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# Mastering CP2: A Comprehensive Guide

1st Edition

Federica Gazzelloni



Modelling Practice, An IFoA & IAI Exam




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# Introduction

Welcome to the CP2 Manual for Actuaries.

This manual has been developed to support candidates preparing for Core Practice 2 (CP2), the Modelling Practice examination, with a focus on building a clear, repeatable workflow for use under timed conditions. This exam assesses practical modelling, documentation and communication skills in a structured environment that reflects real actuarial work. Candidates are expected to build a model, record their decisions in a transparent way and present the results to a senior actuary.

Success relies on a disciplined approach. Technical accuracy is important, but the exam places equal emphasis on the reasoning behind the model, the clarity of the audit trail and the ability to explain results in a concise and professional manner. A structured workflow, documented as it develops, is often the difference between a pass and a fail.

This manual sets out a practical method for approaching the exam. It outlines how to plan time, organise work, build models with purpose and communicate findings in a way that supports business decisions. Each chapter introduces one component of the CP2 workflow and shows how that component contributes to the overall structure used on exam day.

The manual includes:

- An overview of the exam structure and the allocation of marks
- A step-by-step approach to planning workflow under timed conditions
- Worked examples illustrating common modelling patterns and documentation styles
- Templates and checklists designed to support consistent practice
- Practical guidance on common pitfalls and methods to avoid them

The material is suitable for both first-time candidates and those refining their approach after an earlier sitting. The aim is to support the development of a professional, organised and transparent modelling practice. The habits formed through this preparation extend beyond the exam and align with the standards expected in actuarial work.

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# Know Your Author

Federica Gazzelloni is a fully qualified actuary with the Ordine degli Attuari in Italy. She was previously an Affiliate of the IFoA and worked in pensions research. Her experience spans actuarial modelling, public health metrics, and applied data analysis. This work includes academic research, consulting projects, and contributions to the Global Burden of Disease Study at the Institute for Health Metrics and Evaluation (IHME). She has developed R packages for managing complex datasets, designed analytical workflows, and communicated results to both technical and non-technical audiences in professional settings.

Federica has a strong interest in reproducible research, transparent modelling, and clear communication, principles that align closely with the objectives of the CP2 examination. She has contributed to international training initiatives through The Carpentries and the R Consortium and has collaborated on open-source projects in statistics, health analytics, and data visualisation. Her work consistently emphasises documentation, auditability, and the effective communication of analytical results.

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# Chapter 6

# Typical Model Patterns

*"Logic will get you from A to Z; imagination will get you everywhere."*
*— Albert Einstein*

Data modelling is the centre of Paper One. After checking and transforming data, the next step is to understand what model is required to solve the business problem. Although every exam tells a different story, the underlying spreadsheet structures repeat with surprising regularity. Learning these structures is the key to working with confidence and speed. The more familiar each pattern becomes, the more time remains for careful documentation, checks, and conclusions.

This chapter provides a detailed explanation of these patterns. Each section describes the purpose of the model, the typical structure, the assumptions that usually apply, and the checks that give the examiner confidence. A short comparison between reasonable and unreasonable outputs is included to help develop judgement. For each model type, examples from recent exam years are listed to illustrate the context in which the pattern has appeared.

The aim is simple. When a candidate reads the exam intro, the model pattern should be recognised almost immediately. Recognition reduces cognitive load. It also prevents the common mistake of building something more complex than required.

## 6.1 The Modelling Mindset

In actuarial science, modelling is at the heart of professional practice. It is the process of turning uncertainty into decision-making tools. In real world cases, models help organisations understand risks, price products, allocate capital, and plan for the future. Complex situations are translated into a clear sequence of instructions and outputs that inform decision makers about potential outcomes.

Professional modelling guidance describes a model as a simplified representation of real-world relationships. It takes inputs, applies processing logic, and produces outputs that support explanation, prediction, estimation, or decision making (Actuarial Standards Board 2020; American Academy of Actuaries 2019).

Models are often expected to handle uncertainty, variability, and incomplete data, while reflecting the real business problem closely enough to support a decision. In practice, every model is a simplification. It is built under constraints of time, data availability, and computational power. It involves judgement, assumptions, simplifications, and professional discernment. While models are powerful tools, they are not perfect representations of reality, and so a margin of error is always present (American Academy of Actuaries 2019).

It is for this intrinsic nature of modelling that this assessment focuses on clarity, simplicity, and transparency. The exam does not test the ability to build complex models but the ability to build clear models. The emphasis is on clean structure, well-documented assumptions, and reasonableness checks. The candidate must demonstrate that they can translate a business

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problem into a model that is easy to follow, easy to update, and easy to explain (Institute and Faculty of Actuaries 2025b; Institute and Faculty of Actuaries 2025a).

The modelling mindset is practical before it is technical. The first decision is not *which formula do I know?* but *what shape does this problem need?* A strong candidate separates the business story from the workbook structure. The story may involve trustees, schools, customers, premiums, grants, or investments. The workbook usually needs one of a small number of structures: a projection, a cashflow, a balance roll-forward, a price build-up, an expected-value table, a scenario table, or a controlled combination of these.

The useful discipline is to simplify before building. If the question asks for a short projection, build a short projection with visible assumptions and checks. If it asks for a comparison of assumptions, build one calculation block and a clear scenario comparison. If it asks for expected cost, build probability times outcome, not a complex stochastic model. Precision is sufficient when it is enough to answer the business question, support the audit trail, and allow another actuary to follow the calculation.

Table 6.1: Modelling Mindset Decisions

| Scenario | Basic design | Strong design |
|---|---|---|
| Classifying the model | Treating the narrative as unique and starting from a blank workbook design. | Identifying the model family first, then choosing the workbook spine. |
| Separating story from structure | Building a bespoke sheet for every paragraph in the question. | Translating the story into inputs, calculations, checks, and outputs. |
| Choosing precision | Adding extra drivers, charts, or formulas because they seem actuarial. | Using the simplest transparent calculation that answers the required question. |
| Handling uncertainty | Building many scenarios without a clear comparison. | Testing the few assumptions that drive the result and explaining the movement. |
| Maximising marks under pressure | Continuing to refine a fragile model with hidden logic. | Producing a simple workable structure, visible checks, and clear limitations. |

### 6.1.1 Model Patterns

The challenge is not to memorise formulas but to recognise familiar model structures. Candidates must identify the purpose of the model and translate the scenario into a projection, cashflow, pricing, risk, hybrid, or other suitable structure. Recognising the likely inputs, calculations, outputs, and checks makes planning faster and keeps the model transparent.

Operational pattern recognition means asking what the problem becomes in Excel. A scenario about future service demand usually becomes rows or columns by period. A scenario about a fund usually becomes opening balance, inflows, outflows, and closing balance. A scenario about premium adequacy usually becomes exposure, expected cost, expense loading, margin, and comparison.

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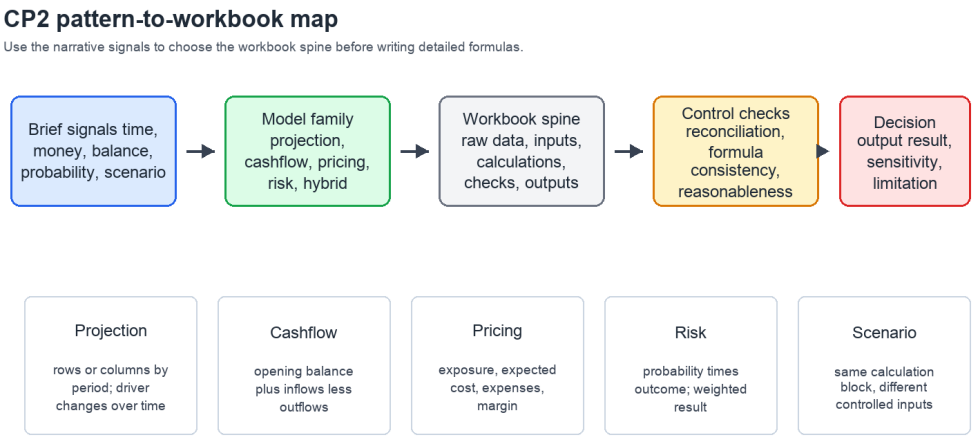



Figure 6.1.1: Pattern-to-workbook map for turning narrative signals into workbook architecture.

**Use the following prompts before writing formulas:**

Table 6.2: Quick Classification Prompts Model Patterns

| Prompt | Key indicators | Expected model structure |
|---|---|---|
| Does something develop through time? | Dates, months, years, growth, trend, retention, claims inflation, policy counts. | Projection rows or columns with the driver stored as an assumption. |
| Is money moving in and out? | Contributions, rent, grants, payments, costs, investment income, surplus, deficit. | Cashflow roll-forward with a reconciliation check each period. |
| Is one balance being repaid or accumulated? | Loan balance, savings account, repayment, interest, target balance. | Opening balance, interest, payment or contribution, closing balance. |
| Is a price, charge, or premium required? | Exposure, claim cost, expense, margin, cost per unit, adequacy. | Expected cost build-up, loading, final price, and driver sensitivity. |
| Are likelihoods or outcome weights given? | Probability, chance, expected value, severity level, outcome band. | Probability times outcome table with a probability-sum check. |
| Does the question ask “what if”? | Base, high, low, stress, alternative assumption, sensitivity. | Scenario table linked to one calculation block and one output comparison. |
| Is the task to review an existing workbook? | Provided model, inherited file, audit trail, summary, issue identification. | Trace outputs back to inputs and rank structural weaknesses before adding work. |

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Misclassification often happens when the narrative is more detailed than the calculation. A charity story may still be a cashflow. An insurance story may still be a projection if the task is to roll premiums forward. A probability story is usually an expected-value model unless the question explicitly supplies random numbers or a simulation rule.

A long list of assumptions does not mean a complicated model is required, it usually means the inputs need to be organised before the calculation starts.

## 6.2 Model Families

Models typically found within past papers can be grouped into a set of families based on their purpose and structure. The most common families are:

- Projection Models: These models extend historical data into the future based on specified assumptions. They often involve trends, seasonal patterns, or step changes.
- Cashflow Models: These models track the movement of money over time, capturing inflows, outflows, and balances across periods.
- Loan, Repayment, and Investment Models: These models track the financial evolution of a single balance, usually governed by a repayment schedule or interest accumulation.
- Pricing Models: These models calculate premiums or prices based on expected costs, expenses, and profit margins.
- Risk and Expected Value Models: These models assess uncertainty by calculating expected values based on probabilities and outcomes. A variant of these models are Simulation Models.
- Scenario and Sensitivity Models: These models explore how results change under different assumptions or parameter values.
- Hybrid Models: These models combine elements from multiple families to address complex problems.

Each family has a distinct structure, yet they share common principles of clarity, simplicity, and transparency. By recognising these families early in the exam, candidates can allocate their time more effectively and ensure that their models meet the expectations set out in the guidance.

**Optional supplementary modelling example**

The financial mathematics examples workbook provides prior-subject modelling background through technical actuarial calculations involving data, assumptions, checks, outputs, audit trail, and communication. It is useful for understanding the modelling patterns in this chapter, but is not part of the formal CP2 Practice Problems set. When using it as optional background, state the business purpose, centralise assumptions, add checks that a reviewer could understand, and write a short audit-trail note for any derived rate, yield, reserve, or Goal Seek result.

### 6.2.1 Framework Checks

Checks should be planned at the same time as the model structure. In CP2, the aim is not to add a large number of checks, but to add enough evidence that the model is controlled, propor-

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tionate, and reviewable. A useful timed-exam rule is to include checks at three levels: the data going in, the calculation logic, and the outputs being used for the conclusion.

Table 6.3: Practical Check Types for Models

| Check type | Simple Excel implementation | Audit trail wording |
|---|---|---|
| Data integrity | Use `COUNT`, `COUNTIF`, `MIN`, `MAX`, and missing-value flags to test completeness, signs, ranges, and units. | The input data were checked for missing values, unexpected signs, and values outside the expected range before being used in the model. |
| Arithmetic reconciliation | Use `SUM` and direct reconciliation checks, for example opening balance plus inflows less outflows equals closing balance. | The reconciliation check confirmed that each closing balance followed from the opening balance, inflows, and outflows. |
| Formula consistency | Copy formulas across rows or columns and check that formula patterns remain consistent across the calculation block. | Formula consistency checks confirmed that the projection rows used the same calculation logic throughout the model. |
| Reasonableness | Compare outputs with historical averages, recent trends, expected bounds, or simple back-of-envelope estimates. | The reasonableness check compared the projected output with recent historical experience and did not identify an unexplained jump. |
| Scenario or sensitivity | Change one key input at a time and confirm that outputs move in the expected direction and order. | Scenario outputs followed the expected ordering, with the high assumption producing the highest result and the low assumption producing the lowest result. |
| Communication | Check that the final output table answers the question asked and that units, labels, and scenarios are clear. | The output table was reviewed against the question requirements to confirm that the required scenarios and units were clearly labelled. |

**The check should match the model family:**

- **Projection models**: compare the first projected value with the last actual value, check that growth is plausible, and confirm that the projected trend has no unexplained jump.
- **Cashflow models**: reconcile opening balance, inflows, outflows, interest, and closing balance for each period.
- **Loan, repayment, and investment models**: check the timing of interest and repayments, and confirm that a target balance or Goal Seek result is documented.
- **Pricing models**: compare expected claims cost, expenses, margin, and final premium, and check whether the premium is plausible relative to the expected cost.

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- **Risk and expected value models**: confirm that probabilities sum to one and that the expected value lies within the range of possible outcomes.
- **Simulation models**: check that each random number maps to exactly one outcome and that simulated results stay within permitted bounds.
- **Scenario and Hybrid models**: confirm that only intended inputs change across scenarios and that each linked module updates consistently.

> **Exam Use**
>
> Do not wait until the end to add checks. Use a small check beside each calculation block, then record the check outcome in the audit trail while the logic is still fresh.

### 6.2.2 Projection Models

Projection models appear often in Paper One because they provide a straightforward, intuitive framework for actuaries to investigate possible futures. Fundamentally, these models take observed past behaviour and convert it into a transparent set of assumptions that can be projected forward. A typical workflow starts with a **table of historical observations**, for example, **monthly sales**, **quarterly claims counts**, or **annual costs**, from which the model estimates a growth rate, average change, or seasonal index. That assumption is then applied repeatedly to extend the series into future reporting periods.

This is the formula at the heart of most projection models:

$$\text{Future value (t)} = \text{Current value (t-1)} \times (1 + g) \tag{6.2.1}$$

where $g$ is the growth rate derived from historical data or specified in the assumptions. The growth rate $g$ can be calculated in several ways, depending on the nature of the data. A common method is to use the average growth over a defined period:

$$\text{Growth rate} = \frac{\text{Current value} - \text{Previous value}}{\text{Previous value}} \tag{6.2.2}$$

The type of projection varies from paper to paper. Some show a **steady trend**, where values grow at a constant rate that must be calculated from the historical data. Others show **seasonal movement**, where the pattern resets every month or quarter. There are projections that respond to a **step change** in behaviour after a certain date, and projections that are tied to an **external driver**, such as capacity, demand, temperature, or policy count. The complexity of the narrative changes, but the shape of the model does not. Every projection begins with a careful reading of the data, followed by a clear expression of the assumption that drives future values.

As an example, consider a projection that includes both **step changes and seasonal factors**. A step change applies a new rule after a specified period:

$$\text{Future value after change} = \text{Previous value} \times (1 + \text{new rate}) \tag{6.2.3}$$

Seasonal projections repeat a pattern derived from historical cycles. For example:

$$\text{Projected month value} = \text{Average for that month} \times \text{Seasonal factor} \tag{6.2.4}$$

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where the seasonal factor is calculated as:

$$\text{Seasonal factor} = \frac{\text{Month average}}{\text{Overall average}} \tag{6.2.5}$$

The projection is not a prediction but an illustration of what the assumption produces. The examiner looks for the link between data, assumption, and projected output. If that chain is visible, the model is sound.

In Excel, a projection model usually becomes a controlled time-series block. The safest structure is: historical data, prepared driver, assumptions, projection, checks, and output comparison. The calculation should move in one direction. The value for period $t$ should be based on the value for period $t-1$ or on a clearly labelled driver. Scenario assumptions should sit outside the formula block so the projection can be rerun without rewriting calculations.

Table 6.4: Robust and Common Projection Structures

| Projection element | Robust structure | Common structural error |
|---|---|---|
| Time axis | One complete set of periods with consistent labels and units. | Mixing monthly, quarterly, and annual assumptions without conversion. |
| Starting point | Last reliable actual value or clearly stated opening value. | Starting from an average when the question requires the latest value. |
| Assumptions | Growth, trend, retention, inflation, or lapse rates held in visible input cells. | Hard-coding rates inside projected cells, making later changes invisible. |
| Formula flow | Formula copied consistently across the projection horizon. | A different formula in one period because a manual adjustment was made. |
| Scenarios | Same projection block or same formula pattern for each scenario. | Separate scenario formulas that cannot be checked against each other. |
| Checks | First projected value, horizon length, scenario order, non-negative or boundary checks, and movement analysis. | Checking only the final output and missing an error earlier in the chain. |

The Life lapse workbook, introduced in Section 4.2.5.2, is a useful source example for this structure. It keeps lapse scenario multipliers in the `Inputs` sheet, projects policy counts in a repeated calculation block, and checks non-negative closing policies, scenario ordering, and output reconciliation. The motor premium projection exercise uses the same pattern for premium growth and stress assumptions, although the workbook review notes classify it as needing repair before it should be treated as a polished model answer.

When simplifying under pressure, choose the driver that the question actually needs. If the task is to compare lapse stresses, a transparent lapse multiplier may be enough. If the task is to project premium income, premium growth and retention may be enough. Avoid adding a

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second trend, a separate seasonality layer, or extra segmentation unless the question requires it. A simple movement table that explains why the output moved from the base case to the stress case is often more useful than a more detailed but uncheckable projection.

For an assumption-led projection task, use the *mortality assumptions* exercise brief together with the Excel workbook. It asks you to keep mortality improvement and stress assumptions visible, project base and stressed claims, reconcile the reserve movement, and explain what the assumptions are doing.

**Discussion of Past Paper Examples**

Projection structures frequently appear in scenarios involving sales, usage, volumes, or other quantities that evolve over time. Sometimes the historical data must first be aggregated or cleaned before any pattern is visible. In other questions, the historical pattern is already clear and the task is to extend it under explicit assumptions. The business story changes, but the modelling pattern remains familiar.

Projection structures appeared in:

- 2019 (Apr) School performance trends
- 2021 (Apr) Household solar electricity usage
- 2022 (Apr) Hospital admission volumes
- 2023 (Sept) Production output projections
- 2024 (Apr) Student attendance patterns
- 2025 (Sept) Pooled Retirement Benefit Plan – contribution and pension benefit projections
- 2026 (Apr) Country Z population projection and state pension sustainability

The April 2026 Paper One is a strong example of a demographic projection model. Candidates were asked to project the population of Country Z over 20 years, allowing for births, deaths, immigration, and emigration. The model also required the population to be grouped into younger than working age, working age, and pensioner groups, with an employed-population-to-pensioner ratio calculated for each year. The same projection structure was then repeated for two policy proposals, one based on higher fertility rates and one based on increased immigration, including a Goal Seek-style calibration to find the annual visa growth rate needed to restore the ratio after 20 years.

A closer look at two examples:

- A good example from one of the past papers, involved **projecting energy usage for a household with solar generation**, in this case the hourly values were highlighted as *noisy* and required *aggregation* before any pattern could be seen. Once the data had been summarised, the model extended those patterns into future days under the assumption that conditions remained stable.
- Another example is taken from the first exam paper (2019), it asked candidates to project **school performance scores** after applying an adjustment for subject difficulty. Once again, the essence was the same. Past values were cleaned, transformed, summarised, and extended under an explicit rule. The story changed, but the method remained familiar.

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Table 6.5: Assumptions and Pitfalls in Projection Models

| Assumptions | Pitfalls |
|---|---|
| Growth is constant unless stated otherwise | Overfitting the data with unnecessary calculations |
| Past data is representative of future behaviour | Calculating growth rates incorrectly |
| Missing periods are adjusted before projection | Forgetting to check units |
| Negative values are not permitted unless the context supports them | Not explaining why a specific method was chosen |
| Units remain consistent across periods | Projecting a jump that cannot be justified |

#### 6.2.2.1 Case Study 1: Projection Model

A regional call centre tracks the number of customer enquiries it receives each month. The past twelve months show a moderate upward trend. Management wants a projection for the next six months to support staffing decisions. The model begins by summarising the historical values and calculating the monthly growth rate. A simple way to do this is:

$$\text{Growth rate} = \frac{(\text{Value this month} - \text{Value last month})}{\text{Value last month}} \tag{6.2.6}$$

The average growth rate over the past year is then calculated. The projection then extends the series using:

$$\text{Projected month t} = \text{Previous month} \times (1 + \text{growth rate}) \tag{6.2.7}$$

The assumptions are simple: no structural change and no external shocks. The projection should link smoothly to the last observed value. Reasonableness checks include comparing the growth factor to recent behaviour and creating a small chart to show the shape of the series. If the projected values jump unexpectedly, the candidate returns to the data to check for errors.

This example mirrors many past paper structures even though the story is different.

### 6.2.3 Cashflow Models

Cashflow models are fundamental to financial analysis. They track the movement of cash through time by starting with an opening balance, applying all inflows and outflows to calculate a closing balance, and then rolling that closing balance forward as the next period's opening balance. This chain of movements provides a continuous view of the fund's liquidity and financial trend.

$$\text{Opening balance} + \text{Inflows} - \text{Outflows} = \text{Closing balance} \tag{6.2.8}$$

That closing balance becomes the opening balance for the next period:

$$\text{Opening balance}_t = \text{Closing balance}_{t-1} \tag{6.2.9}$$

If interest applies, the model adds it directly:

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$$\text{Interest} = \text{Opening balance} \times \text{Interest rate} \tag{6.2.10}$$

If costs depend on volumes or usage, they are linked accordingly:

$$\text{Outflow} = \text{Unit cost} \times \text{Volume} \tag{6.2.11}$$

If the question requires the value of future cashflows to be assessed at a single point in time, discounting may also be needed. The key requirement is not advanced financial mathematics but a transparent structure in which the discount rate is stored as an input and each cashflow is discounted period by period.

A simple present value calculation is:

$$\text{Present value} = \frac{\text{Cashflow}_t}{(1+r)^t} \tag{6.2.12}$$

where $r$ is the discount rate and $t$ is the number of periods from the valuation date.

When several future cashflows are involved, the model should calculate the discounted value of each row separately and then sum them:

$$\text{NPV} = \sum_{t=1}^{n} \frac{\text{Cashflow}_t}{(1+r)^t} \tag{6.2.13}$$

The discount rate should be kept visible. It is important to avoid embedding it directly inside multiple formulas, and explain clearly in the audit trail how the present value or NPV has been calculated.

Although the scenarios may vary, the logic remains stable. Some papers explore the suitability of a community project funded by grants. Others explore the sustainability of a maintenance fund with uncertain inflows. Some examine the accumulation of reserves as part of a savings policy. Interest is applied consistently. The balance moves forward step by step. It also contains built in checks that confirm the balance behaves as intended. For example, a negative balance triggers a warning. A sudden jump invites comment. If inflation or interest rates are involved, the model shows their effect one period at a time.

The key workbook decision is sign discipline. Inflows should be positive, outflows should be shown consistently, and the balance reconciliation should be visible. If outflows are entered as positive values, subtract them in the reconciliation. If outflows are entered as negative values, add them consistently and label the convention. Do not mix both approaches in the same model.

Table 6.6: Cashflow Model Sequencing and Checks

| Cashflow task | Practical build choice | Check priority |
|---|---|---|
| Trace sources of cash | Keep contribution, income, grants, payments, expenses, and investment income in separate columns. | Component totals agree to the prepared data or source summaries. |
| Roll balance forward | Use opening balance, inflows, outflows, interest if relevant, and closing balance in that order. | Opening balance in period $t$ equals closing balance in period $t-1$. |

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| Cashflow task | Practical build choice | Check priority |
|---|---|---|
| Handle timing | State whether flows occur at the start or end of the period when it affects interest or discounting. | Interest or discounting is applied once and to the intended balance. |
| Flag deficits | Add a warning for negative balances or funding shortfalls. | Deficit flags agree with the closing balance sign. |
| Communicate result | Show the period of first deficit, final balance, total inflows, total outflows, and main driver. | Output table reconciles back to the calculation sheet. |

Broken cashflow models usually fail in predictable ways. A closing balance may be typed manually instead of linked. A deficit may be hidden because the sign convention changes halfway through the table. Interest may be applied to the closing balance in one period and the opening balance in another. The pension cashflow projection exercise is useful practice because it separates raw monthly cashflow data, preparation, calculations, checks, and outputs, while the workbook asset review notes that its checks need strengthening before it should be treated as release-ready.

**Optional supplementary modelling example**

Investment appraisal is a useful cashflow variant because each row has a timing convention, a cashflow, a discount factor, and an output check. The cashflow and investment appraisal workbook gives compact prior-subject examples of this structure. It is technical background, not a formal CP2 Practice Problem.

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**Project appraisal cashflows**

| | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 5 | | | **IRR** | **Target return** | | |
| 6 | | | 0.0656 | 0.045 | | |
| 7 | **Year** | **Year End cashflow** | PV @ IRR | Net present value @ Target return | Cumulative NPV | Finding DPP point |
| 8 | 1 | -300,000 | -281,536.56 | -287,081.34 | -287,081.34 | |
| 9 | 2 | -50,000 | -44,034.91 | -45,786.50 | -332,867.84 | |
| 10 | 3 | 25,000 | 20,662.39 | 21,907.42 | -310,960.42 | |
| 11 | 4 | 25,000 | 19,390.73 | 20,964.03 | -289,996.39 | |
| 12 | 5 | 25,000 | 18,197.33 | 20,061.28 | -269,935.11 | |
| 13 | 6 | 127,500 | 87,094.64 | 97,906.71 | -172,028.41 | |
| 14 | 7 | 130,050 | 83,369.11 | 95,564.44 | -76,463.96 | |
| 15 | 8 | 132,651 | 79,802.94 | 93,278.21 | 16,814.25 | 1 |
| 16 | 9 | 135,304 | 76,389.30 | 91,046.66 | 107,860.91 | 1 |
| 17 | 10 | -111,989 | -59,334.98 | -72,112.82 | 35,748.09 | 1 |
| 18 | | Total | -0.000205 | 35,748.09 | | |
| 19 | | | | | | |

Figure 6.2.1: Project appraisal worksheet extract showing year-end cashflows, PV at IRR, NPV at a target return, cumulative NPV, and the discounted payback indicator.

Table 6.7: Supplementary financial mathematics examples for cashflow and investment appraisal

| Worksheet | Key concept | Practical application |
|---|---|---|
| `Interest rates` | Converts between effective interest, discount, nominal, and continuous rates. | Use as a short assumption-conversion block before discounting. The converted annual rate should be labelled and used consistently. |
| `Annuity PV and AV` | Accumulates and discounts regular payments under different timing conventions. | Use beside cashflow timing guidance, shows payment timing, accumulation or discount factors, total, and a formula-based cross-check. |
| `Project Appraisal` | Calculates IRR, NPV at a target return, and discounted payback period. | Use as an investment appraisal example. Keep the target return visible, calculate period PVs row by row, and explain the first period where cumulative NPV becomes positive. |
| `Price of Property` | Discounts monthly rent in advance and a sale proceed to find an investor price. | Use as a dated cashflow model. Useful practice is handling monthly timing, escalation, sale proceeds, and the total PV reconciliation. |

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| Worksheet | Key concept | Practical application |
|---|---|---|
| `Fixed-Interest Security` | Builds coupon, tax, redemption, capital gains tax, and net-yield cashflows. | Use as a compact investment cashflow schedule. Separate gross cashflows, tax, discount factors, PV, and the solved yield. |
| `Index-Linked Bond` | Applies an inflation-index lag to coupons and redemption cashflows. | Use as an index-linked cashflow example. The key check is that each payment uses the correct lagged index value. |
| `Term Structure of Interest Rate` | Links spot rates, forward rates, duration-style measures, and immunisation checks. | Use selectively for term-structure and sensitivity practice. Keeps the focus on the relationship between assumptions, PV, duration, and movement under an interest-rate stress. |

**Discussion of Past Paper Examples**

Cashflow structures appeared in:

- 2020 (Sept) Cost of guarantee and fund value projection
- 2021 (Sept) Social housing cashflow assessment
- 2023 (Apr) Charity grant cashflow
- 2024 (Sept) Maintenance fund analysis
- 2025 (Apr) Clean Transport Programme budget and cashflow sustainability assessment

A closer look at two examples:

- One the paper involved the cost of providing a **minimum guarantee** on a regular savings policy. The question asked candidates to assess whether the fund value would be sufficient under different future conditions. The data was more detailed, but the model underneath was a cashflow. The fund value moved from one period to the next, interest was added, contributions were deducted, and the guarantee was tested at the end of each period.
- In another paper, the task was to track the **financial performance of a housing project** over several years. The inflows came from rent, the outflows from maintenance and administrative costs.

Each of these is a cashflow model disguised as a narrative. Once the pattern is recognised, the structure becomes clear.

Table 6.8: Assumptions and Pitfalls in Cashflow Models

| Assumptions | Pitfalls |
|---|---|
| All flows occur at the end of the period unless stated otherwise | Using hard coded balances instead of links |

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| Assumptions | Pitfalls |
|---|---|
| Interest is applied once per period | Circularity introduced by accident |
| No tax unless stated | Mismatched time indices |
| Inflation adjustments follow the question assumptions | Inconsistent inflation treatment |

#### 6.2.3.1 Case Study 2: Cashflow Model

A city transport fund wants to understand whether its annual budget is sufficient to maintain scheduled repairs. The data includes expected fare revenue, annual grant income, and maintenance costs.

The model follows the standard cashflow chain:

$$\text{Closing balance} = \text{Opening balance} + \text{Inflows} - \text{Outflows} \tag{6.2.14}$$

Interest, if applicable, is added as:

$$\text{Interest} = \text{Opening balance} \times \text{Interest rate} \tag{6.2.15}$$

The closing balance becomes the next opening balance. A simple check should be added to compare the annual maintenance cost to the previous years to ensure it is consistent with the pattern.

> A reasonable flag that can be used:
> If closing balance $< 0$ then flag = *Warning: deficit occurs*

The examiner expects a clean timeline, labelled inputs, and no hard-coded values.

> For a fuller workbook-based practice task, use the **pension cashflow projection** exercise. It asks you to clean monthly pension scheme cashflow data, centralise contribution, expense and investment return assumptions, build base and stress net cashflow projections, and document reconciliation controls for the audit trail. Use the exercise brief together with the Excel workbook.

### 6.2.4 Loan, Repayment, and Investment Models

The purpose of these models is to calculate repayments, interest, balances, or investment accumulation over time.

A typical loan repayment model begins with:

$$\text{Interest this period} = \text{Opening balance} \times \text{Interest rate} \tag{6.2.16}$$

Then the repayment is applied:

$$\text{Capital repaid} = \text{Repayment} - \text{Interest} \tag{6.2.17}$$

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Finally, the closing balance is calculated:

$$\text{Closing balance} = \text{Opening balance} - \text{Capital repaid} \tag{6.2.18}$$

Where each component is calculated in sequence for each time period. The same logic applies to investment accumulation, where contributions replace repayments, and the balance grows over time.

An investment model reverses the direction:

$$\text{Closing balance} = \text{Opening balance} + \text{Contribution} + \text{Interest} \tag{6.2.19}$$

Where interest is still calculated as:

$$\text{Interest} = \text{Opening balance} \times \text{Interest rate} \tag{6.2.20}$$

Interest rates should be parameters. Payments should be explicit. Time periods should run in a single direction with no manual adjustments hidden in cells. When the question involves a target balance or repayment period, it is suggested to use a tool such as Goal Seek, and when used it must be flagged clearly. The important point is to describe and label the Goal Seek step because it affects replicability.

The practical structure is close to a cashflow model, but the main control is the balance. A loan model usually reduces a balance. An investment model usually grows a balance. In both cases, the candidate should make the timing convention visible before adding scenarios.

Table 6.9: Practical structure for loan, repayment, and investment models

| Model element | Loan or repayment model | Investment or accumulation model |
|---|---|---|
| Opening balance | Amount outstanding at the start of the period. | Fund value at the start of the period. |
| Interest | Added to the balance, using a visible rate and a stated timing convention. | Added as investment return, using a visible rate. |
| Payment or contribution | Repayment reduces the balance after interest, unless stated otherwise. | Contribution increases the balance, with timing stated if relevant. |
| Closing balance | Opening balance plus interest less repayment. | Opening balance plus contribution plus investment return. |
| Main check | Balance should move towards the target and not cross zero unexpectedly. | Balance should grow or fall consistently with contributions and return assumptions. |

The most useful simplification is to keep repayments, contributions, interest rates, and target balances as separate inputs. Avoid combining them into one long formula. If the final balance is

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the decision metric, show it directly in the output table and add a check that the balance path is consistent with the timing convention.

**How to use Goal Seek**

Goal Seek is acceptable when the task requires an input to be found so that a specified output reaches a target value. Common examples include finding the repayment required to reduce a closing balance to zero, or identifying the premium needed to achieve a target profit margin.

When Goal Seek is used, the candidate should:

- flag the cell clearly in the workbook
- state which output was targeted
- state which input was changed
- explain the purpose of the calculation in the audit trail

A suitable audit trail entry is:

> Goal Seek was used to determine the repayment amount required so that the closing balance at the end of the projection period was zero. The repayment input cell was adjusted until the final balance cell reached the target value.

The important point is not the Excel command itself, but the replicable logic: what target was set, which variable was changed, and why this was necessary.

> For example, Goal Seek was used to find the repayment needed so that the closing balance at the final period equals zero.

Most errors within these types of models arise from reversed order of operations, incorrect application of interest, or inconsistencies in period timing:

- Ending balances should increase or decrease smoothly
- Payments should behave consistently across the term
- Any unexpected behaviour should be noted and commented on in the audit trail

**Discussion of Past Paper Examples**

Examples from Past Papers:

- 2019 (Oct) Vineyard investment
- 2020 (Apr) Scholarship funding optimisation
- 2022 (Sept) Asset accumulation under varying returns
- 2024 (Apr) Investment projection under fee structures

Table 6.10: Assumptions and Pitfalls in Loan Models

| Assumptions | Pitfalls |
|---|---|
| Interest is constant unless stated | Incorrect absolute references |

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| Assumptions | Pitfalls |
|---|---|
| Repayments occur at fixed intervals | Failure to explain the Goal Seek step |
| No early redemption unless stated | Incorrect placement of repayment in the time index |

#### 6.2.4.1 Case Study 3: Loan or Investment Model

A community project receives an initial grant and deposits it into a savings account to grow over five years. The bank provides a fixed annual interest rate.

The model follows a predictable sequence:

$$\text{Interest this year} = \text{Opening balance} \times \text{Interest rate} \tag{6.2.21}$$

$$\text{Closing balance} = \text{Opening balance} + \text{Contribution} + \text{Interest} \tag{6.2.22}$$

If a repayment or withdrawal schedule exists, the sequence reverses:

$$\text{Closing balance} = \text{Opening balance} - \text{Repayment} + \text{Interest} \tag{6.2.23}$$

The model checks that the final balance behaves as expected across years. A sudden spike or drop signals an error. The candidate documents the timing convention clearly, for example stating that interest is applied at the end of each year.

If the question includes a target (such as reaching a specific closing balance), Goal Seek is used and clearly flagged.

**Optional supplementary modelling example**

A repayment schedule is a controlled roll-forward, not just a use of the `PMT` function. The loan and Goal Seek workbook shows how the repayment, interest, capital repaid, and closing balance should be separated. It provides prior-subject modelling background and is not a formal CP2 Practice Problem.

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**Loan repayment schedule**

| | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 5 | i | 0.055 | | | | |
| 6 | | | | | | |
| 7 | Year | Loan o/s at start of year | Repayment | Interest due | Capital repaid | Loan o/s at end of the year |
| 8 | 1 | 200000 | 26,533.55 | 11000 | 15,533.55 | 184,466.45 |
| 9 | 2 | 184,466.45 | 26,533.55 | 10,145.65 | 16,387.90 | 168,078.55 |
| 10 | 3 | 168,078.55 | 26,533.55 | 9,244.32 | 17,289.23 | 150,789.31 |
| 11 | 4 | 150,789.31 | 26,533.55 | 8,293.41 | 18,240.14 | 132,549.17 |
| 12 | 5 | 132,549.17 | 26,533.55 | 7,290.20 | 19,243.35 | 113,305.82 |
| 13 | 6 | 113,305.82 | 26,533.55 | 6,231.82 | 20,301.73 | 93,004.09 |
| 14 | 7 | 93,004.09 | 26,533.55 | 5,115.22 | 21,418.33 | 71,585.76 |
| 15 | 8 | 71,585.76 | 26,533.55 | 3,937.22 | 22,596.34 | 48,989.42 |
| 16 | 9 | 48,989.42 | 26,533.55 | 2,694.42 | 23,839.14 | 25,150.29 |
| 17 | 10 | 25,150.29 | 26,533.55 | 1,383.27 | 25,150.29 | 0 |

Figure 6.2.2: Loan schedule worksheet extract showing opening balance, repayment, interest due, capital repaid, and closing balance reducing to zero.

Table 6.11: Supplementary financial mathematics examples for loan and Goal Seek modelling

| Worksheet | Key concept | Practical application |
|---|---|---|
| `Goalseek` | Finds the annual interest rate that makes the annuity-due present value equal to a target amount. | Record the target PV, changing interest-rate cell, solved rate, and a PV reconciliation. |
| `Loan schedule` | Builds a level repayment schedule, splitting each payment between interest and capital. | Record the repayment assumption, the final outstanding-balance target, and a check that the closing balance reaches zero without manual adjustment. |

### 6.2.5 Pricing Models

Pricing models appear less frequently than projections or cashflows, yet when they do appear, they follow a familiar structure rooted in expected claims, expenses, and margins. The business context changes, but the mathematical heart of the model stays the same. The pricing process begins by estimating the cost of providing the benefit and then adding allowances for expenses and profit. This is expressed in a simple and transparent chain of calculations rather than in a fully fledged actuarial model.

Most pricing questions start with an expected claims cost. This can be shown in various forms depending on the problem. Sometimes the data provides a frequency and an average severity. Sometimes it provides a historical sample from which the average claim amount must be calculated. In either case, the model needs to produce a clear estimate of the pure premium.

This is usually calculated as:

$$\text{Pure premium per policy} = \text{Expected claims cost per policy} \tag{6.2.24}$$

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If the expected claims cost is built from components, the model often uses:

$$\text{Expected claims cost} = \text{Frequency} \times \text{Severity} \tag{6.2.25}$$

Where:

$$\text{Frequency} = \frac{\text{Number of claims}}{\text{Number of policies}} \tag{6.2.26}$$

and,

$$\text{Severity} = \frac{\text{Total claims cost}}{\text{Number of claims}} \tag{6.2.27}$$

The next step is to allow for expenses. These are normally given either as a fixed amount per policy or as a percentage loading. The model is expected to treat these values as parameters, placed at the top of the sheet, and applied consistently across the calculations. When expenses are expressed as a percentage of premium, circularity can arise. The model must avoid unnecessary circular references. Where expenses are stated in absolute or proportional terms that can be added directly, the basic pricing structure looks like:

$$\text{Office premium} = \text{Pure premium} + \text{Expenses} + \text{Profit loading} \tag{6.2.28}$$

Where each component is clearly defined and linked back to the input parameters.

In some papers, the premium must be tested for profit. This requires a comparison between the office premium and the expected claims cost, sometimes expressed as a margin. The margin is typically shown as:

$$\text{Profit margin} = \frac{(\text{Premium} - \text{Expected claims})}{\text{Premium}} \tag{6.2.29}$$

The purpose of this calculation is not to perform commercial pricing but to demonstrate a clear and controlled method. A well-constructed pricing model keeps the calculations short and builds each line on the one before it. The assumptions are clearly stated. The sheet is easy to navigate. A simple chart often highlights the relationship between expected claims and premium across scenarios.

> A common Paper One variant asks the candidate to estimate an expected cost per unit, test a premium or charge, or compare profitability under changing assumptions. Once the pattern is recognised, the complexity of the narrative becomes much easier to manage.

Under exam conditions, pricing should be built as a short chain of drivers rather than as a full commercial pricing engine. The candidate should be able to point to the exposure base, the expected cost, the expense allowance, the margin, and the scenario driver. Anything that does not affect those outputs should normally be left out or noted as a limitation.

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Table 6.12: Practical pricing workflow under pressure

| Pricing driver | Modelling approach | Communication |
|---|---|---|
| Exposure | Count policies, units, members, claims, or other exposure consistently. | State the exposure basis and whether it is complete. |
| Expected claims or cost | Use frequency times severity, average cost per unit, or another stated cost basis. | Explain the key assumption, not every cell. |
| Expenses | Hold fixed or proportional expense assumptions visibly. | Clarify whether expenses are per policy, total, or percentage-based. |
| Margin | Apply the margin once and label whether it is added to cost or measured against premium. | Avoid false precision, show the main driver of the price. |
| Scenario adjustment | Vary the driver that the question asks to test, such as claims inflation or retention. | Explain whether the result remains adequate under the stress. |

Overcomplicated pricing logic is a common trap. A candidate may build separate formulas for every region, add unnecessary credibility adjustments, or introduce a circular expense loading when the question only needs a transparent expected-cost comparison. A weaker answer may also state that the premium is "reasonable" without explaining whether the conclusion is driven by claims cost, exposure, expenses, or margin. A stronger answer keeps the build-up short and makes the driver of the final price visible.

**Optional supplementary modelling example**

The pricing and reserves workbook is more technical than a normal CP2 pricing task, but the same control discipline applies: benefits, expenses, probabilities, discount factors, and EPVs should stay visible. It is prior-subject modelling background, not a formal CP2 Practice Problem.

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**Benefit and expense present values**

| | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| 16 | **Benefit and Claim Expenses** | | | | | | **66,950.34** |
| 17 | **Time** | SA and Claim Expense | Bonus | Total Amount | Disc factor | Probability of payment | EPV |
| 18 | 1 | 150140 | 2,884.62 | 153,024.62 | 0.9434 | 0.001201 | 173.3798 |
| 19 | 2 | 150140 | 5,769.24 | 155,909.24 | 0.89 | 0.001555 | 215.7877 |
| 20 | 3 | 150140 | 8,653.86 | 158,793.86 | 0.8396 | 0.001797 | 239.592 |
| 21 | 4 | 150140 | 11,538.48 | 161,678.48 | 0.7921 | 0.001999 | 255.9827 |
| 22 | 5 | 150140 | 14,423.10 | 164,563.10 | 0.7473 | 0.002226 | 273.7727 |
| 23 | 6 | 150140 | 17,307.72 | 167,447.72 | 0.705 | 0.002486 | 293.4556 |
| 24 | 7 | 150140 | 20,192.34 | 170,332.34 | 0.6651 | 0.002777 | 314.6212 |
| 25 | 8 | 150140 | 23,076.96 | 173,216.96 | 0.6274 | 0.003108 | 337.7445 |
| 26 | 9 | 150140 | 25,961.58 | 176,101.58 | 0.5919 | 0.003478 | 362.5589 |
| 27 | 10 | 150140 | 28,846.20 | 178,986.20 | 0.5584 | 0.003894 | 389.1841 |

Figure 6.2.3: With-profits gross premium worksheet extract showing benefit amounts, bonuses, discount factors, probability of payment, and expected present values.

Table 6.13: Supplementary financial mathematics examples for pricing and reserve modelling

| Worksheet | Key concept | Practical application |
|---|---|---|
| `Gross future loss random variab` | Expresses a future-loss random variable and solves for a premium condition. | Use as a reminder that a pricing model needs a clear benefit, premium, timing, and probability basis. |
| `EPV and Bonus` | Calculates expected present values for an endowment assurance with bonus structures. | Use to practise separating benefits, bonus assumptions, mortality, interest, and EPV checks. |
| `With-Profits Gross Premium` | Builds a gross premium allowing for benefits, bonuses, expenses, commission, and profit. | Use as a pricing build-up example. In CP2, keep assumptions visible and explain the premium driver rather than reproducing every actuarial formula. |
| `Prospective Reserve_1`, `Prospective Reserve_2`, `Prospective Reserve_3` | Calculates reserves for annuity, endowment, and decreasing term assurance contracts. | Use as reserve-calculation practice where the output should be linked to benefits, premiums, expenses, mortality, and timing. |
| `Death Strain and Mort Profit` | Links reserves, claims, death strain at risk, and mortality profit. | Use to show how a reserve model can feed a profit or experience-analysis calculation. |

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| Worksheet | Key concept | Practical application |
|---|---|---|
| `Retrospective Accumulation`, `Retrospective Reserve` | Builds accumulated past premiums, benefits, and reserves. | Use to contrast retrospective and prospective logic, and to check whether signs and timing are consistent. |

**Discussion of Past Paper Examples**

Examples from Past Papers:

- 2019 (Apr) School Performance: implicit pricing when calculating expected funding adjustments.
- 2020 (Sept) Life Insurance Guarantee: premium adequacy assessment.
- 2021 (Apr) Solar Panel: estimation of unmet-demand cost per unit.
- 2022 (Apr) Scholarship Trials: implicit cost per athlete and expected payout.
- 2023 (Sept) Loan Repayment with Penalties: penalty cost pricing.

Pricing is not always labelled *pricing* in past papers, it often appears as **cost-per-unit**, **expected cost**, or **marginal cost** inside a wider model.

Table 6.14: Assumptions and Pitfalls in Pricing Models

| Assumptions | Pitfalls |
|---|---|
| Frequency of events remains stable over projection horizon | Double-counting costs (adding fixed and proportional incorrectly). |
| Costs per unit are representative of future behaviour | Using raw data instead of cleaned/adjusted values. |
| Claim or cost patterns do not shift abruptly unless stated | Ignoring scaling (mixing per-unit with totals). |
| Expenses are either fixed per policy or proportional | Forgetting to document why a particular cost base was chosen. |
| Volatility beyond given data is not modelled (CP2 does not require stochastic pricing) | Introducing circular references when expenses are expressed as a percentage of premium. |

#### 6.2.5.1 Case Study 4: Pricing Model

A small insurer introduces a simple accidental-damage product for electronics. The task is to calculate a fair premium. The data shows historical claims. The model calculates:

$$\text{Frequency} = \frac{\text{Number of claims}}{\text{Number of policies}} \tag{6.2.30}$$

$$\text{Severity} = \frac{\text{Total claims cost}}{\text{Number of claims}} \tag{6.2.31}$$

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$$\text{Expected claims cost} = \text{Frequency} \times \text{Severity} \tag{6.2.32}$$

$$\text{Pure premium} = \text{Expected claims cost per policy} \tag{6.2.33}$$

$$\text{Office premium} = \text{Pure premium} + \text{Expenses} + \text{Margin} \tag{6.2.34}$$

The assumptions must be written clearly: expenses are constant, claim behaviour is stable, and the margin reflects management preference. Checks include verifying that the frequency and severity values make sense given the data. If the premium appears too low or too high relative to expected claims, the audit trail must discuss the possible reasons.

### 6.2.6 Risk and Expected Value Models

Risk models often appear in the form of expected value calculations. These models express the uncertainty of a future outcome through a probability distribution, and they measure the average result by weighting each outcome by its likelihood. The structure is simple, but the clarity of the assumptions and layout matters greatly.

The expected value is calculated using the standard expression:

$$\text{Expected value} = \sum_{i=1}^{n} p_i x_i \tag{6.2.35}$$

where $p_i$ is the probability of outcome $i$, and $x_i$ is the consequence associated with that outcome.

In spreadsheet form, this is built row by row. Each row contains a probability, an associated consequence, and a calculated expected value. The sum of the expected values across the table produces the final figure. The probabilities must sum to one. The outcomes must reflect the question. Anything outside the stated range is excluded or adjusted following a documented assumption.

In some papers, the model uses conditional probabilities, where a particular event occurs only if a previous condition is met. In others, the outcomes are financial and relate to profit, loss, cost, or savings. The model must show the structure transparently. Probabilities are placed in one column, outcomes in another, and the expected value is calculated in a third. Auto-checks ensure that the probabilities sum to one and that the expected value moves logically when parameters change.

A common variation involves assessing the value of a scholarship or grant by weighting potential outcomes by their likelihood. Another involves estimating the expected cost of a risk event using several severity levels. In either case, the structure does not change. The entire model rests on the clarity of the expected value calculation and on the printed trail of each assumption.

The implementation should stay simple. Build an outcome table, calculate the weighted result in each row, and then sum the expected values. If probabilities are derived from data, show the count basis. If probabilities are supplied in the question, keep them as inputs and do not overwrite them inside formulas.

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Table 6.15: Expected-value model structure and checks

| Expected-value component | Excel structure | Reasonableness check |
|---|---|---|
| Outcome categories | One row per mutually exclusive outcome or severity band. | All relevant outcomes from the question are included once. |
| Probability | Input or derived probability in a separate column. | Probabilities sum to 1, allowing for rounding. |
| Consequence | Cost, benefit, loss, saving, or score in a separate column. | Consequences are within the stated range and use consistent units. |
| Weighted value | Probability multiplied by consequence. | Expected value lies between the minimum and maximum outcome where all probabilities are non-negative. |
| Uncertainty comment | Short note on the most unstable assumption. | The conclusion does not overstate certainty from a small or judgemental probability set. |

The common mistake is not mathematical complexity, it is poor control. Probabilities may be left as percentages in one row and proportions in another. An outcome mentioned in the brief may be missed. A low-probability high-cost outcome may be included in the calculation but ignored in the explanation. The output should therefore show both the expected value and the uncertainty that matters for the decision.

**Optional supplementary modelling example**

The probability and expected value workbook shows how probability preparation feeds expected-value calculations. It is useful prior-subject background, not a formal CP2 Practice Problem. The important CP2 habit is to label the event being valued before multiplying probability by consequence.

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Life table probability preparation

| | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|
| 4 | Age | q[x] | q[x-1]+1 | qx | | lx | dx | px | mu_x |
| 5 | 17 | 0.000427 | | 0.000600 | | 100,000 | 60 | 0.9994 | 0.000600 |
| 6 | 18 | 0.000426 | 0.000548 | 0.000594 | | 99940 | 59.3644 | 0.9988 | 0.001194 |
| 7 | 19 | 0.000425 | 0.000544 | 0.000587 | | 99,880.64 | 58.6299 | 0.9982 | 0.001782 |
| 8 | 20 | 0.000425 | 0.000541 | 0.000582 | | 99,822.01 | 58.0964 | 0.9976 | 0.002364 |
| 9 | 21 | 0.000425 | 0.000538 | 0.000577 | | 99,763.91 | 57.5638 | 0.9971 | 0.002941 |
| 10 | 22 | 0.000427 | 0.000535 | 0.000572 | | 99,706.35 | 57.032 | 0.9965 | 0.003513 |
| 11 | 23 | 0.000429 | 0.000534 | 0.000569 | | 99,649.31 | 56.7005 | 0.9959 | 0.004082 |
| 12 | 24 | 0.000431 | 0.000533 | 0.000567 | | 99,592.61 | 56.469 | 0.9954 | 0.004649 |
| 13 | 25 | 0.000435 | 0.000533 | 0.000566 | | 99,536.14 | 56.3375 | 0.9948 | 0.005216 |
| 14 | 26 | 0.000440 | 0.000535 | 0.000567 | | 99,479.81 | 56.4051 | 0.9942 | 0.005783 |
| 15 | 27 | 0.000447 | 0.000538 | 0.000570 | | 99,423.40 | 56.6713 | 0.9937 | 0.006353 |

Figure 6.2.4: Life table worksheet extract showing qx, lx, dx, px, and force of mortality columns used to prepare probability assumptions.

Table 6.16: Supplementary financial mathematics examples for probability and expected-value modelling

| Worksheet | Key concept | Practical application |
|---|---|---|
| `Life Table` | Converts mortality rates into life table functions. | Use as a data-preparation and probability table. The CP2 check is that rates, survival probabilities, and decrements are consistently linked. |
| `Life Table - 2 lives` | Prepares male and female life-table values for two-life calculations. | Use as a reminder to keep source tables separate from calculation outputs. |
| `Prob involving 2 lives` | Calculates probabilities and EPVs involving two lives. | Use selectively to practise probability logic, ensuring each probability has a clear event definition. |
| `Joint Life Premium Calculation` | Combines two-life probabilities, benefit timing, expenses, and premium calculation. | Use as a hybrid probability-to-premium chain. The audit trail should describe the event being valued, not just the formulas. |
| `Joint Life Reserves` | Calculates assurance and annuity factors for joint-life and last-survivor reserves. | Use as reserve logic practice, with separate checks for factor consistency and reserve movement. |
| `Multiple Decrements` | Introduces exits from one active state to several absorbing states. | Use as an expected-value structure where decrement probabilities should be mutually consistent and explainable. |

### Discussion of Past Paper Examples

Examples from Past Papers:

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- 2019 (Sept) Vineyard Investment (WineCo): simulation of profit/loss distribution using random numbers
- 2020 (Apr) Shooting Team Scholarship: expected selection outcomes
- 2021 (Sept) Social Housing: expected number of units requiring maintenance
- 2023 (Apr) Specialist Training Programme: expected number of successful candidates
- 2024 (Sept) Regional Performance Grants: expected performance score for funding

Table 6.17: Assumptions and Pitfalls in Risk Models

| Assumptions | Pitfalls |
|---|---|
| Probabilities provided are correct or derived from representative data. | Probabilities not summing to 1. |
| Outcomes listed are mutually exclusive and collectively exhaustive. | Forgetting to convert percentages to proportions. |
| Past behaviour is a reliable indicator of future likelihoods. | Mixing totals with averages in outcome rows. |
| Each probability-outcome pair is independent unless stated. | Missing a scenario or category mentioned in the text. |
| | Including impossible outcomes due to poor data cleaning. |

#### 6.2.6.1 Case Study 5: Risk Model – Expected Value

A scholarship programme awards different levels of funding depending on exam performance. The model calculates the expected amount the organisation will need to pay per student.

The structure:

$$\text{Expected value} = \sum(\text{Probability} \times \text{Award amount}) \tag{6.2.36}$$

Probabilities must sum to one, and award amounts must match the scheme rules. A simple auto-check ensures the probabilities are valid.

A reasonableness check involves comparing the expected award to the median or mode of the possible outcomes. If the expected value is higher than the maximum award or lower than the minimum, the model is incorrect.

### 6.2.7 Simulation Models

Simulation models appear less often than projection or cashflow models, but they remain part of the CP2 modelling toolkit. They are typically a variant of **Risk and Expected Value Models** used when the question introduces random variation explicitly, often through a table of `Uniform(0,1)` values or a rule that links random numbers to possible outcomes.

The purpose of a simulation model is not to demonstrate advanced stochastic modelling. It is to show that the candidate can apply a clear, reproducible method for converting random inputs into simulated results, and then interpret those results sensibly.

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A typical simulation workflow is:

- Start with a table of random numbers, often Uniform(0,1)
- Map each random number to an outcome using a defined rule, threshold, or distribution
- Calculate the resulting quantity of interest
- Summarise the simulated outputs clearly
- Comment on whether the results appear reasonable

For example, if a claim amount depends on which interval a random number falls into, the model should show those intervals explicitly and apply the same logic consistently across all rows.

The examiner is looking for:

- a transparent mapping from random input to simulated outcome
- a clear explanation of the rule used
- consistency across rows
- summary results that are checked for reasonableness

A candidate does not need advanced simulation language. What matters is that the process is structured, repeatable, and explained clearly in the audit trail.

**Simulation Example Structure**

A simple simulation model may follow this pattern:

$$\text{Simulated outcome} = f(\text{Uniform random number}) \tag{6.2.37}$$

where the function $(f)$ is defined explicitly by thresholds or intervals given in the question.

Typical checks include:

- confirming that each random number has been allocated to exactly one outcome
- checking that the simulated results lie within the permitted range
- comparing average simulated values with expectations from the question or the input assumptions

### 6.2.8 Scenario and Sensitivity Models

Sensitivity models appear frequently, either as a dedicated section or as part of the main model. They allow the candidate to explore how the results change when the key parameters move. The technique is simple but must be implemented with consistency. The model must anchor its inputs in parameter cells that can be changed without rewriting formulas. The output table must update automatically (Institute and Faculty of Actuaries 2025b; International Actuarial Association 2013).

A scenario model typically uses a base case and one or more alternative cases. The base case reflects the original assumptions. The other cases test different parameter values such as a higher growth rate, a lower frequency, or a change in cost. The model does not require advanced

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Excel tools. It requires clean links from the parameter cells to the calculation sheet and a clear summary table comparing the results.

A typical formula in a scenario model does not differ from the formula used in the base model. Instead, the scenario structure allows the model to reuse the same formulas with different inputs. For example, if the projected value in the base case is:

$$\text{Future value} = \text{Current value} \times (1 + g) \tag{6.2.38}$$

where $g$ is the growth rate defined in a parameter cell, then a **scenario test** might replace the growth rate with an alternative value, such as: $g_{high}$ or $g_{low}$. The formula remains unchanged; only the scenario structure simply points the growth rate to a different parameter cell. The entire model updates automatically.

For a general scenario $s$, the projected value becomes:

$$\text{Future value}_s = \text{Current value} \times (1 + g_s) \tag{6.2.39}$$

where $g_s$ is the growth rate for scenario $s$.

The best scenario models change assumptions, not formulas. Keep a small scenario table with the base, high, low, or stress inputs. Link the active assumption cells to the selected scenario or build parallel columns that all use the same formula pattern. The output comparison should then update automatically.

#### 6.2.8.1 Workbook Extract: Checking Sensitivities

**Aim:** Develop the ability to structure and document key input assumptions clearly. Separating base assumptions, stress parameters, and other model drivers before calculations are built improves transparency, consistency, and the efficiency of sensitivity testing. The workbook contains a series of controlled defects.

**Workbook:** Lapse-stress workbook

**Worksheet:** `Inputs`

**Highlight:** The base annual lapse rate, mass-lapse stress uplift, premium inflation, descriptions, and `Sensitivity` flags.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | **Variable** | **Cell** | **Value** | **Description** | **Sensitivity?** |
| 2 | Base annual lapse rate | C2 | 8.5% | Current best-estimate annual policy lapse rate | Yes |
| 3 | Mass lapse stress uplift | C3 | 3.5% | Additional lapse rate under adverse scenario | Yes |
| 4 | Premium inflation | C4 | 3.0% | Annual premium growth for retained policies | Yes |

Figure 6.2.5: Input register separating the base lapse assumption, adverse stress uplift, and premium inflation, with each sensitivity driver clearly identified.

This structure makes the modelling intent inspectable. The base lapse rate is the central assumption, while the stress uplift is an increment applied under the adverse scenario. Keeping the two values separate prevents the candidate from silently replacing the base case and makes it easier to check that the scenario changes only the intended driver. The descriptions also give the audit trail usable wording without forcing the writer to reconstruct the meaning of each percentage later.

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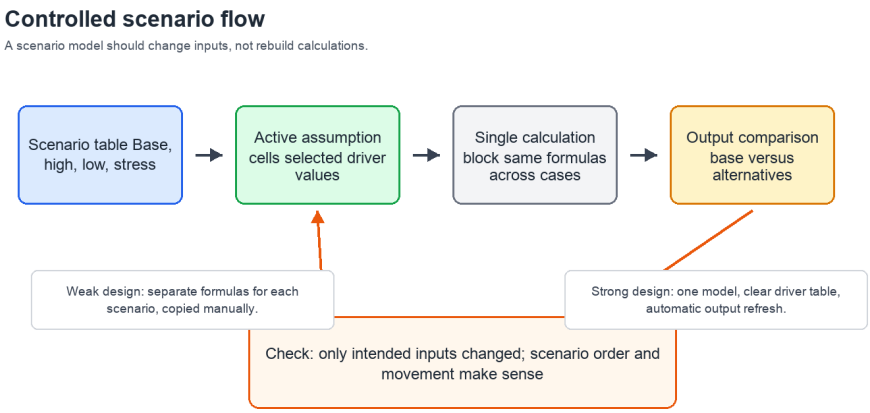



Figure 6.2.6: Controlled scenario flow showing how scenario inputs feed active assumptions, one calculation block, output comparison, and checks.

The lapse-stress workbook also shows why a scenario chart can be more useful than a dense table. The line chart compares the base scenario with the sensitivity test over the projection period, so the reader can see both the direction and the persistence of the stress. This supports the written conclusion that higher lapse assumptions reduce the present value of future net cashflows.

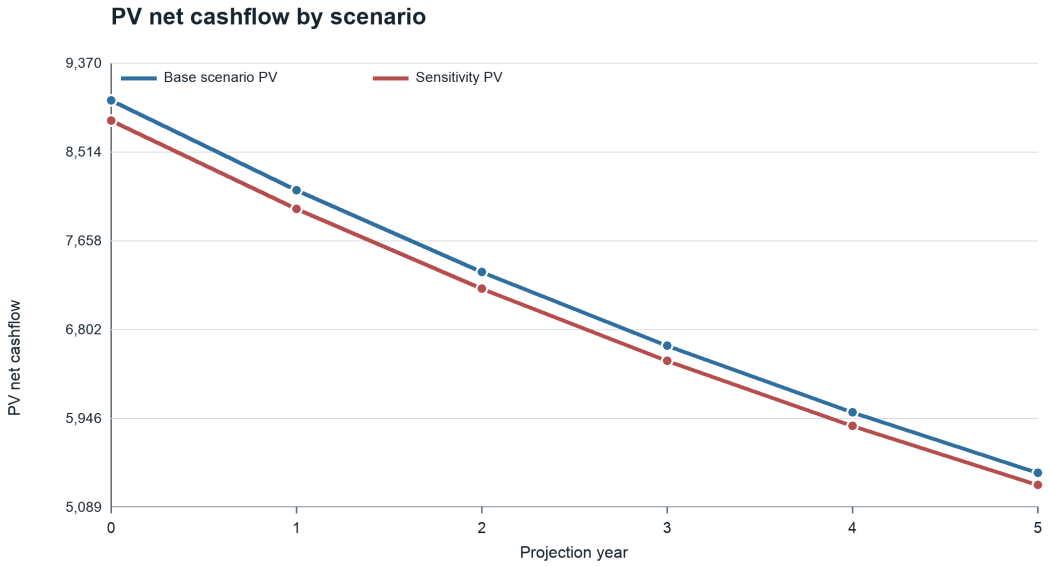



Figure 6.2.7: PV net cashflow by scenario from the Lapse-stress workbook.

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Table 6.18: Basic and strong scenario design

| Scenario | Basic design | Strong design |
|---|---|---|
| Scenario inputs | Inputs hidden inside separate formulas. | Scenario table with named or clearly labelled driver values. |
| Calculation block | One copied block per scenario with small manual differences. | One formula pattern reused across all scenarios. |
| Sensitivity test | Several inputs changed at once without explanation. | One key parameter changed at a time when ranking drivers. |
| Output table | Many numbers with no base comparison. | Base, alternative result, movement, and short interpretation. |
| Check | Only confirming that output cells are not blank. | Confirming intended inputs changed, formulas are consistent, and scenario ordering is logical. |

Sensitivity testing is most useful when it identifies the drivers of movement. A compact output table can show the base result, the stressed result, the absolute movement, and the percentage movement. If several drivers are tested, rank them by effect on the final output. This keeps the communication focused on uncertainty that matters, rather than producing a long list of scenario numbers.

Excessive scenario complexity is a real risk. Three clear scenarios with explained movements are usually more helpful than ten poorly labelled cases. Confusing outputs often arise when the high scenario improves one assumption but worsens another, or when a stress changes both the volume driver and the cost driver without saying why. When this happens, the candidate should either split the sensitivity into separate driver tests or state clearly that the scenario is a combined stress.

In some papers, candidates compare **best**, **base**, and **worst** cases for a financial plan. In others, they test how **changes** in claim frequency affect profit. Scenario models are also used in risk questions, where the consequences differ depending on the scenario. The purpose is always the same. The model becomes a tool for exploring stability, and the candidate must show that each change in the assumptions leads to a result that behaves logically.

**Discussion of Past Paper Examples**

Examples from Past Papers:

- 2019 (Apr) High/low grant adjustments
- 2019 (Oct) WineCo investment stress tests
- 2020 (Apr) Guarantee cost under different market returns
- 2020 (Sept) Minimum return stress
- 2021 (Apr) Solar performance under weather variation
- 2021 (Sept) Fund performance under different rent levels

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Scenario testing is common enough that candidates should actively look for it when reading the requirements.

Table 6.19: Typical Assumptions and Pitfalls in Scenario and Sensitivity Models

| Assumptions | Pitfalls |
|---|---|
| Only specified inputs change across scenarios; structure stays identical. | Re-writing formulas manually for each scenario. |
| Scenarios represent plausible variation around the base case. | Hard-coding scenario results instead of linking to parameter cells. |
| Behaviour between scenarios remains smooth and proportional. | Missing one scenario mentioned in the question. |
| No new logic or formulas are introduced in scenario sheets. | Forgetting to comment on differences between cases. |
| | Scenario outputs not updating automatically. |

#### 6.2.8.2 Case Study 6: Sensitivity Model

A small business uses a revenue projection model based on growth in customer sign-ups. Management wants to test how results change if the growth rate increases or decreases.

The structure does not change. The parameter does:

$$\text{Projected customers (base)} = \text{Last period} \times (1 + \text{growth}_{\text{base}}) \tag{6.2.40}$$

$$\text{Projected customers (high)} = \text{Last period} \times (1 + \text{growth}_{\text{high}}) \tag{6.2.41}$$

$$\text{Projected customers (low)} = \text{Last period} \times (1 + \text{growth}_{\text{low}}) \tag{6.2.42}$$

The model outputs revenue under each scenario:

$$\text{Revenue} = \text{Customers} \times \text{Average spend} \tag{6.2.43}$$

The comparison highlights how sensitive the plan is to assumptions. The audit trail discusses whether the change seems proportionate and whether the model reacts logically.

For a fuller workbook-based practice task, use the **motor premium projection exercise**. It asks you to clean regional premium data, centralise growth and retention assumptions, build base and stress projections, and document the checks that support the output. Use the exercise brief together with the Excel workbook.

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For a lapse-focused stress-testing task, use the **lapse stress testing exercise**. It asks you to clean policy-level data, apply Base, Adverse and Severe lapse scenarios, compare an additional sensitivity, and explain the movement in present value. Use the exercise brief together with the Excel workbook.

## 6.3 Pattern Recognition

Many questions combine two or three of the families described above. What changes from exam to exam is the **scenario**; the underlying projection, cashflow, pricing, risk, or sensitivity structures remain recognisable. Use the first structural signal to choose the workbook spine, then add separate modules only where the brief requires them.

The challenge begins when reading the exam narrative and assumptions. They are not presented as *this is a projection* or *this is a cashflow*. Instead, they arrive as a list of business statements, dates, rates, limits, and requirements. The task is to untangle these statements and see which parts belong to which model family. This step is the key to keeping the model simple. It is also exactly what the syllabus expects when it asks candidates to *plan and produce a spreadsheet model to solve a specified problem* and to *make appropriate assumptions*.

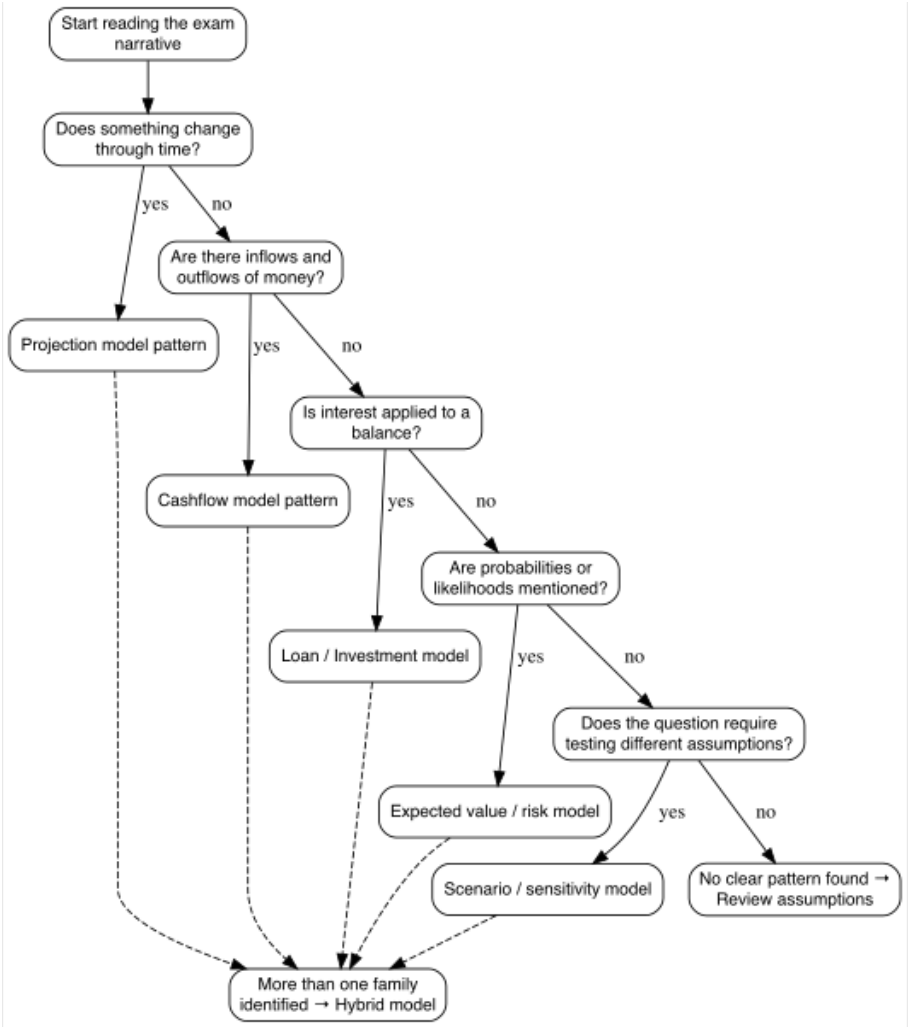



Figure 6.3.1: Model family recognition flowchart

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Use the flowchart as a first-pass sorter, not as a final label for the whole model. Identify the first structural signal, place it in its own workbook section, then look again for additional signals that should be linked as separate modules rather than absorbed into one long calculation.

The easiest way to navigate this is to treat the problem description as a set of small signals. Some assumptions describe **how something evolves over time**. These belong to projection logic. Others describe **money entering or leaving a fund**, and these belong to cashflow logic. Some statements describe **interest or repayment**, and these belong to loan or investment logic. Certain assumptions specify **probabilities or expected outcomes**, which immediately signals an expected-value pattern. When the question asks to *test different assumptions*, the scenario and sensitivity family becomes involved. And when more than one of these signals appears at the same time, which is typical, the model becomes hybrid by design.

> At the start of the exam, the aim is to separate these families instead of mixing their logic. Once separated, they can be connected in a clean chain.

For example, a projected volume may become an inflow. A repayment schedule may sit inside a wider cashflow. A risk-based cost may be fed into a pricing calculation. The structure of each family stays simple, and the model works because each component is kept in its own section of the spreadsheet. This is exactly the kind of clarity encouraged by good modelling practice: separate inputs, separate calculations, and separate outputs, so the logic is easy for another actuary to follow.

A candidate who is able to recognise patterns early will not panic when assumptions look long or complex. Instead, they will see the familiar building blocks hidden inside the text. The apparent complexity is only a combination of simple parts. The **projection** still uses *value at time t equals value at time t-1 adjusted by growth*. The **cashflow** still uses *opening plus inflows minus outflows*. The **loan** still uses *opening balance, interest, repayment, closing balance*. The **pricing** still uses *frequency times severity plus costs*. The **scenario** still uses *same model, different inputs*.

Table 6.20: Recognising Model Patterns underlying structure required in the model

| Model Family | Keywords |
|---|---|
| Projection Models | Project, forecast, next year, growth rate, trend, seasonal |
| Cashflow Models | Opening balance, inflows, outflows, budget, surplus, deficit, fund sustainability |
| Loan, Repayment, and Investment Models | Interest, repayment, amortisation, contribution, target balance, accumulate |
| Pricing Models | Premium, expected claims, expenses, margin, cost per policy |
| Risk and Expected Value Models | Probability, likelihood, expected cost, weighted outcome |
| Scenario and Sensitivity Models | Base, high, low, stress, what-if, test assumptions, compare results |
| Hybrid Models | Any combination of the above in sequence (e.g., projection feeding cashflow, cashflow feeding scenario) |

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**Common patterns**: When reading the exam narrative, look for keywords that signal the model family needed. This helps in planning the structure and allocating time effectively.

- **Purpose**: the business problem the model addresses
- **Structure**: the typical layout and components of the model
- **Assumptions**: the common assumptions that underpin the model
- **Checks**: the validation steps to ensure model integrity
- **Examples**: references to past exam questions that illustrate the pattern

The synthesis is practical. Recognise the family, choose the workbook spine, then decide what can be simplified without losing the business answer.

Table 6.21: Fast recognition and workbook architecture summary

| Model family | How to recognise quickly | Workbook spine | Simplify by |
|---|---|---|---|
| Projection | Something changes through time. | Time axis, starting value, driver, projected values, output trend. | Using one clear driver unless the question requires more. |
| Cashflow | Money moves in and out of a fund. | Opening balance, inflows, outflows, interest if relevant, closing balance. | Keeping one sign convention and one reconciliation line. |
| Loan or investment | One balance is repaid or accumulated. | Opening balance, interest, payment or contribution, closing balance. | Stating timing and separating rate, payment, and target cells. |
| Pricing | A price, premium, charge, or adequacy result is needed. | Exposure, expected cost, expenses, margin, final price. | Avoiding extra pricing theory unless it changes the decision. |
| Risk and expected value | Outcomes have probabilities or weights. | Outcome, probability, consequence, weighted value, expected result. | Keeping probabilities and outcomes in a small transparent table. |
| Scenario and sensitivity | The question asks what changes under assumptions. | Scenario inputs, one calculation block, output comparison, movement. | Testing the most important drivers and ranking their effect. |

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| Model family | How to recognise quickly | Workbook spine | Simplify by |
|---|---|---|---|
| Hybrid | Two or more families appear in sequence. | Separate modules with labelled handovers. | Building the base chain first, then adding scenario controls. |

Table 6.22: Check and communication priorities by model family

| Model family | First check to prioritise | Communication priority |
|---|---|---|
| Projection | First projected value follows from the last actual value, and the horizon is consistent. | Explain the driver and whether the movement is plausible. |
| Cashflow | Opening plus inflows less outflows equals closing balance. | State sustainability, deficit point, or final balance clearly. |
| Loan or investment | Interest and payment timing are applied consistently. | Explain the target balance or accumulation result. |
| Pricing | Expected cost, expenses, and margin reconcile to the price. | Identify the key driver of adequacy or inadequacy. |
| Risk and expected value | Probabilities sum to one and the expected value is within the outcome range. | Communicate uncertainty, not false certainty. |
| Scenario and sensitivity | Only intended inputs change and scenario ordering is logical. | Describe the movement from base and the driver of that movement. |
| Hybrid | Each module works locally and handovers reconcile. | Explain the chain from assumption to final decision metric. |

Across all families, the same structural traps recur. Candidates lose control when assumptions are hidden in formulas, periods are inconsistent, signs are mixed, output tables do not answer the question, or scenarios are manually overwritten. The remedy is also consistent: keep assumptions visible, keep formulas copied consistently, keep checks next to the logic they test, and keep the final output tied to the business question.

This chapter stops at model-family recognition and workbook architecture. Chapter 7 builds on these foundations by showing how multiple model patterns can be combined into hybrid structures and applied to complete modelling tasks. Chapter 8 develops the full audit trail, Chapter 9 and Chapter 10 develop review-heavy Paper Two work, and Chapter 12 provides exam-day control.

## 6.4 Summary

Recognising common model patterns reduces uncertainty and improves execution under time pressure. Each pattern has a distinct purpose, a typical structure, a set of key assumptions,

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and a natural collection of checks. Strong candidates do not attempt to memorise complete solutions. Instead, they identify the underlying pattern, adapt it to the business problem, build it transparently, test it systematically, and communicate the results clearly. These patterns form the building blocks of actuarial models. The next chapter shows how they can be combined into integrated structures that reflect the complexity of real modelling assignments.

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