Fall prevention from a system dynamical point of view

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Abstract

Falls are a serious problem for older adults, often causing severe injuries leading to loss of independence and high cost. Although a great effort has already been put into research on falls, the situation concerning the prediction and prevention is unsatisfactory from a practical point of view. A small interdisciplinary team attempted to address the issue in a holistic view using a system dynamics based approach. A simple model which enables the simulation of commonly observed circumstances was developed based on consultations with experts,. This leads us to the assumption that the limited success of research up to now is caused by the fact that common approaches currently in use are not sufficient to accommodate the complexity of the underlying problem. A system dynamics approach is assumed to cope much better with this challenge and to lead to better predictions and case specific interventions.

Older People: More deaths by falls than by traffic accidents! This was the alarming headline to German elderly persons published by www.journalmed.de on the internet in 2008. The same applies for the USA where falls are the primary cause of accidental death in people over 65 [Fuller, 2000]. About one third of people over 65 fall at least annually. In contrast to falls in younger people the elderly often suffer from severe consequences: about one third of falls leads to minor injuries and 2-6 % even cause fractures [Six, 1992 in Grob, 2005]. A survey in Switzerland [Hubacher, Evert, 1997] found hospital costs of 150-200 Million Swiss Francs per year due to fractures. Falls lead to major health problems, for individuals and for the health systems.

Fall prevention – state of the art

Given the magnitude of the problem for the health system and nursing activities, great research efforts have been made in fall prediction and prevention. Particularly the question of influencing factors on the risk of falls and how to identify patients with high risk of falls has been addressed in many studies. Although several fall risk assessment tools are in use the situation is unsatisfactory from practical point of view. Comparing 23 different falls risk assessment tools a German expert standard on the prevention of falls concludes that none of them seem to be suitable [Schiemann et al., 2006]. Some of the tools tend to classify too many persons as endangered while others miss too many persons who later endure falls. Some instruments predict incorrectly in both directions. False prediction either leads to high expenditures of resources in patients who are not in need of fall prevention interventions and - vice versa - patients who are in need of interventions not receiving the necessary care.

As the responsibility for patient falls often is placed to nurses they are keen on tools for risk assessment which also support them in choosing specific preventive interventions, and helps to save resources. Such support is particularly necessary to guarantee the safety of patients, even if the interventions such as constraining patient from moving may be unfavorable for the patients. Apart from the ethical reservations, trials have shown an increased risk of falls immediately after this intervention.

Scope of the project

At the University of Applied Science St.Gallen an interdisciplinary project was started by the Institute of Applied Nursing Science and the Institute of Modeling and Simulation to evaluate the potential of a system dynamics approach addressing fall prediction and decision support concerning interventions, especially the fixation of fall prone patients. The aim of this project was to develop a simple basic model of cause - effect relations leading to falls. The model should be capable of simulating the following scenario: the mechanical fixation of a patient as an intervention for preventing falls and the dynamic consequences of this intervention on the probability of further falls. The model was required to be semi-quantitative which means that it should be able to calculate commonly known qualitative effects correctly (e.g. increased risk of falls after fixation). However, the model was not expected to be conclusively developed for practical use. The general idea was to use the prototype of the model to demonstrate the advantages of a system dynamical approach to practitioners and researchers from hospitals, nursing homes etc. in order to support follow up research projects leading to more sophisticated models.

We conducted the following two steps:

1. We summarized the underlying interrelations leading to falls based on literature research and graphical presentation of the main causal structures found.
2. We conducted quantitative simulations of typical scenarios based on a mathematical model (with parameters distilled from the literature): We aimed at simulating long-term consequences on the probability of falls on using different strategies for fall prevention.

As quantitative validations of the model were not possible at this stage of the project, we decided to check at least the plausibility of the behavior of the model by peer review. Two peers – experienced experts from praxis – were asked to ascertain whether the behavior of model when fed with various inputs would react at least in the right direction from their practical vantage point.

Findings from Literature

As the issue of falls has already been the object of extensive research we were able to base our analysis on meta-studies summarizing the results of numerous individual studies [Neyens et al., 2006; Chang et al., 2004; Grob, 2005; Schiemann, 2006]. All authors stated that the falls of elderly are a multi-factorial problem with the risk of falling increasing significantly with the number of risk factors observed. The following risk factors have been identified in a large number of individual studies:

- Previous falls
- Mobility impairments
- Gait disorders
- Medication
- Dependency in activities of daily living (ADL)
- Disturbed balance
- Muscle weakness
- Cognitive problems/confusion
- Disturbed vision
- High age

Analyzing this list it becomes obvious, that most factors are interdependent on the others: Muscle weakness for example might lead to gait disorders, which may result in a dependency in the activities of daily living or might even have led to previous falls. It is astonishing that causal dependency of risk factors has not been tested by those studies. Many assessment tools do not seem to take this interdependency into consideration and evaluate different risk factors that can be traced to the same genuine cause. Hence, the genuine cause concerned is weighted much stronger by the assessment than a cause represented in the assessment by a single causative risk factor. This might explain some of the inadequate sensitivity of fall prediction instruments criticized above. Fall prediction based on risk factors representing different levels or aspects of the same cause and effect chain may represent a methodical limitation of medical research.

Possibilities to conduct clinical experiments are – quite rightly – limited by ethical reasons. It would for example be irresponsible to observe whether patients with an obvious high risk of falling fall or not without applying usual interventions to prevent them from falling. For this reason the typical approach to data collection for quantitative risk factors are statistical post hoc analysis leading to correlations between various available observations and the falls. This method is usually restricted to observations which are systematically tracked, that can be measured and quantified. To attain high statistical confidence comprehensive databases supplied by hospitals or nursing homes are usually used. However, such databases are usually not generated to track risk of falling. Therefore many data do not strictly fit the issue of falls. This situation can be compared with a marketing specialist who has to predict the sales of sports cars exclusively based on income data gathered by the tax office.

Another phenomenon observed in our analysis of the literature is the missing link between results from risk assessments and patient specific interventions. That means that assessment tools assume the risk of falling at a highly aggregated level. Following assessment it is a separate task to compose the individual invention program for the patient. Interventions can be categorized as follows:

- Optimizing extrinsic factors (the surface of floors, lighting, shoes, spectacles etc.).

- Support by nurses in critical situations.
- The education of patients in order to change dangerous behavior.
- Physical exercise programs.

In most cases a combination of different interventions is used, which makes it difficult to detect the effects of the individual interventions. For this reason research on the efficiency of different interventions conclude that multi-factorial interventions are the most successful strategy [Chang et al., 2004]. The literature suggests that exercise programs alone are successful on their own although Schiemann [2006] cites a study showing the absence of the effect of exercise programs on the risk of falling.

The development of the model

The starting point of the model was the observed causal interrelations between the reported risk factors for falls. In a first step project team (two nursing scientists and one modeling expert) set out to identify cause and effect chains based on the results of published studies. This approach was not particularly successful, mainly due to the fact, that studies do not follow the logic of cause effect relations but simply analyze correlations between different risk factors or impacts and falls. We found no hints concerning inter-relations or even causal structures underlying the system.

The second step employed an expert based approach. Due to the fact every member of the team was familiar with findings from literature the model was developed in alternating sessions of modeling and critical evaluation by the practitioners. The sessions were carried out according to the following scheme:

1. The part of the model developed at the previous session was discussed and accepted or changed and then finalized.
2. The development of the qualitative structure of the new part of the model was based on know-how of the practitioners (without the direct use of literature) in very lively discussions. The immediate graphical representation of the results of the discussions was helpful and assisted the recognition of patterns and causal structures. We used the software VENSIM which supports graphics even at the level of qualitative structures and noted the model structures directly on the computer. The following steps were taken:
    a. Identification of parameters and their interrelations.
    b. Identification of the characteristics of the behavior of parameters and distinction between variables and stocks.
    c. Refinement of model structure by adding variables (especially auxiliary variables) and interrelations within and external to the part model under scrutiny.
3. 'Quantification' of the newly developed part of the model (with the direct use of literature if necessary) taking the following steps:
    a. Definition of how to measure parameters.
    b. Determination of calculation rules for quantitative values and quantitative settings (e.g. min/max values).

c. Testing of the newly developed part of the model or sub-models on plausibility of system behavior.

4. Definition of the issue for the next session.
5. Re-working of the session findings by the modeling expert and addition of parts, not completed in the session. To some extent missing input was delivered subsequently by the nursing experts. Interrelations to other parts of the model were added in this phase of the work in most cases.

As the direct consultation of the literature during the sessions tended to break the flow of the modeling process assumptions were made on missing information (e.g. do tranquilizers influence blood pressure?) and checked between sessions.

With regard to the contents of the model it turned out to be efficient to start with a very rough abstract main structure of the model which we term the "backbone" (see below). Although it took us two workshops and some individual discussions to reach a consensus on this structure on a qualitative level the time investment was worth while because it provided the foundation for developing the separate sub-parts of the whole model. The 'Quantification' of the backbone was achieved by synchronizing the sub-parts of the model at the final stage of the development.

'Quantification'

As we were not able to adequately quantify the model – due to missing data – we use the term quantification quotation marks. The aim of the model was to predict the right direction of variations and to simulate the character of temporal dynamic of changes. At this stage of the project we were only able work on the basis of approximated time scales and we were not able to investigate the inter-dependence of different input variables in the right quantitative proportions.

Nevertheless, the step of "quantification" was important for the quality of our model and included the following steps:

- Check of qualitative concepts: Some ideas which seemed convincing as causal loop model elements melted like snow on trying to quantify them.
- Dynamic of output variables: "Quantification" is necessary to ascertain the temporal dynamic of the model. The fact that this dynamic is crucial for fall prediction was marked by the key issue mechanical fixation: During fixation the risk of falling is zero, but afterwards it is higher than at the starting point.

For these reasons opted to quantify the model, even if 'quantification' only means qualified guessing. In our model all variables concerning diseases or medication have values from 0 (variable not active) to 1 (maximum influence of the variable). Up to now we have for example no idea, which dosage of medication is dedicated to which value, nor do we know anything about weighting impacts of different substances. We learned a lot about causal inter-relations of the risk of falling by the fact that influences are tracked by figures and the dynamic of consequences becomes visible.

The Backbone

Many research studies on falls are based on the question: "What do people have in common who suffered a fall?" Our basic starting point for the development of the backbone deviates considerably from the general approach by posing the question: “Which factors have to come together to generate a fall?” The answer is quite simple: First of all, the person has to move or even try to move. This mobility of daily living (further referred to as mobility) is sine qua non for falling. As mechanical fixation leads to zero mobility, the risk for a fall is also zero. Whether mobility leads to a fall or not depends on a second condition: If the fitness (defined here as the ability to walk) of the person exceeds the requirements of the situation concerning walking abilities, falls become unlikely. The proportion of fitness and requirements was indicated as a risk of falling.

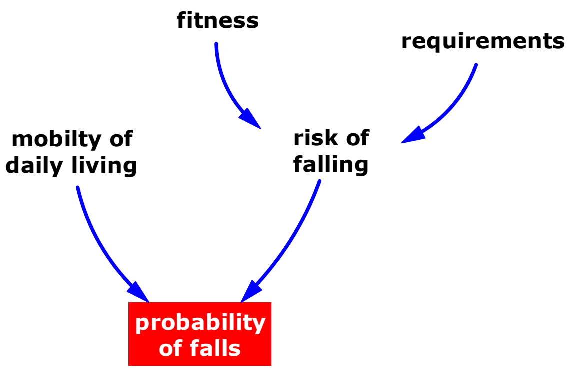

Figure 1: Backbone of the model

Fitness (ability to walk)

Fitness is characterized by the physical capacity of a person to manage mobility in daily living. Fitness can be seen the result of three factors: strength, coordination and balance. As fitness requires all three components - meaning de facto that none can be substituted by the others - we modeled fitness as the product of this three values.

Strength, coordination and balance are physical capabilities built by training and which continuously diminish in the absences of training. Usually diminution does not occur, because training by activities of daily living and diminution are in steady state. Diminution becomes evident when activities are stopped e.g. if a leg can not be used because of a fracture or complete immobility due to a coma.

Older adults build up their strength, coordination and balance especially by means of mobility of daily living, in contrast to specific physical exercises which have much greater impact than mobility. For the ‘quantification’ of the three values we decided to use hours [h] as an equivalent for time of the training effect derived from daily mobility.

For the three fitness factors the actual available value can vary from the stock. Circulatory disturbances for example may affect the equilibrium organ leading to impairments of balance even if the person has attained good fitness by training. Effects like these can be calculated in the model.

Requirements of walking abilities

The requirements of walking abilities represent the sum of all factors characterizing the physical environment of the patient. Typically these are lighting, furniture and structure of floors. In addition, requirements increase when unsuitable shoes are worn. If assistive devices are used in an adequate way, this might reduce requirements, but there is also the possibility of increased requirements, for example when devices are used inappropriately or if they are deposed in unsuitable places.

The ‘quantification’ of walking requirements was based on a comparison to the standard requirements at nursing homes with requirements corresponding to this level receiving a neutral value and higher ones indicating increased requirements. Requirements will be measured in the same unit as fitness.

Mobility (of daily living)

The construction of mechanisms to simulate the extent of mobility turned out to be the most difficult part of the model. This part of the model is intended to answer questions such as why do some patients go to the toilet at night without asking for assistance, even if they are in high risk or why some patients do not walk at all, although they are physically able to do.

A stimulus – usually an intention or aim – is required to induce mobility. In the presence of a stimulus people will consider – consciously or unconsciously – carefully whether their abilities to walk are sufficient to manage the requirements of the individual situation. Based on this they will decide to walk or, alternatively, wait for assistance. As this decisional process is usually based on a subjective estimation patient with cognitive or emotional impairments may misjudge the situation. The stimulus itself also may be influenced by diseases like depression or dementia or by psychotropic substances such as tranquilizers.

Central feedback loop

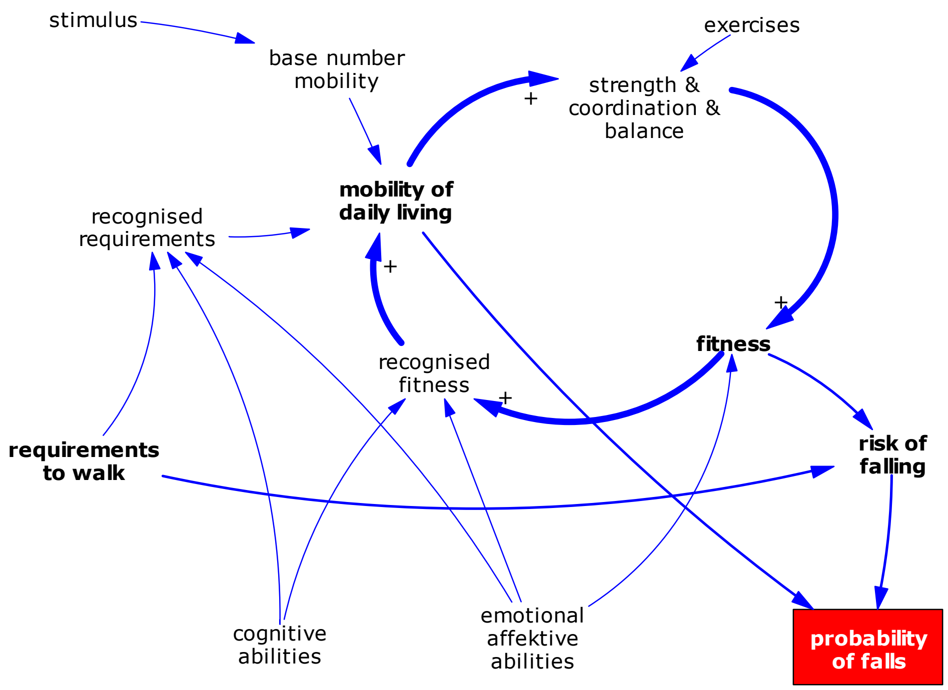

Figure 2: Central feedback loop

A central reinforced feedback loop was identified (Figure 2), which seems to be crucial for systems behavior: Fitness – the result of strength, balance and coordination – enhances mobility and mobility is the main source of strength, balance and coordination. As explained above it is not only the objectively available fitness which leads to mobility but also the subjective degree of fitness estimated by the patient.

This mechanism accounts for various observations of continuously decreasing abilities of the elderly to manage their activities of daily living. As fixation sets mobility to zero for a time period, it also explains an increased risk of falls directly after fixation.

Integration of risk factors from literature

It was possible to integrate most of the risk factors reported in the literature and used by assessment tools into the model as an input variable. Even observations like the increase of falls probability by poly-morbidity and poly-pharmacy are reflected by the model. The risk factors ‘age’ and ‘sex’ were not integrated into the model based on our contention that these variables have no functional relation to falls. In fact, the occurrence of several other risk factors correlates to these indicators.

Some risk factors mentioned in the literature are state variables of the model, like ‘disturbed balance’ (meaning ‘present balance’ with a low value) or gait disorders (meaning ‘fitness’ with a low value). Information concerning those factors might be used to validate the model in further research projects.

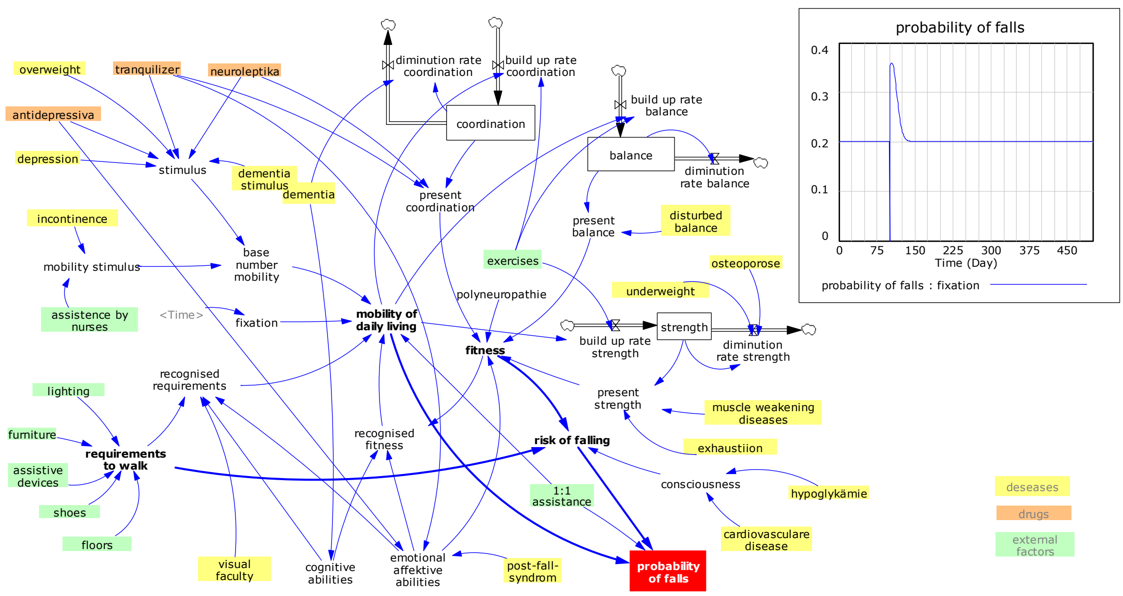

Figure 3: The basic fall prediction model

In addition, it became obvious, that some risk factors affect the probability of falls by different mechanisms. For instance in ‘weight’ (low or high body mass index) overweight may lead to reduced stimulus on mobility whereas underweight may increase the diminution rate of strength due to degradation of musculature. We assume that the analysis of functional relations will sharpen prediction by recognizing such impacts in a more differentiated manner and that the comprehension of the underlying mechanisms will lead to case specific interventions.

Check by Peers

We asked two experienced peers, a medical director and the director of nursing of a geriatric hospital, to critically supervise the modeling process at the following three stages of the project:

1. Start of the Project: Presentation of the project, basic introduction to the system dynamics approach.
2. Conceptual Model: Presentation of the backbone and primary ideas for further details of the model.
3. Final test of plausibility: Simulation of different practical scenarios.

We specifically invited input by the practitioners mainly in the second and third sessions. At the second session where we presented the concept of the backbone of the model, we got numerous feedbacks for the concept and many hints for the enhancement of the detailed model.

In the third session the peers seemed rather overwhelmed by the complexity of the model, although we had introduced it step by step. After presenting some typical scenarios, the peers attested the behavior of the model to be plausible. Given the intended continuation of the project the peers advised us to recruit peers situated at a research institutes or geriatric hospitals involved in research activities.

Conclusions

Modeling falls by system dynamics demonstrates that the underlying system is complex as it includes several feedback loops and delays. It is therefore not surprising that assessment tools based on simple isolated correlations do not lead to satisfactory fall predictions in many cases (see also Sterman, 2000). The management of falls turns out to be a pretentious problem as the system is dominated by the following dilemma: On the one hand the only way to increase fitness and in consequence to reduce the risk of falls is mobility but on the other hand mobility is the prior condition leading to falls, and might cause seriously reduced fitness.

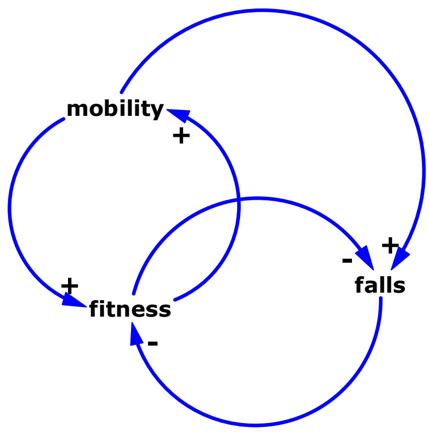

Figure 4: Dilemma of fall prevention

According to these findings the systems dynamics approach seems to be appropriate and we expect research in falls prevention to reach a new level based on this approach. Apart of the fact that the complexity of the system would be better recognized by system dynamics models, this type of modeling may support and catalyze interdisciplinary research (e.g. pharmacology, physiology, physiotherapy).

Another advantage resulting from the use of simulation models is the incorporation of temporal dynamic of change into the concept of fall prevention, which enables to investigate the sustainability of different intervention strategies. This is crucial for the assessment of interventions with delayed impacts like exercises or changes in living conditions that lead to increased mobility in daily living.

Given the complexity of the system it becomes obvious that calculating the probability of falls is not sufficient to design case sensitive interventions. This insight may lead to the perception, that general assessments of intervention strategies are of limited value. For example for a patient with high level of physical fitness but cognitive impairments in combination with acute disorders of balance, short term fixation might be the optimal strategy, whereas a frail and anxious patient has to be kept in movement to fortify his physical abilities.

Future research avenues

The following two issues have to be addressed in future research on the topic:

1. The communication concept: Obviously many health care professionals are not used to reading causal loop models and working with simulation models. To enhance the acceptance it is therefore important to communicate models in an easy and attractive way to the main stakeholders for further development of the model.
2. The quantification of the model: Further quantification – in much greater detail than we could achieve in this project – and validation research in multidisciplinary projects are necessary.

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