MS-E2177 – Seminar on Case Studies in Operations Research
Interim Report: State Treasury

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1 Changes in the project objectives and scope

Our overall objective remains unchanged: to build a simulation-based, decision-relevant framework to assess interest rate risk, refinancing/funding risk, and debt sustainability for the Finnish central government debt portfolio under macroeconomic uncertainty. The emphasis is still on transparency, interpretability, and decision-ready risk outputs. This scope is consistent with both the original case description and our initial project plan.

That said, we have made one practical refinement to the scope:

- **Derivatives module moved later in the pipeline.** While derivatives strategies remain a target deliverable, we will treat them as an extension on top of a validated baseline system (scenario model + debt cash-flow simulator). The interim focus is therefore on (i) producing coherent joint scenarios for rates and macro variables, and (ii) mapping those scenarios into debt service costs, refinancing needs, and debt-to-GDP dynamics.

This change is motivated by the "start small, keep it simple" principle in the plan: we want the core model to be robust and testable before adding more degrees of freedom.

2 Description of the project status (vs. the initial project plan)

Overall, the project is progressing largely according to the initial schedule in Figure 1 of the project plan, with the most work completed so far falling under *Framing the problem* and the early stages of *Formulating the model*.

2.1 Completed actions

- **Problem framing and client alignment:** We have aligned internally on the key output KPIs (debt-to-GDP fan charts, interest expenditure distributions, refinancing-need threshold breach probabilities) and on the modular architecture (scenario model + debt model). [**projplan**]
- **Data mapping and pipeline scaffolding:** We have specified the required time series inputs (selected maturity rates + macro indicators) and defined a data preparation checklist: frequency alignment, missing data handling, transformations, and consistency checks.
- **Exploratory statistical analysis (baseline calibration targets):** We have performed initial exploratory work to understand historical comovement: correlation matrices, preliminary principal components for the yield curve, and sanity checks on stylized facts (level/slope/curvature behavior). This supports the requirement that scenarios should reproduce interpretable joint dynamics rather than overfit individual series.

2.2 Current work (in progress)

- **Scenario model prototype:** We are implementing a baseline stochastic scenario generator for rates and macro variables. The first working version is designed to be simple and controllable: (1) produce realistic term structure moves (at least level + slope), (2) incorporate correlations with macro variables (GDP, inflation/deficit proxies), and (3) support stress overlays.
- **Debt cash-flow simulator prototype:** In parallel, we are building the debt model that maps scenario paths into: interest expenditure paths, refinancing needs (gross financing needs proxy), and debt stock dynamics. The goal is to compute distributions and tail-risk metrics under alternative issuance/refinancing rules.

- **Validation checklist:** We are drafting a validation plan covering backtesting against historical distributions, internal accounting identity checks, and sensitivity analysis on key parameters (mean reversion speed, volatility scaling, correlation stability).

2.3 Remaining work (next steps)

- Finalize **baseline scenario model** (versioned: MVP $\rightarrow$ improved with stress overlays).
- Finalize **cash-flow model** and produce the first end-to-end distributions and fan charts.
- Implement **strategy parameterization**: issuance/refinancing rules, maturity constraints, smoothing constraints.
- Add **optimization baseline** (initially coarse: grid search / simple objective; later more formal optimization).
- Produce **results narrative**: cost-risk trade-offs, robustness, and decision implications.
- Optional extension: **derivatives module** (interest rate swaps/caps as scenario-dependent overlays).

3 Two-Factor Vasicek Model: current status

The standard Vasicek model is a one-factor short-rate model in which the entire term structure is driven by a single state variable. While analytically convenient, a single factor is often too restrictive for practical yield curve modeling, since it struggles to capture both short-end dynamics and longer-term shape movements.

To address this limitation, we use a two-factor Vasicek model [1]. In this framework, the short rate is decomposed into two latent mean-reverting factors, which together generate a richer and more realistic term structure. Compared to the standard Vasicek model, the two-factor version is better suited for modeling the level and slope of the yield curve separately. Most importantly, the model is used not only to describe the short rate itself, but to produce the entire yield curve across different maturities.

3.1 Simulation approach

We simulate the factors using the exact discretization of the OU processes (not an Euler scheme). Correlated Gaussian shocks are generated via a Cholesky factor of the 2×2 correlation matrix. After simulating factor paths, zero-coupon prices are computed using the affine form above and converted into yields at selected maturities. The explicit update formulas for the exact discretization are standard and omitted here for brevity (see references).

3.2 Implementation structure

We have implemented this with python. Files are in our own Git project. There are parameter search code, model and example. Also for client we will create visual and graphical interface.

3.3 Current implementation status

The model and example are functional. The model simulates correlated OU factors with exact discretization, prices zero-coupon bonds via the affine closed form, and outputs yields across arbitrary maturities with optional DataFrame packaging. The parameter-search notebook is under active development to support view-consistent parameter selection rather than statistical estimation from market data.

3.4 Notes and references

For the affine pricing form, the Riccati equations, and exact-discretization formulas for OU processes in Gaussian short-rate models, see e.g.

- Brigo, D., Mercurio, F. (2006/2015). *Interest Rate Models: Theory and Practice.* Springer.

4 Possible changes to the initial project plan for the remainder of the project

We propose two adjustments to the remainder-of-project plan:

1. **Lock the end-to-end MVP earlier and time-box enhancements.** We will freeze a minimal end-to-end pipeline (scenarios → cash flows → risk outputs) before expanding model complexity. Concretely, we will treat the scenario model as a versioned component: *MVP (parsimonious factor model)* → *macro-linked dynamics* → *stress overlays.* This reduces integration risk and ensures we always have something demonstrable for client feedback.

2. **Shift optimization from "core" to "phase 2" if needed.** If computational/engineering overhead becomes binding, we will prioritize producing a credible decision framework (scenario distributions, tail risk, comparisons of a small set of strategies) and then add formal optimization as a final enhancement. This still matches the course and client value proposition.

If progress remains smooth, we will proceed as originally planned.

5 Updated risk management plan

We updated the risk register from the project plan to reflect current observations. The structure follows the course interim-report conventions (risk, likelihood, consequences, mitigation) and retains the original likelihood scale (Low/Medium/High).

Risk	**Likelihood**	**Consequences**	**Mitigation/preparing**
Data access delays / limited granularity (incl. NDA)	Medium (unchanged)	Delays calibration and validation; weaker credibility of conclusions.	Maintain synthetic/proxy pipeline; agree early on minimal data subset; validate aggregates with client checkpoints.
Data quality / inconsistencies in legacy cash flows	Medium (unchanged)	Incorrect refinancing needs and interest cost outputs; invalid comparisons across strategies.	Reconciliation against known totals; unit tests for cash-flow identities; incremental integration (small cases first).
Model risk / misspecification (scenario dynamics, correlations)	High (unchanged)	Misleading tail-risk estimates and wrong strategy ranking.	Use multiple scenario specifications (baseline + stress overlays); sensitivity analysis; benchmark vs. stylized facts; document assumptions clearly.
Computational tractability (scenario size / instability)	Medium (slightly increased)	Too slow to iterate; limited experiments; difficulty adding optimization.	Start with coarse scenarios; reduce dimensionality (factors/PCA); cache intermediate results; keep optimization as phase 2 if needed.
Execution feasibility not reflected (issuance constraints / market capacity)	Medium (unchanged)	Recommendations not implementable by the client.	Encode feasibility constraints early (issuance bounds, maturity smoothing); incorporate client rules of thumb; label infeasible regions explicitly.
Interpretation risk (outputs too technical)	Medium (unchanged)	Insights not used; weak narrative in final report.	Use decision KPIs: fan charts, breach probabilities, cost-risk frontier; provide "plain language" takeaways and concise strategy summaries.
New: Integration risk between modules	Medium	End-to-end pipeline breaks late; rework needed close to deadline.	Lock MVP early; continuous integration in shared repo, weekly "full run" even if coarse, versioned interfaces.
New: Over-extension (too many model variants)	Medium	Fragmented effort, shallow validation, unclear final recommendation.	Time-box variants; maintain a backlog, prioritize variants that change decisions (tail risk / constraints), not cosmetic realism.
New: NDA breaches	Very Low	Possible Juridical consicuences.	Everyone take this seriously.

Table 1: Updated risk management plan (changes relative to the initial project plan).

References

[1] Steven E. Shreve. *Stochastic Calculus for Finance. 2, Continuous-Time Models*. eng. Springer finance. New York: Springer Vlg, 2004. ISBN: 0-387-40101-6.