PENSION SYSTEM DYNAMICS MODELLING, POLICY DESIGN AND RISK ANALYSIS

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Abstract
The paper develops a hypothesis that some risk elements and gaps of national and public pension system come from typical mental models, system’s archetypes and patterns of behaviours, as a result of many demographic, macroeconomic, financial, political and global factors, particularly closed loop feedback relations with delays and amplifications. There are important messages in the paper for social insurance policies design, structures and management, the meaning of data mining and collection, and for model refinement with modelling approaches in a systems’ thinking way. The shortcomings of national social insurance systems in dealing more effectively with upstream social insurance risk prevention in population are systemic, and include also a failure to empower members of population and involve them in their own, entrepreneurial downstream care. The paper contains a system dynamics point of view, as a method of macroscopic, continuous simulation modelling, to surface and explain some cycles and discrepancies between demography, management policies, system’s aspects of national social insurance, particularly pension system. The conceptual and simulation model presented in the paper, followed by experiments’ results, uses SD method approach with causal loop diagrams (CLD) and stock-and-flow diagrams (SFD), displaying delays, amplifications and structure cycle dynamics in national pension system. Further research should concentrate on the detailed analysis of additional modelling requirements in order to conduct more profound multi-factor experiments to forecast and evaluate contemporary national politics, and to test some new assumptions in social insurance.

Keywords: pension system, simulation, social insurance, system dynamics.

JEL codes: H55, J32, G20.

1. Introduction
The basic factors influencing the ageing population are fertility and birth rate decline and increasing life expectancies. Generally, people are expected to live up until 74 years in 2045-2050 while in developed countries, life expectancy will rise to 82 years (according to the data from “The Population Division of the United Nation Secretariat” 2003). In a country like Poland, being classified between developing and developed countries, population of people aged 60 years and above in total population was 15,7% in 1995, and is expected to increase to 23,6% by the year 2020 and is estimated to increase to 24,7% by the year 2025, while life expectancy for ageing population increased to 73,6 years for males and 81,6
years for females in the year 2015 (GUS 2016). In terms of coefficients of: demographic age, work activity, work resource ageing, work resource load, “early pensioners” and generations replacement, even some forecasts for Poland seem to be more optimistic, than for all EU countries (as averages), generally the process of ageing population is a progressive process. These demographic trends are believed to exert pressure on the public pension system as well as have a major impact on governmental social and economic policies. For these reasons, pension has become one of the most important issues for the policy makers where in most countries pension spending is projected to grow substantially subject to the increased number of retirees. The ageing population also creates concerns on the dynamic, and particularly sustainability of the public pension systems.

Most countries are reforming their pension systems with the intention that the pension system will continuously and in a sustainable way function to provide the pensions to the retired people (Balcerowicz-Szkutnik et al. 2010). Poland is also confronting the same phenomena when the public pension system reform was developed in 1998 and implemented in 1999 (Iglicka 2017, pp. 1-4). Now some pension system modifications are still being implemented (Matyjaszczuk 2016, pp. 61-76), as contemporary changes in the second (OFE) pillar (e.g. premium decrease, new rules of investments, new accounting procedures, voluntary access), consolidation of the first (ZUS) and second (OFE) pillar, decreasing and unifying retirement age for males and females, development new offers for third pillar (e.g. IKZE investment), and development of supplementary pension scheme (Jedynak 2016, pp. 34-48). Also some new political ideas and concepts are being discussed and suggested, as “citizen retirement” pension system proposal (no premium and pensions financed by central budget), “repartition-alimentary” pension system proposal by Koliber organisation (pensions financed by central budget and 3-pillar system based on social “citizen retirement”, pro-demographic bonus motivation benefits caused by children alimentation, and capital investments), and “pension savings account” (EKO) proposal by Polish Financial Supervisory Commission (KNF) – as governmental institution (new third pillar based on individual and employer 3-partition premium payment with some tax benefits), some professions’ retirement privileges elimination (e.g. retirement in mining, agriculture, military-police-custom services, judicature), and differentiation of pension system for males and females proposal by a popular party (PSL) - an agriculture political party (family status influence with increase of premium-payment periods by non-premium-payment periods for females having children).

Due to demographic and economic changes and increasing pension expenditures, pension systems around the world (not only in Poland) are in volatile condition. This condition is caused not only by many uncertainties or inherent risk that affects the pension systems, but also by the specific dynamic pension system features, mainly determined by system’s structure (“structure drives behaviour” paradigm). The existence of risks and structure specific features will also affect the national pension system expenditure. Among the risks that the national policy (polities) makers in public social insurance are exposed to, are demographic risk,
economic growth risk, financial market risk, national budget as subsidy source risk (Bednarczyk and Raszewski 2017, pp. 13-19), salary risk, and ironically saying even a “political risk” (in a context of next elections to parliament). This research focuses on only demographic and some selected economic risks (particularly GNP growth and average salary level). Demographic risk is always defined as the increasing risk due to population ageing while salary risk refers to the salary growth affecting the premium payments and cost of providing pension benefits, as social indemnity payment. And still there is an issue, how will the risk and pension system structure influence the pension system functioning? The complex phenomenon of demographic (particularly ageing structure and dynamics) and economic (particularly gross national product GNP and average individual salary) changes in a public (national) pension system performance involve numerous factors which are inter-connected in different directions. Therefore, this study attempts to develop a dynamic generic and archetype (rather a synthetic one) pension system model with social policy design factors, which analyses pension expenditure as a result of some demographic and economic risk. Finally, after next-step calibrations of the model (with the up-to-date precise statistics of Polish pension system indicators) some short, and long-range forecasts and rough verifications of “worst-case” scenario will be possible.

2. Research method

For the research purpose, a dynamic, continuous simulation policy design model of Polish public pension system is developed with an application of System Dynamics (SD) method. This method, originated by J.W. Forrester (Forrester 1961), is belonging to systems thinking and macroscopic continuous simulation modelling methodologies, and also risk analysis and management approach by scenario testing is to be applied. The main focus of this modelling research is to analyse pension system dynamic features, particularly in terms of costs and expenditures as a result of demographic and economic factors. It also includes a proposal of pension system archetype (or generic) structure and assumptions used for the pension system expenditures’ forecasts. Cause-effect and causal-loop relations (as influence and structure diagrams), quantitative SD models of these (as a set of mathematical differential equations translated into Vensim PLE simulation modelling package notation and as a simulator interface), and some selected results of simulation one-, and multi-factor experiments are presented.

2.1. System Dynamics simulation of pension system

The System Dynamics method relies extensively on system’s structure (particularly feedback loops and delays) in order to analyse and explain how system structure drives behaviour and leads to particular patterns of behaviour. Even some formal methods are being developed for an analysis of “structure-behaviour” relation (e.g. loop polarity dominance, behavioural analysis for loop dominance, pathway participation metrics, graph theory measurements), still practical analysis by simulation modelling and one- and
multi-factor experimenting have largely been restricted to laboratory simple examples as guides to intuition. In social pension systems’ SD modelling and analysis practice, large-scale models with many loops are still analysed in a largely informal way, using trial-and-error simulation (Sapiri at al 2014, pp. 1450046-1:24). Although this is not a weakness, any formal tool that might help identify important structures in the model as they affect a particular mode of behaviour could be of enormous utility, particularly in large models trying to map complexity relations in social systems (Pictroń 2014, pp. 301-320). System dynamics applied to pension system research can be interpreted as a systems thinking approach and a branch of management science, which deals with the dynamics, and controllability of managed pension systems. SD method implementation in business and organisation systems’ modelling and analysis usually focuses and addresses on the following basic research issues:

- circumstances in a system to use different policies in order to control its behaviour as time passes and circumstances change;
- system’s policies design to become robust against change and ability to create and exploit opportunities and avoid, or defend itself against, setbacks;
- information feedback structure design to ensure that effective policies become possible.

The basic viewpoint and associated methodologies of SD approach require a definition of a ‘system’. Pension system is a collection of parts organised for a purpose, and this system may also fail to achieve its purpose. Knowledge acquisition, system activities, decision making choices and learning consequences of choices need time – there are 3 delays (Fig. 1) in: data and information mining and acquisition to develop knowledge (basically national demographic and economic statistics), governmental and individual activities in making decisions (social insurance, economic acts and regulations made by parliament and government, individual personal life decisions made by individuals and employers), and experiencing consequences of decisions in a pension system state.

![Diagram](image)

**Fig. 1.** The information/action/consequences paradigm of System Dynamics
Source: author's own elaboration.

SD method of system modelling allows to analyse a managed pension system so as to:

- model the ways in which its information, action and consequences components interact to generate dynamic behaviour;
- diagnose the causes of faulty behaviour;
- tune its feedback loops to get better behaviour.
The first stage (Fig. 2) in SD application to pension system modelling is to recognize the problem and to find out which people care about it, and why. It is rare for the right answers to be found at this stage, and one of the attractive features of SD as a management science methodology is that one is often led to re-examine the problem that one is attempting to solve. Secondly, and the first stage in SD as such, comes the description of the pension system by means of an influence diagram, sometimes referred to as a “causal loop diagram” (CLD) or “cause-effect diagram”. This is a diagram of the forces at work in the system, which appear to be connected to the phenomena underlying people's concerns about it. Influence diagrams are constructed following well-established techniques – basically “least-extension” technique. Having developed an initial diagram, attention moves to Stage 3, ‘qualitative analysis’. The term simply means looking closely at the influence diagram in the hope of understanding the problem better. This is, in practical SD, a most important stage, which often leads to significant results (sometimes it is the end of modelling project). If qualitative analysis does not produce enough insight to solve the problem, work proceeds to Stage 4, the construction of a simulation model. At this stage, we exploit the important property that the influence diagram can be drawn at different levels of aggregation. It is usually not even necessary to show every single detail, because, if the influence diagram has been properly drawn, the simulation model can be written from it without a separate stage of flow-charting. Stage 5 is where results based on quantitative analysis start to emerge. Initially, use is made of the insights from the bright ideas and pet theories from qualitative analysis. This stage represents exploratory modelling of the system's characteristic patterns of behaviour by laboratory experimenting with the aim of enhancing understanding and designing new decision rules for pension system stakeholders.

![Diagram](image)

**Fig. 2.** The structure of SD approach to pension system modelling

Basically, SD simulation modelling method is an approach used to study a nonlinear system and feedback control in engineering, economic, social and human sciences. With the aid of computer continuous simulation, supported by Iceberg Model of systems thinking approach in collecting knowledge through the simulation runs, it is a powerful tool in understanding complex systems. SD is originally based on feedback control theory which includes both hard (quantitative) and soft (qualitative) approaches in analysing dynamic behaviours of the development and changes of a system. SD assists to improve decision making process and policy formation through its characteristics of incorporating all relevant cause-effect relationships as well as feedback loops in dynamic behaviour modes of systems. By developing a mathematical model as a set of differential equations solved by numerical integration (using basically Euler integration method) and in an environment of computer simulation technologies, SD is capable to resolve a dynamic, inter-dependent, counter-intuitive and complex system such as problem of investigating the impact of demographic and economic risk on public pension system expenditure.

Public pension system involves a long-range forecasts horizon and political (mainly economic) consensus in social insurance policy design, therefore, risk management approach plays an important role in facing this problem – by absolving, resolving, solving and maybe finally dissolving it. Also, the complex phenomenon of demographic and economic volatility in a public pension systems involve numerous factors which are inter-related. Due to these reasons, a problem such as analysing risks in a public pension system requires a technique that would deal with complexity and allow the problem to be holistically viewed. As a consequence, an integration of risk management and a simulation modelling end experimenting methods in developing a public pension system expenditure model are needed, and to discover dynamic and macroscopic properties of such a system, SD method is the most appropriate method in modelling and analysing social insurance risk management problem in Polish public pension system. Risk management is a process consisting of the following activities (steps): risks identification to examine all the important risks involved in the system, risk analysis of the expected consequences of risk factors on specific other factors (variables), and monitoring of risk exposure to evaluate the exposure of risk based on decision making information.

2.2. Risk identification in social insurance

In this research, Polish public pension system is studied and modelled to analyse system expenditure due to basic demographic and ageing risks, economic GNP growth risk, average gross salary in economy risk. In Poland, public pension system is also exposed to the other risks, e.g. financial and investment risks, political risks in reaching consensus of public pension system transformation and reform, and some risks concerning overdue liabilities from the past (old system liabilities in a new system). These risk factors are identified to be basically as time dependent relations, estimated on the base of time-series statistical data.
3. Pension system SD model development

SD method basic paradigm is that a system’s behaviour depends on underlying causal feedback structure, decision rules, amplifications and delays. Causal loop diagrams (CLD) and stock-and-flow diagrams (SFD) are used to represent cause-effect structure (open and closed relations as feedback loops) with delays in information and physical flows. The CLD and SFD diagrams of pension system generic and archetype model are presented in Figure 3 and Figure 4. The dynamic equations of the model refer to nonlinear relations between identified basic variables and data estimated with an application of some empirical official statistics regarding public pension system indicators.

3.1. Pension system mental model and dynamic hypothesis

Causal loop diagramming is a recommended part of SD modelling stages in order to analyse complex relationship that exists in a dynamic system. A causal loop is referred to as closed influence diagram (or mathematically known as directed graphs) with polarity signs. A causal loop enlightens a dynamic process of a system in which the chain effects of a cause are traced, through a set of related variables, back to the initial cause. A causal loop is formed when a set of variables has been linked together in a connected path. There are two types of causal loop namely “reinforcing loop” (indicated by symbol R or plus sign) and “balancing loop” (indicated by symbol B or minus sign). Balancing loops generally (and always for 1st and 2nd order feedback loop) tend to stabilise the system while reinforcing loops always tend to destabilise the system. The loop is defined as positive (known as reinforcing loop) when the number of negative relationships is even (or multiplication of polarity signs within loop gives plus sign), otherwise the loop is negative one (known as balancing loop). Causal loop is also represented by an arrow headed line with sign “+” which means that a change in the influencing variable produces a change of the target variable in the same direction, while sign “-” means that a change in the influencing variable produces a change of the target variable in the opposite direction. The holistic summary analysis of causal loops relations is a helpful tool to predict the impact of desired factors in the system (even sometimes this is quite difficult activity in complex and many different in polarities feedback loop structures – which feedback loop is a dominant structure?).

Causal loop diagram of simple generic public pension system model in this research consists of four parts (Fig. 3): causal loop diagram of population ageing sub-model, causal loop diagram of public pension system central fund sub-model with basic incomes and expenditures, causal loop diagram of economic growth sub-model with influence of economic investments, and causal loop diagram of average salary estimation sub-model, as a base to calculate social insurance premium annuity and finally the pension system liabilities. The first part diagram is mapping general population with ageing stages – population in the age between 0-18 years, economically active population in the age between 18-65 years, and retired old population in the age above 65 (65+). This sub-model is a rather
sensitive structure for births and deaths rates, and in the model some statistics from the past are taken as multiplier time functions. To simplify analysis, the assumption that unemployed population always (after a delay) can find a job is taken into account. The second part diagram is modelling the essential part of any public pension system – central fund which finances social insurance indemnity payment (basic expenditure), sourced by regular premium payment by insured population, and some incomes from financial investments based on interest rates. Also this sub-model is rather a synthetic representation, without detailed structuring of types of financial sources, national budget donations, legal constrains, etc. The third part diagram is mapping an economic growth sub-model by gross national product (GNP) level as a result of two feedback loops (reinforcing and balancing loops) influenced by investment ratio in national economy. And also for this sub-model official GNP and investments rate official statistics from the past are taken as multiplier time functions. The fourth part diagram is describing roughly the estimation of average salary level as a result of economic growth (measured by GNP) influence to salary payment by employers to employees. And this relation is also calibrated using official statistics from the past to set multiplier GNP related functions. As we can notice, the SD generic and synthetic model of public pension system, which is a result of risk factors’ identification in this research, has five balancing (B) feedback loops and five reinforcing R feedback loops.

Fig. 3. Causal-loop diagram (CLD) of generic public pension system model
Source: author's own elaboration.
3.2. Pension system SD model concept and simulator

In this research, all factors presented in Fig. 3 were translated into stock and flow diagrams (Fig. 4) with an application of Vensim PLE software package to build the SD model of public pension system expenditure. The development of SD model includes several types of variables such as stocks, flows, auxiliary variables, lookup functions, constants and connectors. Stock, which is also known as level, acts as an accumulate (integration) reservoir of quantities (represented by rectangle) and describe the state variable of the system. The increasing flow (inflow) and decreasing flow (outflow) of a stock are also known as rates (represented by valve). The condition of the stock depends on the rates while the rates can be influenced by the other factors affecting inflow or outflow which are known as converters or auxiliaries (sometimes represented by circle). Finally, the connector that represents cause and effect links within the model structure is represented by the single-line arrow with polarity sign.

Fig. 4. Stock-and-flow diagram (SFD) of generic public pension system model
Source: author's own elaboration.
4. Simulation results

The simulation experiments on the research model which was developed for the purpose to verify some common sense opinions have proved, that the financial crisis in social insurance, particularly public pension system in current system’s structure and under current constrains, is nearly certain. For the laboratory experimenting, some rather unrealistic assumptions were made. As an example, initial level of FUS was set as equal to 100.000 mln zl, which imply in reality a budget subsidy at this level. Indeed, currently running demographic processes for presumed birth, death, and unemployment rates, as time dependent multiplier functions, allow to forecast rather negative demographic and employment tendencies in Poland in long-range time horizon (Fig. 5, Fig. 6).

![Selected Variables](image1)

*Population 0-17*: Exp 0
*Population 18-65*: Exp 0
*Population 65+*: Exp 0
Unemployed Resource: Exp 0

**Fig. 5.** Population levels in basic (Exp 0) experiment
Source: author’s own elaboration.

![Selected Variables](image2)

Births: Exp 0
Deaths: Exp 0
Maturity: Exp 0
Retirement: Exp 0

**Fig. 6.** Population flows in basic (Exp 0) experiment
Source: author’s own elaboration.
In the financial system aspects (public social insurance) an increase of social premium annuity payment to FUS fund (as a result of average salary increase in economy) is not compensating FUS basic expenditure – payments of social indemnity for social insurance liabilities (Fig. 7). But it can be reasonable to search for some possible remedies in system structuring and tuning to avoid rapid financial crisis. Some solutions can be found by an attempt to calibrate system parameters, for example a change of replacement coefficient from 1 (pension amount is equal to 100% of the last salary) to 0.5 (pension amount is equal to 50% of the last salary). It is even possible in the model to find a break-even point for this parameter to allow sustainable growth of FUS fund (Fig. 8).

**Fig. 7.** Financial levels and flows in basic (Exp 0) experiment
Source: author’s own elaboration.

**Fig. 8.** National FUS pension fund with a change of replacement coefficient from 1 (Exp 0 experiment) to 0.5 (Exp 1 experiment)
Source: author’s own elaboration.
5. Conclusion

This research paper discusses the SD methodology and a generic, public pension system model, which can be used in discussing and tuning the structure and dynamic properties of pension systems, and in the first steps to analyse, test and design some proposals (as recommendations) for decision makers. The SD generic model of public pension system, presented in this research consists of four sub-models: ageing population, central pension fund with basic incomes and expenditures, economic growth with influence of economic investments, and average salary estimation as a base to calculate social insurance premium annuity and finally the pension system liabilities. The first simulation experiments results have proved that for the relevance of representation and next practical application of this model, some multiplier and lookup functions must be recognised as very sensitive input data parameters – thus they must be calibrated on real data bases. Basic dynamic behaviour of the system under consideration (as a complex of 5 positive and 5 negative feedback loops) is that the system tends continuously in long-range horizon to financial deficit and must be subsided by external financial source. Or the dynamic system structure is to be transformed into more sustainable behaviour. Therefore, in the next and more profound research simulation testing and results analysis, some other effects of demographic and economic risks on public pension system expenditure will be possible to identify, and to formulate rough forecasts with scenario for recommended structure changes.

References
