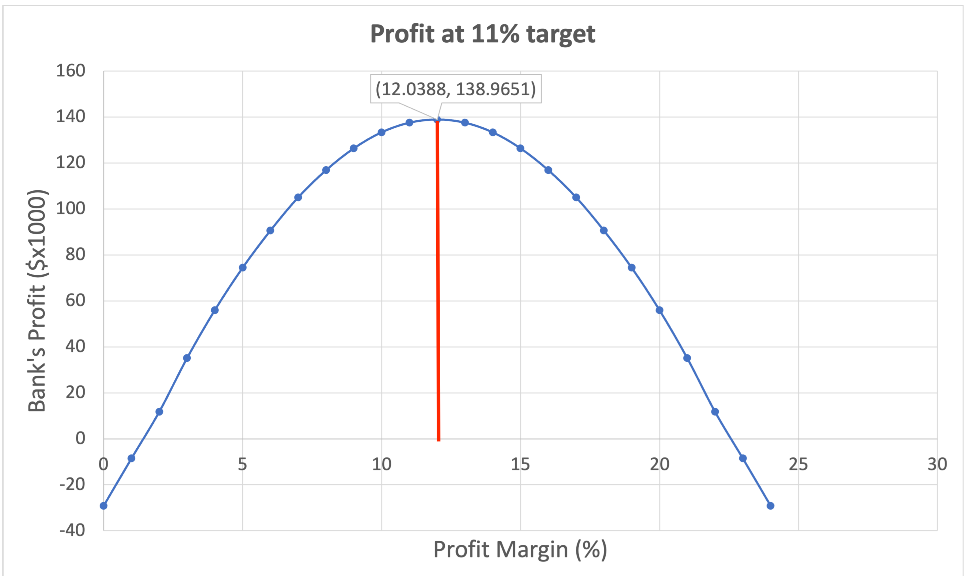


Figure 7: Bank's Profit Margin at 11% Performance Target

Figure 6 compares the allocation of bankers by Model 2 and Model 3. The exact assignment of bankers to branches can be clearly seen as well as the total amount of loan we expect the banker to process (which has been summed in column 'Utilised').

Although Model 2 generates more profit overall for the bank at 139 units, it does so at the expense of less efficiently utilizing the capacities of the bankers, having 150 units of excess banker capacity. Meanwhile, model 3 maximizes the profit generated per banker, leaving only 50 units of excess capacity. However, there is a trade-off at this allocation in that Model 3 does not give us the most optimal allocation in terms of maximising the banks' overall profit (at only 114 units).

Borrowing from Ferrier and Lovell, 1990's idea of constructing an efficient production frontier, we created our own frontier measuring bank's total profit given different percentages of profit margin. From this simulation, we obtain a maximum profit of approximately 139 units at 12.0388% margin as seen in Figure 7. In our analysis, the profit margin obtained from Model 2 was 12.0388% and Model 3 was 12.0007%. The margins are much closer than we expected, but we suspect this is due to the small dataset we are running the model over. From our initial hypothesis, we expected Model 3 to generally be less than Model 2 margins but only by a small confidence interval. Since both Model 2 and Model 3 acquire their optimal solution at around 12% margin, we attempted widen the gap by using an exponential function $R(r) = exp(-3r/24)$ instead to model the profit margin but the optimal solution took too long to reach even for a dataset this small.

## 8 Conclusion and Recommendations

The problem of banker allocation is a difficult one, however, results from using optimisation can be greatly beneficial in determining the optimal allocation of resources. Decisions need not be based on intuition anymore, but rather take advantage of scientific ways of obtaining a logical outcome.

As shown in our results, the optimal target to set in the case of {*6 bankers, 3 branches, 15 loans*} is either 11% or 20%. The optimal margin is 12.0388% with a profit of 138 units and the most efficient allocation gives us the optimal margin of 12.0007% with a total profit of 114 units, based on 11% target. Some avenues that we could not explore but would have like to include are:

- **Incorporate time period analysis:** Resource allocation is by no means limited to one period. We recommend that this analysis be extended to account for multi-period staff allocations based on private company data. Over time, you can analyze the change or movement in bankers to gauge market demand in suburbs and uplift popular branches to enhance customer experience.

- **Reformulate model to reduce run-time:** As the number of variables increases, the time required to run the model also increases significantly, a crucial improvement would be to reformulate the problem in such a way that the run-time or the solution space is reduced.

- **Optimising the starting point of the search for optimum:** We found that merely increasing number of loans to 20 (from 10), bankers to 10 (from 5), and branches to 3 (from 2), will increase the run-time quite drastically. The run-times varies between milliseconds and 2 hours. This shows that the starting point for some optimisation has quite a significant impact on the efficiency of finding the optimal solution.

- **Reducing reliance on binary variables:** Our reliance on binary variables stemmed from our goal of finding the exact allocation of bankers. This came with a very high computational cost as binary variables are the most constrained variable type; giving us a complex combinatorial problem. We can obtain an approximate optimal solution if the bankers and loans are combined or binned together into "types". For example, a banker of "type" 1 would have a salary range of 80k to 90k and stays in Caulfield and loans of "type" 1 would have a loan amount of 300k to 400k and is an investment type loan. This way we can reduce the number of binary variables and use integer variables to track the allocation of bankers and loan types.

- **Run the models with a larger dataset and on a more powerful computer:** We were not able to show the discrepancy between the profit margins obtained from Model 2 and Model 3 due to the size of our dataset and computational limits. The models will need to be reformulated as well if we want to include more bankers, banks or loans so it is less of a combinatorial problem and the optimal solution can be found in a reasonable time.

- **Using an exponential function for $R(r)$:** We intended to run Model 2 and 3 using $R(r) = exp(-3r/24)$ to find out if the models would obtain two profit margins with a larger difference. However, this step inflated our problem space and it took too long for the optimal solution to be found. We hypothesize that by using an exponential function to model the relation between the present value of the loans and its' nominal value, the differences between the strategy employed by Model 2 and Model 3 will be more apparent.

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