Combining System Dynamics and Asset-Liability Management in Pension Funds[1]

Ricardo Matos Chaim

University of Brasília; DATAPREV; Fundação Getúlio Vargas
SAS Q. 02, bloco E/F, 1º andar
70.000-000 Brasília-DF Brazil
Phone: ++55(61)3313 - 3171/9273-1863/3346-6172
rmchaim1@yahoo.com.br

Abstract

System dynamics (SD) may amplify asset and liability management (ALM) methodology capability to be risk oriented. Therefore, this paper aims to apply SD principles to ALM models, in the specific case of pension funds. Conceptual issues assigned to ALM variables are described and a dynamic ALM approach, based on SD general principles and risk factors, is then examined.

Risk must be defined in tangible operational terms. Pension funds need to produce a high-income return to correspond to actuarial expectations and to pay different kind of benefits. Its underlying assets non-financial nature and long-term liabilities dictate the nature of risk management. In a changing and complex environment, pension funds wealth management need a more robust investment allocation approach, than the static mean-variance analysis. In this context, ALM may provide some advantages.

Finally, since decisions under uncertainty become complex specially because of the low comprehension of system long term best interests as a whole, system dynamics methods may provide an holistic overview to the ALM analysis results. The combination may improve the managers ability to explicit tacit knowledge, understand complexity and design better operating policies enhancing, this way, the discussions and learning about businesses strategies.

Key words: system dynamics; asset/liability management(ALM); ALM risk management; social security; risk factors models; pension funds

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Introduction

ALM is a balance-sheet oriented approach and system dynamics may amplify its capability to better manage risk factors. Risk must be defined in tangible operational terms. In a changing and complex environment, Pension Funds wealth management need a more robust investment allocation approach, than the static mean-variance analysis. In this context, ALM may provide some advantages. The primary contribution of this paper is to detail ALM variables using SD principles.
Since decisions under uncertainty become complex, specially because the low comprehension of system long term best interests as a whole, system dynamics methods may provide an holistic overview to the analysis of ALM results. The combination may improve the managers ability to explicit tacit knowledge, understand complexity and design better operating policies enhancing, this way, the discussions and learning about businesses strategies.

To place the issues into perspective, this paper is organized into five sections. Social security stated as a policy with inherent risks associated is first observed. Next, concepts about risk management and asset liability management followed by a dynamic approach of ALM using some SD propositions is examined. Last in the conclusion with summary comments about some risks factors that may be treated by an ALM SD approach.

1 Context - Social Security and Pension Funds

The Social Security policy is considered an efficient way to promote social transfers and thus promote social justice and welfare. It must protect workers and their families against social risks like sickness, incapacity, death, involuntary unemployment, advanced age, maternity and prison. Current trend regarding social security systems is the shift from pay-as-you-go schemes to funded schemes.

In Brazil, a complementary private pension entity is authorized to administrate pension-based defined benefit (DB) or defined contribution (DC) benefit plans. They are controlled by specific legislation, chiefly by Complementary Acts 108 and 109, Resolution 3.121 of the National Monetary Council (CMN) and other rules issued by the Complementary Pension Secretariat (SPC) and by the Complementary Pension Management Council (CGPC). Specially during the last decade, pension funds in Brazil are a growing segment of more than US$ 146 billion (feb/2006) and shared interests among different segments of the Brazilian economy (given the total invested capital and the great quantity of participants).

As a non-financial institution and with non speculative nature, assets and liabilities management is different than those of financial institutions. So is the risk management. DAS (1997, p. 551) points out the underlying assets as “real assets, such as properties, plant and equipment, intangible assets such as goodwill

(surplus on acquisition), intellectual property and brand names, as well as financial assets in the form of equity or other investments". For workers and corporations who pay contributions to a pension fund, the liabilities may be linked to pensions released when of the workers retirement. This long-term nature of financial assets implies many risks that must be dealed.

These are inherent risks to benefit plans and represent its liabilities. Its mission is to structure many investment policies looking for an optimal allocation strategy and to act seeking sustained growth and a socially responsible behaviour. Their complex goal is to offer benefit plans and obtain an adequate income return to maintain an actuarial equilibrium.

2 Risk Management

As defined by CTPA (2001),

> risk management is not new in fundamental concepts although as a specialist management approach or process it is still developing. Over the last few years, it has become increasingly preferred by organizations to assist them in reducing risk exposures to new products, advanced technologies and global market competition, and to enable them to allocate and use their scarce resources as efficiently and effectively as possible.

The term 'risk management' can be somewhat misleading as 'management' tends to imply some ability to influence or 'control' events and this is not always the case. In reality risk management is a formal process whereby risk factors for a particular context are systematically identified, analysed, assessed, ranked and provided for. It is a proactive, systematic analysis of possible events and responses to them rather than a mere reaction mechanism to those limited events that are detected. It is about managing the future rather than administering past events.

Das (1997, p. 548) lists several factors to the increased focus on risk management:

- the deregulation of financial markets;
- the increasing role of securities and derivative products in financial intermediation;
- the increase in the risk profile of organizations, with increased emphasis on activities which require the assumption of risk, deliberately;
- the volatility of markets and its impact on financial institutions;
- the pressure from capital market investors for returns related to the relative riskiness of their investments; and
- the regulatory requirements for a risk management framework.

Financial risk management includes the assumption, management and pricing of different classes of risks: credit, market, liquidity and operational. DAS (1997, p. 547) defines each of them:

- credit risk: refers to the risk of loss arising from the default of the counterparty, i.e. the failure to honour and meet its legal obligation;

- market risks: refers to the risk of loss sustained as a result of changes in the values of market prices or factors used to value financial instruments;

- liquidity risk: refers to the risk of loss arising from either inability to make payments or the inability to re-finance obligations as and when they mature or the inability to re-finance at anticipated rates;

- operational risk: refers to the risk of loss from a broad range of risks including: operational (processing failure); technology (systems failure); legal (non unenforceability of contracts); and regulatory (breach of regulatory requirements).

Financial activity is a set of processes to assure asset-liability equilibrium. It should be stressed that no transaction should be affected when in disagreement with the corporate purposes. Since a pension fund is a service organization, the goal of risk management will be to protect business present value against individual risk factors (reputation/image, market volatility, solvency, liquidity and credit) in order to maintain a good client perception.

3 Asset/Liability Management (ALM)

Much attention has been paid to ALM for pension funds. A balance-sheet oriented methodology can help managers to better known the debt structure, the comprehension of the business expand, the results of assets allocations and the wealth of the company. Balance sheets allow them to identify and analyze trends. “It affects the entire scope of the operations including lending, marketing, product pricing, investment analysis, cash management, internal controls and data processing”. (LEE, 2005).

Pension funds have to decide periodically how to allocate the investments over different asset classes and what the contribution rate should be in order to fund its liabilities. Because of its long term obligations, Pension Funds’ planning horizon is large. The solvency of the fund must be guaranteed by acceptable investment and contribution policies. The process requires a great amount of information about the organization, its operations and market performance. It comprises: (1) better understand the wealth of the organization by evaluating balance sheet; (2)

executing actions to control credit, liquidity and market risks (3) based on statistical and mathematical methods, predict, forecast or foresee how the future should be or define a finite number of scenarios to model uncertainty.

In a deterministic way, ALM is always combined to one or more mean-variance models or techniques to quantify financial risks: Markowitz portfolio theory, Capital Asset Pricing Model (CAPM), Asset Pricing Teory (APT), Value at risk - V@r, Sharpe, Duration and many others. Generally attempting to predict the future based on past behavior or to take the present value of a future position, they try to know more about time series and thus mitigate uncertainty.

A stochastic programming model for the ALM process of a pension fund is dynamic since the information on the actual value of uncertain parameters is revealed in stages. For Drijver, Haneveld & Vlerk (2002), it is assumed that:

(1) Because of the risks of underfunding, decisions on asset mix, contribution rate and remedial contributions are made once a year;
(2) Uncertainty is modeled through a finite number of scenarios given by a scenario tree. Each scenario demands a complete set of decision variables at each time period:
    - Total asset value
    - The portfolio market value given the value of investments in each asset class
    - Total value of liabilities

Cariño et al (1994) proposed a multistage stochastic dynamic ALM model which includes stochastic controls and shortfall penalties. Also, techniques like brownian motion have been used in search of better results (KAUFMANN, 2005).
Boulier(1996) considers that “stock returns are uncertain in efficient markets, so stochastic control would help in finding the optimal investment policy, as well as the adequate level of contribution” (CARIÑO et al 1994). Kaufmann (2005) used stochastic volatility models with jumps to estimate quartiles of financial risks for two week period.

Due to uncertainty, its difficult to quantify risk, specially in some special cases. This way, Aderbi, Nordio & Sirtori (2006) studied the properties of expected shortfall from the point of view of financial risk management. “As a measure for assessing the financial risks of a portfolio”, they conclude that “expected shortfall appears as a natural choice to resort to when v@r is unable to distinguish between portfolios with different riskiness” (ADERBI, NORDIO & SIRTORI, 2006). Expected shortfall may be defined as “the average loss when value-at-risk is exceeded” giving “information about frequency and size of large losses” (KAUFMANN, 2005).

4 Dynamic ALM in Pension Funds

Boulier (1996) states that “portfolio management and the contributions scheme are clearly interdependent”. Causal loops relations may represent the uncertainty and may predict the impact of each of it in the system as a whole. The use of system dynamics in combination with asset-liability management model (ALM) represents an opportunity to amplify its capability to become risk oriented. Thus, macroeconomics, biometrics and actuarial class of variables must be holisticly considered and allowing the model to incorporate risk factors and constraints (shortfalls).

Risk factors attempt to maximize the benefit or minimize the loss for the amount of uncertainty assumed. There are many actions based on a forward-looking statement that involves risk and uncertainty. The risk factor may be related to a particular pension fund or to the segment as a whole. Risk analysis may differ to risk management because the latter must consider the inter-relationships among operations, investments and financing, each carries risks alone: operations drive revenue and expense; investments assure wealth growth, discounted costs; and, financing are related to how the organization is capitalized and how to manage market risks.

Risk, risk analysis and risk management are different and inter-related concepts. The former need to identify and detail the events and their impact over the organization. The second need to quantify their impacts over business and use historical information, scenarios analysis and previous behavior to estimate it and predict future consequences. The latter, require plans and discussions by decision makers about business strategic perspective. Therefore, it is important to consider:

- It’s necessary to structure many dynamic hypothesis based on risk events. They must be modeled as causal loops to better predict their impact over the system and to encourage people to identify the elements of dynamic complexity normally absent from mental models;

- The liabilities and shortfalls must be managed. The structure of the system (and thus their behavior) must be represented in SD mental model. Shortfall means controls over the uncertainty and a way to control variances. By computing the amounts out of the estimates, they act like constraints imposed to the model and become a way to quantify it;

- The scenarios must consider the complexity of the system and their implications. SD simulations may be a good way to determine the probabilities and to test their impact over a quantified risk factor.

As stated by (SANTOS, 1992),

> to use computational based models it is necessary to define world in terms of variables ... “To imagine the world in terms of variables, to understand rates of change, to think at a system level and to understand causation in a system.

Thus, figure 1 shows the dynamic of implementing new benefit plans. Each new participant represents a deposit income. The future cash flow must be projected and is associated with each account. The liability management decisions must consider the uncertain outcomes of events relevant to the company's business environment: regulation, multiple accounts, multiple horizons for different goals, provisions for end effects, the uncertainty of future assets and liabilities.

Asset Liability Risk Management Causal Loop Flow

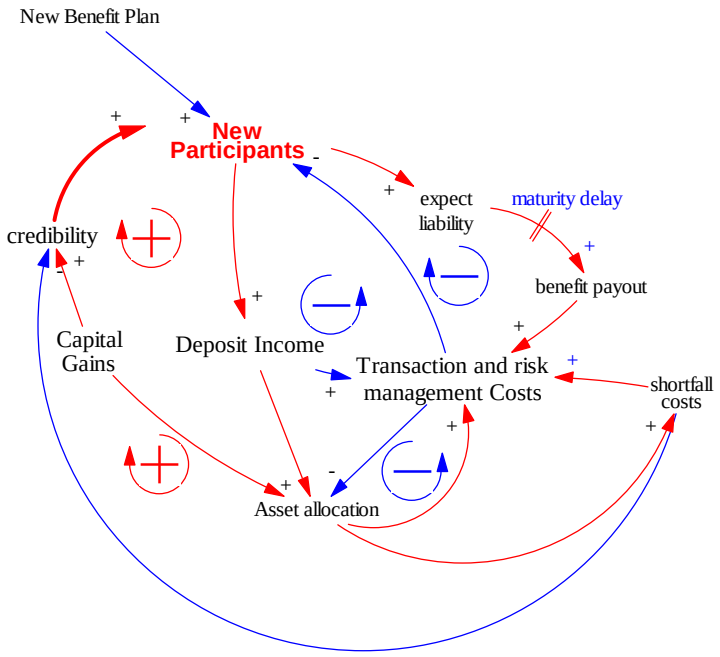
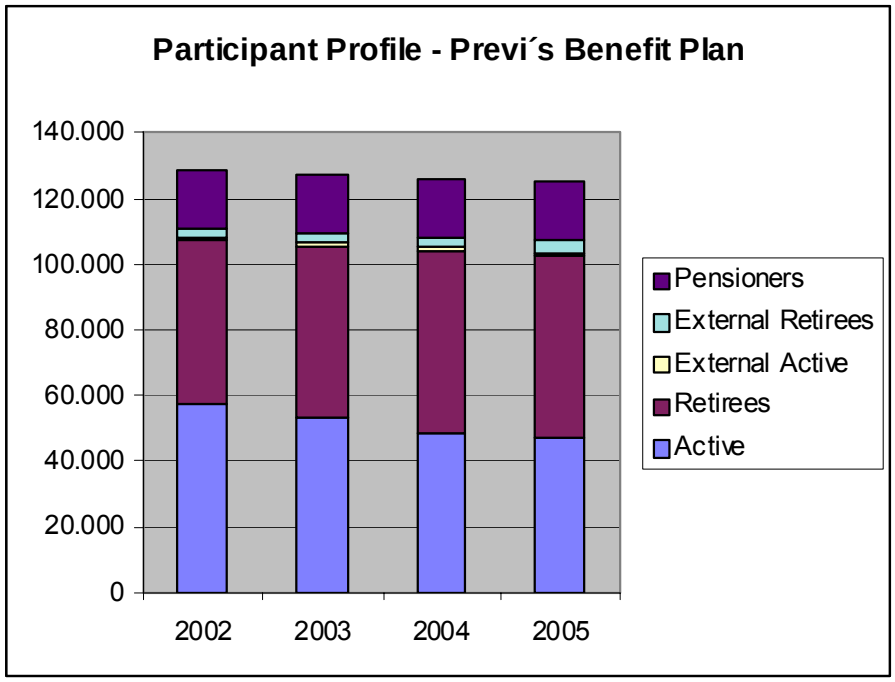


Figure 1: The dynamic of implementing new benefit plans

Loop (1) and (2) reflect exponential growth and represent the expected Pension Funds` power of accumulating income over time. If the asset allocation is not efficient it can generate less capital gains which may affect the pension fund credibility.

The better and the more pro-active a risk management program is, the better the asset allocation, which implies in more credibility to the pension fund. The worst it is, more costs it may generate, affecting credibility. Fewer participants mean less wealth.



Graph 1: Participant profile of Previ's benefit plan 1
Source: Based on information available at www.previ.com.br

There are many particular risk factors that explain the system behavior since a defined benefit plan reaches maturity, as shown in graph 1. As the number of acitve participants decrease and pension paymentes increase, it becomes more important to hedge against liquidity risks. The complexity of maintaining the Pension Fund solvency in this stage implies to obtain more interest return. ALM served an important role in eliciting requirements to better elaborate benefit and investment plans' or to review the predictions underlying choice preferences. It had a significant impact on the structure and parameterization of the final simulation model.

The difference between defined contribution and defined benefit plans is the lower cost of the former because of losses sharing among participants. There are many risk factors for each of these situations. SD methods may aid to simulate these particularities.

4.1 Model specification

The model represents Pension Funds' mission expressed by Boulier et al (1996) as an important principle: "Workers and sponsors' pay contributions to a pension fund, which invests them over a very long period of time and releases them when the workers retire, in the form of pensions". According to Cariño et al (1994), it was possible to detail the variables of the stock and flow diagram (figure 2) which may incorporate risks restrictions by shortfalls penalities:

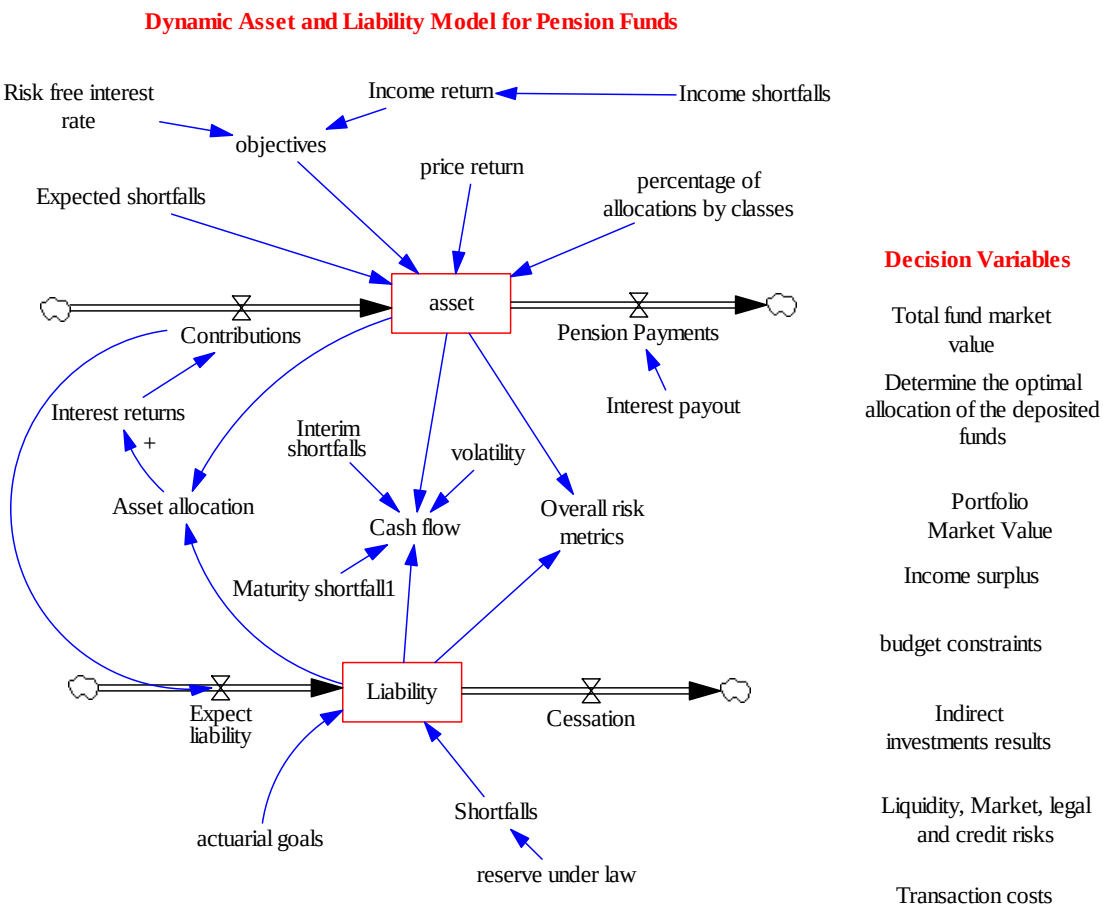


Figure 2: Stock and flow diagram including risks restrictions
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The variables can be defined as follows:

1 Asset: subdivided into current or short-term and long-term. The management of pension funds encompasses asset allocation and control the future flows of contributions. The basic role is to invest these deposited funds to earn return from which to pay the maturity refunds. The policy allocation's return is simulated to check income goals and solvency or reserve requirements. It tested the allocation's performance against the goals by comparing the probability of missing them with a minimum allowable probability of failure. If a particular asset allocation policy did not meet a minimum-probability-of-failure level, then another policy may be tested on the efficient frontier. The risk depends on the portfolio characteristics. It is a level variable because it grows with the deposit income and interest returns and decrease with pension payments

2 Price return: A stochastic programming model requires scenarios of the possible paths of stochastic elements. The random elements of the model include price and income returns for all of the asset classes as well as policy crediting rates. Creation of scenario inputs is analogous to creation of means, variances, and correlations

for a mean-variance model. They are an expression of the decision maker's probability beliefs. The problems of creating good scenario inputs are not unique to the stochastic programming approach. They are essentially the same problems as those of forecasting asset returns for any asset allocation method.

3 Percentage of asset allocation by class: The various accounts are inter-related because of regulatory restrictions on allocation for different assets' classes that extend across accounts.

4 Objectives: A useful asset/liability model would have to be able to balance the dual objectives of high income return to maintain and attract policyholders with the firm's desire to maximize its underlying capital. The objective of the model is to maximize the firm expected market value at a defined date less accumulated penalties for shortfalls of various types, while taking into account end effects. The use of shortfall costs to characterize risk allows more tangible expression of risks decision makers feel they actually face, than does the traditional risk measures (total return variance).

5 Risk free interest rate: We may consider in Brazil a CD-indexed rate for fixed income;

6 Income return: The total return.

7 Income shortfalls: Income earned in a year must be greater than or equal to the interest credited. It is used to apply penalty costs in the objective function

8 Expected shortfalls: The penalty costs of shortfalls may be based either on the firm expected financial impact for missing a goal or on psychological costs. The financial consequences might include higher borrowing costs if there is a downgrade on credit rating or the loss of policyholder confidence. Psychological costs may be tied more to management's beliefs on how the firm should be run - how conservatively.

9 Liability: Pension fund has three sources of funding its liabilities: revenues from its asset portfolio, regular contributions and remedial contributions if the value of the assets is too low compared to the value of the liabilities. Liability management decisions must consider the uncertain outcomes of events relevant to the company's business environments: regulation, multiple accounts, multiple horizons for different goals, provisions for end effects, the uncertainties of future assets and liabilities. In a stochastic world, credit ratings are uncertain since they depend on market conditions; new policy sales can also be uncertain. We cannot say with certainty what future cash flows or balances might be. We can, however, calculate projected liability cash flows and balances under various scenarios; liability variables are scenario dependent. One major module of the system computes these scenario-dependent cash flows and balances, aggregated over all benefit plans.

10 Actuarial goals: Biometric, demographic and the plan equilibrium are checked by these set of constraints. It represents the evolution of the mass of participants over time.

11 Shortfalls: Income shortfall constraints. There are mean-variance models that measure risk as return volatility, as less appropriate for pension fund's planning activities than shortfall models, which measure risk as the cost of falling below given return target. Shortfall models specifically address the desire for positively skewed distributions and more accurately reflect investors' aims.

12 Reserve under law: used to measure the amount by which total asset values falls below total liability values. Losses of principal due to market value fluctuations are may be deducted. Reserve of shortfalls is penalized.

13 Maturity shortfall: Results of duration and convexity studies about the liabilities to ensure that maturity cash flows are met.

14 Cash flow: a trend in actuarial finance is to combine technical risk with interest rate risk. Because interest rates are uncertain, one than must considers several scenarios for this cash flow and often uses simulations to model them. ALM techniques include simulation of cash-flows of obligations (claims to be paid) and investments. ALM can synchronize the cash flows of assets with liabilities over time, the projections consider the future premium income and the future payments (GOOVAERTS and KAAS, 2002). The objective of the model is to allocate fund value among available assets to maximize expected wealth at the end of the planning horizon t less expected penalized shortfalls accumulated throughout the planning horizon (CARIÑO et al, 1994).

15 Overall risk metrics: Liability balances and cash flows are computed so as to satisfy the liability accumulation relations

16 Interim shortfalls: In addition to ensuring that the maturity cash flows are met, the firm must seek to minimize interim shortfalls in income earned versus interest credited. Such shortfalls can have regulatory as well as market impacts on the company. In fact, it is the risk of not earning adequate income every quarter that more concerns decision makers. If decision makers were assured that, with certainty, adequate income could be achieved, then they would invest in a more efficient way, ignoring total return volatility.

17 Volatility: total return volatility as a measure of risk bears little resemblance to the risks that decision makers felt they actually faced.

DECISION VARIABLES

18 One-stage risk: The risk of underfunding at time t+1measured in a way to be described. Pension fund management specifies a maximum acceptable value for the one-stage risk. It's a risk based on the funding ratio, in such a way that values

below this parameter “are considered to be risky; they should be avoided if possible” (DRIJVER, HANEVELD & VLERK, 2002).

19 Total fund market value: The stochastic linear programming model (the base problem) has uncertainty in many coefficients; this uncertainty is modeled through scenarios. Given that each scenario has a discrete probability of occurrence for any finite horizon, the stochastic linear program is equivalently represented by a large deterministic linear program in extensive form called the grand linear program. In an ongoing business, its true situation might be modeled as an infinite horizon problem. Given the size of the problem induced by many variables and scenarios, it is not practical to solve the infinite horizon problem directly; a modeler must use an approximation. One approach is to simply truncate the problem at a finite horizon.

20 Determine the optimal allocation of the deposited funds: Since we can revise the portfolio allocations over time, the decision we make is not just among allocations today but among allocation strategies over time.

21 Portfolio market value: assets value.

22 Income surplus: The current ratio measures how liquid a company is and its ability to pay short-term obligations. It is calculated by dividing current assets by current liabilities. The debt to equity ratio measures how much debt a company has compared to the amount of equity. It indicates what proportion of debt a company has relative to equity and is calculated by dividing total debts by equity.
These ratios are derived from the income statement and the balance sheet at an exact point in time. They are not indicative of the health of the company. They just indicate potential problems. Ratios out of normal ranges should be treated the same as when the income statement is over or under budget and that means that something wrong is happening. In a stochastic control it is just the time to alter the decisions the scenarios pre-determined. These measures are used to apply shortfalls penalties over the SD model.

23 Budget constraints: any budget constraints to the model

24 Indirect investments results: results with loans interests or others.

A key feature of dynamic systems is the ability to do multiple simulations on a model under different conditions, test the impact of different policies and predict the side effects and the reactions provoked by many decisions over the system. Although that was not an aspect explored in this article, it is possible to consider a model enhancement that would permit the generation of an efficient set of alternate balance sheets. It will be possible to explore the price of risk associated with the trade-off between investment and underwriting opportunities. Regulators, by contrast, would be able to observe useful information about the firm's ability to mediate risky managerial decisions and risky economic environments.

24 Liquidity, market, legal and credit risks: Constraints varying by the actual stage of the plan, if it is on the accumulation phase or in maturity phase.

25 Transaction costs: The costs to maintain the benefit plan.

All of these variables are useful for a precise decision making process where ALM generally imply difficult communication to stakeholders. ALM and SD may add value to both risk analysts and decision makers. So, to be useful, a SD model must represent the actual stage of the plan. It must consider the risks governing different stages over the plan's maturity. Table 1 illustrates these stages and the correspondent risk factors.

Table 1: Inherent risks by maturity stage of a benefit plan

PF phase	Decisions drivers	Inherent Risk Factors	Typical Actions
Accumulation	↑Strategic asset allocation	↑ High-income (market risks); ↓ low-solvency (liquidity risks) ↑ Higher returns	- A portfolio with more risky assets is structured because the need of credibility and participants expectations; - Interest on new adhesions to reduce costs and get more income. - Loans and other facilities to add value to participants
Maturity	(Strategic asset allocation Punctual payments	↓ low-income (market risks); ↑high-solvency (liquidity risks) ↓ lower returns	- A portfolio with less risky assets is structured to assure liquid yields to pay liabilities; - The adhesions generally are closed; - The loans follow a historical behavior to maintain credibility and continue being atractive
All stages	Authorize new benefits plan Better manage the assets Low Costs Good Solvency Higher yields	- Legal risks: out of the limits fixed by the regulation - Compliance - Legal obligations and schedule - Bad corporative governance Reducing transaction costs	- Market monitoring - Actuarial assessments - Emphasis on actuarial constraints and the plan equilibrium. - A program to maintain good internal controls is desirable to assure better corporate governance Economies of scale through volume of transactions and controlling the information flow to better decide and act accordingly the needs.

Table 1: Inherent risks by maturity stage of a benefit plan

5 Conclusions

The mathematical relations among dynamic asset and liability model variables must consider different risks according to different maturity stages of a pension fund.

Because most decisions are made without advance knowledge of their consequences, it is sometimes still difficult to a manager to obtain precise information on the right timing at a low cost. This way, heuristics have been made based on tacit business knowledge.

As we see, causal thinking may be used to identify risk factors and quantify their impacts on the system. The basic modes of behavior in system dynamics like exponential growth, goal seeking, and oscillations created by positive or negative feedback with time delays or not, are potential sources of risk that may be considered in an ALM analysis, amplifying it capability to be not just balance-sheet but also a risk oriented approach.

Since the decisions under uncertainty become complex, specially because the low comprehension of the long term best interests of the system as a whole, it is possible to say that ALM combined to SD methods is useful to provide an holistic overview to the analysis of ALM results. Thus ALM may help managers to improve their skills to consider complex, driving the formulation of better business strategies.

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