Prediction diagnostic for smart cities systems

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Abstract

Systems applied in the last few years for an improvement of the operation of tools ensuring the most critical functions in large cities must provide their functions exploiting various methods from the area of advanced informatics and system theory (see [1,3] e.g.). One of the most important of them is the **prediction diagnostics** being a tool allowing to estimate

how long particular system (or the whole smart cities system alliance) can still operate well, or when it approaches to the end of such reliable state (see [2-7] eg).

In this contribution the possibilities of prediction diagnostic apparatus are discussed as well as limitations coming from the fact that these systems must be very often considered as uncertain, especially

if they interact with human factor (see [8,9,10,11,12] e.g.).

The operation reliability of many real systems, focused on keeping the life conditions in large cities has to be significantly improved.

These systems are still more complicated and also the requirements on their functions are continuously rising.

The decrease of their function power, or even their failures can cause critical or even catastrophic states.

For preventing such unhappy situation a very high importance has to be given to the estimation, how long the system as a whole will be able to function well and when its operation reliability begins to decrease, or eventual fail completely.

An application of prediction diagnostics methods can be fruitful approach for such important task.

Methods of prediction diagnostics are considerably long time developed for the design of complex technical systems.

Though their apparatus is still not complete and much work in this field has to be done, the conventional approaches to prediction diagnostics give very good results.

However, **application of conventional prediction diagnostics can appear to be problematic for smart cities systems** from several reasons.

One is the **very high complexity of these systems**,

the other factor is their **parameter and sometime also structure variability,**

and the third comes from **interaction with human subjects or their groups**.

Character of smart cities system operation

Very many properties of each Smart City system and of course of their alliance can be read from the moves of the system vector X in the system parameter space.

They are caused by impacts of various independent variables, namely the time t. These moves follow the so called **life curve $\psi(t)$.**

Suppose, that one is able to investigate with acceptable accuracy not only the probable shape of system life curve $\psi(t)$, but also the speed with which the vector of system parameter $\mathbf{X}$ moves along it.

The life curve $\psi(t)$ is to be understood as the trajectory of the system parameter vector $\mathbf{X}$ in the system parameter space under the influence of the whole set of independent variables **$\mathbf{P}$,** from which the most important is time t, which.in real cases is still one-directional and one cannot have any influence on its run.

In such a case one can **predict the time t_{crit} in which ψ(t) will approach so close to the boundaries of acceptability R_A**. This is the region in system parameter space **X,** in which the system parameter values must be placed for well operating system.

If ψ(t) approaches to R_A boundaries, a danger exists that it can break it. Such event one needs to predict.

This is very important possibility, because it **allows in - time warning before the end of functional life of particular system,** or alliance.

The respective method is known as the prediction diagnostics. It has many forms now. The basic mechanism of the use of it for in – time warning purposes is explained on simple example shown in Fig. 1.

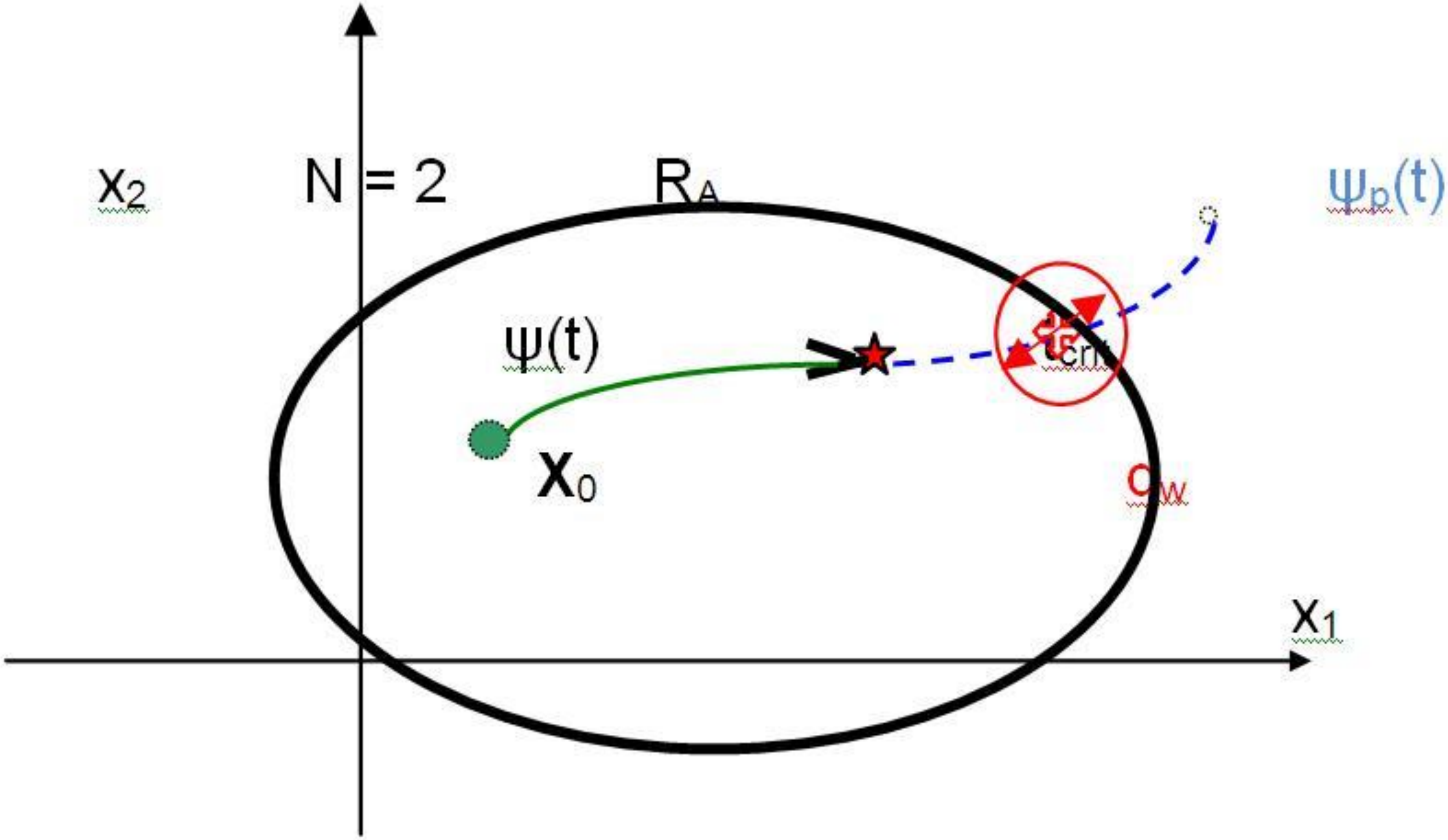

Fig. 1:To the principle of in-time warning on the base of prediction diagnostic – strongly simplified ideal case.

Suppose that the trajectory of life curve ψ(t) is known up to the certain point denoted in Fig.1 by red asterisk.

In this point the further extension of ψ(t) is started to be predicted (dotted blue line $\psi_p(t)$ in Fig. 1).

In the moment when this prediction approaches to the boundary of the region of acceptability R_A closer than the warning distance d_w the warning procedure starts.

In - time warning

The distance of the intersection of the predicted life-curve $\psi_p(t)$ with the circle of the diameter d_w around the point t_{crit} marked by small red cross in Fig. 1, measured along the $\psi_p(t)$ represents the **time reserve Δt_w for warning**.

The reliability of the prediction of $\psi_p(t)$ has to be considered as **critically important for the above mentioned prediction diagnostic procedure**.

If the estimation of $\psi_p(t)$ is not enough reliable and accurate, either the **false warning or neglecting of warning** can appear. Both these cases can be very dangerous.

The **false warning** brings un-useful expenses and moreover, if appears more frequently, it leads to degradation of credibility to particular warning system.

The **neglecting of warning** can cause evidently high losses.

The prediction of $\psi_p(t)$ itself must be done so that the decision that warning is necessary can be done at least in the time interval Δt_w before the real failure of respective system or alliance.

The value of Δt_w must be in any case large enough for:

- distribution of warning signals
- warning understanding
- acceptance the necessity of prevention or restoration procedures
- realization of effective prevention or restoration actions.

Unfortunately, in many real cases especially the last two of these four main warning operations are not made in time or eventually are totally neglected.

The efficient warning procedure exploiting fully the advantages of prediction diagnostics is evidently very complicated procedure, requiring the knowledge of at least some critical parts of R_A, analysis of $\psi(t)$, good (enough precise and reliable) prediction of $\psi_p(t)$ and in-time realizing of all the four above mentioned warning activities. Especially in more complicated cases (for higher values N of respected system parameters) it can represent a very laborious and expensive task.

However, quite often, the saved amount of money, health and social expenses can be significantly higher than the warning expenses.

Reliability problems

The apparatus of system reliability investigation and prediction diagnostics, discussed in previous part suffers from some serious drawback.

One of them is the problem of the **necessity to operate in many-dimensional space,** which somebody calls as a curse of dimensionality.

If one wishes to take into account too many parameters and characteristics of considered system – and the smart cities systems are usually of multidimensional nature - one faces not only difficulties in respective numerical calculations, but one has also fight with influence of natural inaccuracy in determination of considered numerical values.

In general - if one wishes to deal with system models respecting N parameters, one has to determine their values to about at least N/2 decimal places. This says very old rule of thumb.

The numerical experiments which we made recently have shown that such dimensionality curse practically does not depend on the shape of the respective regions of acceptability.

If the values of system parameters are determined with certain inaccuracy, the considered R_A^s are encased by some shadow envelope of uncertainty, the thickness of which rises with N.

Therefore it is recommended to restrict the considered number of system parameters below, say N = 10.

This is of course very serious disadvantage for dealing with really complicated systems or system alliances, because their approximation by a set of simpler models can neglect some important factors and events.

One of possible ways out of these problems can be seen in replacing the above considered dealing with system parameters X space above which the relatively simple system functions F are considered by direct operation in the system function space {**F},** which dimensionality K is usually significantly smaller than N.

Suppose that the trajectory of life curve ψ(t) is known to the certain point denoted in Fig.1 by red asterisk.

In this point the further extension of ψ(t) is started to be predicted (dotted blue line $\psi_p(t)$ in Fig. 1).

In the moment when this prediction approaches to the boundary of R_A **closer *than* the warning distance d_w** the **warning procedure has to be started.**

In-time warning problems in detail

The distance of the intersection of the predicted life-curve $\psi_p(t)$ with the circle of the diameter d_w around the point t_{crit} marked by small red cross in Fig. 1, measured the $\psi_p(t)$ represents the time reserve Δt_w of warning. As critically important for the above mentioned prediction diagnostic procedure the reliability of the prediction of $\psi_p(t)$ has to be considered. If the estimation of $\psi_p(t)$ is not reliable and accurate enough, either the false warning or neglecting of warning necessity can appear.

Suppose some **uncertain system**, the very simple example of which is sketched in Fig. 2, where for simplicity only 2 system parameters are considered.

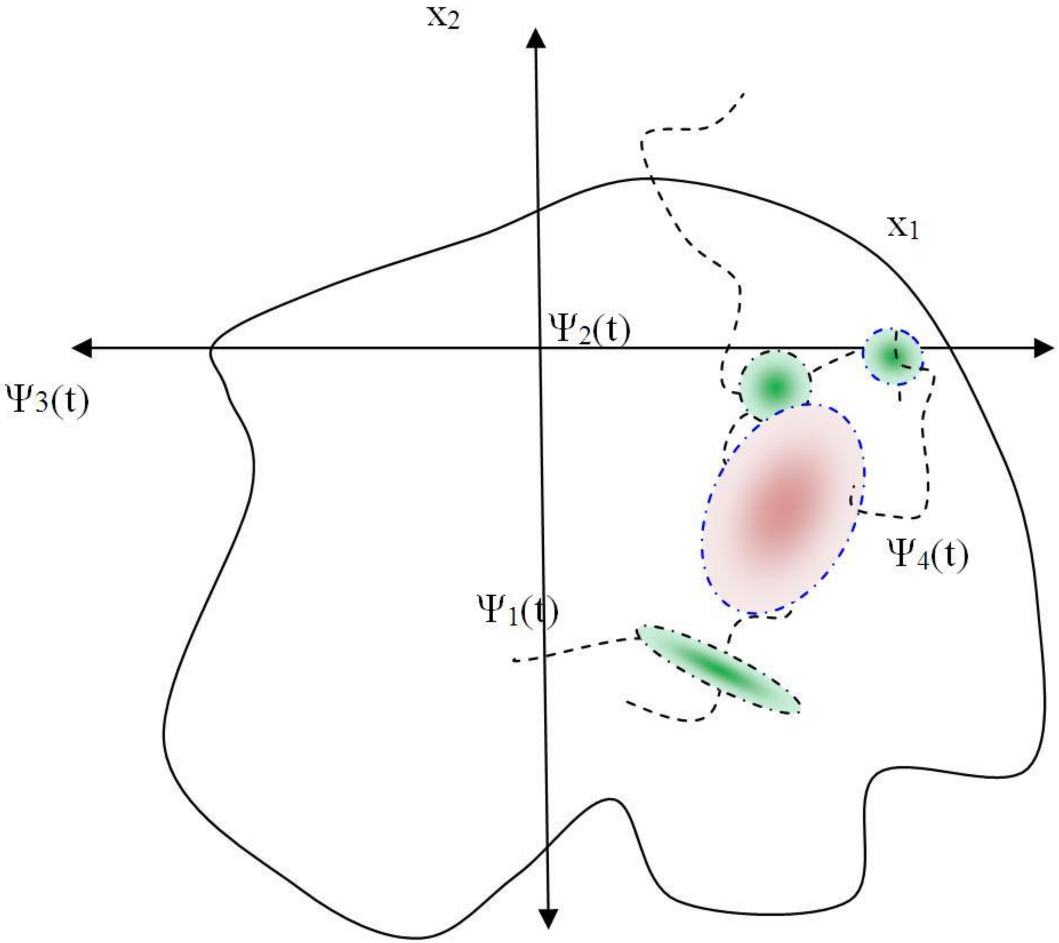

Fig.2: Example of areas in the 2 dimensional parameter space, where nevertheless that the whole life curve trajectory Ψ(t) is principally uncertain, some knowledge on its nature can be reached in some its parts (here the part Ψ_4) from mining more examples of its typical cases (pink area). In contrary in some others parts (green areas), no hidden information can be found.

Even, that also in the by pink color marked area in Fig. 2 no direct information concerning the actual shape of $\Psi_4(t)$ exists, the knowledge of the possible spread of typical $\Psi(t)$ trajectories can help to understanding the possible variations of life curves.

Evidently, in such case one has to be very careful with warning and select if **it has to be started even if the danger of system failure is not quite sure or if the risk of missing warning is acceptable.**

Both these cases can be very dangerous.

The prediction of $\psi_p(t)$ itself must be done so that the decision that warning is necessary can be done at least in the time interval Δt_w before the real fail of respective system or alliance.

The value of $\boldsymbol{\Delta} t_w$ must be in any case large enough for:
distribution of warning signals, allow the warning understanding, the acceptance of necessity the prevention or restoration procedures, realization of effective prevention or restoration actions.

Unfortunately, in many real cases especially the last two of these four main warning operations are not made in - time or eventually are totally neglected.

The **efficient warning procedure** fully exploiting the advantages of prediction diagnostics is evidently very complicated procedure, requiring the knowledge of at least some critical parts of R_A, analysis of $\psi(t)$, good (enough precise as well as reliable) prediction of $\psi_p(t)$ and in-time realization of all the four above mentioned warning activities.

<u>Especially in more complicated cases (for higher values N of respected system parameters) in can represent a very laborious and expensive task</u>.

However, very often, saved amount of money and suppressed health and social losses can be significantly higher than the expenses.

Problems of system uncertainties and expected ways for their solution

Another, very important aspect causing serious difficulties is the very often existing **uncertainty in considered smart city system parameter values and sometimes also in its structure**.

All this can have not only the fuzzy nature, but can also change under impact of many independent variables, besides the time.

Moreover, if the respective smart city system has to interact **with living organisms, or – what is very often the case -, if the human subjects or their groups form directly their part, the problems of enough accurate and reliable prediction diagnostics and in-time warning against the considered system operation failure** can be much serious. The uncertainty of human factor causes special kinds of problems.

Actually we have to say that the **conventional methods of prediction diagnostics are often not fully sufficient is such conditions and that novel approaches have to be searched**.

The respective problems are quite hard, both in theory and also as concerns the practically applicable methods and prediction and warning tools.

Some hope can be however be seen in new prepared projects, hoped to be started in not too far future in international cooperation

Thank you for your kind attention