A Model for Simulation of Study Process Optimization in Rural Areas

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Abstract: Europe including Latvia is facing enormous socio-economic and unprecedented demographic challenges in the context of volatility, uncertainty, complexity and ambiguity. In the light of these challenges, higher education in rural areas is struggling to adopt the best approach, pursuing efficiency in the organisation of the study process. Therein, optimization of the study process in higher education within rural areas such as a lecture room of a proper size, staff to be employed, etc. has attracted a lot of attention. In order to optimize the study process in an efficient way, a simulation model is required. Models which concentrate only on the students’ probability are not exact enough to describe the study process. A new simulation model based on binary students’ behaviour should reflect both criteria such as students’ probability as well as concentration in the study process. The research question is as follows: How can the study process based on binary student behavior be realistically modeled via gap processes? The aim of the research is to carry out mathematical analysis of gap processes underpinning elaboration of a simulation model of optimization of the study process based on binary student behaviour in higher education within rural areas. The meaning of the key concepts of study process optimization, binary student behaviour, model and gap is studied. For the analysis of this issue, the synergy between higher education, business and telecommunications can be used as the phenomenon of the study process based on binary student behavior as well as bit-errors in data transmission appear to be of a similar nature, namely, the bursty nature. Such models that describe the bursty nature of bit-errors in data transmission have been successfully implemented in telecommunications for optimizing data communication protocols and will be adopted in this work to the study process in higher education within rural areas. The novelty of this paper is presented in the new model that allows a realistic description of binary student behavior based on gap processes.

Keywords: study process optimization, binary student behaviour, model, gap, higher education.

Introduction

Europe including Latvia is facing enormous socio-economic and unprecedented demographic challenges, including regional disparities, aging populations, high rates of low-skilled adults and of youth unemployment, low birth rates, changing family structures and migration (Lifelong Learning..., 2008, 4) in the context of volatility, uncertainty, complexity and ambiguity. In the light of these challenges, higher education in rural areas is struggling to adopt the best approach, pursuing efficiency in the organisation of the study process. Therein, optimization of the study process in higher education within rural areas such as a lecture room of a proper size, staff to be employed, etc. has attracted a lot of attention.

In order to optimize the study process in an efficient way, a simulation model is required. Such simulation models have been developed for business planning and economic forecasting (Erdman, 1993). It should be noted that higher education is adopting a business model as well considering the students to be clients or customers. These simulation models for business planning and economic forecasting (Erdman, 1993):

- on the one hand, focused on nonlinear and simultaneous relationships as well as dynamic processes,
- on the other hand, used such economic indicators as the gross national product as business planning is closely related with the economic system.

Analysis of the simulation models for business planning and economic forecasting revealed that these simulation models focused on the process dynamism:
on the one hand, do not take into consideration the bursty nature of phenomenon,
on the other hand, use indicators that show phenomenon’s developmental dynamism rather than criteria that serve to structure, assess and evaluate (Špona, Čehlova, 2004, 88).

Therein, a simulation model for optimization of the study process in higher education within rural areas is of great research interest.

For the creation of a new simulation model, such an everyday situation is considered as students have to solve an issue formulated already in 1603 by William Shakespeare (1564-1616) in his play Hamlet such as "To be, or not to be" (Shakespeare, 1825). Regarding a modern interpretation of students’ contemporary problems, Shakespeare’s words may sound as “to study, or not to study”. It should be noted that “to study, or not to study” is considered as binary student behavior.

Binary students’ behavior influences the organization of the process of higher education. Figure 1 shows a typical scenario in which visiting a lecture by students is highlighted (represented by “x”) among the students who are potential visitors of this lecture (represented by “-”).

![Figure 1. Simulated lecture visits by the students (represented by “x”) among potential lecture visitors (represented by “-“).](image)

However, the students can be more independently distributed over e.g. a lecture or they can appear really concentrated as highlighted in Figure 2.

![Figure 2. Simulated bursty nature of the students who visit a lecture (represented by “x”) among potential lecture visitors (represented by “-“).](image)

In general, the students’ probability can serve as a clear criterion of how often students decide to visit a lecture. However, the students’ probability does not deliver any information about how concentrated this process is. In situations, where binary decisions in higher education are made such as visiting a lecture, not only the event of students’ visiting a lecture is of any interest but also how concentrated students are to visit a lecture. That is why models which concentrate only on the event of students’ visiting a lecture with a given probability are not exact enough to describe the study process.
Models which concentrate only on the students’ probability are not exact enough to describe the study process. A new simulation model based on binary students’ behavior should reflect both criteria such as students’ probability as well as concentration in the study process. The research question is as follows: How can the study process based on binary student behavior be realistically modeled via gap processes?

The aim of the research is to carry out mathematical analysis of gap processes underpinning elaboration of a simulation model of optimization of the study process based on binary student behaviour in higher education within rural areas.

The novelty of this paper is presented in the new model that allows a realistic description of binary student behavior based on gap processes.

Methodology

The meaning of the key concepts of study process, binary student behaviour, model and gap is studied.

For the analysis of this issue the synergy between higher education, business and telecommunications can be used as the phenomenon of students in the study process as well as bit-errors in data transmission appear to be of a similar nature, namely, the bursty nature. It should be noted that by bursty nature of phenomenon, intervals of high-activity alternating with long low-activity periods within a fat-tailed inter-event time distribution is meant (Karsai, Kaski, 2012). Such models that describe the bursty nature of bit-errors in data transmission have been successfully implemented in telecommunications for optimizing data communication protocols and will be adopted in this work to the study process in higher education of rural areas.

The interpretive paradigm was used in the present study. The interpretive paradigm aims to understand other cultures, from the inside through the use of ethnographic methods such as informal interviewing and participant observation, etc. (Taylor, Medina, 2013). Interpretative paradigm is characterized by the researcher’s practical interest in the research question (Cohen, Manion, 2007). The researcher is the interpreter.

Exploratory research was employed in the empirical study (Phillips, 2006). Exploratory research employed in the empirical study is aimed at generating new questions and hypothesis (Phillips, 2006). The exploratory methodology proceeds from exploration in Phase 1 through analysis in Phase 2 to a new research question/hypothesis development in Phase 3.

The present contribution involves theoretical methods such as analysis of theoretical sources and modelling.

Results and discussion

This section starts with the conceptual framework for simulation of study process optimization based on binary student behavior.

By model, a pattern of individual’s or individuals’ interpretation of a phenomenon is meant. Models can be presented in a variety of forms such as verbal, graphic, computer, etc. A model can be characterized as demonstrated in Figure 3. The model characteristic is described by parameters such as the students’ probability and the students’ concentration.

![Figure 3. Model elements, where parameter 1- the students’ probability; parameter 2- the students’ concentration.](image)
By a parameter, definable, measurable, and constant or variable characteristic, dimension, property, or value, selected from a set of data (or population) to understanding a situation (or in solving a problem) is understood (Business Dictionary, 2015).

In turn, simulation model is identified as patterns of the management of phenomenon change in real-world situations. A simulation model should map the characteristic of the real world process with the required precision. The real world process in this work refers to study process that includes lecture visit, etc. where binary decisions are made.

In the study process, the bursty nature of the students is taken into consideration. Taking the bursty nature of students into account, the students’ ratio is no longer sufficient to describe the characteristic of the study process. The students’ ratio (in the following referred to the students’ probability \( p_e \)) is defined as the number of students entering e.g. a lecture room divided by the number of students who are potential lecture visitors. Here, using a model with only one parameter is difficult to project the real students’ characteristic onto the parameters of the model. This leads undoubtedly to an inaccuracy between the model setup and the real world characteristics. Hence, an additional parameter has to be introduced to describe the concentration of students in the study process in higher education.

Within the binary decision paradigm, study process in higher education is a success, if the process receives an outcome, for example a certificate of participation in a lecture. Gap in the present contribution means no lecture visit by a student from potential lecture visitors, in other words, without the outcome. By a gap process, the students’ concentration as well as the students’ probability can be taken into account in a realistic way. Therein, the gaps between two lecture visits are assumed to be statistically independent from each other.

Figure 4 highlights the theoretical basis for the new simulation model, where the study process is described by gap-processes and illustrates the process between two lecture visits, i.e. how often students visit a lecture and how concentrated they appear. For the optimization of study process related parameters e.g. the expected time between two students a simulation model such as the proposed one can be helpful.

Analyzing the students’ characteristic, we can define a block interval \( n \) (identified as the probability \( p_B(n) \)) where at least one student appears. The parameter \( n \) refers e.g. to the total number of students entering a lecture room in a given time e.g. Choosing the parameter \( n = 1 \) the probability \( p_B(n) \) equals the students’ probability \( p_e \).

Now we can assume that the probability \( p_B(n) \) can be described as a function of the students’ probability \( p_e \) and the block interval length \( n \) (Formula 1). Here the following approximation is used (Wilhelm, 1976; Ahrens, 2000).

\[
p_B(n) = \begin{cases} 
p_e \cdot n^\alpha & 1 \leq n \leq n_0 \\
1 & n > n_0 \end{cases}
\]  

(1)

The value \( \alpha \) denotes the linear dependence between \( \log_{10} p_B(n) \) and \( \log_{10} n \) and is a measure for the students’ concentration (also referred to the concentration of lecture visit). The value of \( n_0 \) indicates the maximum block length to which the linear-dependence can be maintained (Figure 5).
Figure 5. Relationship between the probability \( p_B(n) \) and the block interval \( n \) for different parameters of the \( (1 - \alpha) \) at a student’s probability of \( p_e = 10^{-2} \).

The analysis of concentration parameters \( (1 - \alpha) \) (referred to the concentration of lecture visit) has shown that parameters in the range of 0.0 until 0.5 describe realistic scenarios. Thereby, a parameter \( (1 - \alpha) = 0 \) describes the situation where the students appear independently distributed from each other. With increasing parameter \( (1 - \alpha) \) the students appear more and more concentrated and the probability \( p_B(n) \) decreased for a given \( n \). With the assumption that the distances (gaps \( k \)) between neighboring students are statistically independent from each other, the students’ characteristic, namely the occurrence of bursty students, is defined by the students’ gap-distribution function \( u(k) = P(X \geq k) \) which describes the probability of a gap larger than \( k \). The setup:

\[
p_B(n) = \begin{cases} 
  p_e \cdot \sum_{k=0}^{n-1} u(k) & 1 \leq n \leq n_0 \\
  1 & n > n_0 
\end{cases} 
\]  

(2)

is used to develop the student’s gap distribution function \( u(k) \) for the students’ gaps step by step. Comparing Formulas (1) and (2), one gets (3):

\[
\sum_{k=0}^{n-1} u(k) = n^\alpha \quad 1 \leq n \leq n_0
\]

and for the searched error-gap distribution \( u(k) \) we yield:

\[
\begin{align*}
  n = 1 & \quad : \quad u(0) = 1^\alpha \\
  n = 2 & \quad : \quad u(0) + u(1) = 2^\alpha \\
  n = 3 & \quad : \quad u(0) + u(1) + u(2) = 3^\alpha \\
  \vdots & \quad : \quad \vdots = \cdots \\
  n \leq n_0 & \quad : \quad u(0) + u(1) + \cdots + u(n - 1) = n^\alpha .
\end{align*}
\]

The student’s-gap distribution function \( u(k) \) can be defined as follows:

\[
u(k) = \begin{cases} 
  (k + 1)^\alpha - k^\alpha & 0 \leq k < n_0 \\
  0 & k \geq n_0
\end{cases} 
\]  

(4)

Re-writing of \( u(k) \) leads to the student-gap density function \( v(k) = P(X = k) \), which describes the probability of a gap \( X \) equal to \( k \):

\[
u(k) = v(k) + v(k + 1) + v(k + 2) + \cdots
\]

and by calculating the difference between \( u(k) \) and \( u(k + 1) \) the student-gap density function \( v(k) = P(X = k) \) can be obtained:

\[
v(k) = u(k) - u(k + 1) .
\]  

(5)

Assuming that the students are independently distributed, i.e. \( (1 - \alpha) = 0 \), and using equation (4) and (5) one gets the following result (6) for the student-gap density function \( v(k) \):
With this result, the disadvantage of the model setup becomes evident. The model setup defined in (1) leads to a deterministic student-gap process. In situations, where the students appear concentrated, i.e. \((1 - \alpha) > 0\), one can also find an enlarged value at \(v(n_0 - 1)\). This error leads to engraving inaccuracies in the simulation process. The reason is the discontinuity at \(n = n_0\) in equation (1). A modification of this model setup is necessary. The following solution can be assumed: the linear increases of \(\log_{10} P_B(n)\) can only be accepted for small parameters of \(n\). The value of \(\log_{10} P_B(n)\) has to change steadily into the value \(\log_{10} P_B(n) = 0\) for larger \(n\). To the minimization of the model inaccuracy at \(v(n_0 - 1)\) equation (4) has to be multiplied by the value \(e^{-\beta k}\) (Phillips, 2006). For the student-gap distribution function \(u(k)\) the following expression arises:

\[
u(k) = \begin{cases} 
1 & k = (n_0 - 1) \\
0 & k \neq (n_0 - 1)
\end{cases}.
\]

(6)

Figure 6 illustrates the student-gap distribution function \(u(k)\) for different parameters \((1 - \alpha)\) assuming a student’s probability of \(p_e = 10^{-2}\).

The resultant student-gap density function \(v(k)\) is depicted in Figure 7.

Finally, the proposed system setup is highlighted in Figure 8.
Figure 8. Approximated relationship between the probability $p_B(n)$ and the block interval $n$ for different parameters of the $(1 - \alpha)$.

Now, the students’ characteristic can be modelled by two parameters (the student’s probability $p_e$ and the student’s concentration value $(1 - \alpha)$).

With the assumption that the distances between neighboring students are statistically independent from each other the model characteristic is described completely by the student’s distribution function $u(k)$. For the creation of the gap processes a uniformly distributed random number $Y$ is identical to the function $u(k)$ and the corresponding value of the student’s gap is determined. For this, the following equation

$$Y \equiv u(k)$$

has to be solved numerically.

**Conclusions**

The theoretical findings on the inter-relationship between the bursty nature of students and gap processes allow determining such criteria for optimization of study process based on binary student behaviour as students’ probability and concentration.

A new research question has been put forward: What are advantages and disadvantages of the model for simulation of study process optimization based on binary student behaviour in higher education?

The present research has limitations. The inter-connections between simulation model, binary student behaviour, the bursty nature of students and gap processes have been set. Another limitation is the theoretical analysis carried out only. Nevertheless, the results of the research, namely the newly defined research question, may be used as a basis of the promotion of the model for simulation of study process optimization based on binary student behaviour in higher education within rural areas.

Further research tends to search for relevant methods, tools and techniques for evaluation of the simulation model. Future research proposes to analyse the implementation of the simulation model characterized by two criteria such as students’ probability and concentration. A comparative study of use of the model for simulation of study process optimization based on binary student behaviour in different rural areas could be carried out, too.

**Bibliography**


