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New computerized method for analysis of long-term financial stability in local government. Implementation of multi-criteria optimization

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Abstract
New method is developed for decision making regarding long-term financial planning by local government (LG). It helps formulate polices for safe long-term investment and debt, which minimize the infrastructure gap when fiscal rules and budget liquidity are satisfied. The method links long-term financial planning and budgeting for results and outcomes. It includes LG budget financial flows-stock model and supports generation of alternative budget projections based on H. Simon concept of multi-stage formation of goals, which can be modified. Reference point multi-criteria optimization technique is applied. Criteria are simultaneously maximized (cumulated investment) and minimized (debt service costs). Numerical solutions are presented.
Keywords: long-term financial planning, local government, financial safety, multi-criteria optimization, satisficing behavior theory.

1. Introduction

New innovative method is developed for facilitating financial safety and stability in public sector and analysis of policy regulations. The method supports long-term financial planning and ensures budget liquidity every year of the planning period. It offers new approach to the projection's generation process, determination of the acceptable and unacceptable levels of risk associated with debt, and investigation of fiscal rules impact on future budgets of local governments[1]. The method implements operations research, in particular multi-criteria optimization theory, enables simultaneous consideration of several goals when many substitutable real-life conditions are satisfied. The method can be implemented by local government (LG) finance officers and treasurers.

1.1. Long-term financial planning

The LG goal is often to create sustainable improvements for the public. Long-term financial plan (l-tfp) generates strategies that are made operational in consecutive budgets and helps a LG remain effective over long-term. It presents revenue and expenditure projections, debt position and important financial policies. L-tfp also identifies resources constraints, so that strategic initiatives including service

[1] The rules for local governments are determined by the regulator (or central government).

preferences can be realistically prioritized and the long-term financial implications of current decisions examined to address potential financial imbalances. L-tfp process integrates strategic planning and budgeting and helps financial managers identify emerging problems – difficulties and opportunities - before they pass by. It also helps evaluate risks at the outset of the l-tfp. The benefits from l-tfp include: clarification of strategic intent and stimulation of long-term thinking; advance recognition of potential problems; recognition of fiscal rules impact on financial stability of local government and incorporation of financial perspective into organizational planning and fixed assets management (Kavanagh 2007, Vogt et al. 2009, Miranda, Picur 2006, GFOA Recommendation 2013a, 2013b, 2011, 2010a, 2010b and 2008).

1.2. Safety and financial stability

Safety of financial management and risk control is highly valued in financial management. Together with solid long-term financial planning these factors are assessed and affect the rating outcomes of rating agencies. The implemented methodologies are designed to reflect the key credit fundamentals and to assess risk. Assessing risk should help the government determine when risks are reaching unacceptable levels, and control and mitigate such risk. Assumptions for revenue and expenditure projections must be prudent, the polices and guidelines on debt should be clear, debt structures must not exceed nominal levels of risk – avoid high or rapidly changing debt costs, and finally, liquidity must be ensured. Quality of tools used for planning is also assessed together with exceeding fiscal targets. For example the Moody's Rating Agency (2013) evaluates financial performance and debt profile with the help of several indicators, including: gross operating balance (operating surplus), interest payments and net direct and indirect debt – all in relation to operating revenues. When the operating surplus exceeds 10%, or the debt burden is below 35% and interest payments below 1% of the operating revenues, the assessment is very good. When these values are correspondingly: between 0 and 5%, 65% and 100%, and 3% to 5% - the assessment is rather low. However, when the relative value of the operating surplus is below 0, value of the total debt - between 100%-200%, and the interest constitutes between 5%-7% of the operating revenues, the assessment is critical (very low).

Safe debt policy is the key (Kavanagh 2007; Miranda, Picur 2006, GFOA 2013). Rubin (2014: 1-2) writes "Budget ,…, implies balance between revenues and expenditures,…, supported by safe borrowing. Borrowing is part of budget choices,.., but one has to have a plan how to pay the loans back and ensure budget liquidity when the debt will be paid off in future years". Detroit city failed to ensure funds to pay the loans back and maintain liquidity. Assumed too high risk. Presently, the challenges of Detroit are enormous, all the city does contributes to direct recovery, including public health, connectivity across the city, housing and green infrastructure.[2] Assessing risk and uncertainty and determination of the acceptable and unacceptable levels of risk and if such risk can be mitigated is a must in debt and investment policy (GFOA Recommendation 2015).

The fiscal process can be stabilized by establishing how much investment and debt a government can afford over a several years period maintaining budget's liquidity. In the paper we develop and implement the method - a tool, which helps determine how much investment and debt should be selected in consecutive years to facilitate safe infrastructure and services development.[3]

The objectives of the paper is twofold:

- development of a tool, including budget financial flows model, which helps generate safe investment and debt and enables minimization of infrastructure gap between a given country[4] and developed countries
- presentation and discussion of select fiscal rules effectiveness, introduced by regulator to minimize debt and facilitate development of efficient policy regulations[5]

In a poor infrastructure country, a local government decision maker (dm) has two goals: to maximize planned cumulative investment over a given planning period and simultaneously minimize the total cost of debt (investment financing debt service) until it's maturity. The method ensures optimal selection of the goals' values and enables update of policy goals' values. The dm observes values of the objectives resulting from her previous decisions and attempts to improve the objectives consistently with her

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[2] The City government has long been in a bit of a triage mode. For instance open natural spaces in the city are often viewed as blight.

[3] In many countries LG sector is the largest public investor and its contribution to the public sector debt is small (in 2013 LG's share of debt in GDP was below 9%, in Poland - below 5%, Bitner, Cichocki 2014).

[4] Countries which joined the EU after 2004, Ukraine, or countries at war, where infrastructure must be rebuilt or renovated could be included. We consider a city's budget in such a country.

[5] Analysis of fiscal rules effectiveness and their impact on investment is subject of a separate paper.

preferences. The method combines optimization results and decision maker (human) judgment to come to a "satisficing" solution introduced by Simon (1959). The dm judgment is related to her/his aversion to risk and looks for a consensus between the needs and the risks associated with excessive debt and investment.

LG budget reflects various important priorities and goals. Many goals reflecting functions of government (COFOG, ESA 2010, ch. 23, 541-543), other than presented in the paper can be included in the method. They can be selected by the decision maker (finance director, CFO) based on local governments needs and public consultations

Budget planning requires a decision-making process which ensures decisions made in proper order and envisage long-term consequences of capital planning and borrowing (Kavanagh 2007: 60, 68; Miranda, Picur 2006: 37 - the U.S. and Canadian examples).

The presented analysis helps determine future investment and safe debt, which ensure budget liquidity each year, and reduce, to a maximum extent over a given period, a gap between the currently financed projects and the projects identified as necessary. Implementation of all these projects would be desired, although the dm knows it is not feasible in the assumed period given a financial status of the LG, its existing indebtedness and fixed assets maintenance costs. The dm looks for maximum number of investment projects (their maximal nominal value) to be implemented in a given period at the minimum debt costs. A list of needed investment projects, their costs and ranking is given in the method as a result of previous analysis and consultations.

2. The method

The proposed method includes construction of a mathematical model describing LG budget flows, formulation of multi-criteria decision making problem - an interactive procedure deriving Pareto optimal outcomes (values of selected criteria) according to preferences of the dm. The procedure utilizes concepts of the satisficing behavior theory formulated by Simon (1959). The method was experimentally implemented with the help of a computer based system which enables generation of outcomes preferred by the dm and the resulting values of decision variables. Scenarios for various assumptions regarding goals and side conditions of the budget flows model were analyzed. These conditions are formulated as constraints in the formulated optimization model.

2.1. LG budget flows model

The LG budget financial flows model encompasses various categories of *flows:* operating, capital and total revenues and expenditures, new debt, interest and other debt proceeds, and *stock*: indebtedness and fixed assets - defined each year of an investment period – several future years following the budget year. The budget flows in a given year t, with some simplifications, are presented in Diagram 1. The division of the budget into operating (current) and capital (investment) budgets is assumed. It is related to the "golden rule of public finance": current expenditure is financed from current revenue (regular and cyclical); inflows from capital, including debt and non-regular revenue should exclusively serve investment financing (Cichocki 2013: 145, 179-180; GFOA Recommendations 2010a, 2007a; Rossi, Dafflon 2010; Kavanagh, 2007: 161-165; Vogt 2004, Vogt et al. 2009; Dafflon 2002). Some flows are decision variables (eg. investment), some are values computed based on these variables, other are exogenous in the model. Debt can increase investment, but must be repaid, and generates new operating expenditures (interest). Investment contribute to the value of fixed assets - GFCF, which often facilitate better services, but increases operating expenditures - costs associated with maintenance of new assets - and decreases the operating surplus – LG funds, which can finance investment.

Model assumptions

The operating revenues and basic operating expenditure projections, excluding debt service and fixed assets (GFCF – gross fixed capital formation) maintenance costs, base on historical trends updated by inflation, GDP and local growth rates. Ceilings for the EU funds are projected based on historical data.[6] Interest rates for bonds, medium and long-term credits, and for revenues from property sales of as well as capital non-regular revenues are assumed known (exogenous). In section 3 the model is formally described.

[6] The EU funds can be used for financing investment only when a LG provides its own share from the budget or/and from debt. The maximum share of the EU co-financing equals 85% of the total individual project's value.

Decision variables

The model variables are defined for an investment (projection) period [t_1, T_N], and are used for calculations at time instants t_1,.., T_N, T_{N+1}, T_M, where t_1 denotes an initial (budget), and T_N the final year of investment activity and debt issuance; T_M is the last year of debt repayment; M > N are integers - number of years. Selection of T_M results from debt structure - bond covenants and loan repayment terms. The model starting point is a year t_0 – end of the year preceding the budget year t_1. The model decision variables at year *t* include: investment expenditure, medium term credits, long-term credits and medium term bonds - all disaggregated into co-financed by the EU funds, and financed only by the LG budget and debt. The debt issued at time *t* is the summation of credits and bonds at *t*. Other categories of credits and bonds can be added. Repayments include the initial debt, issued prior to t_1 (results from past contracts) and future debt (issued over t_1, T_N). The repayment schedule is calculated based on debt structure computed by the model.

The model constraints

The model constraints include budget liquidity and fiscal rules regarding limiting operating expenditures and debt service costs to prohibit excessive debt of LGs and budget deficits [7]. Time dependent relations between financial flows and stocks, including the model decision variables are also specified. The financial flows model is consistent with the Polish and EU legal regulations, and was used for calculations (see sections 3). However, the model can accommodate other fiscal rules and constraints.

In the model, decision variables are looked for which maximize planned cumulative investment over a given planning period and simultaneously minimize the total cost of servicing debt after that period, until debts' maturity. They are considered goals (criteria) in the decision making process.[8]

The model enables, each year, determination of safe investment (and its financing structure) and debt - bond covenants and medium and long-term credits, when the model constraints are satisfied. The

[7] Other rules may regard outstanding debt, debt related to operational or total revenue, and deficit (Kavanagh 2007:148-149, Cichocki, Leithe 1999).

[8] The developed method can include various goals reflecting functions of government (COFOG, ESA 2010, ch. 23, 541-543).

debt service includes repayment of debt principals, interest on the outstanding debt and guarantees given by a LG to other institutions. It includes the initial debt, issued prior to t_1 (results from past contracts) and future debt (issued over t_1, T_N). The debts are safe, conform to legal fiscal regulations which are incorporated in the model and each year ensure budget liquidity and the balance of operational accounts.

The model and the optimization procedure can be implemented for various initial values of indebtedness and GFCF, different revenue projections and various basic operating expenditures structure.

2.2. Multi-criteria decision making; Interactive procedure based on Simon's theory.

The proposed approach is described for two optimization criteria but can be easily extended to a greater number of them. Lets assume that the LG's manager thinks of two conflicting criteria: y_1 - the cumulative investment over $[t_1, T_N]$, and y_2 - the total costs of servicing debt over $[T_{N+1},T_M]$. She looks for decision variables satisfying the model constraints [(3)-(5) in section 4] that maximize the criterion y_1 and, simultaneously, minimize the criterion y_2. An increase in investment, facilitates usage of debt for projects' financing, and contributes to the increase of debt service costs. A decision how much to invest in the future is crucial for local development. Investment is also a driver of debt issuance, and debt service costs. LG investment needs can be associated with aspirations of a LG and the decision maker, who wants to satisfy a large portion of needs in a given period. One can consider several investment scenarios, which depend on satisfaction of a given degree of investment needs and on future LG's revenue, quality of management and economic growth.

The multi-criteria optimization problem is defined in two spaces: the first space of decision variables, elements of vector $\boldsymbol{x}$ and the second space of criteria $\mathbf{y} = (y_1, y_2)$. The model constraints define a set $\boldsymbol{X}_0$ of decision variables' admissible values. The optimization problem and the budget flows model relations define a set $\boldsymbol{Y}_0$ of the criteria' attainable values. For mathematical formulation see section 3 and the appendix.

The proposed approach and the selection of the outcome most preferred by the dm, bases on Herbert Simon's satisficing behaviour theory (Simon 1959) and, supported by a computer based system, interactively, in a number of iterations finds a solution that satisfies the dm aspirations. In each iteration the dm defines her aspirations as a reference point in the space of criteria). Then, using the optimization solver, the system derives a Pareto optimal outcome closest to the reference point, and calculates respective decision variables. The derived solution, including the decision variables for each year, and the criteria values are presented to the dm for analysis. In consecutive iterations the dm collects information about attainable Pareto optimal outcomes, and adaptively modifies aspirations, as she uncovers the set of outcomes and implications of her decisions. Finally, she finds the preferred outcome - is satisfied with good-enough decision variables and the outcome corresponding to her aspirations.

The interactive decision supporting optimization procedure can be presented in the following steps:

Step 0. The dm sets exogenous variables and initial data of the budget flows model.

Step 1. The computer-based system (cbs) solves the optimization problems:

1. a.: first, she maximizes y_1, expression (1), with respect to the decision variables x, subject to the model constraints; she receives the maximum value of the criteria (1) – a limit for maximum investment cumulated over t_1, T_N that can be implemented given the model constraints; *this outcome is associated with maximum acceptable risk*

1.b.: second, she minimizes y_2, expression (2), with respect to x, subject to the model constraints; she receives the minimum value of cumulated debt service costs, when no new debt is issued during the investment period t_1, T_N – *no risk is associated with debt issuance* in this solution, which yields minimal investment that can be implemented over t_1, T_N (see figure1)

The model solutions: the decision variables, obtained values of the criteria - outcomes of the model and other model variables are saved in a data base.

Then, the multi-criteria optimization procedure starts. It is executed in a repetitive way and in its each iteration the dm analyzes and compares the solutions stored in the data base.

Iteration number is set at $i = 1$.

Step 2. The dm assumes a reference point – a vector defined by her aspiration – in the two criteria model for the criterion y_1, and the criterion y_2

Step 3. Using the reference point method the cbs solves the problem (A1), with respect to the decision variables $\boldsymbol{x}$, subject to the model constraints and additional constraints of the reference point method.

The reference point and the model solutions are saved in the data base.

Step 4. The dm analyzes the current solution, decision variables and the outcome, and compares it with the previous solutions and outcomes, including the solutions obtained in Step 1.

Step 5. The dm decides whether she is satisfied with the current solution.

If yes, then the procedure ends,

if no, then the number of iteration increases, $i = i+1$, and the dm returns to Step 2.

Steps 3 – 5 in the procedure are repeated in a sequence of iterations. The computer-based system solves the optimization problems of the Steps 1 and 3. The steps 0, 2, 4, 5 are executed by the dm - she assumes exogenous variables and initial data of the model, selects the aspiration levels, makes analysis of the solutions derived by the computer-based system and makes the final decision regarding ending of the procedure. Full sovereignty of the dm is assumed.

The final optimal solution of the multi-criteria problem, and the budget flows model, allow to select each year of the period $[t_1, T_N]$, the level of investment, financed from the LG's budget, EU funds, debt and medium and long-term credits and bonds, which maximize cumulative investment over $[t_1, T_N]$, and minimize over $[T_{N+1}, T_M]$ the total debt service costs cumulated until all debts mature.

3. Formulation of the multi-objective optimization problem

We look for a financial projection resulting from the maximization of investment cumulated over a period $[t_1, T_N]$, where $t_1 = t_0+1$, and, simultaneously, the minimization of the total costs associated with debt service over $[T_{N+1}, T_M]$. Investments are implemented and debt is issued only over $[t_1, T_N]$. All debts are repaid until T_M. Mathematical formulation is as follows.

Given initial values of the model variables and parameters at the initial period t_0, the time periods $(t_1,\ldots,T_N, T_{N+1},\ldots,T_M)$, and select projections over $[t_1, T_M]$, find, for every $t \in [t_1,T_N]$, such values of investment expenditures, Inv^{UE}_t and Inv^b_t, credits and bonds, C^{1EU}_t, C^{1b}_t, C^{2EU}_t, C^{2b}_t, B^{EU}_t, B^b_t, used for financing investment, which **maximize** y_1 - **cumulative investment** over $[t_1, T_N]$,

$$y_1=\{\sum_{t=t_1}^{T_N} Inv_t\} \textbf{ \textit{is maximized}}, \tag{1}$$

where $Inv_t = Inv^{EU}_t + Inv^b_t$, $Inv^{EU}_t \geq 0$, $Inv^b_t \geq 0$, (1a)

and simultaneously **minimize**, over $t \in [t_{N+1},T_M]$, y_2 - **the total cost of servicing debt** issued during $[t_1, T_N]$

$$y_2=\{\sum_{t=T_N+1}^{T_M} RD_t+intD_t\} \textbf{ \textit{is minimized}}, \tag{2}$$

where debt repayment RD_t includes repayment of the cumulated new debt and the old debt D_0, (issued prior to t_1) outstanding at time t. Repayment schedule of D_0, over $t_1,..,T_M$, is given - results from commitments made prior to time t_1.[9] Repayment of new debt includes repayment of credits C^{1EU}, C^{1b}, C^{2EU}, C^{2b}, repurchase of bonds B^{EU}, B^b, issued starting t_1.

New debt issued at t $\in$ $[t_1,T_N]$

$$ND_t=C^{1EU}{}_t+C^{1b}{}_t+C^{2EU}{}_t+C^{2b}{}_t+B^{EU}{}_t+B^b{}_t, \tag{2a}$$

$$\text{where } C^{1EU}{}_t \geq 0,\ C^{1b}{}_t \geq 0,\ C^{2EU}{}_t \geq 0,\ C^{2b}{}_t \geq 0,\ B^{EU}{}_t \geq 0,\ B^b{}_t \geq 0 \tag{2b}$$

The indebtedness (debt) D_t at t

$$D_t=ND'_t+D_{0t} \tag{3}$$

The cumulated new debt outstanding at the year $t = t_1, t_2,\ldots,T_N$, equals

$$ND'_t=\sum_{k=0}^{t-t_1} \delta\mathrm{ND}_{t-k} \tag{3a}$$

where

$$\delta ND_t=ND_t-RND_t, \tag{3b}$$

is a change in the new debt ND_t issued at t, RND_t is the repayment of the cumulative new debt at t.

A change in debt outstanding at t, δD_t, equals a change in the cumulative new $\delta ND'_t$ and old debt δD_{0t}

$$\delta D_t=D_t-D_{t-1}=\delta ND'_t+\delta D_{0t}, \tag{3c}$$

where D_t and D_{t-1} are the total indebtedness at the end of year t and t-1.

The debt repayment RD_t at t includes the repayments of the old debt, RD_{0t}, and the repayments of the new debt RND_t, cumulated over $[t_1,t-1]$, which include the four year credits, $RC^1{}_t$, the ten year credits, $RC^2{}_t$, and five year bonds, RB_t issued starting time t_1 (the bond repurchase takes place once in five years)[10]

$$RD_t=RD_{0t}+RND_t=RD_{0t}+RC^1{}_t+RC^2{}_t+RB_t. \tag{4}$$

The repayment of debt issued at t, starts the next year, at t+1. Equal credit repayments are assumed.

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[9] D_0 is the outstanding initial (old) debt at time t_0. For some excessive D_0, the model solution may not exist.

[10], More bond's and credit's categories and any bond maturity can be assumed in the model.

The interest cost incurred at period *t*, $intD_t$ on the outstanding debt D_t is the sum of interest on the initial debt, $intD_{0t}$ and cumulative new debt $intND'_t$ outstanding at t, and is calculated separately for each debt category.

$$intD_t = intND'_t + intD_{0t} \tag{5}$$

We assume, for simplicity, that each year the debts' repayments and bonds' repurchases take place at the same time as the new debt issuance. Then, the interest at time *t* is calculated based on the indebtedness at the end of year *t*-1and the year *t* .[11] For example interest incurred on the medium-term credits C^{1EU} (financing investment co-financed by the EU funds) equals

$$int(\sum_{j=t_1}^{t} \delta C^{1EU}{}_j)_t = ½ ic_{1t} (\sum_{j=t_1}^{t-1} \delta C^{1EU}{}_{t-1} + \sum_{j=t_1}^{t} \delta C^{1EU}{}_t), \tag{5a}$$

where ic_{1t} is the interest rate paid at *t* on the credits $C^1{}_t$, and $\sum_{j=t_1}^{t-1} \delta C^{1EU}{}_t$ is the credit $C^{1EU}{}_t$ outstanding at *t*. The interest (5a) is summed up with the interest on credits C^{1b}, C^2 and the bonds *B* (with interest rates ic_{2t}, and ib_t) and serves calculation of interest costs for the new debt, issued at *t*, and the old debt.

The model's objectives (1) and (2) is satisfied under constraints - conditions which result from principles of financial management and valid fiscal rules. Three major constraints for each $t \in [t_1, T_N]$ are introduced. The first one, (6), ensures budget liquidity each year *t*. All budget inflows minus operating and capital expenditures must be nonnegative - the revenues, expenditure and debt each future year $t_1,..,T_N$ must ensure the LG balanced budget

$$OpS_t + \delta D_t + CapRev_t + OthRev_t + Cab'_{t-1} - Inv_t \geq 0. \tag{6}$$

OpS_t denotes operating surplus funds: operating revenues $OpRev_t$ minus operating expenditures $OpExp_t$ at *t*, $OpS_t = OpRev_t – OpExp_t$. The larger the OpS_t, the more funds available for investment's financing at t. The operating expenditures include interest costs of the outstanding debt and the fixed assets maintenance costs.

Capital revenues, $CapRev_t$, consist of three major parts: the EU funds (calculated in the model over $[t_1, T_N]$), special capital grants and revenues from sales of property (determined exogenously). Other

[11] Such simplification was assumed in the U.S. law (2009-2010 Wisconsin States Annotations, 6703, p. 2).

budget *net* inflows, $OthRev_t$ (revenues minus expenditures) include inflows from privatization, capital shares owned by the LG, and other *net* inflows not associated with debt.

The current accounts balance at t, Cab'_t, includes two separate balances: the budget revenue and expenditure balance, and the debt account balance (Cab_{t-1}), which equals the debt balance from the previous year, Cab_{t-1}, plus debt receipts minus debt principals repayment at t, and the revenues and expenditures balance from the previous year, BB_{t-1},

$$Cab'_t=Cab_{t-1}+ND_t-RD_t+BB_{t-1}, \text{when } BB_{t-1}<0. \quad (6a)$$

When a deficit occurs in the previous year, $BB_{t-1} < 0$, then, the current budget account in year t must be financed by additional new debt. The current accounts balance at time t, Cab'_t, must be non-negative for all $t=t_1,..,T_N$

$$Cab'_t\geq 0. \quad (6b)$$

It is a modification of the golden rule (includes surplus funds from previous year).

The values of OpS_t and δD_t can assume negative values, the model decision variables C^1_t, C^2_t, B_t, Inv_t - only nonnegative values. Capital revenues, the operating surplus, *net* debt proceeds at t, other inflows and funds from previous year, when available, are used to finance investment.

The second constraint (7), ensures operating expenditures, which in a given year do not exceed operating revenues enlarged by surpluses on the account balances from the previous year

$$OpRev_t-OpExp_t+Cab'_{t-1}\geq 0, t=t_1,..,T_N, \quad (7)$$

where the operating revenues are specified for all sources of revenue (PIT, CIT, VAT, property taxes, fees and charges, intergovernmental transfers and incidental revenues, for example earmarked grants). Revenue and operating expenditure projections are described in Kavanagh, 2007, ch. 6 and Cichocki 2013: 59-70.

The total operating expenditures $OpExp_t$ consist of basic expenditures, $BOpExp_t$, and the interest and fixed assets maintenance costs

$$OpExp_t=BOpExp_t+intD_t+\Phi_t\cdot GFCF_{t-1}. \quad (7a)$$

$GFCF_{t-1}$ denotes fixed assets at time t-1, and Φ_t is a ratio of the GFCF maintenance costs at t. GFCF depreciates over time.

The third major constraint (8), is a fiscal rule, imposed to restrain LG's excessive debt. It can assume various forms. In calculations we implement the rule, currently used in Poland, to limit at time t the total debt service costs related to the total revenue.[12] These costs include all credits repayments and bond repurchases, interest on the outstanding debt charged every period t, and payable guarantees extended by a LG, and cannot exceed a limit depending on the past LG's performance: the average value, over three years preceding the year t, of the operating surplus enlarged by the revenue from sales of property, in relation to total revenue.[13]

$$[(RD_t+intD_t)/Rev_t]\leq 1/3\sum_{i=1}^{3}[(OpRev_{t-i}-OpExp_{t-i}+SalGFCF_{t-i})/Rev_{t-i}] \tag{8}$$

The costs of debt service are calculated for each credit and each bond issue separately, on the debt outstanding at time t-1, plus new debt taken at time t, minus debt repayment at t. The interest costs are computed on the total debt – the old debt and the cumulative new debt outstanding at time t. The value of the left hand side of (8), and of the limits for the total debt service (the right hand side of (8)), are calculated from the model. When, in any year $t_1,\ldots, T_N$, either the operating revenues are lower than projected, or the basic operating expenditure higher than projected, then, the upper limit for the costs of debt service is lower, and less debt can be issued in future years. The constraints (6), (6b), (7) and (2b), (6a) must be satisfied over $[t_1, T_N]$, the constraint (8), over the whole period $[t_1, T_M]$, otherwise, the LG's council cannot approve the budget and the obligatory financial plan for the three following years.

4. Illustration of the optimization procedure; exemplary solutions

The developed model and the procedure of safe financial planning are presented for Polish LG's data . Historical data of 2011-2013 are taken from the LGs' financial reports and projections of operating revenues and basic operating expenditures over 2014 - 2023 and over

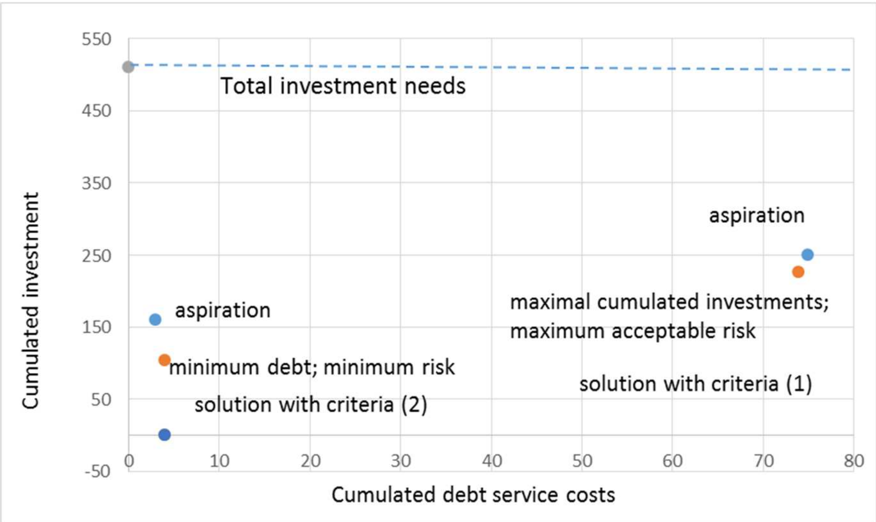
[12] Public Finance Law (Lpf), 2009, with amendments, art. 242, constraint (7), and art. 243, constraint (8). These constraints can be replaced with any other rule.
[13] To calculate the costs of debt service limit in (8) at t_1,t_2, one has to know the data for t_1-1, t_1-2, and t_1-3.

2024-2033, when the debts mature - from long-term LG's projections included in the database of the Ministry of Finance. The investment period covers years 2014 – 2023. The obligatory share of a LG's budget in investments co-financed by the EU funds is fixed at 20% in the model, and an upper limit, over 2014-2023, for the EU funds used for investment financing is assumed. These values can easily be changed. The issue time and value of credits and bonds result from the model solution.

4.1. The decision making supporting procedure

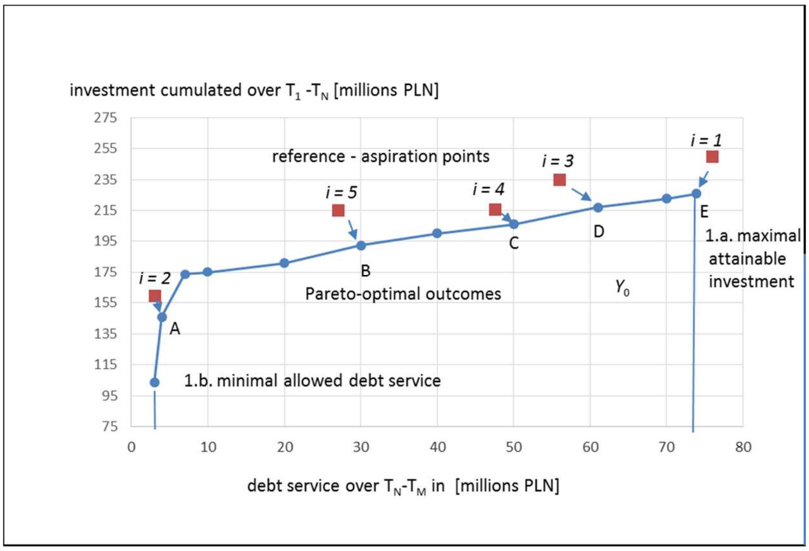
Let us assume that the investment needs are known in a LG. They equal 510. The procedure starts from determination of upper and lower limits for elements of outcome – a maximum value of the investment cumulated over 2014-2023 and a minimum value of the debt service costs over 2024-2033. They depend on the model constraints and the LG's initial indebtedness and fixed assets. The dm, solving the model with criterion (1) finds that the maximum cumulated investment equal 226, and the corresponding debt service costs equal 73.9 (figure 1 and figure 2 point 1a). These limits constitute thresholds which cannot be broken. Solving the model only with criterion (2), she finds a minimal debt service costs of 4, which result from debt commitments made prior to 2014, and the corresponding investment of 103.5 – when no new debt is issued during 2014-2023 (figure 2 point 1b). The values are in millions PLN, but in the text we omit these units.

Figure 1 Maximum feasible investment and investment needs



In figure 2 select results of the interactive procedure - solutions of the multi-criteria optimization problem (A1) are presented: reference points used in the computational procedure are illustrated by square points, the vector valued Pareto – optimal outcomes of the procedure - the sum of investment over 2014-2023 and the sum of the debt service costs over 2024-2033 - by bullets, denoted A, B, C, D and E.

Figure 2. Select Pareto-optimal outcomes of the decision supporting procedure



The optimization problem's outcomes are the results of the A1 problem solution in consecutive iterations – are computed based on decision variables obtained from solution of (1) and (2), subject to (6), (7) and (8). They belong to the Pareto frontier of the admissible set $\boldsymbol{Y}_0$ (figure 2).

Suppose the dm tries an ambitious goal of reducing 49% gap between the currently financed projects and the projects identified as necessary over 2014-2023, and in the first iteration assumes the reference point with 250 investment and assessed 76 of debt service cost. This is her initial aspiration (the values of 250 and 76 are elements of the reference point vector). From solution of the maximization problem she obtains the Pareto outcome E: investment equal 226 and debt service - 73.9 (the limits 1a in- figure 2).

The dm analyzes the obtained values of the criteria and the decision variables in consecutive years. The Pareto-optimal solution E of the model yields very low investment in 2014 and 2015, which strongly decreases in 2018 . In addition, no EU funds for financing investment in 2015-2016 are utilized (figures 3, 4.). Such a solution, although ensures the investment cumulated over 2014-2023 larger than in other solutions, may not be acceptable in practice because it bears the highest risk. Some investment projects will have to be continued in 2014 and 2015, and when a source of revenue fails, the budget funds might be not sufficient to continue these investments. The debt service costs cumulated over $[T_{N+1},T_M]$ is very high, and it reaches the limit in 2026-2028 (figure 7). There is a risk for the outcome E, that high cumulated debt issued over 2014-2023 will generate very high service costs over 2024-2033, which, although satisfy the model constraints (fiscal rules), might not guarantee budget liquidity when a disturbance occurs.

The dm tries another reference point. In the second iteration she tries a very conservative reference point with investments planned for 2014-2023 equal 160 – 31,4% of the investments needed over 2014-2023, and estimates the debt service costs at 3.. The solution procedure yields outcome A – 146 in total investment and 4 of debt service costs over 2024-2033, which result only from the debt issued prior to 2014. The decision maker is not satisfied with the decreasing investment, especially during 2020-2023 (figure 3), and the GFCF value of 124.9 in 2024.

She looks for an outcome between the limit points A and E. She could increase investment and debt incrementally and safely remain in the admissible set Y_0. However, since in A the debt service costs are well below the limit and the needs for investment and the GFCF in 2024 are high, in the third iteration the dm assumes the reference point of 235 in investment, and 56 of debt service. She obtains the Pareto solution D, with the total investment of 217.1 and debt service of 59.1. Similarly to the solution E, in 2015-2016 no EU funds are used and investments in 2014 and 2015 are very low. She has to lower her aspiration but still wants to maximize investments and selects the reference point between A and D, of 216 in cumulated investment, (42,3% of investment needed over 2014-2023) and 47.5 in debt service. She obtains the Pareto outcome C. The cumulative investments are 205, the debt service over 2024-2033 equals 50, and GFCF is 174.9 in 2024. The decision variables of the solution C are acceptable, they do not have deficiencies of the solutions D and E (figures 2, 3, 4). The dm can be satisfied and stops the procedure in point C. Then, the investments presented in figures 3 and 4, and the debt (figure 5) will be implemented in consecutive years.

If the dm were more debt risk averse, she could select first the reference point of 215 in investment and 27 in debt service. Then, the outcome B would yield 195 cumulated investment and 30 of debt service costs. Solutions for point B are presented in figures 3-9. The dm can select either point C, or point B. The choice of the outcome C yields higher investments and GFCF, but lower cumulated operating surplus because the debt service costs and fixed assets maintenance costs are higher than in B.

The set of outcomes which satisfies the dm decreases during the optimization process because her knowledge about the previous decisions (selected aspirations) implications - attainable Pareto outcomes and the solution variables increases. The Pareto outcomes yield the model optimal decision variables which satisfy all model constrains – liquidity and fiscal rules. The solutions of Pareto outcomes E and D of the model are much more risky than the solutions A, B and C. Especially the outcome E, located on the edge of the admissible set Y_0 and the Pareto frontier is very risky. A slight change in exogenous projections of revenues might shift the solution outside the admissible set. When it happens, the constraint (8), or (6)will not be satisfied and no new debt can be issued.

The dm is not fully aware of her preferences when she starts analysis of the multicriteria optimization problem - she does not know attainable outcomes. In step 2 of the procedure she analyzes solutions in consecutive years and defines a first approximation of the Pareto frontier of an attainable outcomes set (see the procedure in appendix 2). Points 1.a., 1.b. determine limits for these outcomes. The aspirations are adapted as optimization proceeds in consecutive iterations. The number of the derived outcomes increases.

The set $\boldsymbol{Y}_0$ of attainable outcomes (cumulated investment and debt service costs) decreases when a city had generated large initial debt. When the indebtedness is very large, one cannot invest in future years because all revenues will be used for debt service.

5. Presentation of decision variables and select constraints

In figures 3-9 projections of select model solutions are compared. They are associated with the Pareto outcomes A, B, C and E, which for the initial debt D_0=15 satisfy the model constraints (6)-(8), maximize the criterion (1) - investment expenditures cumulated over $[t_1, T_N]$, and simultaneously minimize the criterion (2) - debt service costs cumulated over $[T_{N+1}, T_M]$. In figures 6, 8, 9 we present debt, interest and operating surplus in relation to operating revenues consistently with Moody’s methodology.

The share of investment expenditures in the total LG's investment expenditures, and the share of the EU co-financed investment in the investment expenditures over the planning period t_1=2014, t_N=2023 are volatile, and the EU financed investment in 2015 and 2016 equal zero for the Pareto point E, for which the cumulated investment is higher than for the point C (figures 3, 4).

Figure 3. Investment expenditures to total expenditures

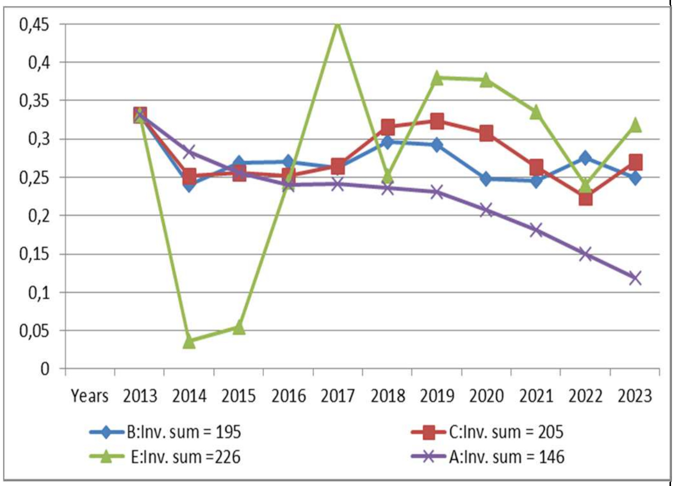


Figure 4. Investment expenditures co-financed with the EU funds to total investment

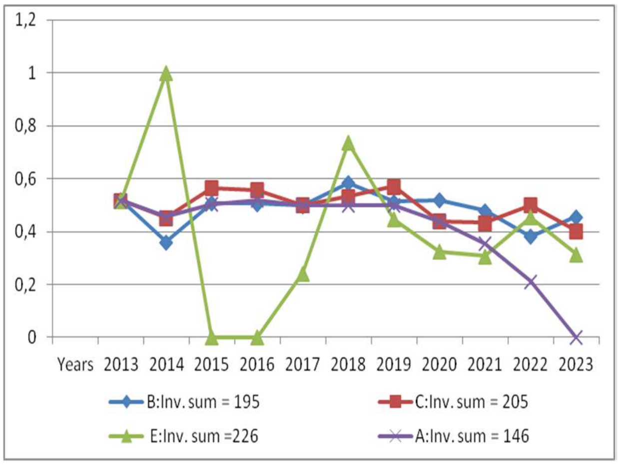


Figure 5. Total outstanding debt

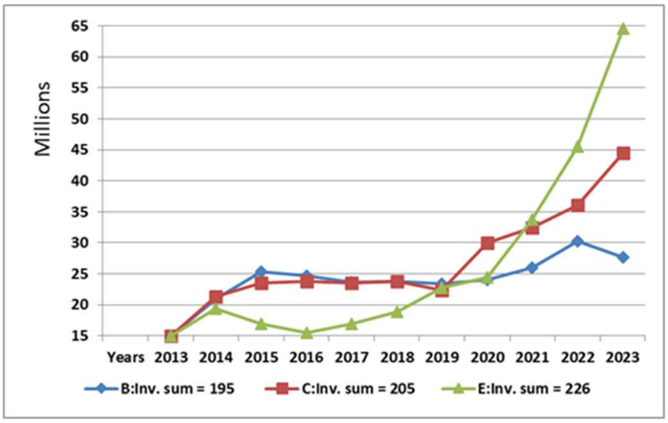
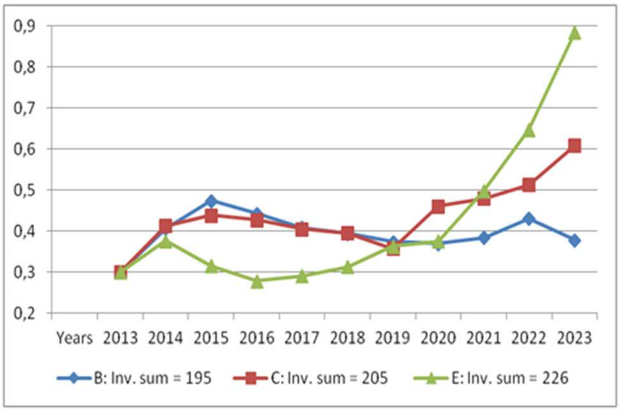
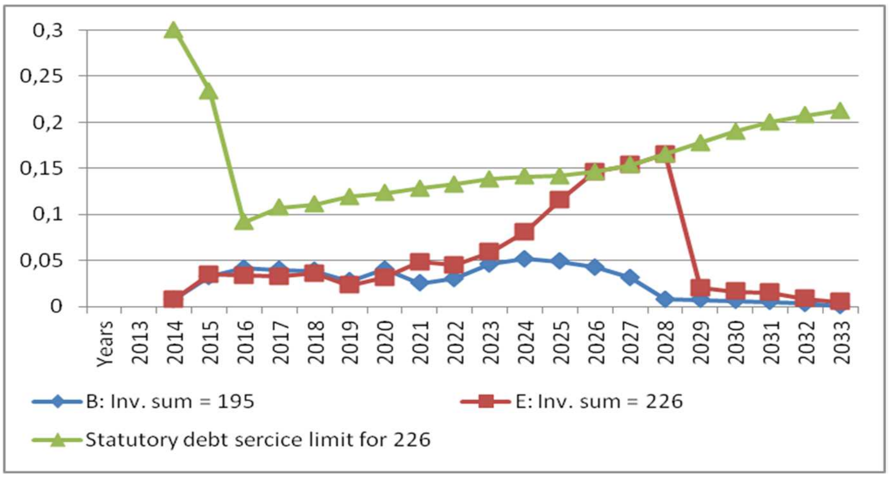


Figure 6. Debt outstanding to operating revenues



The outstanding old debt issued prior to t_1 is repaid in 2025 and the new debt, for Pareto points B, C, D an E - in 2032. The total debt for the outcomes B and C is similar until 2019, then the debt for the outcome C grows because a larger debt service after 2023 is allowed (limit in figure 7). For the output E the outstanding debt grows very fast starting 2021 as a result of decreasing operating surplus - LG’s own funds (figures 5, 9). In Figure 6 the debt outstanding to operating revenues is presented as a measure of debt profile implemented by rating agencies, which also asses the interest payments (figure 8) and the LG’s financial performance by analyzing liquidity and operating surplus (balance) related to operating revenues (figure 9).

Figure 7. Debt service to total revenue; model constraint (8)



The fiscal rule of the Polish law on public finance requires that the total debt service, including repayment of debt principals, in relation to the total revenue (left hand side of the constraint (8)) is below the statutory limit (right hand side of (8)). In point E, the debt service costs grow over 2023-2028, equal the limit in 2026-2028, and sharply decreases in 2029, as a result of cumulated cost minimization [model criterion (2)]. The debt service to revenue for points B and E is close over 2014-2020 (figure 7).

Figure 8. Interest payments to operating revenue

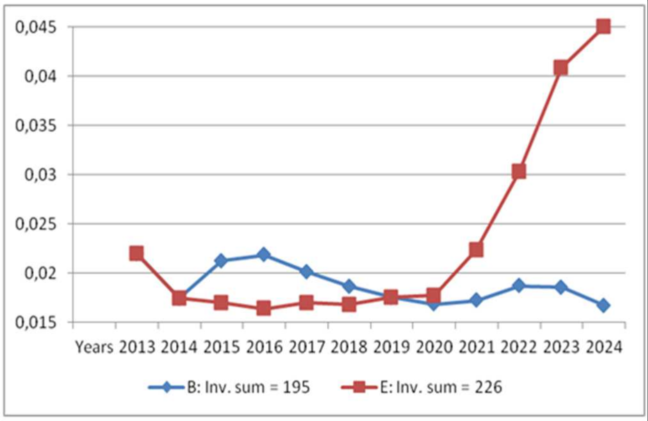
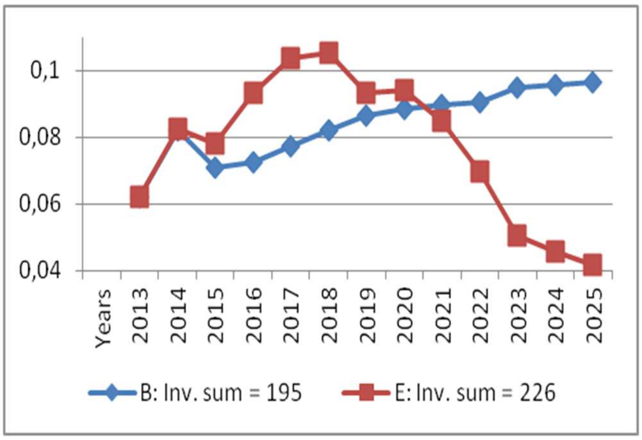


Figure 9. Operating surplus to operating revenues



The share of the operating surplus in operating revenue until 2020 is higher for the Pareto outcome E than for B and C, but starting 2021 it falls sharply, together with the operating surplus (figure 9), because of the rising operating expenditures - debt service costs and the GFCF maintenance costs. The fixed assets, starting 2021, grow faster for the outcome E than for the outcomes B, C, and A, and their maintenance costs are the highest.

The implemented in Poland fiscal rule limiting the debt service to revenue indicator (art. 243, public finance law) does not prohibit the debt from fast growth – contrary to the intension of the regulator. The rising debt service costs contribute to the drastic fall of the operating surplus after 2021 (figure 9). A local government dm observes pictures 6, 7, 8 and 9, and should definitely reject solutions of the output E as too risky. Although the indicators conform to the limits of law, she should be well informed about the rating agencies criteria. For example for the outcome E, debt to operating revenues indicator is above 65% in 2022-2023, during 2023-2025 the operating surplus falls below 5% of the operating revenues (this may be the reason of the non-investment rating by Moody's), and the interest burden approaches 5% of the operating revenues in 2024, above which Moody's again offers the non-investment rating.

6. Summary

A new method supporting local government decisions regarding long-term budget planning is developed. The method utilizes a mathematical model reflecting interrelations between budget financial flows and stock over time and the iterative decision supporting procedure implementing multi-criteria optimization. Budget liquidity and fiscal rules included as constraints in the LG budget optimization model are satisfied over long-term.

Implementation of the method supports decisions made by LGs' managers – helps determine decision variables - affordable levels of investment, EU funds, and safe medium and long term debt, totally and each year of the projection period. Upper (and lower) limits for cumulated investment and debt service costs - elements of the dm goals are determined. The limits determine acceptable risks associated with debt issue and safe investment. The method enables selection of various goals updated during the projection process and generation of the variables and criteria values (outcomes) associated with these goals ("aspirations"). A dm can analyze consequences of her decisions regarding investment, fixed assets formation, debt until its maturity and budget balance. The model is solved iteratively with new aspirations resulting from rational valuation of alternatives [14]. It can be repeated the same year and in future years for a crawling horizon.

The iterative procedure bases on H. Simon satisficing behavior theory and implements the reference point solution method of multi-criteria optimization. Outcomes are Pareto optimal. The dm looks for a preferred outcome in an iterative learning process - adapts her aspirations using information on outcomes and decision variables resulting from previous solutions of the model. The procedure includes analysis of scenarios as discussed in Kavanagh 2007: 157-159, for long-term analysis of infrastructure needs (Edmonton city), by Vogt 2004 and Cichocki 2013: 71-76. The computer-based procedure, using the LG budget flows model, derives an outcome closest to the reference point representing the dm aspirations, and calculates respective decision variables.

The method accommodates approaches presented in literature - incremental and punctuated budget projections (thanks to assuming alternative goals), budget's dynamics analysis (Lindblom 1959, Baumgartner and Jones 2002, Breunig 2006, Citi 2013), and one criterion optimization model with constraints (Cichocki 2013)[15]. Implementation of the method increases the LG potential as discussed by Steward 2014. We introduce a local dm who attempts to minimize inappropriate interventions of fiscal rules imposed by the central government.

The presented method supporting long-term financial planning and budget projection with the dm involvement and her learning about implications of today actions is new in literature. It increases budget safety and stability in long-term. Looking for the preferred projection scenario with adaptation of aspirations (alternative goals assumption), based on Simon's ideas, as well as the utilization of the LG budget flows model and implementation of multi-criteria optimization solution technique are novelty in the budget planning literature. The extensions of the presented budget projection method include: simultaneous consideration of several goals; implementation of the Simon's concept of multi-stage formation of aspirations related to goals, implementation of multi-criteria optimization and learning in the projection selection process, considering explicit debt structure and extension of the analysis period until all debts' maturity and finally, selection of the satisficing solution by the dm, who knows local specificity and rating agencies methodologies.

Investments must be planned very carefully because the new fixed assets maintenance costs grow very fast and budget operating funds may fall dramatically. When the goals are too ambitious, the debt used for investment financing might grow very fast and the debt service may drastically restrain investing in future years.

[14] Explicit assignment of weights to the model criteria could exclude some important Pareto optimal solutions.
[15] A model was formulated to maximize, over several years, total funds for financing investment (from budget and debt), subject to constraints. Each period, upper limits for safe debt and investment were determined.

The fiscal rules implemented in the model come from the Polish law, however, country specific rules can be incorporated in the model, and the method can be used in many countries with various goals assumed. The method can also be implemented by the central government to analyze alternative fiscal rules' impact on LGs' debt, deficit and investment[16].

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[16] The rules of the Polish law hinder, or allow for, growing debt and decreasing operating surplus (figures 5, 8, 9 and Cichocki 2013).

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Appendix

Consistently with the theory of multi-criteria optimization (Keeney and Raiffa 1976; Wierzbicki 1986), we look for an outcome (and decision variables) which is Pareto optimal in the set $\boldsymbol{Y}_0$ and satisfies the dm preferences. An outcome is Pareto optimal if there is no other outcome dominating it in the set $\boldsymbol{Y}_0$ - with greater cumulative investments and lower total debt service costs. The Pareto optimal points in $\boldsymbol{Y}_0$ and the corresponding decision variables in $\boldsymbol{X}_0$ are not known. They are uncovered in the computational solution procedure. Generation of achievable Pareto optimal outcomes is carried out with an aid of the reference point method, which utilizes the order approximation achievement functions (Wierzbicki 1986). Outcomes belonging to the Pareto frontier are derived by solving the below optimization problem:

$$\max_{x \in \boldsymbol{X}_0} [s(y(x), y^*)] \qquad \text{(A1)}$$

where:

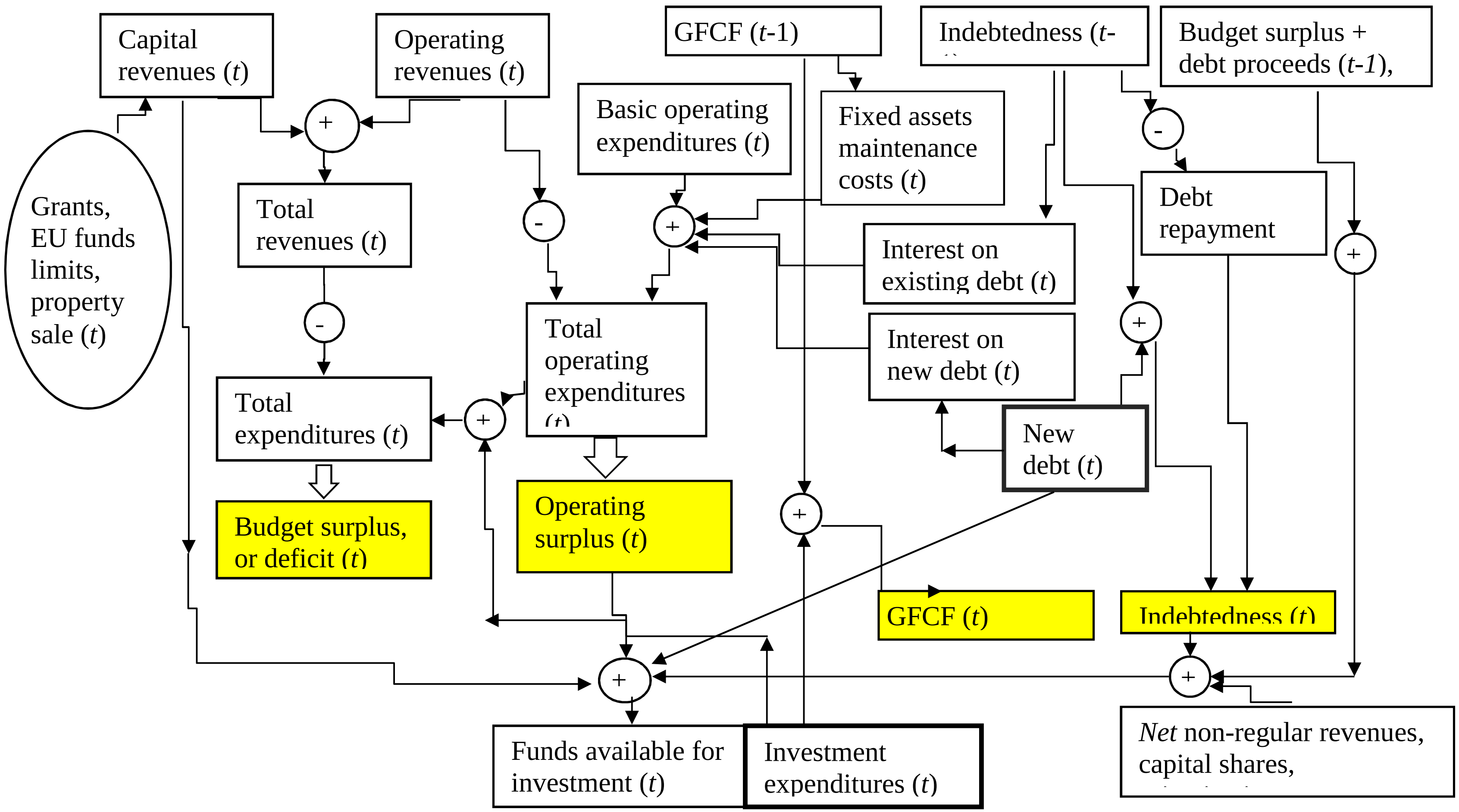
$\boldsymbol{X}_0$ - a set of admissible decisions defined by the model relations,

$y^* = (y_1^*, y_2^*)$ - a reference (aspiration) point assumed in the space $\mathbf{R}^2$ of the criteria y_1 and y_2,

$s(y, y^*)$ - an order approximating achievement function.

The assumed achievement function is a version of the order approximation function [(34) in Wierzbicki 1986]. The optimization problem (A1) is solved by a specially constructed computer-based system which uses the solver embedded in the MSExcel environment. It is solved for a given reference point y^* assumed by the dm. The solution includes a Pareto optimal outcome, all corresponding decision variables, and other variables of the model calculated with the use of the decision variables.

Diagram 1. Financial flows and stock of the local government budget



t denotes a current year, *t*-1 - the year proceeding the year t