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Efficient Education Environment at University Level

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Abstract: Technology changes in the last twenty years accelerated and speeded up the life around the World. Nowadays new generations arise having no paper based textual information, technology based and thinking young people are coming to the universities in the next years. The universities and the education systems are currently not prepared to handle the different thinking, living, learning mechanism of them. Our study highlights the possible problems and show a way how to cover in short time the gap and offers new directions as well.

Keywords: education, e-learning, enterprise resource planning, efficiency, generation change

1. Introduction

The ability to teach and educate people in an efficient way is depending not only on the well-trained teacher and the availability of equipment (e.g. in experimental physic) nowadays. The master should be regularly trained, retrained, and brought nearer to the IT world. The education should be supported by means of new technologies, web based sources and other special tools. The generations coming to the universities represent new era and the education should follow them or in better case show the right way.

The universities educate not only young students, but also several people coming from other generation, having different behavior, learning habits. So the university should offer diversity in education forms, methodologies and techniques. To manage it some technological enhancement and aid tool should be implemented and applied.

In the following sections we go through the different generations and their problems and requirements, we show the tools available and usable for educating new generations, and the place of this software in the university environment.

2. Generation and cultural gap

We all heard, know and say many times, that it was different in my ages. It was true, it is true, and it will be true at any time because the World, the people are changing. But we can now realize that the time periods are shorter and shorten between changes. From technical point of view the television was introduced in (almost) every flat, we have recognized that computers can be small and at home we can use them for many purposes, we have learned the Internet boom, we have cell phones, day by day we use home entertainment equipment (audio, video, games, etc.). If we look back all these changes were made within a short century. If we try to buy a cell phone today, we do not think about a phone anymore, but a small computer having its own operating system and color display, which is better than the standard television. We did not recognize step by step the changes, but many daily used tools today have their own computers and the people went far away from the tool itself. For example ten or more years ago the mechanic could repair the car or wash machine, but today the computer of the car should be checked first, or the electronic panel of the wash machine should be changed (not repaired!) as a unit. The daily used tools are so complex and specialized, that nobody can learn alone the whole structure, architecture of them. Much more information, practice and special knowledge are needed to manage them, than a single person can achieve.

In psychology and demography studies we can read about new generations. As we show with natural examples above the changes are constant, but accelerated. The generations follow the changes, because the little child who lives with grandparents and every minute someone reads a textbook to him brings not only different relationship to books, reading, than others who immediately have got a pad to play. The small computers, games, videos are nowadays in the families; the small children learn how to use them immediately. Different demography generations still active or learning:

- **1920-1945 – Builders:** After the World War I the main event in this period was the Great Depression, which generated efficient individuals in learning and working using cost conscious living.
- **1946-1964 – The Baby Boomer:** As the name says this generation is very large, started after the World War II. Natural rebuilding of population. (Mainly in US.) In Europe the communism changed the thinking, generated collaboration, underground organizations and mistrust in anyone. Governmental control predefined how, what to learn and closed the communication, information flow and progression achieved by the non-communist states. (This modified the behavior of the adults (older generation), but influenced the children of this generation as well.)
- **1965-1980 – Generation X:** This generation is smaller than the previous one (in US, but in communist states a small growth can be recognized). These people are independent, hardworking persons, but skepticism and liberalism are in focus as well originating from the semi-stabile living environment.
- **1981-1999 – Generation Y:** Seeing the years of the period, we realize the starting ear of home computers. The children in this generation faced early with technology and electro-mechanical tools. They live with them, so they are confident if not even always brave enough. The members of this generation are technologically advanced, because they did not learn, but use the tools immediately as standard parts of the life. They are sometimes unrealistic, fighting, and demanding. They try to be connected technically, but they are lonely.

- **2000-2009 – Generation Z:** This generation has received little attention in the literature thus far, but they do not know how to live without Internet. They act instantly and they are available every time, but unscheduled. If they have no access, they are upset and cannot find their way for a period of time. This generation shares everything, more than having sense. Everyone from this generation shares the knowledge, experiences and the others accept it without control. Anyone can be an expert. They believe in Internet, anyone with similar or less skills can be better source of information than the living persons from older generation. Not too much self-knowledge, rather common, „crowd" knowledge is accepted. They cannot focus on one single topic, they are multitasking all the time, even they are face-to-face with others. Less unorganized, unstructured gaming is available, because they are connected vie a device and they cannot leave it for the time of playing with others. This leads to less conflict resolution skills or even face-to-face communication problems.
- **2010-present – Generation Alpha:** This generation is very young currently and we do not know too much about their characteristic. The beginning of this (and the previous one) generation is not really definite. The members are those children, whose life is completely digital, living in Internet as child, having iPad as teddy bear. A child born earlier in 21th century, but digitally infected, can be considered as member of the generation.

If we just look back, our universities are facing with the Generation Y persons nowadays, but in a few years the Generation Z comes to the institutes with a fundamentally different behavior, thinking, learning mechanism, interest and basic knowledge. So the main focus is the last two generations, because the currently reigning educational system cannot handle these generations and their behavior.

The earlier student grew up as empty sheet of paper, which should be filled up with the knowledge available. Mainly lexical knowledge, and some coherency and dependency build the information to be learned. On the other hand these information year by year throve with experiences and practice. The students learned how to solve a specific problem. In the life they could originate any solution in the learned examples or already experienced ones. New problems could be solved using the mixture of the already known techniques.

The new generations follow Einstein's sentence: "Never memorize something that you can look up." This can be good or enough if same basic, lexical knowledge is available as foundation, and the student has a good problem solving skill using the references he know. If they cannot see the correlation between the parts of a problem, or they cannot analyse and split it to smaller, easier pieces, they can quickly loose. New learning methods and tools should be provided soon to help them to find the right way in learning.

3. Institute level trainings

We have to realize that different types of students are around the institutes (e.g. universities). In the second section we have discussed the general, young university students' behavior, requisite and capabilities. But at each university the picture is much more colorful.

Students are part of international student programs, evening course, correspondence course, doctoral school, adult education, etc.

As we described in the earlier sections the students are changing dramatically, especially at the standard day school. The older generations, building mainly the other, not standard day courses follow the old fashion, worked well models, techniques. With the new technology era, like smartphone or pads are at any students, portable computers are in the case, the teacher many times does not know what to do, how to keep the students away from their equipment during the classroom training. We can realize that when the teacher is closer to the generation of students, he can take the equipment more effectively part of the training. Not forbid, but use them.

But at the university not only they are the only students, but other level of education is taking place as well. Just as a short list we have here the other possible students:

- Full time course (older generation, currently educated)
- Correspondence (different generations could occur)
- Continuative education (e.g. for engineers)
- Doctoral school
- Postgraduate course (for teachers at the university, proficiency career)

As you can see, the different types of education target different learning groups, generations. We cannot say that each type has a well-defined, restricted age period, because except the case of regular full time course the others educate students, people from almost any age. But almost each of these types of students has already experience with the currently applied education system and they can accept it for further studies as well. Of course in most of the scientific areas (e.g. Bachelor of Arts, natural science, or even informatics) we have to follow the challenges standing for the education of the newest generation. The cause of that is laying in the changing of the whole World and daily life of the people. The Y, X or older generations learn and use day-by-day the potential offered by the new technology era and they require the changes as well.

The difference ages and the modified authority of a student (sometimes teacher) leave us to think about offering fuzzy education as well [1]. The nature of thinking is not changing so quickly, than the technology world around us. As in the referred paper you can read the student brings the uncertainty to the system.

The education at universities is nowadays like the basic commercialism, because the universities should follow the demand of the student with the supply or offerings. The next section goes a bit beyond.

4. Education and e-learning

Early 70s Ivan Illich publicized a reform theory about education [6]. The World immediately answered and from year to year this paper is referred and reflected because of its strong directions.

From today's problems and availability we have to check it again with reference to education of Generation Z and beyond. Before going deeper we have to see some thoughts of this theory. The reform education in his work liberate the students from following the well-defined, "engraved in stone" curriculum, but let them access to the sources of educational knowledge, which may help them to find their way to acquire knowledge.

The chapter "Learning Web" of Illich's paper defines four parallel living approaches, which

1. Reference Services to Educational Objects:
   These could enable access to different learning elements, information sources and processes. The sources should be stored in an easy accessible manner for anyone. (Meaning scientific or manufacturing results, certificates, and authority control should be provided.)
2. Skill Exchanges:
   Some forms and forums should be provided, where individuals can share their skills and the way, conditions how they reach them. This could serve as a model for the individual himself and for others in learning process.
3. Peer-Matching:
   Cooperation or collaboration of equal parties in a communication network, where the individuals can find proper partners for their interest and learning goals.
4. Reference Services to Educators-at-Large:
   Services should be provided enabling students to find the professional or non-professional educators, by searching their access, knowledge and skill descriptions, and conditions of consulting. The educators can be ranked and commented by the individuals, students.

If we look back to the second section of this paper, we can easily realize that the life, daily movements of the newest generation corresponds to the described offerings by Illich's idea. The listed approaches are almost enabled by the Web technologies and Internet. Just as short, but not complete listing of features offered by the today available Web elements we show here some practical enables of the approaches (these are global examples, not institute relevant ones):

1. Reference Services to Educational Objects:
   Video (e.g. YouTube) or step-by-step tutorial of learning objects (offered by companies, institutions, etc.). Virtual, online museums (e.g. http://onlinetitanicmuseum.com/main/) or web gallery. Online book availability (e.g. http://www.readanybook.com/), e-books (e.g. http://books.google.com/), and voice books give online or offline availability of learning materials in written or read out form.
2. Skill Exchanges:
   In information technology you can find the development networks (e.g. http://scn.sap.com/), or Open Source com-munities (e.g. http://www.apache.org/) as primary source of information. Other form is the Wiki.
3. Peer-Matching:
   Forums and chat services for different products, themes, thoughts.
4. Reference Services to Educators-at-Large:
   Currently for companies and employees there are some recruiting help functionality (e.g. http://www.linkedin.com/). Not all the prescribed requirements

are fulfilled, but self-descriptions, skill lists can be provided and individuals could rank and probate others (using work experience).

As we see the new technology enabled many ideas from the 70s, and the new, Internet generations would like to live, learn according the approaches.

From institutional point of view it is not so easy just offer the services described and hope that everything will go in a right track. To handle and really benefit from the approaches described above, some control, mentoring, regular surveying, measuring and qualifications are necessary.

To manage these challenges an e-Learning or LMS (Learning Management System) would be useful. (According to our study we cannot say that this is the only and complete solution, but is seems to be necessary for the current and coming educational challenges.) In the market we can find many offerings from different vendors for different prices. The main ERP (like SAP) software companies offer solutions because trainings, and further education of employees are many times key point of interest to keep the company's common knowledge and bench in up-to-date level in daily competition. In general these learning solutions as ERP system extensions are mainly coupled with human capital management (or human resources) components. The human resource component manages not only the employee's administration (like name, address, bank information, salary, etc.) and organizational labeling (e.g. department, job, position), but it could prepare, record and follow events or qualifications as well. Events can be obligatory trainings, certification exams or any other organized or not organized business event. An event (or training) is handled in more levels and link with other objects. As an example we can define for the employees English lessons. To define events we use grouping hierarchies like in our example:

- Language trainings [groups level 1]
  - English courses [groups level 2]
    - English for beginners [type 1]
    - English Intermediate [type 2]
    - English Upper-Interim. [type 3]
    - Business English [type 4]

The bulletin levels show the hierarchies of the groups and the different event types defined in a specific group. Of course each of the trainings (events) should be linked to resources, like room (or class), instructor (or educator), material, etc. The resources should be configured before assigning them. One understandable reason could be that the event planning contains not only the event publications, but the resource allocation as well, and the organizer should know how many trainees would take part, because corresponding training room should be allocated. So the capacity (and available equipment) should be known for each training room before allocating them to an event. Other property of resources is of course the cost. The trainer should be paid according to length of the training and the number of participants. This property is important for cost planning not only in human resources component, but in financial and controlling areas of the ERP application as well.

The business events or trainings can or should be provided in a catalog, like at the universities. In the catalog two additional properties can be added: schedule and prescribe. There could be standard trainings regularly organized, or on request organized trainings as well. If training is required for a job or for everyone joining a company, it is mentioned in the catalog for each employee.

Another part of the integration with human capital management is the qualification management. At a company the jobs or positions could require some educational level, certificate. In the qualification management two important parts can be handled:

- qualification of an employee
- qualification(s) needed for a job or position.

To manage these information in an integrated way the event management should be linked to the qualification management. The qualification should be defined as level of knowledge, which can be linked to a specific training or some trainings, certificate. The completed training should be recorded not only in event management, but also as a new qualification. These could help within the company to find the right person for an internally new or vacancy position.

The connection between jobs, positions, trainings, qualifications are independent technically, so a graph can be drown from the connection list. It is a useful small enhancement if the jobs and/or the qualifications can be grouped, because less information should be stored by arranging the qualifications and jobs into (separate) hierarchies.

A learning management system manages these information if required and it offers not only the event management, but making, storing and playing of training materials. These e-Learning systems provide different types of learning materials, especially SCORM (Sharable Content Object Reference Model) compatible objects, but other electronically formed contents, like MS PowerPoint, MS Word, PDF, etc. formats are acceptable. The SCORM has about ten year's old history. It is used to define a standard form and protocol to create and play e-Learning content in a way, where the progress can be followed. This last part is very important because of the measurement of the progress and achieved level of knowledge. In connection with human capital management the linked learning management system can share information about the training progress of each participant. This leads cost and qualification controlling immediately.

As we described the event management can assign resources, like training room (class) to an event (training). This is important in case of a class-based training. There could be other kind of trainings, events as well. First of all we have to distinguish between synchronous and asynchronous education. Synchronous education supposes that the trainer and the student are available in the same time. According to the second and fourth sections it does not mean definitely that they are in the same place as well. If we are speaking about distance learning no classroom is required. On the other hand we can imagine that though this event does not require allocated classroom in a building, but communication line, bandwidth for sharing screen, camera output and voice should be provided, or made available, or in other words allocated to the course. We can go one step further to the asynchronous education, where the training is an offline or interactive material, which is available for a given period of time, but no physical or virtual classroom should be allocated. The learning management system has to deal with the problem of follow-up or tracking. If the training material could contain and handle progress information, like the SCORM compatible materials do, some authenticated synchronization needed to receive the offline progress centrally in the e-learning system.

Another important way of knowledge measurement is the testing. Testing means here web based questionnaire using different formats and mechanism. The learner should time-to-time measured. For that some basic questions should be answer:

- Did I understand the training content?
- Do I remember the important visual information?
- Do I understand the overall logic of the training content?
- Do I remember the important lexical learning?
- Can I apply the learning in practice?

The teacher's task is to formulate interesting questions effectively. In the following some typical and usable test scenarios are listed.

- Simple true/false questions
- Decision or multiple choice (according of the task definition only one or more answer could be accepted)
- One word answers (the answer is one word, but more correct answer could be accepted)
- One number answer (same, but a number, e.g. a result is in question)
- Match the answers to the questions etc.

This short list just summarizes the frequent types of tasks or questions. But sometimes we give opportunity to the student to a short text, e.g. an essay. To help the student answering the question some additional text or even image would be helpful.

It is advisable to configure the available time for the answer. In some cases it is better to set this limit for each question, but generally an overall time limit is given. The testing environment should provide rethink or later modification possibilities. The measurement can be done according to the achieved number of points, but the execution time can correct this value as well. In general case the test system does not give a sign for the work, but only percent of the performance and the teacher later can assign signs to the test results.

These are only a recommendation and some minimal requirement from the learning management system. To be able to integrate the solution to the central university student management system (or at a company to the qualification management) the results (and the progress) should be interfaced to the connected systems. Generally the testing is a synchronous process. If you want to execute it offline, a special offline tool should be provided which stores the progress and results securely without any violence.

The testing or questioning phase in the education process where the fuzzy logic can play bigger role [3]. The learner activity is in the focus during this phase. But the decisions are not only interesting at this point, but during the education process the student can use his own or any available device to understand the learning content better. (Here we have to refer to the 3rd section, where the teacher does not forbid the use of device, but let the student decide whether to use any. Another reference should be made as well to the next section, where the possible trainings are discussed.)

The e-Learning systems have further capabilities, like forums, chat (instant messaging), dashboard, and even wiki or glossary functions for collaborations. It makes possible to organize brainstorming. But not each of the learning management system offers features to store information about the masters; many times they cannot always get evaluation. At university we have to be careful with this "Reference Services to Educators-at-Large" approach defined by Illich, because the people evaluating the educators are sometimes not really competent, or even have bad temper. This kind of unrealistic or bad natured comments, evaluations can destroy the life of a teacher, even hurt privacy lows. To handle this kind of issues moderator or group of moderators (committee) are needed. This is true for forums as well.

If we look back to the learning web approaches, we realize two interesting phenomenon:

- The approaches from 70s almost cover the behavior and demand of the generation Z
- The e-learning systems almost cover technically Illich's approaches.

This figures out, that a change in the education at the university can be managed mainly with the help of a learning management system.

5. Training possibilities

As we described till now we have two main directions in Education:

- Traditional: class based, well-defined, structured, traceable, static
- e-Learning based: collaborative, self-defined, follow-up system, dynamic, digitally aided

Both have a place in education, but we have to go forward to follow the next generations to build well-educated persons from them as well. Some of the e-Learning systems can help us to enhance the classes and motivate the young generation.

According to our simple survey (not detailed in this paper) the students (generation Y) feel many times the standard lecture boring, while they are too slow. It does not mean that they are so fast and clever, but they live in a higher speed and the lectures are lack of activities, movements. The newer generations loose very quickly their interest if it is a bit slower than they're used to live. The interest goes to access others and communicate with them. This recognition led us to rethink e.g. the presentation style. The common presentation style is a linear progressing process with many textual enumerations, maybe some graphics enhance the content. If the presenter uses the prezi (https://prezi.com/), the presentation is not yet static having a linear path, but it extends to the possible connections (linked subject) as well. According to the progress, students' condition/combination and behaviour the educator can select what is important, what should be highlighted or hidden. The presenter should be much better prepared, because not an ordinary slide order is used, but he should "improvise" on the fly as occasion requires. This produce a more living presentation, which is closer to the new generations.

The e-Learning systems can help to manage lectures with more activities, because it supports many collaboration functionalities. In smaller groups the agile project management methodology could be used. It helps to keep the interest for the whole time of the lecture. The devices should be involved into the exercises. Fuzzy education can be another solution here.

The borders of this paper do not let us to detail further options available and applicable in such an environment, and other not e-Learning dependent techniques are neither discussed.

6. Economical, cost efficient education

Each of the universities has a unified study system (e.g. in Hungary Neptun or ETR). This kind of system manages the students' progress (semester, credit), the offered trainings, timetables, default curriculum, taken courses, exams, financial content (banking data, fee status, etc. The system handles not only the student view, but the teachers view as well. This is important because the teachers should define the course data, exam information, provide additional data, set the timetable, consultation occasions, record the results, etc. The system has simple collaboration functionalities, qualification information and dormitory management as well.

For cost efficiency an Open Source e-Learning system, the Moodle is advisable [4], because this has the offerings we described in previous sections for Enterprise use as well. The Moodle provides a lot of possibilities as standard, but with the development environment own functionalities can be added as well. As we described in the third section, the e-Learning system should handle offline Education as well. To fulfil this mechanism some extension should be used [5]. The Moodle offers the collaboration functionality to provide connectivity to the young generation and make possible to apply moderated and motivated trainings to bring the students taking part actively on the lesson.

As we mentioned an e-Learning environment can be used for qualification control and management as well, but in many cases these functions are out of scope. This is natural, because these functions belong to the ERP system. The previously mentioned unified study Systems define the Education management in the environment, the e-Learning provides the training contents and collaboration functionalities with the measurement, test scenarios. The unified study system collects the information and provides to the teacher, moderator, mentor or supervisor. The employees of the university, like the professors can be trained or continuative educated. The results can be stored as qualification, which is connected to the human capital management component of the ERP system. The ERP system manages the financial and controlling data as in connection with the unified study system, where the semester cost, dormitory cost, salary of the visceral educators and so on are coming from the study system. The ERP, unified study system and the e-Learning system can build an integrated whole. Before integrating the parties' performance and consistency simulation is recommended [2]. The self-defined Moodle extensions should be checked as well using the performance simulations.

7. Summary

In the paper we have collected the different type of student coming from different ages. As you have seen the new upcoming generations, and their behavior is totally different, than the currently living education systems with old fashion techniques can offer. Their requirements are very close to the Illich's web learning model, which can almost fulfilled with today's Internet and web technologies.

The e-Learning systems can build a bridge between the current and future education systems, but the feature sets are not enough, the teachers should be able to use these functionalities to pull out everything from the representatives of the new generation. They should motivate them to be active during the lectures as well, and the lessons should be animated and moderated, and the daily used devices (e.g. cell phones, laptops) should be involved not prohibited. Special education methods should be used, for testing and learning fuzzy education can help as well.

The e-Learning systems provides toolset to measure the learning effectiveness by testing, questioning. In the university environment the e-Learning system integrated to the ERP and unified study system, builds the main engine of the institute.

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A Survey on the Attributions of Students' Exam Performance

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Abstract: A peculiar tendency has been recently observed in the training process of would-be engineers. Passing Mathematics and the majority of the core subjects means such hard work for our students that only few of them are able to fulfil the requirements in the current semester when the subjects should be completed. A direct consequence of this phenomenon is that the number of students signed up for these subjects accumulates in the 2nd and the 3rd semester and as a result, compared to a normal situation, a multiplied number of engineering students wants to do, redo and 're-redo' the above mentioned subjects. Our survey tends to have a picture about how engineering students think about this phenomenon, the underlying reasons for their exam performance, how much the reasons are affected by the results of the exams, the personal factors and the amount of time spent in higher education. The calculated ranking order of attributions has been compared to the results of another similar survey undertaken among the students of the Humanities at Eötvös Lóránd University, Budapest in 1998-99.

Keywords: attribution, satisfaction, dissatisfaction, motivation, learning

1. Introduction

Industrial development, the continuous change and renewal of our environment and society mean a constant challenge and the necessity of lifelong learning for all people. Learning at any level and from any reasons cannot be carried out without motivation. In today's research programmes motivation for learning means not just an inner force for doing a long-lasting activity that is of importance for the students themselves but it is "a self-developing, hierarchic, complex system of components which can be examined in a multi-factorial and multidisciplinary way" [7]. In accordance with Réthy's statement, attribution theory is a model that interprets and examines motivation from an unusual aspect.

Attribution derives from the natural human feature of attributing our achievements to certain reasons and we are related to them in accordance with the presupposed reasons.

The attribution theory examines how various situations generate different attributions. In case of situational performance attributing refers to the reasons of success and failures in a direct way. Individuals' attributions are usually in harmony with their opinions, views and prejudices [1].

Although Heider's life's work meant a milestone (1958) in attribution research, the first empirical researches started in the 1970s. "Heider's proceeded from the fact that people originate the result of their actions from two factors: the person (motivation, abilities, intelligence etc.) and the environment (the difficulty of the task, coincidences etc.). The first factor is the power of the individual, while the second one is of the environment." [7].

According to Graham [4] motivation examined in the above mentioned way is a particular sociocognitive approach which investigates the individual's social experience, perception, interpretation and the conclusions made on them relating to their environment. [7].

In Hungary it was Endréné Réthy who made an empirical research on learning attributions between 1990-92 in which she analysed the attributions of 281 students of humanities concerning their exam performance. Due to the changes of the tertial education the repetition of the research was needed and carried out in the academic year of 1998-99. Seeing the results, which will be reported further on, some questions arouse: What is the situation in the technical area? What are the reasons of the engineering students' poor exam performance? Do they regard their poor GPA (Grade Point Average) as a success or as a lack of success?

On the basis of the scientific literature we can suppose that there is a difference between the attributions of freshmen (just starting their studies at a university) and seniors (attending a university for more than 1 year). While first-year students tend to consider external attributions, choosing internal ones is more frequent with senior students to explain their performance. The level of students' satisfaction and dissatisfaction of their exam performance can differ as well. We presume that in the case of students who are satisfied with their performance internal reasons dominate and students who are dissatisfied with their achievements blame external reasons.

In our survey we used the already tried (ELTE 1990-1992; 1998-1999) and tested questionnaire. The students participated in the survey were expected to consider and they evaluated 14 attributions in a 9 rate Likert response scale with appropriate background variables (see Fig.1):

Questionnaire

Gender:
Age:
Year:
Course:
Number of exams in the semester:
Have you achieved the expected results in your exams?
How much were your exam results influenced by the reasons mentioned below?
(Consider the presumed reasons below and rate them from 1-9 where 1 has ***the least*** 9 ***the most*** influence on your exam results. 5 means ***indifferent*** and the rest of the numbers represent transitions among these numbers.)

	9	8	7	6	5	4	3	2	1
Intelligence									
Creativity									
Certain abilities									
Diligence									
Professional talent									
Luck/Bad luck									
The difficulty of the exams									
The difficulty of the subject matter									
Your learning method									
Your interest in the subject									
Others' help to prepare for the exam									
Your attitude towards the examiner									
Lecture style of the lecturer									
Desire for perfoming well									

Figure 1. Questionnaire of the attributions

2. Sampling frame

The basic population of the survey comprised the first-, second- and third-year mechanical engineering, transport engineering, engineering management and computer engineering students of Széchenyi István University, Győr. Completing Drafting is compulsory for all of them. The questionnaire was filled by 269 mechanical engineering, 120 transport engineering, 50 engineering management and 26 computer engineering students (Tab 1).

As it can be seen in the chart, the average age of the students was also taken into consideration to be able to make a difference. It shows that due to the credit system the progress of the students is not steady during their studies. In the case of mechanical engineering students the higher average age and the higher number of successful exams are likely to be the result of the failed or not even tried exams in the first semester.

Table 1. The distribution of the examined sample

Students	**Mechanical**	**Transport**	**Engineering**	**Computer**
Total number	269	120	50	26
Average age	21.29	21.08	20.98	20.65
Number of successful exams	6.86	6.33	5.75	6

3. Sampling process

The data were collected at the end of the spring exam period in 2012 to have fresh memories and experience about sitting for an exam from the students.

Taking into consideration the fact that in situational performance the attributions refer to the perceived reasons of success and failure in a direct way [7], the students had to fill the questionnaire right after writing a test. The completion of the anonymous questionnaire happened in groups and it was voluntary.

4. Data procession and analysing attributions

Mathematical-statistical methods were used to analyse the results. We used SPSS programme to proceed the given data.

The characteristic features of the attributions are shown in Tab 2 [9]:

Table 2. The characteristic features of attributions

Attributions	**External**	**Internal**	**Stable**	**Instable**	**Controllable**	**Uncontrollable**
Intelligence		+	+/-	+/-	+/-	+/-
Creativity		+	+/-	+/-		+/-
Certain abilities		+	+/-	+/-	+/-	+/-
Diligence		+	+/-	+/-	+	
Professional talent		+	+/-	+/-		+
Luck/Bad luck	+			+/-		+
Exam difficulty	+		+/-	+/-		+
Subject matter difficulty	+		+/-	+/-		+
Learning method		+	+/-	+/-	+	+/-
Interest in the subject		+	+/-	+/-	+/-	+/-
Others’ help	+		+/-	+/-	+	
Attitude towards the lecturer		+	+/-	+/-	+	
Style of the lecturer	+		+/-	+/-		+
Desire for performing well		+	+/-		+	

The attributions were analysed on the whole population and by courses. (Tab 3.)

Table 3. The hierarchy of courses summarized and one by one

Attribution	All courses		Mechanical Engineering		Transport Engineering		Engineering Management		Computer Engineering	
	Place	Value	Place	Value	Place	Value	Place	Value	Place	Value
Intelligence	7th	6.32	9th	6.14	2nd	6.77	6th	6.28	4th	6.46
Creativity	11th	5.90	12th	5.81	9th	6.12	9th	6.22	11th	5.39
Certain abilities	13th	5.78	13th	5.73	11th	6.02	12th	5.90	12th	5.31
Diligence	3rd	6.67	3rd	6.70	3rd	6.69	5th	6.62	6th	6.35
Professional talent	12th	5.84	11th	5.90	13th	5.83	13th	5.53	10th	5.69
Luck / Bad luck	4th	6.53	5th	6.39	1st	6.82	1st	6.70	3rd	6.58
Exam difficulty	1st	6.83	1st	6.93	4th	6.66	2nd	6.70	2nd	6.96
Subject matter difficulty	2nd	6.74	2nd	6.78	5th	6.63	3rd	6.70	1st	7.04
Learning method	8th	6.20	8th	6.27	8th	6.13	10th	6.04	8th	6.04
Interest in subject	6th	6.41	7th	6.30	7th	6.48	4th	6.68	5th	6.38
Others' help	10th	5.92	10th	5.92	10th	6.08	11th	6.04	13th	5.23
Attitude tw lecturer	14th	4.98	14th	5.00	14th	5.01	14th	5.14	14th	4.42
Lecturer's style	9th	6.18	6th	6.32	12th	5.88	8th	6.26	7th	6.04
Desire for perfoming well	5th	6.50	4th	6.51	6th	6.58	7th	6.28	9th	6.00

Having a look at the hierarchy of the whole sample it can be seen that external reasons stand in the 1st, 2nd and 4th place. Although diligence is in the 3rd and desire for performing well is in the 5th place (which are both internal reasons), it is most surprising that creativity, professional talent and certain abilities are ranked to the last three places. The hierarchy of the three internal attributions might be the result of 'self-defence' and it reflects the students' view saying that you cannot use certain abilities profitably in a test and talent is not a determining factor in preparing for an exam.

Comparing the hierarchy of the mechanical engineering students to the 'All courses' one, we can clearly state that the attributions in the first places are similar – except the Lecturer's style which has a difference of 3 places, but in all the other aspects there are no bigger difference than 2 places. This result was anticipatory, since more than half of the students of all courses are mechanical engineers.

The ranking of computer engineering students is also similar. However, the importance of an external attribution – having luck (1st place) among transport engineering and engineering management students must be mentioned. Finishing in the first place demonstrates that these students do not rely on themselves and they may not be self-reliant enough in their learning techniques. The 2nd and the 3rd place of the difficulty of the exam and the subject matter attribution among engineering management students seems to support this idea.

Transport engineering students put an internal attribution to both the 2nd and the 3rd place, namely intelligence and diligence. The silver medal of intelligence right after luck / bad luck reflects that these students are insecure regarding the external and the internal reasons. Ranking diligence into the 3rd place is essential because as an internal, partly instable but controllable general attribution it can be influenced effectively by the individual.

5. The changing of attributions compared to the levels of satisfaction of exam performance

Although nearly 25 % of all the students did not answer the question of being satisfied or not with their exam performance (Tab 4.), it can be clearly seen that our would-be mechanical engineers and transport engineers are half satisfied and half dissatisfied with their performance. Engineering management students and the ones of computer engineering are more dissatisfied. It is related to our presupposition that – talking about exam performance - placing external reasons into the front is more characteristic to dissatisfied students.

Table 4. Being satisfied with the exam performance (students of all courses and by courses)

	Mechanical Engineering	Transport Engineering	Engineering Management	Computer Engineering	All courses
Satisfied	106	52	11	5	178
Dissatisfied	83	50	22	16	172
No response	80	18	17	5	126
Total	269	120	50	26	476

This indicator can be perfectly demonstrated by examining the changing of the hierarchy of the attributions in the light of the satisfaction with the exam performance. (Tab 5.)

Table 5. The attributions of the students satisfied and dissatisfied with their exam performance

Attribution	Satisfied		Dissatisfied	
	Rank/ Place	Value	Rank / Place	Value
Intelligence	3rd	6.79	9th	5.62
Creativity	10th	6.38	11th	5.46
Certain abilities	13th	6.15	13th	5.38
Diligence	1st	7.01	4th	6.35
Professional talent	12th	6.16	12th	5.43
Luck / Bad luck	9th	6.39	2nd	6.71
Exam difficulty	4th	6.74	1st	6.77
Subject matter difficulty	5th	6.64	3rd	6.69
Learning method	7th	6.46	7th	5.97
Interest in subject	6th	6.57	5th	6.29
Others' help	8th	6.40	10th	5.53
Attitude towards the lecturer	14th	5.15	14th	4.84
Lecturer's style	11th	6.24	6th	6.15
Desire for performing well	2nd	6.99	8th	5.94

You can find such internal reasons among the top three attributions like diligence (7.01), desire for performing well (6.99) and intelligence (6.79) in the hierarchy of the attributions of students being satisfied with their exam performance. These changes compared to the hierarchy of the total sample reflect the presupposition that the self-satisfied students believe in working hard and their right attitude to learning. Our dissatisfied students place external reasons into the first places, practically exempting themselves from the responsibility of studying. Tab 5 shows that the difficulty of the exams, luck and the difficulty of the subject matter highly determines this group. Nevertheless, intelligence and creativity with their 9th and 11th places hardly play any role while taking an exam. This must be generated from the mechanism of the protecting the self.

Continuing the analysis, we can see that two external reasons are coming up even among satisfied students. They are the difficulty of the exam and of the subject matter, which quite surprising for us, since intelligence was playing such an important role for them, we expected an external reason such as the difficulty of the exam more at the back. Then again an internal reason, the interest in the subject comes. In the case of the dissatisfied students, the above mentioned 3 external reasons are followed by 2 internal ones, diligence and the interest in the subject.

Taking into account of all the attributions of both the satisfied and dissatisfied students, the greatest difference is in valuing the importance of coincidence. Luck, as an external reason takes only the 9th place among satisfied students, but the 2nd place among the representatives of the other group. There is a similarly great difference between the positions of the desire for performing well. It reaches the distinguishing 2nd place among satisfied, and only the 8th among dissatisfied students. Intelligence also shows big difference with its 3rd and 9th place. As it has already been mentioned, this difference in placing demonstrates that dissatisfied students consider external reasons more important when they assess their exam performance. Meanwhile, the difficulty of the exams can be stated fewer determinants among satisfied students than among the other group. The attribution ranked to the first place by the dissatisfied students can only be found in the 4th place on the other side. There are totally opposing opinions about diligence: it is in the first place among the satisfied students and in the fourth place among the dissatisfied ones. This group thinks that hard work hardly plays any role in the result of their exams. It supports their view about the difficulty of the exams. Investigating the rest of the motives, we can only find big differences between the evaluating the style of the lecturer (6th place among the dissatisfied and 11th among satisfied students), which supports our presupposition of the theory of being more influenced by external reasons if you are dissatisfied and by internal ones if you are satisfied with your exam performance. Processing the data we realised that learning method with its 7th place has the same importance for both groups and there is congruency in the case of professional talent, certain abilities and the attitude towards the lecturer in the 12th, 13th and 14th rank. These attributions are not considered influential by any of the groups. According to the satisfied students' ranking none of the attributions belongs to the indifferent group, and among the dissatisfied students it is only the attitude towards the lecturer that counts indifferent to them (4.84).

According to the result of the two-sample t-test there are significant differences in the case of 7 attributions between the two groups. We must mention creativity, certain abilities and learning methods of which places in the hierarchies are almost the same (there is only one rank difference in the case of creativity), but there is a significant difference in their value.

Table 6. Two-sample t-test for certain attributions of the students being satisfied or dissatisfied with their exam performance

Attribution	t"	Degrees of freedom	Probability (p-value)
Intelligence	5.76	349	0,000 100%
Desire for performing	4.926	349	0,000 100%
Creativity	4.27	349	0,000 100%
Others' help	3.87	348	0,000 100%
Diligence	3.166	346	0,002 99,8%
Certain abilities	2.838	347	0,005 99,5%
Learning method	2.644	347	0,009 99,1%

Our presupposition of having a strong influence of the time spent in tertial education on the ranking of the attributions has not been justified (Tab 7.) One of its possible reasons can be that our students involved in the survey are rather closer to the beginning of their studies than the end and it can be seen from the average age as well.

Table 7. The hierarchy of attributions examining the time spent in tertial education

Attribution	First-year student		Senior student	
	Rank/ Place	Value	Rank/Place	Value
Intelligence	8th	6.28	6th	6.39
Creativity	11th	5.85	10th	5.98
Certain abilities	13th	5.7	12th	5.90
Diligence	3rd	6.71	3rd	6.61
Professional talent	10th	5.99	13th	5.61
Luck / Bad luck	4th	6.62	5th	6.40
Exam difficulty	1st	6.86	1st	6.77
Subject matter difficulty	2nd	6.79	2nd	6.67
Learning method	7th	6.35	11th	5.97
Interest in subject	6th	6.44	7th	6.37
Others' help	12th	5.79	8th	6.13
Attitude towards the lecturer	14th	5.12	14th	4.76
Lecturer's style	9th	6.24	9th	6.09
Desire for performing well	5th	6.51	4th	6.48

The difficulty of the exams and of the subject matter and diligence still has leading roles at both age groups. Professional talent losing 3 places from the freshmen's 10th place to the seniors' 13th is worth noticing. The place of this internal, instable and partly controllable special attribution affirms the several times aforementioned view that school / institutional education does not prepare students for their professions (LIFE) entirely, it will happen only in real working life.

In the question of the importance of choosing the appropriate learning method there is also a big difference. On the one hand, younger students placed it into the 7th, on the other hand, older students put it into the 11th place. The fact that this controllable, internal attribution is placed more at the back makes me think about it more because others' help appears more ahead in the 8th place in the seniors' ranking. Although being an external attribution, I still feel some kind of connection between this and the learning method. Students having been learning for longer time get to know each other better and presumably they call in the other's aid. I do believe that realizing the fact that they can ask for help to understand the subject matter better connects the two motives.

Only the intelligence factor shows a difference of 2 places, the rest of the attributions have a difference of just 1 rank.

6. The attributions of the students of the two universities

In the possession of the above-mentioned results I compared the students of humanities' hierarchy of the attributions to the ones' in the technical tertiary education.

Table 8. The summarized hierarchy of the attributions (ELTE and Széchenyi University, Győr)

Attribution	ELTE		SZE	
	Rank/ Place	Value	Rank / Place	Value
Intelligence	4th	6.66	7th	6.32
Creativity	11th	5.85	11th	5.90
Certain abilities	9th	6.01	13th	5.78
Diligence	2nd	7.03	3rd	6.67
Professional talent	13th	5.72	12th	5.84
Luck / Bad luck	7th	6.36	4th	6.53
Exam difficulty	8th	6.26	1st	6.83
Subject matter difficulty	6th	6.37	2nd	6.74
Learning method	5th	6.63	8th	6.20
Interest in subject	3rd	7.00	6th	6.41
Others' help	14th	3.67	10th	5.92
Attitude towards the lecturer	12th	5.78	14th	4.98
Lecturer's style	10th	5.96	9th	6.18
Desire for performing well	1st	7.05	5th	6.50

Comparing the results of the two faculties we can state that there are differences between them – as it has been expected. According to the humanities students' hierarchy internal reasons occupy the first five places and only the sixth position is gained by the difficulty of the subject matter as an external reason.

One of the possible reasons of this difference is assumed to be that today's faculties of engineering – primarily because of financial difficulties – are being forced to admit more and more students and to keep them among their walls. The dissatisfying level of our students' Mathematics and science knowledge gained in primary and secondary schools and the decreasing efficiency of education have an enormous influence on the qualification of the engineering students. While, on the other hand, universities of arts and science can select their freshmen from those whose marks at the final exams (Matura exams) were much better since it is more popular to learn at these universities than at technical universities, and the marks achieved in natural sciences are of minor importance for the university applicants.

Students' course load is decreasing, the lesson numbers of the core subjects are not even stagnating but show a decrease in spite of the well-known fact that with such a small number of contact lessons engineering students cannot be taught for the basic technical knowledge unlike the students at the universities of natural sciences.

Moreover, even the students who perform at an average level scarcely have a proper future prospect, they are unmotivated and they just live for the day.

We also have to mention that the system neither motivates the students to achieve the proper standard nor creates the conditions of it. University lecturers have a large number of lessons, especially regarding the contact lessons not included in their timetable. These lessons, however, are extremely needed since, because of lack of time, the teachers cannot consult properly with the huge number of students during the seminars. Although one part of the talented students' performance is drawn back by the poor performing mass, we can deal with the rest who still shows interest in these 'private' lessons.

The credit system enables the students to get to know each other well and to form communities. But these gatherings would be suitable to help each other mutually and students would be motivated for studying when they join a group.

The aim of our survey was not to find out all the inner problems of technical education – and we were not capable of executing that – but we may have highlighted some motives which can underlie in the background of the result of our survey and can be the reason for the poor performance and at the same time it can cause the different hierarchies of attributions in case of humanities students and would-be engineers.

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Modelling of Electric and Magnetic Fields Around 132kV Transmission Line

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Abstract: Exposure to natural and manmade extremely low frequency (ELF) electromagnetic fields (EMF) have been a concern during previous years. Schumann Resonance (SR) phenomenon is the source of natural ELF EMFs. High voltage (HV) Transmission Lines is one of the major sources of manmade ELF EMFs. Staying around or close to transmission lines have reported to cause ill effects on human health. The health effects can be analyzed by measuring the external and internal fields. The main objective of this study is to do exposure assessment around high voltage alternating current (HVAC) transmission line and model the same using a program developed in MATLAB. A double circuit 132kV, 50Hz transmission line was selected for this purpose.ELF EMFs around HV line were measured using a low frequency analyzer ME 3830B. Measured external field levels were modelled using Regression Analysis, Support Vector Machine (SVM), Neural Network (NN) and Hybrid Technique. Finally comparative analysis of all modelling techniques was presented.

Keywords: extremely low frequency, electric and magnetic fields, neural network, support vector machine, hybrid technique

1. Introduction

Living body on earth is exposed to ELF EMF from inception to death. ELF EMF is produced by natural phenomenon as well as manmade technological developments too. Tropical thunderstorms are the source of natural ELF EMFs, which are also called as SR signals [1]. Electric power generating stations, distribution lines, HV lines and almost all appliances operating on power frequency are the source of manmade ELF EMFs. Living bodies during their life span exposed to both types of ELF EMFs. Bio activeness of ELF EMF was agreed by fraternity of scientist since last few decades. Detrimental effects of ELF EMF were also reported. Exposure to natural ELF EMFs is the million million years old phenomenon as compared to exposure to manmade ones.

During evolution process, natural defending mechanism or process could have been developed in biological bodies, against natural ELF EMF. However, for the life on earth, exposure to manmade ELF EMF is a recent phenomenon, which is attracting the researchers worldwide.

With the increased demand for electric energy, the number of power generating stations, high voltage transmission lines and utilization of electrically powered machinery and household equipments have been increased to a large extent. Peoples are continuously exposed to ELF EMF produced by these sources at their workplace as well at the place of residence [2]. There is a growing concern among the public about exposure oriented health effects especially due to high voltage transmission lines and electrically powered equipments and machines. The first scientific study to attract serious interest in the issue came in 1979. An epidemiological study by Wertheimer and Leeper [3], showed an association between the type and proximity of electricity supply cables outside the home and the incidence of childhood cancer. The association increased risk of cancer with conductive plumbing was also reported [4].This study had a major impact both on the general public and on the scientific community and stimulated much subsequent research. Various international agencies have recommended exposure limits for both residential as well as occupational exposure. Efforts to address bioeffects and potential adverse health effects carried out since then were reported in [5, 6].

Exposure assessment is usually done in three steps. First step involves measuring the external EMF generated by the specific source. This field interacts with the living body. Interaction with external EMF induces internal fields in body. So, measuring internal fields stands as second step. The internally induced field may lead to certain biochemical change in body which may further lead to effect on specific organ depending upon the dielectric properties of that organ [7-9]. Measuring the initiated bio chemical changes stood to be third step to arrive at conclusive effect of any exposure assessment.

The paper is organized as: Section 2 describes the background, section 3 will give details about the instrument used for measurement, section 4 will deals with the site selection and measured readings of EMF field, section 5 will show the modelling results and section 6 concludes the paper.

2. Background

As a matter of fact most of the scientific studies have been conducted for the occupationally exposed persons consisting of adults who are trained to be aware of the potential risk and to take appropriate precautions, while the untrained general public comprises of all ages and of varying health status and may include particularly susceptible groups or individuals. Also the period of exposure of these general public living nearby the transmission line is much more than the occupational exposure [10-12].

The main purpose of this study is to measure and model the external ELF EMF around the double circuit 132kV, 50Hz high-voltage transmission line. The data obtained during this survey is used to model the electric and magnetic fields, by using various functions such as Regression Analysis, Support Vector Machine (SVM) and Neural Network. An innovative Hybrid Technique is also developed which is the combination of SVM and NN. Finally comparative analysis of all the modelling techniques was presented. Comparatively best performance was judged according to closed approximation to the calculated values. The procedure is explained with the help of flowchart shown in figure 1.

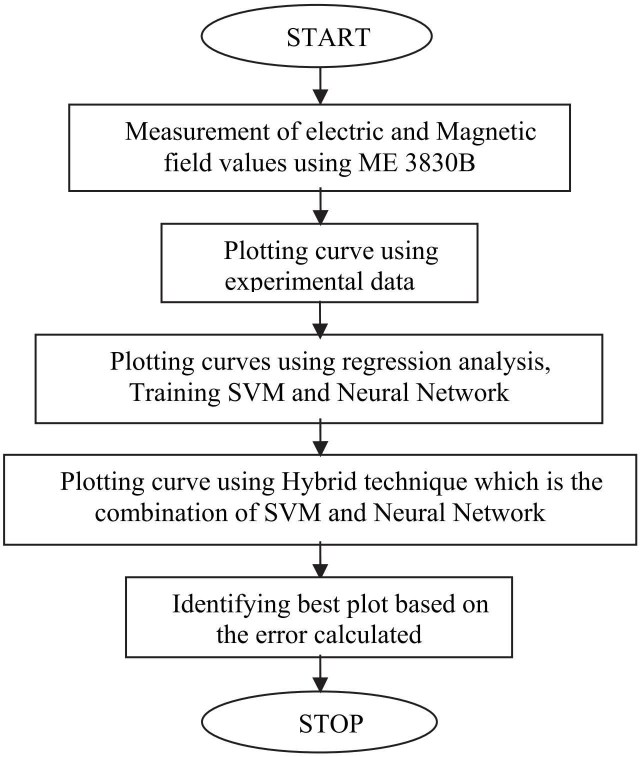

Figure 1. Flowchart of the Proposed System

3. Site selection and Measurement

A double circuit 132kV, 50Hz HVAC transmission line was selected, spanning from Deepnagar to Pachora in Jalgaon region of Maharashtra, India. Figure 2 shows the photograph of the site at which measurements of both the electric and magnetic fields were taken. Measurements were carried out along the span at a distance 15m from the centre of tower (ground line) at every 5 meters.

Figure 2. Site Selected for Measurement of Electromagnetic Field Emanating from Double Circuit 132 kV Transmission Line

Both electric and magnetic field intensities were measured using Gauss/Tesla meter ME 3830B [9].

4. Modelling the ELF EMF fields

4.1. Objective

Exposure assessment deals with measurement of external fields manually (with available Gauss/Tesla meters) and calculating internally induced fields in reference to measured external fields. The intensity of the internally induced fields varies according to intensity of external fields, and other electrical properties of living body. Each organ has different electrical properties such as, conductivity, permeability and permittivity. Fields induced internally will vary according to distance from source too, since the values of external fields vary as we move away from source of power frequency fields.

Since there is no direct method for measurement of internally induced fields, different models and modelling techniques are used for calculation of internal fields. These models and techniques seeks the perfect values of external fields which will be operated along with conductivity, permeability and permittivity values of specific organs to calculate organ specific induced fields. The accuracy of internal dosimetry depends upon proper selection of electrical properties and the exact input values which is to be operated as input. These input values are nothing but the external fields measured along the path of exposure assessment at different locations and distances. In external exposure assessment there are chances that external field readings may be deteriorated due to manual handling of the measuring instruments, which may lead to loss of smoothness and significance in measured values at particular locations. So there is always need to determine graph of best fit which represents best possible readings at that particular exposure location or path. This can be done by Regression Analysis, SVM and Neural Networks.

The objective of the modelling done in this paper is to generate the best dataset representing the external field values. These values will be operated to calculate organ specific internal fields and current density at the point of interest from power frequency source.

4.2. Electric field

External field values obtained during survey functions as input to the MATLAB program. Modelling was done using Regression Analysis, Neural Network, SVM and Hybrid Technique (HT). HT is the combination of NN and SVM. The graph of the actual measurement data is shown in fig. 3.

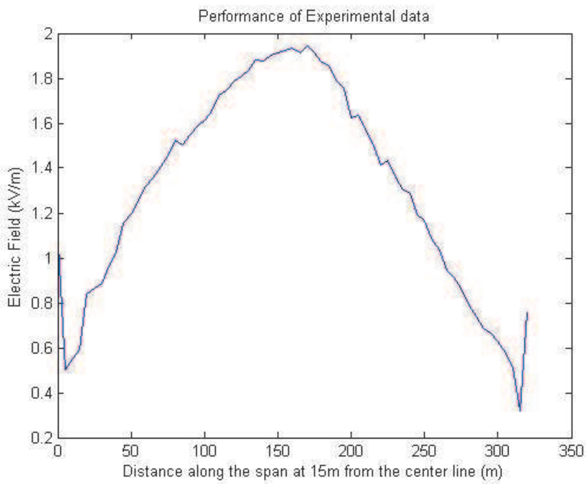

Figure 3. Graph of Experimental Data of Electric Field vs Distance Along the Span at 15 m from the Centre Line (m)

From the experimental data graphs are plotted using Regression Analysis for various degrees. Regression Analysis is used for modelling and analyzing several variables. It gives the relationship between a dependent variable and one or more independent variables. In present study the dependent variable is the electromagnetic field which is dependent on the position of the meter, *i.e.* distance from the center of the structure and distance along the line in meters.

Once MATLAB program plots the graphs for various degrees using Regression Analysis, it finds the graph which gives least errors by comparing the Regression Analysis graphs at various degrees with the experimental data. The Regression Analysis for 9^{th} degree has given close approximation to the actual experimental data, so the graph for 9^{th} degree was selected as the performance of the Regression Analysis as shown in fig. 4. Taking the dataset obtained by Regression Analysis for the 9^{th} degree, the error value obtained is 2.2507.

The error value provides an overall measure of how well the model fits the experimental data. The error value becomes smaller when the data points are closer to the line. Readings generated by modelling techniques with least error value will be served as best dataset of external field values. Smaller error values are good because it indicates that modelled field values are closer to the measured once.

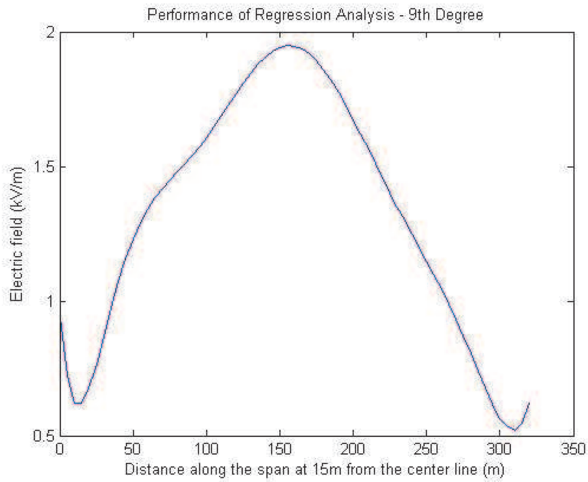

Figure 4. Performance of Regression Analysis Based on the Least Error

SVMs are powerful machine learning techniques for classification and regression. In our proposed method SVM was used for the modelling of electric and magnetic fields for different distances along the transmission line. The SVM is classified into two different types i.e. binary classifier based SVM and multiclass classifier based SVM. In proposed method more than two classes are used, so multiclass SVM classifier is used. A new dataset generated by SVM, with error value obtained as 2.696. The performance of SVM technique is shown in fig. 5.

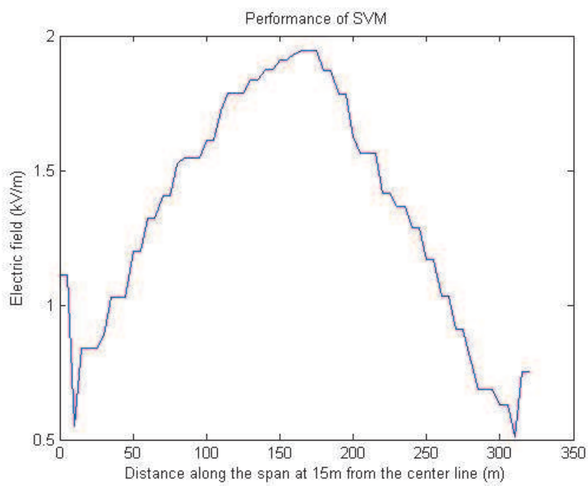

Figure 5. Performance of SVM for Electric Field vs Distance Along the Span at 15 m from the Center Line (m)

Neural Network was used for modelling of electric and magnetic field. Usually Neural Network consists of two stages namely; training stage and testing stage. In the first stage, Neural Network was trained by using the training dataset and in the second stage; the graphs of electric field and magnetic fields were generated. For the training purposes of Neural Network back propagation algorithm is used. A new dataset was generated by training Neural Network, which gives error value of 4.8342. The graph obtained by training of Neural Network is shown in fig. 6.

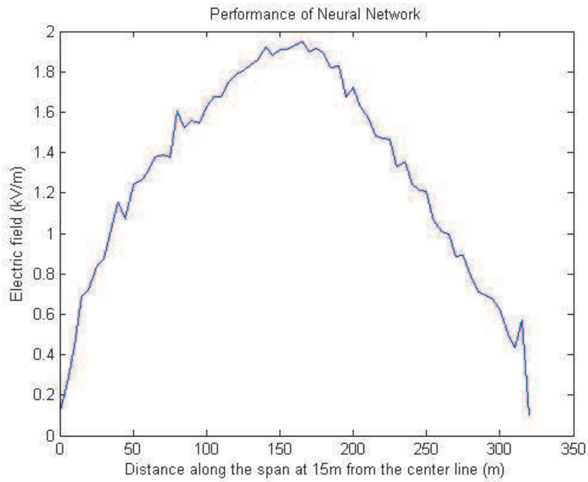

Figure 6. Performance of Neural Network for Electric Field vs Distance Along the Span at 15 m from the Center Line (m)

After training Neural Network and SVM individually the data was combined by using Hybrid Technique, which gives the average of the two data. The error value of 3.3999 was generated. The graph obtained for the Hybrid Technique is shown in fig. 7.

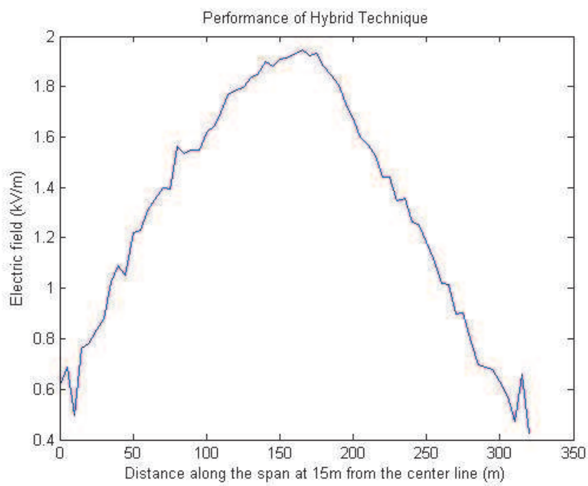

Figure 7. Performance of Hybrid Technique for Electric Field vs Distance Along the Span at 15 m from the Center Line (m)

4.3. Magnetic field

Measured values of Magnetic fields were treated as input to the MATLAB program. Modelling using Regression Analysis, NN, SVM and HT was carried out in the same manner as that of electric field modelling.

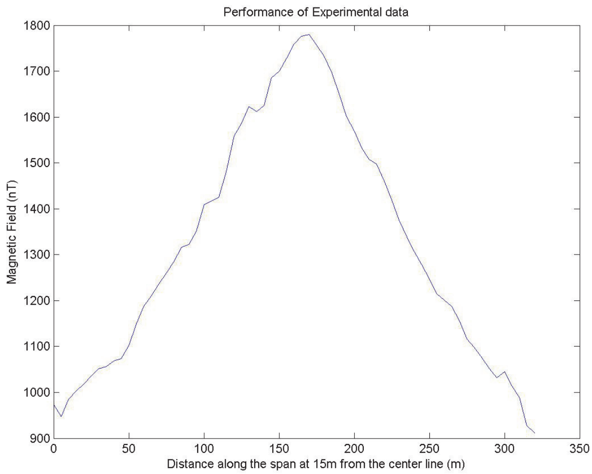

Figure 8. Graph of Experimental Data of Magnetic Field vs Distance Along the Span at 15 m from the Center Line (m)

The Regression Analysis of 10th degree had given close approximation to the experimental data. Error value of 921.772 was generated for the new dataset, using Regression Analysis for the 10th degree. The performance of Regression Analysis is shown in fig. 9.

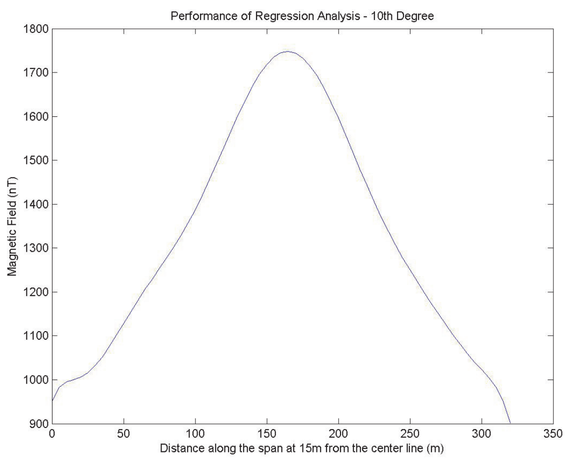

Figure 9. Performance of Regression Analysis Based on the Least Error

The new dataset obtained by the SVM had given error value of 847. The performance of SVM is shown in fig. 10.

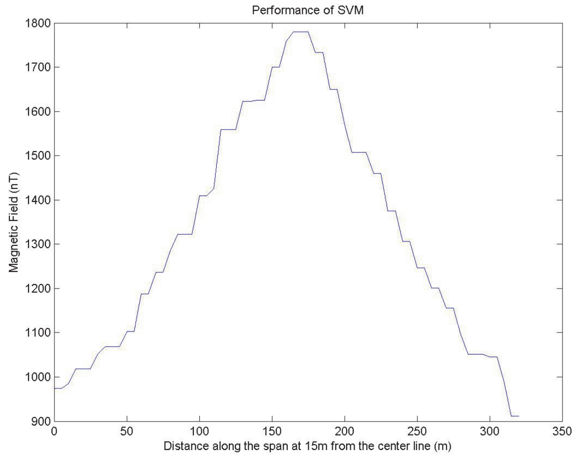

Figure 10. Performance of SVM for Magnetic Field vs Distance Along the Span At 15 m from the Center Line (m)

The error value of 1356.64 was generated for the Neural Network, whose performance shown in fig. 11.

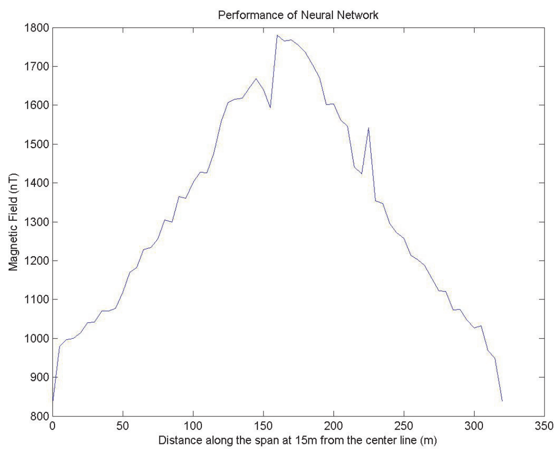

Figure 11. Performance of Neural Network for Magnetic Field vs Distance Along the Span at 15 m from the Center Line (m)

New dataset generated for Hybrid Technique with error value of 940.96, performance is shown in figure 12.

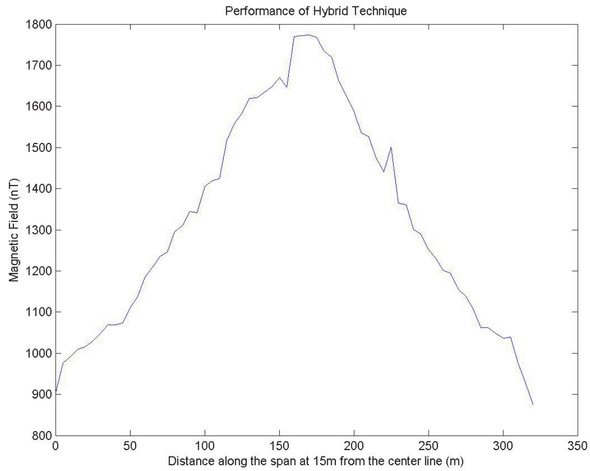

Figure 12. Performance of Hybrid Technique for Magnetic Field vs Distance Along the Span at 15 m from the Center Line (m)

5. Conclusions

External exposure levels are measured with low frequency analyzer. The maximum values of Electric and Magnetic field were obtained at the point of sag. The Electric and Magnetic fields measured at the sag were 1.947 kV/m and 1780 nT respectively. These positions will need maximum attention while calculating internal induced electric field and induced current densities.

The modelling was carried out by a program developed in MATLAB using Regression Analysis, SVM and NN. Regression Analysis was performed for various degrees and then these graphs were compared together to find the least error model, which was taken as the Regression Analysis model. After training SVM and Neural Network individually the data was combined by using Hybrid Technique which was a combination of Neural Network and SVM. Finally the models obtained from Regression Analysis, Neural Network, SVM and Hybrid Techniques have been compared to find the approximation with the experimental data.

The results obtained by these modelling techniques give close approximation with the measured dataset.

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Comparative Estimation Between Computer Simulation Results of the Bus Body Section Rollover and Experimental Data

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Abstract: This paper deals with a rollover computer simulation (according to ECE R66 Regulation) of the bus section, which is performed on the base of a light commercial vehicle. It gives an overview of the used simulation approaches. Comparison between the calculative and experimental data is implemented on the base of one of the specified methods. It considers in details the bus rotation process, which occurs when the bus impacts with ground. The results of the analysis allow us to make a conclusion about the bus rotation influence on the bus body deformation.

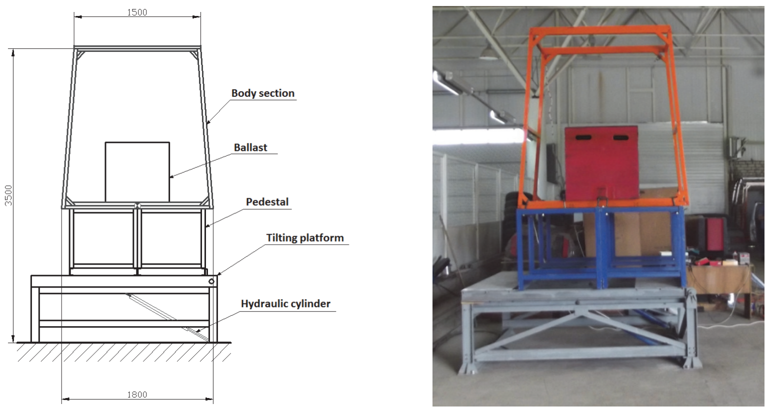
Keywords: ECE R66, finite element method, simulation, overview

1. Introduction

The bus passive safety in rollover conditions is estimated according to ECE R66 Regulation. This Regulation allows to carry out estimation of the strength of the bus superstructure by using computer simulation. In addition, ECE R66 prescribes simulation model that should be able to describe the real physical behaviour of the bus superstructure during the rollover [1]. Nowadays there are different modelling approaches of the body structure load conditions during the bus rollover [2-7]. In many of them the model loading is implemented with predetermined kinetic energy [3-7], but these approaches don’t consider the bus rotation process which occurs when the bus impacts with ground. The positive side of these approaches is that they are easy to use. So there is a logical question: is it necessary to consider bus rotation process during the rollover and how it influences the results which can be obtained by computer simulation? This task can be solved by carrying out experiment and subsequent comparison between the test and the simulation data.

2. Object of study

The object of study has contour and structural elements similar to corresponding parameters of the body structure middle section of a typical bus, which is performed on the base of a light commercial vehicle. The tilting platform fully complies with the requirements set out in Annex 5 of the Rules. During tests the section is set to external support (pedestal), which provides position of the section's centre of gravity and the axis of rotation like in a typical complete vehicle. The centre of gravity of the section is also regulated by a box with ballast. The box and pedestal are attached to the base of the section without increasing the strength of superstructure. However, the box with ballast can influence the deformed shape of the section. It can occur after impact interaction between the box and section pillars. In this case, the deformed shape of the section will not correspond to deformed shape of bus construction obtained in the test for approval. Nevertheless, this assumption is not significant for conducted validation of computer simulation in the paper. Also there are no mass or dummies simulating the presence of passengers in the construction. This situation can occur in approval if the vehicle is not equipped with restraint systems (Annex 6 of the Regulation).The general scheme of the test equipment including the body section, pedestal, ballast and tilting platform as well as their actual image is shown in figure 1.



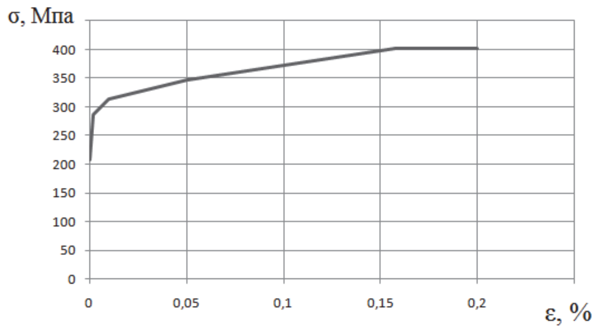
a) *b)*

Figure 1. The section mounted on the tilting platform: scheme (a), photo (b)

3. Finite element simulation

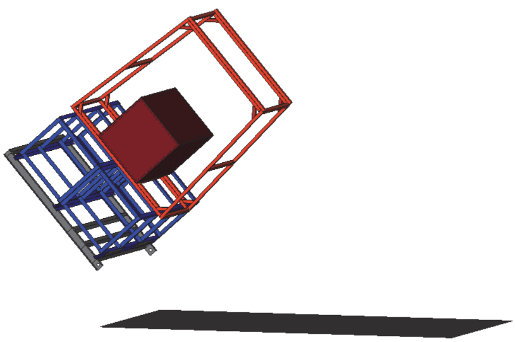
The uniaxial tensile test of the specimens extracted from thin-walled tubes of the body section was conducted preliminary. Subsequently, the "stress-strain" curve obtained for plastic deformation area was assigned to the finite element model of the body section. A fragment of tensile test and the obtained plastic hardening curve are shown in figure 2.

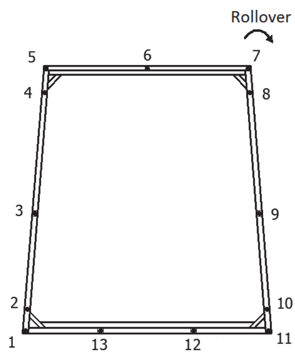
The numerical simulation of the rollover process was similar to the approach of Niii N. and Nakagawa K., described in the study [2]. Finite-element analysis was conducted by using nonlinear explicit dynamic code LS-Dyna. The section pedestal, box with ballast, tilting platform and ditch surface were modelled by rigid bodies. The body section's material (*MAT_PIECEWISE_LINEAR_PLASTICITY) was switched to rigid by using *DEFORMABLE_TO_RIGID_AUTOMATIC option, during body section free fall. The whole rollover process takes 2.2 seconds; so FE analysis can require significant calculation time. During the material properties switching the time step size of the solver can be increased by 10 times and even more that's why calculation time can be decreased respectively. The gravity loading acts to model from time = 0 sec to time = 2 sec, and from t = 2 sec to t = 2.2 sec its value decreases to zero, allowing to measure residual deformations of the model. All model structural members are presented by shell elements. The average model finite element size is 10 mm. At assumed locations of plastic hinges emergences the element size is 6 mm, at the tilting platform shoulders the element size is 2.5 mm for contact interaction accuracy ensuring between the shoulders and body section pedestal. Total shell element number is equal to 230567. The composed model view is shown in figure 3.



a) *b)*

Figure 2. The fragment of uniaxial tensile test (a) and obtained plastic hardening curve for steel (b)





a) *b)*

Figure 3. The designed finite element model (a) and the control measured points location (b)

4. The comparison between the simulation and test data

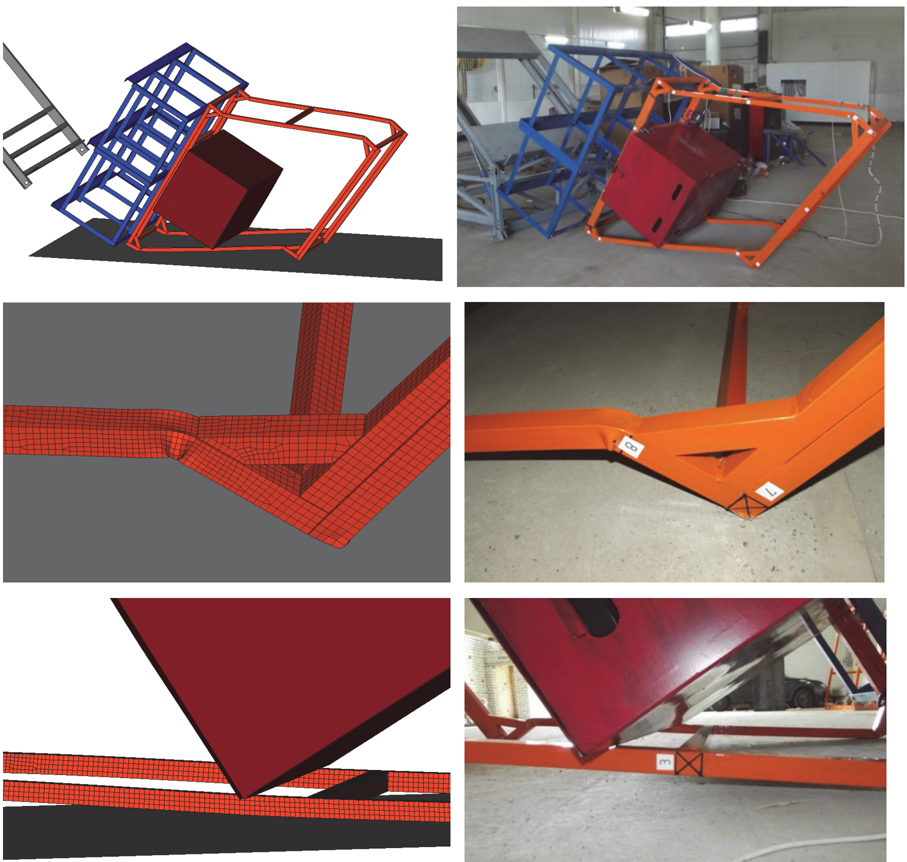
The distance between the control points before the impact and after it is measured in simulation and test. The residual deformations after unloading are measured after the impact. Comparison between the simulation and test results is conducted by the comparison between these distances. Maximal deformations during the impact is not measured in calculation. This is a shortcoming of the study. On the other hand, the stress-strain curve is a linear at elastic deformation. At plastic deformation the relationship between stress and strain is more complex, non-linear and requires a large number of iterations. The description of the behaviour of structures in the range of elastic deformation is more simple task of finite element analysis than simulation of plastic deformation. Thus, in this case we can assume that obtaining good convergence of plastic strain values between experiment and calculation a good accuracy of elastic deformation modelling should be expected. Location of the control points is shown in figure 3. The measurements are shown in table 1. As it is seen from the table, the difference between the simulation and test results has range from 0,36 to 7,29 %. The obtained result means that the considered approach allows to get a good correlation with experimental data. A good correlation between the results is also confirmed by comparison of the body section deformations as shown in figure 4.

Table 1. Comparison between the calculation and the test data

Numbers of control points	***Change of the distance, mm***		***Difference between the results, %***
	Test	***Calculation***	
1-7	***640***	***650***	***1.56***
1-8	***669***	***686***	***2.54***
6-2	***400***	***403***	***0.75***
6-3	***327***	***335***	***2.45***
3-13	***-153***	***-162***	***5.88***
4-12	***-384***	***-412***	***7.29***
3-12	***-247***	***-259***	***4.86***
5-11	***-427***	***-449***	***5.15***
11-4	***-478***	***-504***	***5.44***
6-10	***-261***	***-273***	***4.60***
6-9	***-211***	***-221***	***4.74***
9-12	***231***	***226***	***2.16***
8-13	***550***	***552***	***0.36***
9-13	***312***	***334***	***7.05***

It is seen from figure 4, that the box with ballast touches the vertical pillars of the body section. This situation also takes place at calculation. It is also seen, that locations of the plastic deformations areas at the calculation are the same as in the experiment.

Change of the kinetic energy (it is shown in figure 5) during the rollover process shows the fall of the pedestal from the tilting platform shoulders at time t = 1.69 sec. It is confirmed by sharp increasing of the kinetic energy. Sharp decreasing of the kinetic energy means that there is contact between the pedestal and the rigid ditch surface. A similar change of energy is described in details in M. Matolcsy and C. Molnar study [8], which analysed the energy balance of the bus rollover process. That is to say, the kinetic energy portion is dissipated by the impact between lower parts of the section and the rigid ground. This impact practically doesn't have any influence on deformation of the upper parts of the section. Sliding of the body section along the ground surface is the most obvious parameter which influences the time moment of the fall of the pedestal from the tilting platform shoulders. If the fall occurs later, more amount of kinetic energy is dissipated by deformation of the upper parts section. So, if the friction coefficient between the construction and the ground surface is higher, section upper parts deformation is more significant.



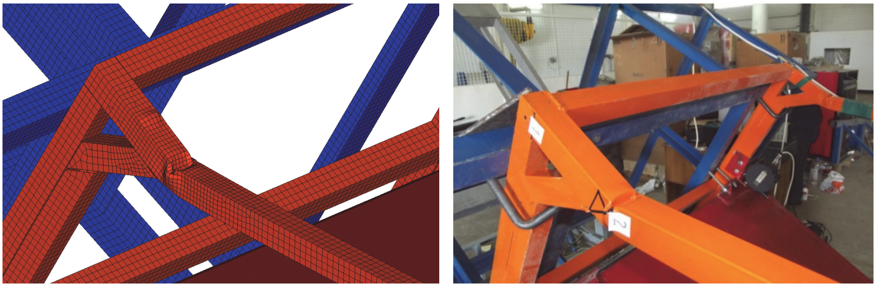


Figure 4. Body section deformation condition at the simulation (on the left side) and at the test (on the right side)

The rotation axis of the bus body construction changes during the rollover process. The tilting platform shoulders and the pedestal positions at different time moments are shown in fig.6. The rotation axis changing influences the moment of inertia of the rotating bus body construction, and so influences the kinetic energy value. Also, the "S" distance between the lower edge of the pedestal and rotation axis influences the time moment of the fall of the pedestal from the tilting platform shoulders.

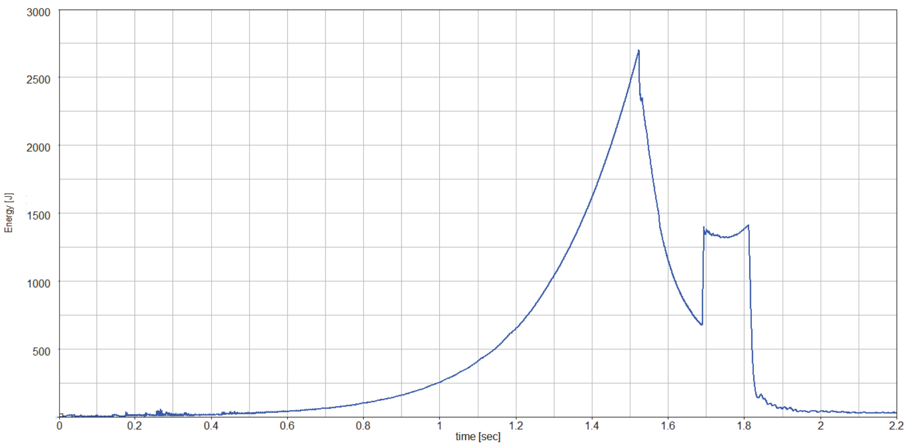
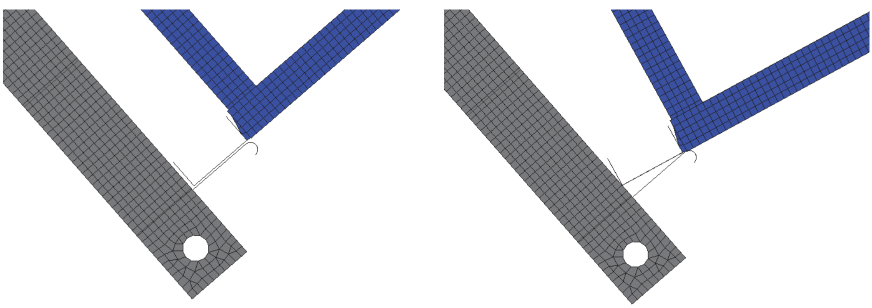
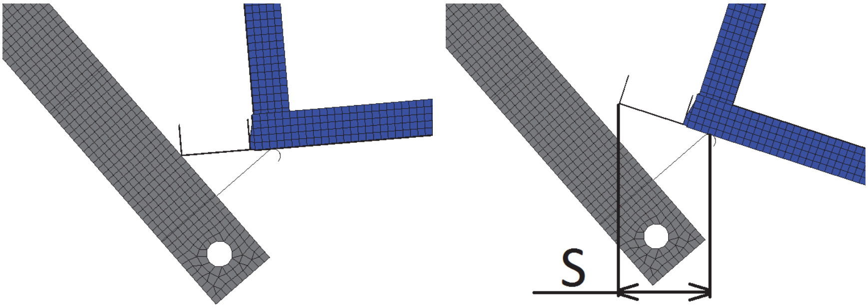


Figure 5. Kinetic energy distribution versus time



a) b)



c) d)

Figure 6. The tilting platform shoulders and the pedestal position at time:
a) t=0 sec, b) t=0,9 sec, c) t=1,3 sec, d) t=1,5 sec

Rotational motion of structure during deformation influences the value of structure strain. Motion of structure during deformation occurs along the radius R, which is equal to the distance between the zones of plastic deformation, arising at the base, and corresponding zones located in the upper corners of the section (figure 7). With the decreasing of the radius the drop of the section base (bus chassis) from tilting platform happens with smaller bus superstructure deformations. Finally, above mentioned factors influence the bus body deformation.

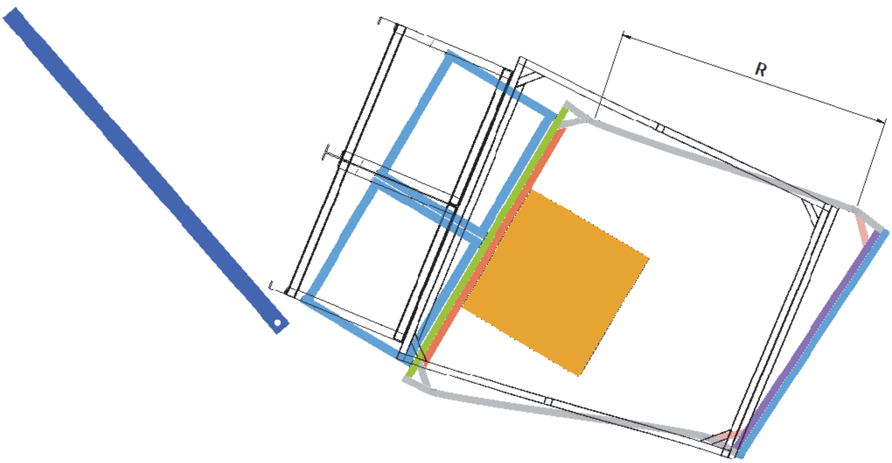


Figure 7. Changing of the vertical pillars length projection during deformation

5. Conclusions

On the basis of the performed study, it can be concluded the finite-element simulation of bus rollover considering bus rotation process coincides with the experimental data. Other computer simulation approaches used nowadays, where the fixed bus body construction is impacted by the rigid body [6],[7] (pendulum, rigid wall with translational or rotational motion) don't consider the fall of the bus from the tilting platform shoulders, change of the bus rotation axis during the rollover process and mass distribution along the bus body construction. There is a computer simulation approach, where the bus model turns into the contact position with the ditch surface at the initial time of the simulation, and the angular velocity is assigned to all nodes of the model [3-5]. This approach doesn't consider the change of the bus rotation axis during the rollover process. Therefore the fall of the bus from the tilting platform shoulders occurs at the dissipated kinetic energy amount that doesn't correspond to its real value. All this shortcomings are eliminated by the rollover modelling considering bus rotation process before the impact. One more phenomenon, which can be considered only by this rollover simulation approach, is the additional bus rotation components. These components occur due to different COG heights of the individual sections of the bus. Due to it the first bus body construction impact into the ditch surface is occurred by one of the extreme corners of the roof (front or rear). Numerical value of this phenomenon influence can be obtained at the rollover test of more difficult asymmetrical construction, which has irregular mass distribution. All the above mentioned factors influence the bus body construction deformation values.

Thus, at the bus passive safety estimation by using computer simulation, considering the bus rotation process during the rollover, is important for obtaining more accurate results.

It is important to consider the process of bus rotation which occurs before the bus impacts with ground surface at passive safety estimation by using computer simulations. Also, the motion of the bus during deformation has an effect on the obtained results of simulation. It indicates that for obtaining a more accurate result of the calculation such features of the rollover as a free fall of the bus and his contact with the tilting platform should not be neglected. Thus, at the approval, the known methods of verification such as experimental tests of separate elements of bus structure [4], analysis of the balance of the calculative values of the energy [9] and implementation of experimental modal analysis [10] cannot be sufficient to obtaining accurate results of finite element modelling of the bus rollover. Based on the above mentioned, it is also desirable to conduct the experimental verification of the adequacy of finite element model motion on the example of a single section of the bus.

Acknowledgement

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Methodology of Roadway Impacts Modelling to Predict the Fatigue Life of Vehicles Parts

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Abstract: This paper describes methodology of disturbances formation from the road surface to predict durability of suspension elements and the supporting system of light commercial vehicles. This methodology is designed on the basis of theoretical and experimental researches. Classification of asphalt concrete roads is formed taking into account deterioration of the coverage. It gives models of the road profiles representing public roads. The synthesis method of sequences of ordinates of road profiles is based on the use of probabilistic characteristics of microprofile. It shows the measuring equipment to determine the road sections with different states of coverage by the length of the routes selected for the research. It presents the results of the selection and justification of the range of modes of motion reflecting the real operating conditions of vehicles in urban environments. The results are obtained by carrying out statistical studies of the traffic intensity on the selected routes using a web mapping service.

Keywords: operating conditions, roads microprofile, light commercial vehicle, durability

1. Introduction

Probabilistic methods for quantifying the durability of suspension elements and the supporting systems in motor vehicles are considered the most perfect now. These methods allow us to take into account the random nature of changing parameters that affect the dynamic characteristics of the systems [1]. The main issue when calculating the vehicles details resource is adequate modeling of operational stress loading. It is necessary to have the values and nature of roadway impacts, the range of movement modes, reflecting the real operating conditions of vehicles in urban environments for the calculation. The main cause of dynamic loads determining the durability of structural elements of cars is oscillatory process occurring in the car while driving on rough roads.

This is discussed in details in [2-5], in [2] The model of operational loading of the test components of vehicles is not based on analysis of statistical data of car traffic, and model of road impact is not spatial. In the sources [3-5] in the formation of the model of distribution of car mileage on different types of roads is used insufficiently substantiated or outdated statistical findings. Currently, there is the growth of rate of developing of light commercial vehicles designs and limitation of approaches to modeling of their operational loading in the task of quantitative assessment of vehicle durability. Therefore, car manufacturers are looking for advanced technologies to produce a rapid and accurate data on the road impacts.

2. Features of a road microprofile

2.1. Classification of asphalt concrete roads

During the research the classification of asphalt concrete roads in view of deterioration of the coating is formed. Formation of this classification was based on the systematization of the experimental data on the number, size and nature of the alternation of roughness.

The road is divided into the following groups according to the coating: the road in good condition, a little worn road, badly worn road and a broken road. You can see detailed specifications of listed groups below.

2.2. Mathematical models of road profiles representing public roads

Formation of mathematical models of generated set (library) of road profiles representing public roads in Russia was carried out by the example of roads in several districts of Nizhniy Novgorod.

The methodology outlined in [6] is used for modeling of a microprofile of asphalt concrete road. The parameters of the correlation function of a microprofile of automobile road will be presented in Section 2.3.

The degree of deterioration of road surfaces is modeled by constructing separate laws on the basis of the distribution of roughness from the experimentally obtained data on the number, size and nature of their alternation (distances between the asperities).

The exponential law of distribution is most suitable for mathematical modeling [7]. In determining the number of roughnesses of their length and the distance between the roughnesses we have the following dependence

$$n(x) = A\frac{1}{\lambda}e^{-\frac{x}{\lambda}}, \qquad (1)$$
$$x = 0{,}5\,(x_i + x_{i+1}),$$

where $A = a \cdot \Delta x$, $A, a, x > 0$ – parameters of this distribution, $x_{i+1} = x_i + \Delta x$, Δx – discretization step of sizes of roughnesses, a and λ – empirical coefficients.

The results of the analysis conducted by the authors are the dependences to describe the asphalt urban roads. These parameters are summarized in Table 1.

Table 1. The averaged model parameters of deterioration for road sections

№	**Characteristics of a road**	**Type of roughness**	**Size parameters**		**Distance settings**		**The average depth of roughness, cm**
			a	λ	*a*	λ	
1	Road in good condition	Potholes	-	-	-	-	-
		Cracks	-	1	180	5	-
2	Little worn road	Potholes	185	15	100	15	1
		Cracks	-	2	120	5	-
3	Badly worn road	Potholes	100	45	110	6	2
		Cracks	-	3	60	5	-
4	Broken road	Potholes	190	150	190	5	3

Distributions of roughnesses depending on the length and distance between each other are illustrated by Figures 1-2.

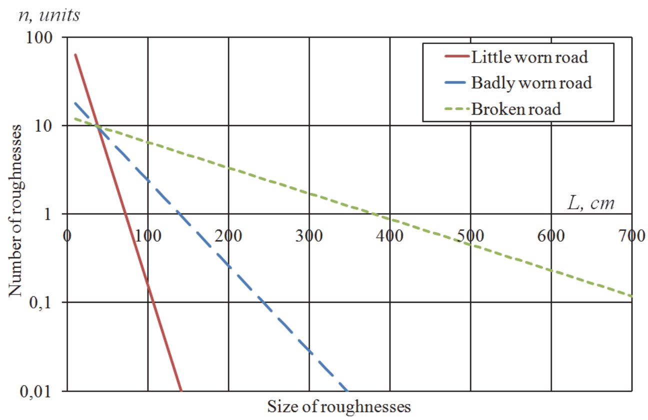

Figure 1. The distribution of roughnesses depending on the length

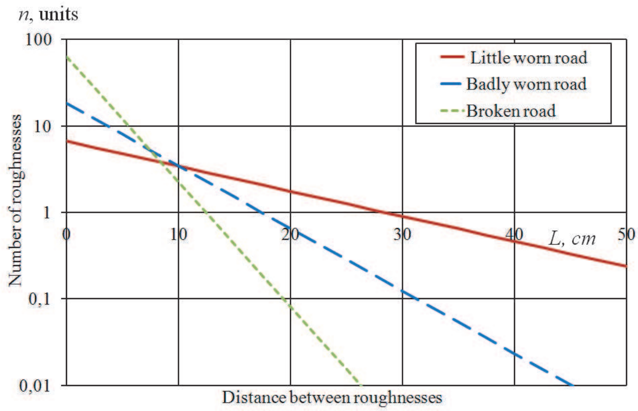

Figure 2. The distribution of roughnesses depending on the distance between each other

2.3. Generating of a road microprofile

Function of a microprofile of any road can be represented as a superposition of harmonic functions with different frequencies, amplitudes and phase angles, which were chosen so that the characteristics of the random process (average quadratic deviation, variance, the spectral density, the correlation function) began to coincide with similar characteristics of real roads.

The synthesis of numerical sequences of ordinate traffic profiles of the library was based on the probabilistic characteristics of microprofile. In the proposed program we added the roughness distributions characterizing the state of the road surface.

Let us consider the basic steps of generating of the road microprofile as a table function, which characterizes the dependence of the change of roughnesses height versus length of path. The method is based on algorithms for numerical simulation of stationary normal random processes with the use of common types of correlation functions [6].

Let us achieve the goal to receive the numerical sequence of ordinates of road profile. Here we assume that the sequence of random numbers must satisfy the stationarity, ergodicity and also must be normally distributed and have a correlation function of the exponential-cosine form:

$$R(\tau) = R(0)e^{-\omega_*|\tau|}\cos\omega_*\tau \qquad (2)$$

where $R(0) = \sigma^2$ − dispersion of road microprofile; $\omega_* = \alpha V$ and $\omega_0 = \beta V$ − parameters of the correlation function, e.g. α = 0,22, β = 0,44 (1/m) − asphalt road, V (м/с) − speed; σ − average quadratic deviation of a road microprofile.

Algorithm for obtaining the ordinates of microprofile consists of the following sequence of operations [6]:

1. First step is to obtain a uniformly distributed pseudo-random number sequence.

2. Then normally distributed sequence is formed from a uniformly distributed one.

3. At the last stage we have a normal-distributed ”white noise“. A pseudo-random number sequence with the given ”color“ of the spectrum must be obtained. For this purpose the ”white noise“ is passed through a digital filter with the specified parameters.

3. Determination of the average statistical operating conditions of light commercial vehicles in urban environments

3.1. Route selection for research

The main criterion for selecting routes for further research within Nizhny Novgorod is the presence of frequent changes of areas with different state of the roadway, as well as elements of the road network (tram tracks, rail crossings, etc.).

3.2. Experimental work to determine the states of coverage by the length of routes selected for the research

Experimental work to determine the states of coverage by the length of routes selected for the research was carried out with the use of the car GAZ 2310 ”Sable“.

The vehicle was equipped with the following instrumentation:

1. System contactless measurement of motion parameters (GPS-technology) Racelogic VBOX 20SL3 20Hz GPS Data Logger With Slip, Pitch and Roll Angle (Figure 3).

Figure 3. Data acquisition unit RaceLogic system (right) and the appearance of antennas (left)

2. The data acquisition system for dynamic testing DC-204R from the acceleration sensor ARJ-AD (Figures 4-5).

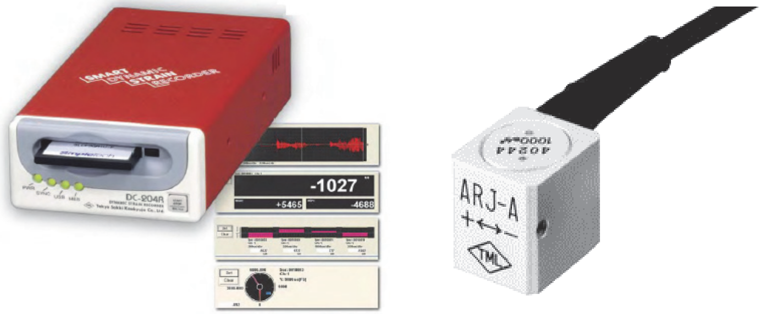

Figure 4. Recording device DC-204R and accelerometer ARJ-AD

The initial stage of experimental research was the series of races on the GAZ 2310 on road profiles selected as reference (classification) with different speeds. Example of the measured effects of roads by equipment is shown in Figure 5. As a result, database was created for each road profile (Figure 6). Databases contain oscillation parameters (vertical acceleration of the unsprung mass of vehicle) versus the longitudinal velocities of the vehicle. According to the testimony of the median longitudinal velocity and average square value of the vertical acceleration on the path can be determined indirectly by road surface condition, and as a consequence, the distribution pattern of roughnesses.

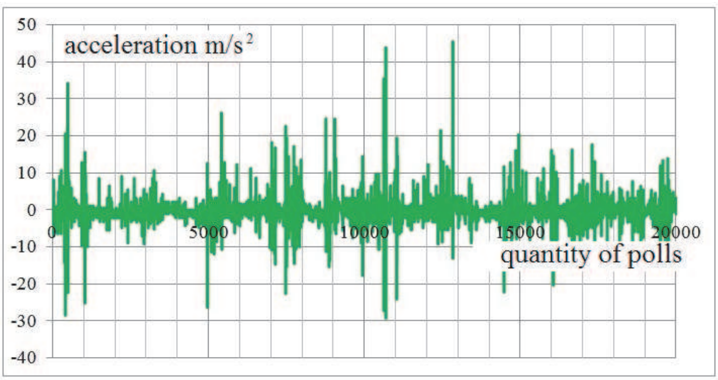

Figure 5. Example of measuring of the road impact

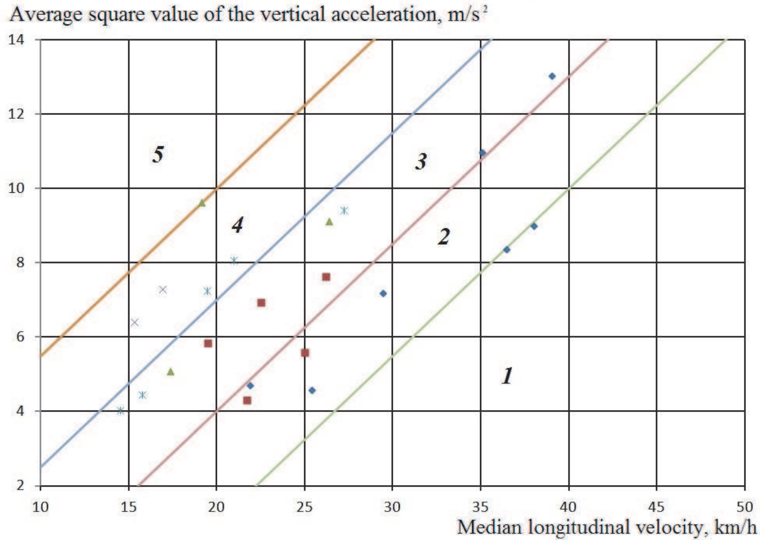

Figure 6. Influence of the vehicle speed on the vertical acceleration of the unsprung mass of vehicle when driving on typical road coverings: 1 - Road in good condition, 2 - Little worn road, 3 - Badly worn road, 4 - Broken road, 5 - Elements of the road network (tram tracks, crossings, etc.). The dots show the experimental data

The main stage of experimental research was the implementation of movement on the car GAZ 2310 with the measuring equipment on selected routes. Function of control the vehicle movement is implemented by using GPS-receiver system Racelogic VBOX, and memory accumulate navigation data and data on speeds.

3.3. Share distribution of the road sections with different states of coverage for a total length of routes

To determine the share distribution of road sections with different quality coverage for a total length of routes that pass through the roads of the territory under consideration (Nizhny Novgorod), analysis of graphs of unsprung mass vertical acceleration GAZ 2310 was conducted.

Reverse operation of finding perturbations using the oscillation parameters at fixed velocities gives the characteristic of individual section flatness of the investigated roads. Analysis of the mean-square value of the vertical accelerations of unsprung mass and longitudinal velocities allows in accordance with the characteristics shown in Figure 6, to differentiate sections of road with different deteriorations by the total length of routes (Figure 7).

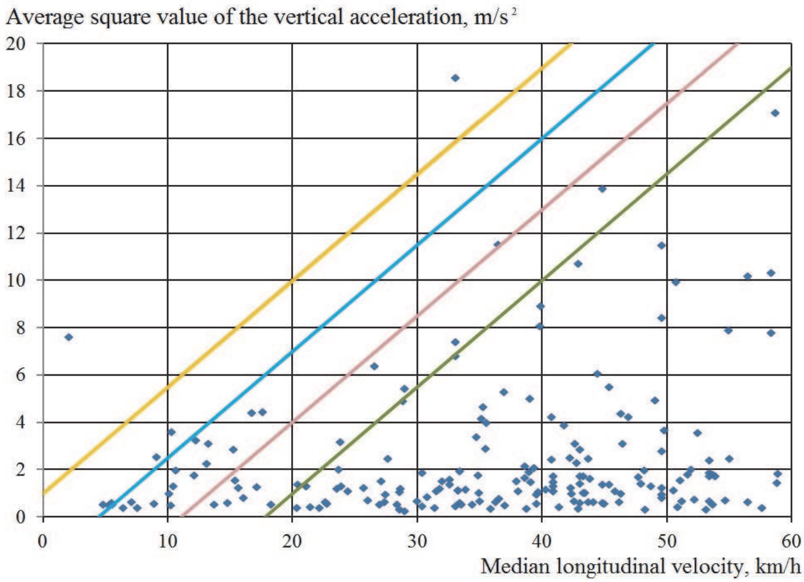

Figure 7. Example of differentiation of road sections with different deteriorations (shown by dots) using the ratio of the vertical acceleration of the unsprung mass and longitudinal velocities of the vehicle

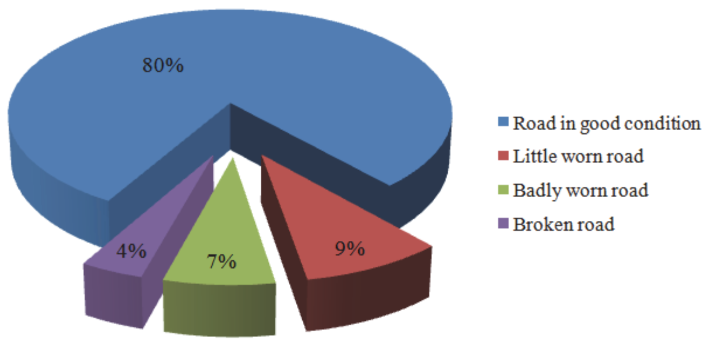

Figure 8. Share distribution of length of road sections with different state of coverage for the routes in question (experimental results)

3.4. Modeling of the velocity distribution of vehicles on roads with different states of coverage

Statistical studies of the traffic intensity on selected routes were carried out using a web mapping service. Analysis of the travel time on selected routes was produced based on the speed. The total recording of traffic intensity on the routes was equal more than 120 hours and about 3500 km. Figure 9 shows the share distribution of time of car traffic on roads with different deterioration.

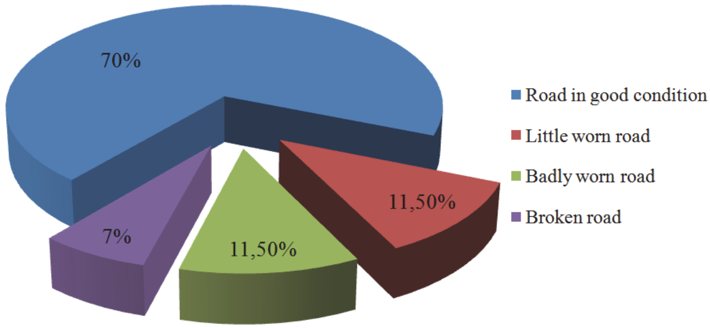

Figure 9. Share distribution of time of car traffic on roads with different deterioration (results of research of road traffic)

Research results were the statistical data on the distribution of vehicle speeds differentially for each state of the roads encountered on selected routes.

For the roads in good condition the distribution of mileage time as a function of speed is described using the normal law of distribution.

$$\varphi(V) = \frac{\Delta V}{\sigma_V \sqrt{2\pi}} e^{-\frac{(V-\overline{V})^2}{2\sigma_V^2}}, \qquad V = 0{,}5\left(V_i + V_{i+1}\right), \tag{3}$$

where $\varphi(V)$ – relative travel time at a predetermined speed, $V_{i+1} = V_i + \Delta V$, ΔV – discretization step ($\Delta V = 5$ km/h), $\overline{V}$ – average speed, σ_V – the mean square deviation from the average speed. For roads in good condition $\overline{V}$ = 38 km/h, $\sigma_V = 9$ km/h.

For other types of roads the distribution of the time of motion at different speeds looks as follows:

$$\varphi(V) = \left(a - bV\right)\left[\sum_{j=c}^{d}\left(a - j\, b \Delta V\right)\right]^{-1}, \qquad V = 0{,}5\left(V_i + V_{i+1}\right), \tag{4}$$

where $\varphi(V)$ – relative travel time at a predetermined speed, $V_{i+1} = V_i + \Delta V$, ΔV – discretization step, ($\Delta V = 5$km/h), $c = V_H / \Delta V$, $d = V_K / \Delta V$, V_H – minimum limit of beginning of changing the speed ($V_H = 5$ km/h), V_K – final speed (for greater speed the studies were not performed).

Table 2 contains the parameters for the mathematical description of the different states of the roadway.

Table 2. Parameters in the formula

Type of road	Coefficients	
	a	b
Little worn road	0,04	1500^{-1}
Badly worn road	0,045	$9*11000^{-1}$
Broken road	0,05	1000^{-1}

3.5. Calculation of the relative time of influence of each road profile in the general run of the car

By the relative influence time of a certain type of road roughness you can jump by dividing the mileage on this road at speed and normalize the obtained values.

The modeling of operational loading is made on the basis of data on the impact time of all roads (or roads in a given ratio). This step is creation of mixed block of loading. Mixed blocks of loading are built using private blocks of loading for each mode of operation in accordance with their share in the working time of movement. Mode of operation is the movement of vehicle on a certain road with a certain velocity. Table 3 was built in accordance with the data. Figure 10 shows a graphical interpretation of the distribution of the relative time of influence.

Table 3. Relative time of influence of the roadway at different modes

Speed, km/h	Share of time of coverage influence, %			
	Road in good condition	Little worn road	Badly worn road	Broken road
5	0,018552	1,925996	2,114213	1,457062
10	0,121911	1,750906	1,902792	1,295166
15	0,588375	1,575815	1,69137	1,133271
20	2,085567	1,400725	1,479949	0,971375
25	5,429413	1,225634	1,268528	0,809479
30	10,38102	1,050543	1,057106	0,647583
35	14,57759	0,875453	0,845685	0,485687
40	15,03453	0,700362	0,634264	0,323792
45	11,38813	0,525272	0,422843	0,161896
50	6,335394	0,350181	0,211421	0
55	2,58853	0,175091	0	-
60	0,776768	0	-	-
65	0,171194	-	-	-
70	0,02771	-	-	-

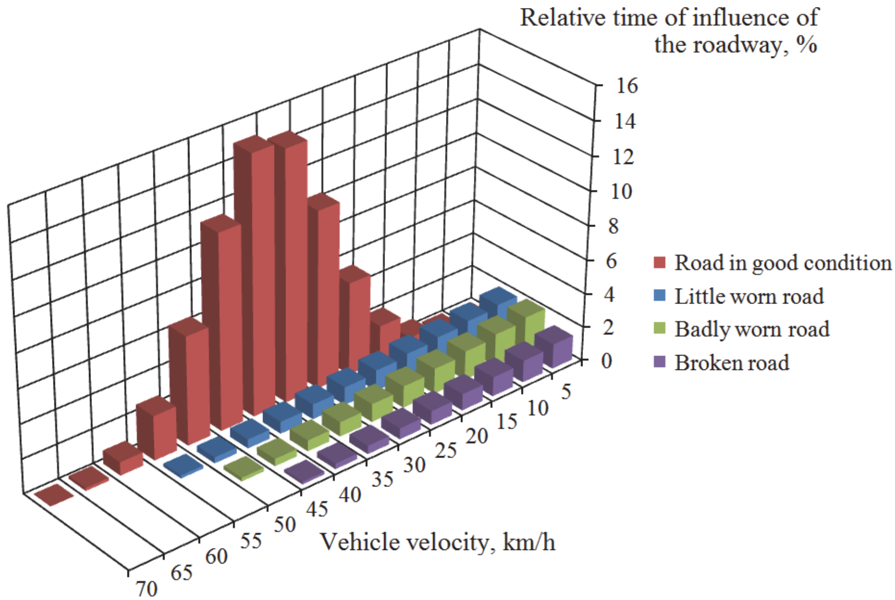

Figure 10. Graphical interpretation of the distribution of the relative time of influence of the roadway at different modes

3.6. Methodology of modeling of roadway impacts for life prediction of the parts of light commercial vehicles

The set of initial data for modeling of the loading history of the suspension and the supporting system characterizing the operating conditions of light commercial vehicles includes two components: 1) library of implementations of roughnesses corresponding to different road surfaces; 2) table of the relative time distribution of roadway influence at different modes.

The first step in roadway impacts modeling to predict the fatigue life of suspension components and supporting system of vehicles is the synthesis of stochastic road profile processes. It is necessary to take into account the data on deterioration of the road surface, obtained by the sampling processing of potholes on specific areas.

The next step is to get the share distribution of road sections with different state of coverage for a given territory using the data obtained in the course of experiments on special areas and routes (see sections 3.2 and 3.3.).

Share distribution is necessary for analyzing running time of vehicle on road sections with different cover condition. Calculation of relative time of influence of the roadway at different speeds of vehicle is produced by dividing the total length of the sections relating to the same classification group and passing the same average speed into this speed (see section 3.5).

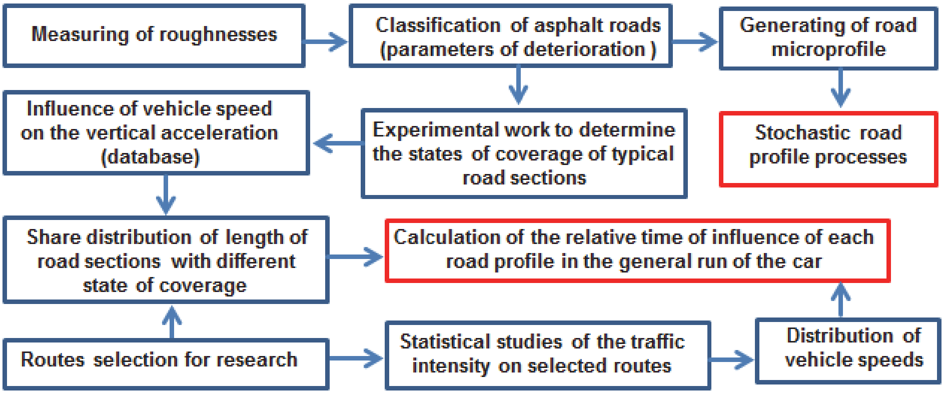

Figure 11. Methodology for preparing of random sampling of road impact

4. Conclusion

Methodology of construction of the generalized random sample of the road impacts in accordance with standard operating cycles of light commercial vehicles was received.

The methodology can be used to produce probabilistic models of the operating loading of elements of vehicles running on the roads of any region for life prediction of the parts of light commercial vehicles.

In this paper it is assumed that the vehicle tracks can pass through any part of the total length of roads in the region. In this case it is necessary to know the distribution of velocities of the vehicles on different types of roads.

The proposed approach in the paper provides fast simulation of disturbances (impacts) from the road to quantify the durability of automotive elements in conditions of limitation (or absence) of data about the distribution of vehicles run on different types of roads.

It is necessary to move to a model of spatial road impacts in further computer calculations of vehicle parts fatigue life. The transition should be carried out with the use of the approach described in [8]. To take into account the effect of the variable vehicle speed at stochastic stationary processes of road impacts the results of [9] should be used.

It is (still) in progress to find ways to further account of the basic elements of the road network (tram tracks, crossings, etc.) when generating the ordinates of a microprofile. The possibility of such add-ons due to the fact that the character of alternation of effects is unimportant for the fatigue calculation methods.

Acknowledgement

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02.G25.31.0006 from 12.02.2013 (Resolution of the government of the Russian Federation on April 9, 2010 №218).

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Accident Prediction Models for Hungarian Two-Lane Rural First-Class Main Roads

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Abstract: This paper describes a modeling effort to define accident prediction models for first-class main roads outside built-up areas in Hungary using variables that are available and believed to exert an influence on safety performance. The first part of the paper describes data collection and the segmentation technique. Six years of accident data are gathered for segments only; intersections with a 200m radius are taken out in order to avoid having intersection related crashes in the data. Altogether 1357 homogenous sections are formulated based on AADT (Annual Average Daily Traffic), road width, posted speed, horizontal curve and shoulder width. Models are proposed using the Generalized Linear Modeling (GLM) approach assuming a negative binomial error structure. It is concluded that AADT, roadway width, horizontal curve and segment length significantly influence accident frequency. Estimated model parameters are explained by putting them into international context and it is concluded that the results are in accordance with previous research findings.

Keywords: road safety, safety performance, accident prediction, two-lane rural road

1. Introduction

According to the Hungarian regulations road infrastructure safety management applies not only to the trans-European road network as laid down in the Directive 2008/96/EC of the European Parliament and of the Council [1], but all national main roads from 1 January 2014 on as well as to all the roads with more than 10,000 PCU/day from 1 January 2015 on. In Hungary crash rates are being used for such analyses assuming a linear relationship between exposure and crash frequencies, which is easy to use for practitioners, however, do not sit on scientifically proven grounds. Safety Performance Functions (SPF) as accident prediction models provide professionals with data needed to conduct road safety impact assessment and network safety ranking and accounting for a more realistic relationship between traffic volume and accident occurrence.

To this end, this paper describes a modeling effort to define accident prediction models using variables that are available and believed to exert an influence on safety performance, including traffic volume. The first part of the paper gives a general overview on design characteristics and accident statistics of two-lane rural first-class main roads. Then it describes data collection as well as how the network is split up into homogenous sections. Then models are proposed using the Generalized Linear Modeling approach (GLM) assuming a negative binomial error structure. Five variables are used to predict accident frequencies, AADT, posted speed, curve, roadway width and shoulder width. Traffic volume is used as an exposure to accidents and the length of the homogenous sections as an offset variable in all models.

2. Literature review

Safety performance functions have been widely used in the traffic safety field for analyzing how the safety performance of road facilities is related to various road characteristics. Roughly 25 years ago a few researchers (e.g. [2] and [3]) started to demonstrate problems associated with conventional regression techniques used for accident prediction. Miaou and Lum [3] for instance used four regression models and demonstrated that the conventional linear regression models are not appropriate to make probabilistic statements about vehicle accidents, and that if the vehicle accident data are found to be significantly overdispersed relative to its mean, then using the Poisson regression models may overstate or understate the likelihood of vehicle accidents on the road. To overcome these problems later on the negative binomial modeling method became a widely accepted modeling technique and was recommended by many researchers e.g. [4] and was also used in other road categories such as urban arterials in [5].

There have been several researchers dealing with the safety performance of two-lane rural roads [6], [7], [8], [9], [10], [11]. Cafiso et al. [6] fitted 19 models and considered 14 variables including geometric and operational ones (curvature change rate, paved width, tangent ratio, curve ratio, average operating speed), design consistency variables (e.g. variables considering speed differentials) and context-related variables (roadside hazard, driveway density). Three models were selected as recommended ones, where the first was a basic model with AADT only and the other two having the best fits used at least one variable pertaining to the four main groups of variables listed above. Abdel-Aty and Radwan [4] divided a 227 km long road into 566 segments with homogeneous characteristics in terms of traffic flow and geometry (degree of horizontal curvature, shoulder and median widths, rural/urban classification, lane width and number of lanes), all variables found to be strongly related to the accident occurrence. Mayora and Rubio [8] investigated which are the relevant variables for crash rate prediction and concluded that access density, average sight distance, average speed limit and the proportion of no-passing zones have the highest correlation. Access density is the variable that influences most the rate of head-on and lateral collisions, while in run-off the road and single vehicle crashes sight distance is decisive.

As far as the segmentation technique is concerned, there are a few methodologies and there is no preferred one. Cafiso et al. [12] did a comprehensive study on the application of five different methods and the influence of segmentation on the performance of safety performance functions in terms of goodness of fit and the variables that could be modeled. They concluded that the best results were obtained for the segmentation based on having two curves and two tangents in each segment and the segmentation with fixed length. They also highlighted that a segmentation technique using constant values of all variables, therefore resulting in very short segments, led to the poorest model.

The Highway Safety Manual [13] recommends the use of homogeneous segments with respect to a number of parameters, such as the AADT, number of lanes, lane width, shoulder width, shoulder type, curvature, driveway density, roadside hazard rating, median width and clear zone width. According to the manual there is no prescribed minimum segment length, however a minimum of 0.10 miles (0.16 km) is suggested. Fitzpatrick et al. [14] pointed out that in practice, this type of segmentation is not always easy to achieve as not all the variables are available. Koorey [15] arrived at similar conclusions, namely that variable-length road segments seem intuitively more useful than fixed-length segments, because of the mixed attributes contained in the latter. He added that this advantage is less when shorter lengths are used, and fixed-length segments are computationally easier to create from constant-interval raw data.

3. General overview of first-class main roads

3.1. Design characteristics

The Hungarian road network can be divided into two major categories: the national (31,833 km) and the municipal road network (approximately 170,000 km). The national road network can be further divided into two major subcategories: main roads consisting of motorways, express roads, first-class and second-class roads; and minor (or secondary) roads. In this paper our safety performance analysis has been done for the rural sections of the first-class main roads, therefore the following criteria and figures apply to this road category.

The length of the first-class rural main roads in Hungary is 1659 km, which is 29% of the total rural main road network and 8.6% of the total rural road network. Due to the continuous expansion of the limited access road network, almost 80% of the first-class main roads have a parallel motorway or expressway, so the traffic volume in this road category is moderate (the AADT on these roads is roughly 7500 vehicles/day on average).

A few selected criteria according to design standards are listed below:

- design speed is 90 km/h (in some cases 80 km/h depending on the terrain and land development circumstances),
- minimum curve radius must be at least 250 m (80 km/h) or 340 m (90 km/h),
- maximum gradient is 6%,
- minimum cross-slope is 2.5% and maximum superelevation is 7%,
- roadway width is 7.5 (7.0) m, lane width is 3.50 (3.25) m, shoulder width is 2.50 (2.0) m.

(Figures in parentheses are permitted under special circumstances.)

The general posted speed limit is 90 km/h, 60-70 km/h adjacent to junctions and in dangerous curves. There are a few sections with higher speed limits of 100 and 110 km/h. These sections are exceptions where either the alignment of an already existing road was eligible for a higher posted speed limit or newly built sections where a more generous design was followed.

3.2. Accident statistics

In Hungary according to recent statistics approximately two-thirds of the accidents involving fatalities and personal injuries occur inside built-up areas, whereas 60% of fatal accidents occur outside built-up areas, 20% of which happen on first-class main roads. There has been a major decrease in the number of accidents and victims in the recent years, and in the road category investigated this decrease is above the average.

The number of fatalities was 1232 on the entire road network in 2007 and plummeted to 641 by 2012, which is more than a 47% decrease. In case of the rural first-class main roads these results are slightly better, in the same time period the number of fatalities dropped by almost 56%. As far as the accident types are concerned, run-off road accidents represent 27%, rear-end collisions 20%, head-on collisions 19% and side impact collisions 13% of the total number of accidents.

4. Data collection and segmentation

As a first step of the data survey, the following data were gathered from the National Road Databank [16] for the entire length (1659 km):

- roadway width (pavement width)
- radius of horizontal curve
- shoulder width
- number of lanes
- traffic volume
- posted speed limit

This database is organized in such a way that if there is a change in any of the parameters there is a new record (a new segment begins). As a result, these segment lengths can be really short, in some cases just a few meters; therefore the segmentation technique itself was an important issue to deal with.

In our analysis the following segmentation technique was used (Figure 1):

- As this study focused on rural sections only, all segments inside built-up areas were taken out (marked 1 in Figure 1).
- Crashes within a 200 meter radius of intersections were taken out in order to avoid having intersection related crashes in the data (marked 3 in Figure 1). Not only major intersections, but all minor intersections and connecting streets with a paved surface were filtered out (marked 2 in Figure 1). Intersections with connecting agricultural roads were not excluded from the sample.

- Segments with more than two lanes (four-lane sections, sections with climbing lanes) were taken out.
- Although using a fixed segment length might be the most practical application, it disregards the opportunity that the segment length itself can be a predictor of accidents. Homogenous sections were formulated according to AADT, road width, shoulder width and horizontal curves and posted speed limit.
- As it is indicated elsewhere in the literature [15], [12] too short segments can be biased due to the inaccurate identification of accident locations, therefore segments shorter than 200 m were eliminated from the sample.

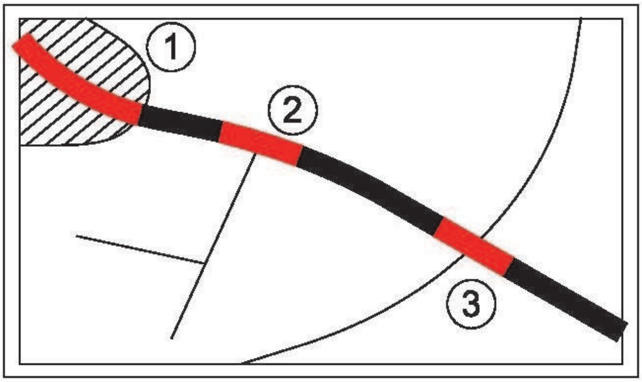

Figure 1. Segmentation technique

As a result of the segment delineation roughly 55% of the entire length (919 km of 1659 km) was used for further analysis. Although vertical alignment data were also collected, since the country has a relatively flat topography and because there were just a few sections with slopes this characteristic was omitted. Another variable that seemed to be an important predictor according to other researchers' work was access point density e.g. in [6]. In our case access points (driveways) were hardly present as our focus was on rural sections, where access points are very limited.

Six years of accident data (2007-2012) including fatal (fatality within 30 days as a result of the accident), serious (injury healing beyond 8 days) and light (recover within 8 days) injury accidents were gathered (altogether 2137 accidents). Property damage accidents were not taken into consideration.

5. Modeling

5.1. Regression technique and goodness of fit

Unlike Poisson models, negative binomial models assume that the conditional means are not equal to the conditional variances. Since the accident data were found to be significantly overdispersed relative to its mean, the Generalized Linear Modeling approach (GLM) with a negative binomial error structure was used. Modeling was done in the R statistical software [17]. Several statistical measures were used to assess the goodness of fit of the models.

The Pearson χ^2 can be calculated by means of the following Equation (1):

$$\text{Pearson}\ \chi^2 = \sum_{i=1}^{n} \frac{[y_i - \hat{E}(y_i)]^2}{Var(y_i)} \tag{1}$$

The Pearson χ^2 of the model must be less than a critical value of χ^2 distribution value that is based on the model's degrees of freedom and a level of significance of α.

The Scaled Deviance (SD) is defined as the likelihood ratio test statistic measuring twice the difference between the log likelihoods of the studied model and the full or saturated model. The full model has as many parameters as there are observations so that the model fits the data perfectly. Therefore, the full model, which possesses the maximum log likelihood achievable under the given data, provides a baseline for assessing the goodness-of-fit of an intermediate model with p parameters [18].

The Akaike's Information Criterion (AIC) can be used for model selection and applicable to compare models. The AIC value is calculated according to Equation (2):

$$AIC = -2\log L + 2k \tag{2}$$

where log L is the maximum log-likelihood of the fitted model, k is the number of parameters in the model. The lower the value of AIC, the better is the model data fit. Given a dataset, several competing models may be ranked according to their AIC, with the one having the lowest AIC being the best.

Cumulative residual analysis was also used to evaluate the model form. The residual is equal to the difference between the observed and estimated values of the dependent variable. Cumulative residuals were plotted versus AADT for each homogeneous section. The closer the curve stays to the x-axis, the more appropriate the model form is, and a curve that stays within 2 standard deviations is considered to be satisfactory [19].

Simple models of accident frequencies were estimated using five predictor variables: AADT, posted speed, curve, roadway width, shoulder width. Traffic volume is used as an exposure to accidents and therefore present in all models. The prediction equation estimated is given in Equation (3):

$$E(Y) = e^{\alpha_0} \cdot l \cdot AADT^{\alpha_1} \cdot e^{\sum_{j=1}^{m} \beta_j x_j} \tag{3}$$

where E(Y) is the expected accident count/year; l is the segment length (in kilometers), AADT is the Annual Average Daily Traffic (AADT) (vehicles/day); x_j is the any of m-additional variables; a_0, a_1, and β_j are the coefficients to be estimated. AADT is scaled to an annual value (multiplied by 365 and divided by 10^7) and included with an exponent, as it is known to have a nonlinear relationship with crash incidence [20]. Here the segment length is included without an exponent to normalize for the variability from one segment to another. However, later the segment length is also used as a predictor. Equation (3) is transformed logarithmically to (Equation 4):

$$\ln E(Y) = \alpha_0 + \ln(l) + \alpha_1 \ln AADT + \sum_{j=1}^{m} \beta_j x_j \tag{4}$$

5.2. Modeling results

As a result of the segmentation 1357 homogenous sections were formed. Table 1 and Table 2 show the variables used. AADT and length are used as continuous variables, whereas variables describing road geometry are clustered into categories for two reasons. Firstly, in many cases these characteristics change quite frequently: there are minor variations in the width of the cross-section elements within a short distance. From a road safety point of view, it can be doubted that for instance a few centimeter change in the width of the roadway would exert a significant influence on accident frequency. Secondly, had all these variations been taken into account it would have led to even shorter homogenous sections causing problems that already have been specified in the literature review section.

Table 1. Continuous variables and their descriptive statistics

Variable	Min	Max	Mean	Standard dev.
AADT	645	25438	6729	3165.53
Length (km)	0.200	6.245	0.677	0.619

Table 2. Categorical variables and their frequencies

Variable	Categories	Frequency
Horizontal curve	tangent	799
	< 750 m	84
	750 m ≤ x < 1500 m	151
	1500 m ≤ x < 3000 m	129
	≥ 3000 m	194
Roadway width	< 7 m	64
	7 m ≤ x ≤ 7.5 m	923
	> 7.5m	370
Shoulder width	< 2 m	692
	2 m ≤ x ≤ 2.5 m	642
	> 2.5m	23
Posted speed limit	< 90 km/h	49
	90 km/h	1267
	> 90 km/h	41

Categories for horizontal curves were defined to have roughly even frequencies and as curves with small radii were underrepresented in the final sample, curve categories in the lower range were not further divided. For roadway width, shoulder width and posted speed limit category boundaries were defined based on the deviation from a reference level for design standards.

The modeling was conducted in two steps. First, each variable was entered into the model alone to see which ones significantly affect accident frequency. Then a full model was built using all the significant predictors. From the one-variable models it turned out that shoulder width and posted speed limit are not significant. The former one is believed to influence accident frequency so that increasing shoulder width has been found to reduce the number of accidents, mostly injury accidents [21]. Table 3 shows the model results for the base model (AADT only) and the two one-variable models with horizontal curve and roadway width. Not surprisingly, AADT is a highly significant predictor of accidents in all models. It has an exponent less than 1, which is in accordance with other research suggesting that the relationship between accident frequency and AADT is non-linear, i.e. shows a decreasing slope with increasing AADT. Model 1 has the highest AIC value, likely because other predictor variables are not used.

Roadway width is a significant predictor in both categories (Model 2), suggesting that narrower pavement width (compared to the design standards) increases the expected number of accidents, whereas wider roadways slightly decreases it. For horizontal curve the lower curve categories have significant coefficients and the expected signs show that accidents are more likely to occur in these curves, to a greater extent in sharp ones (with a radius of less than 750 m) than in curves between 750 and 1500 m. It also seems that higher curve categories (over 1500 m) are not significantly different from the tangent sections (Model 3), therefore it was decided to combine them and run a new model (Model 4).

These two significant variables (roadway width and horizontal curve) were also used in a full model (Model 5) as shown in Table 4.

It was also analyzed whether length as a predictor (in addition to the length as an offset variable) has an exponent significantly different from 1. To do so, the 799 tangent sections were used and length was added as a predictor to the base model. From Table 5 one can conclude that the tangent length itself is a significant predictor and it has a coefficient of 0.10006, which is statistically significant. This means that for each one-unit increase in length, the expected log count of accidents will increase by 0.10006. This parameter is positive, which is in line with our expectation, i.e. the longer a tangent segment is, accident frequency will slightly increase most likely due to speeding and overtaking maneuvers.

Table 3. Model parameters for the base model and one-variable models

No.	Model	Categories	Coefficient	Standard error	p value	*k*	AIC	SD (DF)
1.	AADT	constant	0.14816	0.08703	***0.0887***	0.217	3984.8	1458 (1355)
		lnAADT	0.76252	0.05929	***<0.0001***			
2.	AADT + Roadway width	constant	0.23719	0.09592	***0.0134***	0.211	3979.6	1456 (1353)
		lnAADT	0.81115	0.06156	***<0.0001***			
		< 7 m	0.28672	0.12839	***0.0255***			
		7 m ≤ x ≤ 7.5 m	reference					
		> 7.5m	-0.11543	0.06215	***0.0633***			
3.	AADT + Curve	constant	0.13870	0.08840	0.1167	0.213	3983.8	1454 (1351)
		lnAADT	0.76938	0.05914	***<0.0001***			
		tangent	reference					
		< 750 m	0.30441	0.12974	***0.0190***			
		750 m ≤ x < 1500 m	0.17915	0.09832	***0.0684***			
		1500 m ≤ x < 3000 m	-0.03309	0.09936	0.7391			
		≥ 3000 m	-0.04004	0.08465	0.6362			
4.	AADT + Curve	constant	0.12972	0.08694	0.1357	0.213	3980.1	1454 (1353)
		lnAADT	0.76898	0.05913	***<0.0001***			
		tangent	reference					
		< 750 m	0.31281	0.12885	***0.0152***			
		750 m ≤ x < 1500 m	0.18754	0.09714	***0.0535***			

Table 4. Model parameters for the full model

No.	Model	Categories	Coefficient	Standard error	p value	*k*	AIC	SD (DF)
5.	AADT + Roadway width + Curve	constant	0.21916	0.09572	***0.0220***	0.208	3975.4	1452 (1351)
		lnAADT	0.81636	0.06136	***<0.0001***			
		< 7 m	0.26784	0.12824	***0.0367***			
		7 m ≤ x ≤ 7.5 m	reference					
		> 7.5m	-0.11735	0.06192	***0.0580***			
		tangent	reference					
		< 750 m	0.30278	0.12896	***0.0189***			
		750 m ≤ x < 1500 m	0.18441	0.09699	***0.0572***			

Table 5. Model parameters for tangent sections

No.	Model	Categories	Coefficient	Standard error	p value	*k*	AIC	SD (DF)
6.	AADT + Length	constant	-0.02950	0.10417	0.777003	0.141	2509.8	1221 (1119)
		lnAADT	0.73713	0.06912	***<0.0001***			
		length	0.10006	0.03007	***0.000875***			

Cumulative residuals were plotted versus AADT. Figure 2 shows an example for the base model. Although there are some fluctuations in the cumulative residuals, the model can be considered satisfactory.

It was also tested, whether adding a variable is overall significant or not. To determine if curve and roadway width are overall statistically significant, we can compare a model with and without them. Table 6 shows that the two degree-of-freedom chi-square tests indicates that both curve and roadway width are statistically significant predictors of the number of accidents.

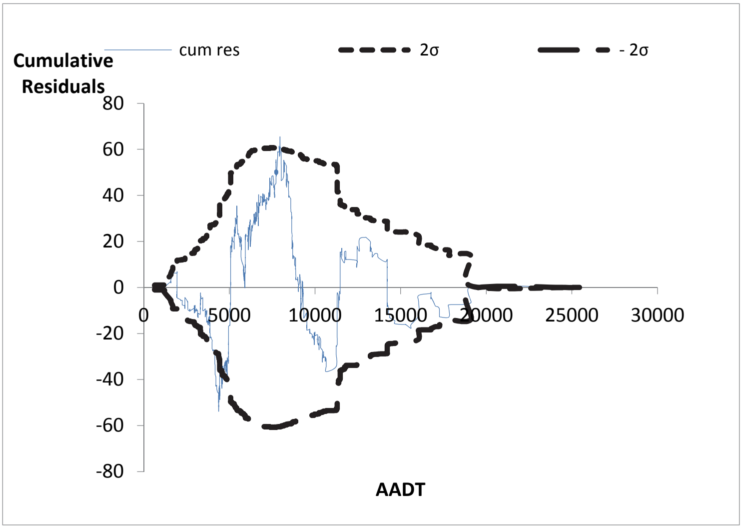

Figure 2. CURE plot of the base model.

Table 6. Likelihood ratio tests

Models	Resid. DF	2xlog-likelihood	DF	LR stat.	*p*
AADT	1355	-3978.837			
AADT + Curve	1351	-3969.845	4	8.992304	***0.061***
AADT	1355	-3978.837			
AADT + Roadway width	1353	-3969.637	2	9.20047	***0.010***

5.3. Numerical examples

To illustrate some of the models two numerical examples are given below. Consider the base model (Model 1) first. Here the coefficients given in Table 3 can be used according to the following Equation (5).

$$E(Y) = 1 \cdot AADT^{0.762} \cdot e^{0.148} \tag{5}$$

If on a road of this kind with a section length of 1 km the AADT is 10,000 vehicles per day, then the expected number of accidents per year will be 0.538 (Equation 6).

$$E(Y) = 1 \cdot \left(\frac{10{,}000*365}{10^7}\right)^{0.762} \cdot e^{0.148} = 0.538\ acc/year \tag{6}$$

For the full model (Model 6) the coefficients given in Table 4 can be used. Consider a 1 km long tangent section with a roadway width of 7.6 m and an AADT of 10,000 vehicles per day. The expected number of accidents per year will be 0.486 (Equation 7).

$$E(Y) = 1 \cdot \left(\frac{10{,}000*365}{10^7}\right)^{0.816} \cdot e^{0.219-0.117} = 0.486 \text{ acc/year} \quad (7)$$

6. Discussion and conclusions

This study focused on two-lane rural first-class main roads in Hungary with an objective to develop accident prediction models. The road network was segmented with a rigorous method and variables that were available and believed to potentially influence road safety were collected. Generalized Linear Modeling approach (GLM) assuming a negative binomial error structure was used. Expected injury accident frequency was predicted by exposure (AADT), length was used as an offset in all models. It was analyzed whether the variables roadway width, horizontal curve, shoulder width, posted speed limit significantly affect the accident frequency. It was also analyzed whether length as a predictor has an exponent significantly different from 1.

The base model only includes the AADT as an exposure and can be easily used by practitioners (auditors, road administration etc.) to conduct analyses such as network safety ranking. The coefficient of AADT (0.75~0.8) is in line with the international research results: Cafiso et al. [6] for instance found in their best performing models that for two-lane rural highways this value is 0.62 ~ 0.75. The full model with two more variables (horizontal curve and roadway width) is a more complex one, but can be still used in practice as the predictors used are relatively easy to collect. Also in the full model the variables showed reasonable coefficients and signs. Roadway widths narrower than what the design standards prescribe tend to increase ($e^{0.26784} = 1.31$), whereas wider roadways slightly decrease the number of accidents ($e^{-0.11735} = 0.89$). Curves below 1500 m increase accident frequency with a smaller value for radii between 750 m and 1500 m ($e^{0.18441} = 1.20$) and with a higher value in the lower range below 750 m ($e^{0.30278} = 1.35$). Our conclusion that accident frequency tends to rise in a non-linear fashion as the segment length increases, does also comply with international research results.

Here it should be noted that according to the international experience there are many more variables that can be used to calibrate sophisticated models, which have their own advantages and disadvantages. An accident prediction model with more variables can help us to better understand how these factors influence and describe road safety. However, it has been already pointed out by for instance Sawalha and Sayed [5] that many researchers find it tempting to include too many variables in a model. Such a model is not stable and will perform poorly when applied to a new sample. In this research our intention was to come up with simpler models that might help to improve road safety management. It is considered to be as a starting point to do similar and even more detailed studies for other road categories.

7. Acknowledgments

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Speech Intelligibility and Subjective Evaluation of Music Playback of Sound Transducers with Glass and Wooden Membrane

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Abstract: Novel state-of-the-art designer loudspeaker solutions offer "invisible audio" applications by applying a relatively small transducer onto glass or wooden plates, surfaces such as windows, tables, doors etc. Although manufacturers promise high quality transmission and good technical parameters, reliable measurement data do not exist. In our former evaluation, the SolidDrive system with glass membrane of different shapes, sizes, fixation methods was analyzed using vibration analysis, acoustic measurements and numerical simulations in COMSOL/FEM. This paper presents experimental results of standardized speech intelligibility measurements as well as subjective evaluation of the system.

Keywords: speech intelligibility, subjective evaluation, STI, sound transducer

1. Introduction

Loudspeakers in general are based on the same electromagnetic principle. A light weight membrane is moved by the coil oscillating in the magnetic field driven by the electric current. In order to avoid acoustic short circuits and to extend the frequency range, speakers are built into cabinets (closed, bass-reflex, loaded horn etc.). Newly designed solutions offer unconventional types of sound reproduction, often called "invisible audio" [1-3]. In this case, sound transducers of the same electromagnetic principle are manufactured and sold as stand-alone exciters without membranes. They can be attached to various surfaces, usually by gluing them on glass plates or screwing them on to wood, such as windows, tables, doors etc. This technique allows unique installations and applications by avoiding the need for large cabinets and by integrating the real sound source into or onto various equipment already installed in the environment. However, relatively low signal pressure levels (sensitivity), limited and unbalanced frequency response and high costs restrict their applicability to special needs, designer solutions and commercial purposes. Furthermore, manufacturers provide limited access to technical information and measurement results of technical parameters in their commercial literature, thus, it is difficult to decide whether a particular device is able to meet a customer's needs. The goal of our investigation was to test a commercially available transducer applied to various surfaces. This included vibro-acoustic measurements using multi-channel accelerometers, measurements of acoustic parameters and comparative evaluation based numerical simulation using FEM models in COMSOL [4,5]. As mentioned, there is only very limited technical information about the system. Most of the parameters cannot be measured without a membrane being attached to the transducer, so the general description of only the transducer of such systems – e.g. about frequency response or directional characteristics – does not provide reliably useful information. Acoustic and vibration measurements are time- and cost-expensive. Therefore, numerical simulations and FEM-based modelling seem to be an adequate alternative for estimating some of the technical parameters for real-life applications: the effect of membranes of different shapes, mass, material, fixing methods etc. can be evaluated without actual measurements.

The rest of the paper is organized as follows. Section 2 gives a short overview about the measurement setup including the objective and the subjective tests. Furthermore, the basic speech intelligibility tests are introduced for selection. Section 3 presents the results of the MRT, SIL and music transmission tests. Section 4 discusses the findings and future works will be highlighted in Section 5.

2. Measurement setups

2.1. Objective evaluation and former results

In our former study, in order to test the simulation method's reliability and the technical parameters in comparison the transducer was applied to various glass surfaces for vibration and acoustic measurements in parallel with a corresponding FEM simulation. Based on these studies, recommendations were given for applications comparing benefits and disadvantages [6-7]. These can be summarized as follows:

- Numerical simulation supports real measurement results, thus, estimations based on FEM modelling can be an alternative solution to measurements.
- Frequency response from 200 Hz – 10 kHz can be realized with almost plane wave propagation.
- The relatively low sensitivity limits the range of propagation and the SPL (nonlinear distortion).
- Placement of the transducer on the plate and fixation methods of the plane do not bias measurement results significantly.
- The system is not able to replace conventional loudspeaker setups if high quality playback is needed.

Figure 1 and 2 shows the SD1g transducer alone and applied on a glass membrane for the measurements.

Figure 1. The SolidDrive SD1g transducer

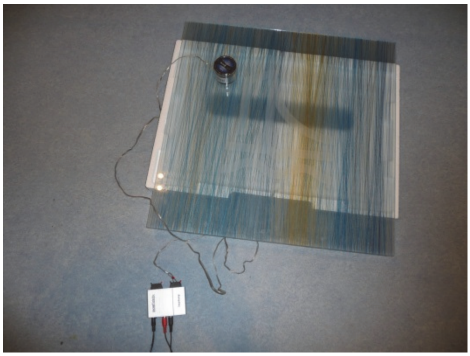

Figure 2. Initial setup for the transducer fixed on a glass plate and with a digital audio amplifier.

2.2. Subjective evaluation

Objective measures can predict musical and speech transmission quality of the system. Still, subjective evaluation of playback systems play a significant role in customers' judgments and selection criteria. The final step of this survey included the following evaluations:

- measurement of speech intelligibility (SI) based on standardized methods for German language in listening tests,
- estimation of the Speech Transmission Index (STI) based on Speech Interference Level (SIL) measurement and
- subjective evaluation of music playback with and without an additional subwoofer.

For the listening tests the following measurement setup was installed in an anechoic chamber. A formerly introduced glass plate of 76*76*0.8 cm (see Fig.2.) was placed on rubber legs in front of the listener. Simultaneously, another exciter of the same model was fixed by screws under the surface of a wooden table of 55*130*2.5 cm. A Yamaha DSP-A2 audio amplifier and a studio monitor loudspeaker for reference were used. Subjects were sitting on a comfortable chair at the table facing the glass plate and a tilted computer screen. They could respond via the screen by clicking with a wireless mouse. Figure 3 shows the installation. Signal level at the listening position was set to be equal for all three radiators at 65dB(A) L_{eq} using white noise. The level could be adjusted in 1 dB steps. 12 female and 20 male subjects participated between 16 and 35 years (mean 24) in 30-minute sessions.

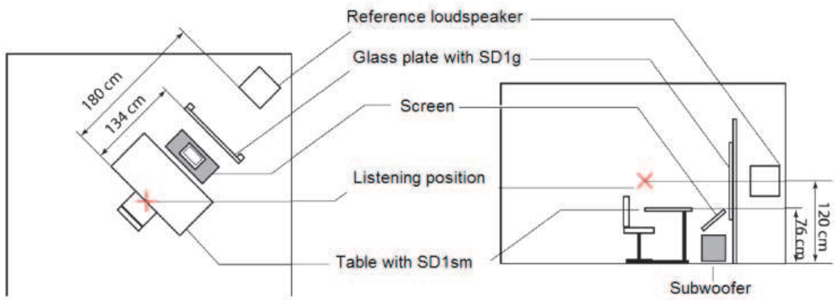

Figure 3. Schematic figure of the setup from above (left) and from the side (right).

For the music test, an additional closed-type subwoofer of 15 litres volume was installed under the table that could be switched on and off by the subject. One session included three one-minute tracks with 10 seconds of intermission. All three tracks were played back for every listener twice (on glass and on wood). These three tracks were selected to represent different bass content, characteristics and tonality of female voices.

Track1: Lena Mayer Landrut – "I like to bang my head" (bass and voice in balance)

Track2: Katie Melua – "Spider's web" (more voice)

Track3: Drum/percussion recording (more bass, no voice)

Figure 4 shows the transfer characteristics of the wooden table with and without subwoofer support. As expected, the low frequency region between 30-80 Hz can be amplified by the subwoofer.

2.3. Speech Intelligibility

Speech intelligibility (SI) can be measured with different methods, usually in the frame of room acoustics and clinical audiology [8-10]. SI is a number between 0-100% and it is different for one syllable, multiple syllable words or sentences. The quality of the speech signal, transmission, subject group etc. also influence the results. Subjective tests can be 'open' where perceived words have to be repeated by the listener or 'closed' where listeners select from a collection of possibilities (forced choice). Table 1 shows comparative summary of different measurement methods corresponding to subjective levels on the left. In medical audiology only subjective testing methods are used targeting the determination of the speech intelligibility threshold, that is, the SPL (dB) where intelligibility is 50%.

Table 1. Comparison of different SI measurement methods (DIN EN ISO 9921-2003). Corresponding to the best STI level, a 98% rate of a MRT is needed.

Classification	Sentence (%)	Words, MRT (%)	CVC Words (no meaning) (%)	STI	SIL (dB)
excellent	100	> 98	> 81	> 0,75	21
good	100	93-98	70-81	0,60-0,75	15-21
acceptable	100	80-93	53-70	0,45-0,60	10-15
poor	70-100	60-80	32-53	0,30-0,45	3-10
insufficient	< 70	< 60	< 31	< 0,30	< 3

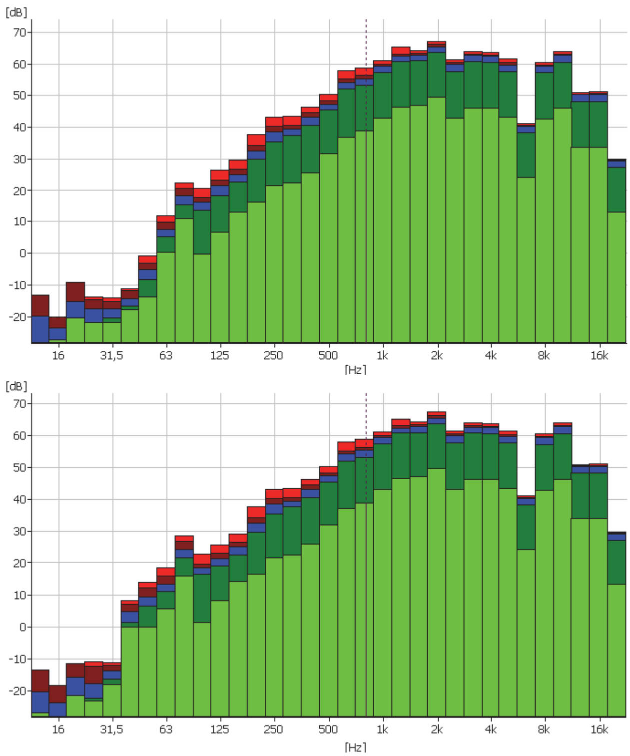

Figure 4. Transfer characteristics of the exciter fixed on the wooden table without (upper) and with subwoofer support (lower). The frequency range between 30-80 Hz is elevated.

Several standardized tests exist for subjective measurement for German language, for example the *Freiburger* test uses 20 one-syllable words and 10 lists containing 10 numbers [11,12]; the *Marburger* test for children [13,14]; the *Göttinger* test with meaningful sentences created from 5 words [15,16] or the *Oldenburger* test with meaningless sentences [16-18]. Based on different considerations and limitations of the measurement system and procedure the so called *Modified Rhyme Test (MRT)* was selected for the subjective evaluation [19,20]. It uses six-word lists of rhyming or similar-sounding monosyllabic words. Each word is constructed from a consonant-vowel-consonant (CVC) sound sequence, and the six words in each list differ only in the initial, the final consonant sound or the vowel. Listeners are shown a six-word list and then asked to identify which of the six was spoken. A carrier sentence can be also used. MRT test results indicate errors in discrimination of both initial and final consonant sounds. Listener responses can be scored as (1) the number of words heard correctly, (2) the number of words heard incorrectly or (3) the frequency of particular confusions of consonant sounds. Examples for German, English and Hungarian MRT lists can be seen in the appendix. In our test, the German database was used assisted by a user interface from the University of BTU Cottbus that is free to download [21]. Figure 5 shows a screen-shot of the application. For recording the speech database, all words were read seven times by a native German male speaker and the best examples were selected for the test after normalizing the levels. Every subject received a 24-word list four times, using glass and wood, and with a low and a high presentation level respectively.

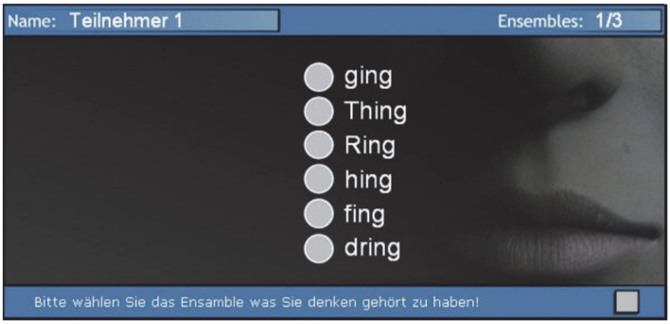

Figure 5: Screenshot of the Simasoft application [21]. The application has also built-in statistics for SI and weighted SI.

There is also a language independent objective measurement for speech intelligibility estimation, called Speech Transmission Index (STI) and Speech Interference Level (SIL) [22-28]. For the STI measurement, loudspeakers and microphones are needed. Excitation signals contain seven octaveband noises between 125 Hz and 8000 Hz, amplitude modulated by a modulation signal of 0,63-12,5 Hz. The STI is recommended if the transmission properties of the playback system and background noise, echo have to be taken in account. In case of room reverberation time less than one second, the STI can be calculated from the measured SIL as follows:

$$4\ \mathrm{STI} = (0{,}1\ \mathrm{SIL} + 0{,}9) \tag{1}$$

For the SIL measurement the same pre-recorded speech signals were used. During the measurement, a presentation level varying from 20 to 65 dB was set and the resulting STI estimation was plotted directly. Due to the anechoic environment in our measurement setup, the STI could be calculated based on the SIL measurement.

3. Results

3.1. Modified Rhyme Test

For the MRT test, the German wordlist was selected (see Appendix). In contrast to the English test and other wordlists, this contains 5-word sub-lists. In order to reduce the probability of guessing in case of misunderstanding, the sixth possibility was set to “no answer”. In the case of 6-word lists, subjects click an answer if they are not sure with a probability of 1/6. Thus, results are usually re-calculated and weighted using different methods. In our case, this was avoided by introducing this sixth possibility. For control purposes, a short white noise signal was also played back randomly in the tests. During the test 1691 false answers were recorded and from this subjects selected “no answer” only 686 times. On the other hand, if the white noise sample was used, subjects never clicked any of the word options, so white noise was really easy to detect.

Table 2 shows mean values and standard deviations for all three radiators for the initial, final consonant and the vowel. The last column shows the weighted (corrected) values. The relatively large standard deviation is due to the short wordlist and low presentation level.

Table 2. Mean and STDV values for all three radiators for high presentation level (top) where intelligibility is between 50-100% and for low presentation level (bottom) where intelligibility is lower than 50%. LS is studio reference monitor, SDg is a glass and SDh, a wooden membrane.

	SI (%)	initial	middle	final	Weighted SI
LS	Mean	55,56	84,58	64,61	68,25
SDg		67,35	83,91	67,84	73,04
SDh		66,74	88,94	68,64	74,77
LS	Stdv	22,57	18,45	20,66	40,80
SDg		19,23	18,53	18,85	10,49
SDh		18,46	11,24	18,49	10,21
LS	Mean	17,55	47,93	26,26	30,58
SDg		9,06	44,30	19,81	24,39
SDh		23,03	42,60	29,29	38,24
LS	Stdv	14,23	21,50	17,59	11,95
SDg		14,56	28,32	17,67	13,25
SDh		22,70	23,15	16,48	14,20

If the presentation level is high enough for the weighted SI to be greater than 50%, the vowel component can be recognized easily. Furthermore, there is no significant difference between the initial and final consonants. Comparing weighted SI values of 73,04% with 74,77% there is no benefit for any of the SD transducers and the results are only slightly below the results of the studio reference loudspeaker. If presentation level is low and SI is below 50%, differences become greater. Although the vowel can be recognized the best, rates are much lower than previously. Furthermore, the final consonant can be recognized better than the initial one, especially with glass. The summarized comparison shows a much better performance for the weighted SI using wood (38,24%) than glass (24,39%). Wood was even superior to the reference loudspeaker.

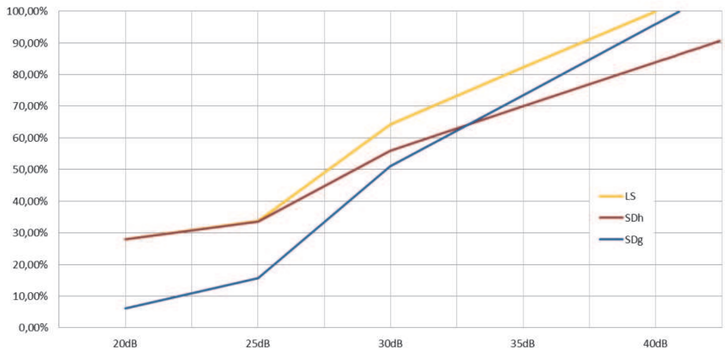

Figure 6. SI as function of presentation level of the reference loudspeaker (yellow), transducer on glass (blue) and transducer on wood (red).

Using all radiators in the MRT, the 98% intelligibility rate could be achieved using wood as membrane at 45 dB(A) SPL and using glass at 41 dB(A) indicating no significant difference between these mediums (Fig. 6).

3.2. SIL measurement

During the objective measurement, the SIL (and thus, the STI) increases rapidly as SPL increases from 20 dB(A) to 65 dB(A). An STI of 0,75 is reached at 47 dB(A).

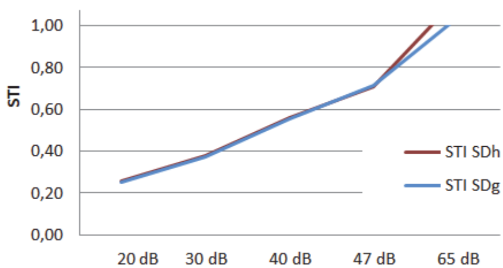

Figure 7. Curves of SLI transformed to STI values as function of presentation level.

At higher presentation levels, wood performed somewhat better than glass. As expected, standard deviations are higher at lower signal levels. Both SIL and calculated STI increase rapidly above 30 dB(A). These results are in agreement with the MRT results.

3.3. Music transmission

The evaluation of overall music transmission quality was based on a ranking in five steps where 1 point corresponds to "insufficient", 2 to "poor", 3 to "acceptable", 4 to "good" and 5 to "excellent". Bass transmission, however, used only three steps from 1 to 3 points.

In overall quality based on all tracks, glass was superior to wood, being "above average" for about 70% of the listeners. The same evaluation for wood showed a result of 45% and "average" was selected most frequently.

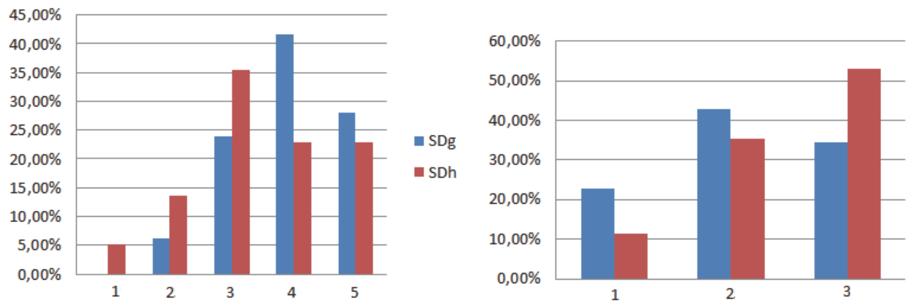

Figure 8. Relative frequency of answers for overall quality (left) and for bass transmission (right) for glass (blue) and wood (red).

In bass quality wood was superior to glass without subwoofer support. Wood was classified as excellent for about 52% as long glass was only for 33%. 45% of the listeners would suggest subwoofer extension in case of wood, and 60% would suggest it in case of glass. Asking an informal question, users suggested they would even pay extra money to have subwoofer extension. Results depend on the tracks: more bass content in the music (track3) reveals the subjective need for subwoofer support.

4. Discussion

Speech intelligibility tests usually target subjects instead of equipment. This means, one subject will be evaluated using different presentation methods of speech samples, so focus is on the abilities of the subject. In our case the opposite happens, the sound transmission quality of a transducer was evaluated by several subjects for whether or not it is able to produce good speech and music transmission.

In the subjective MRT wood performed better than glass if the signal level (thus, the signal-to-noise ratio) was low. With an appropriate signal level, both performed almost equally as well and the studio reference loudspeaker in the anechoic environment. The 98% SI could be reached around 40-45 dB signal level and also the estimated STI for excellent values was around 47 dB. In summary, for speech transmission, a signal-to-noise ratio greater than 50 dB would result in a sufficient SI supporting the manufacturer's claim.

There was also no significant difference between the membranes during music playback. Although they produce relatively low sound pressure levels and they cannot overperform high quality loudspeakers, it is an acceptable option for short distance radiation, such as sitting at a table or near to a window. Using a subwoofer extension may increase the subjective impression further.

It was interesting that subjects reported to be able to detect the location of the transducer on the vibrating plate. They could actually hear where the transducer was placed (screwed) on the table from below. However, this fact did not influence their judgments.

Although not used in the current evaluation, the Hungarian word list was developed based on the German test. In order to represent the relative frequency of the consonants and vowels related to Hungarian language word lists shorter than 5 words are also included. A test using this list, however, would need different presentation and evaluation methods as it differs from the usual MRT lists.

Beside the numerous advantages of this loudspeaker system, some disadvantages have to be listed as well. Independent of the membrane's material we get high costs, low sound pressure levels, fluctuating transfer function and low transmission below 200 Hz and above 12 kHz. Although not measured directly, if the radiated sound was set to "comfortably loud", non-linear distortions of the transducer and the vibrating surface become audible. The vibrating transducer can be easily overdriven. Furthermore, installation of multiple transducers on the same surface can have unexpected effects due to interferences, standing waves etc., and stereo or multi-channel transmission may not be applicable.

5. Future work

Future work includes comparative evaluation of intelligibility of German and Hungarian speech samples. It is expected that using the same testing method no significant difference will appear, that is, databases of results can be merged and evaluated combined, furthermore, that the Hungarian corpus for this test can be used in other similar tests in the future. The sound data base containing these words will be recorded by a native Hungarian speaker as high quality mono sound samples.

As an informal study, future work includes the system installed for a longer time period on a shop-window in a crowded pedestrian zone in the city center. The window will be used as membrane "speaking" to pedestrians and customers, airing some kind of commercial. Shop assistants and customers will be interviewed about this potential solution.

6. Conclusion

Transmission quality of sound transducers applied on wooden and glass membranes was evaluated based on objective and subjective measures. The objective measurement included a SIL measurement installed in the anechoic chamber. From this, STI estimation could be made resulting in a satisfactory value of greater than 0,75 in case of a presentation level of more than 47 dB. The subjective evaluation using the modified rhyme test in German language supported these results as 98% of SI could be reached at 41 dB and 45 dB respectively. It can be concluded that an overall signal presentation level about 45-50 dB greater than background noise could be sufficient in non anechoic environments as well. This signal-to-noise ratio can be achieved in indoor environments.

Using three different one-minute music samples of different genres and bass content, both membranes were judged as average or better for music transmission even without an additional subwoofer support. Although glass performed somewhat better in overall music quality than wood, focusing on bass transmission, wood was better. A subwoofer extension for a better bass quality is suggested.

This study was aimed at a subjective evaluation that extended former objective acoustic and vibration measurements and numerical simulations. Summarized results support the manufacturer's recommendations and measurement results by offering alternative sound production solution if "invisible audio" issues are present.

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Appendix

Examples of the German, English and Hungarian rhyme test corpus can be found in Table 3-7. The Hungarian version was created based on similarly to the German version according to the Hungarian speech databases and distribution values of the vocals [29]. Because some rare vocals could not be represented in equal number to the most frequent ones, some lines and examples may contain fewer words than the German version. This Hungarian word list can be used as a test material for further measurements and test.

Table 3. Wordlist of the German 'WAKO' one-syllable rhyme test used for the tests [29]

Nr.	Anlautteil				
1	Sinn	hin	bin	Zinn	Kinn
2	fiel	schiel	Ziel	Kiel	Nil
3	doch	poch	noch	Joch	Loch
4	sehn	den	Gen	zehn	lehn
5	wisch	Fisch	Tisch	zisch	misch
6	Saum	Schaum	Zaum	kaum	Raum
7	wir	vier	Pier	Tier	mir
8	sahn	Bahn	Zahn	mahn	Lahn
9	sät	tät	näht	jät	rät
10	hieß	dies	gies	nies	ließ
11	sehr	Teer	zehr	Meer	leer
12	Wut	gut	Nut	Ruth	lud
13	Tag	mag	nag	jag	rag
14	vor	gor	Tor	Moor	Rohr
15	weil	Seil	peil	Teil	Zeil
16	Haus	Gauß	paus	raus	Laus
17	Schein	dein	mein	nein	rein
18	war	gar	Kar	Jahr	rar
19	weiß	beiß	Geiß	Reis	leis
20	fad	bat	Tat	Naht	Rat
21	Fund	Schund	Hund	Mund	rund
22	vorn	Born	Dorn	Zorn	Korn
23	wumm	summ	dumm	Mumm	Rum
24	Sicht	dicht	Gicht	nicht	Licht
25	Haff	baff	gaff	Kaff	raff
26	Schuß	Bus	Guß	Kuß	Nuß
27	sind	find	schind	bind	Rind
28	wenn	Fenn	denn	nenn	renn
29	säng	häng	peng	meng	läng
30	was	Haß	das	Paß	naß
31	Fest	best	Test	Nest	Rest
32	wann	dann	Tann	Mann	ran
33	Wacht	dacht	Macht	Nacht	Jacht

Nr.	Vokalteil				
34	schief	Schiff	Schaf	schaff	schuf
35	Mehl	Mal	Moll	Mull	Müll
36	Wild	Wald	wählt	Welt	wühlt
37	Wind	Wand	wohnt	wund	wähnt
38	bis	Baß	Bus	büß	bös
39	seht	Saat	satt	sät	Süd
40	hin	Hahn	Hohn	Huhn	höhn
41	wieg	Weg	wag	wog	wäg
42	hier	Heer	Haar	Herr	hör
43	Kien	Kinn	Kahn	kenn	kühn
44	dir	der	Dur	dürr	dörr
45	biet	bitt	Beet	Bett	böt
46	lieg	leg	lag	Leck	lüg
47	viel	fehl	Fall	Fell	füll
48	Ritt	Reet	rot	rät	rett
49	Sinn	sehn	sann	Sohn	Senn
50	Stiel	still	Stahl	Stall	stell
51	Trieb	Trip	trapp	Trupp	trüb
52	back	Bock	bück	bög	Böck
53	schiel	Schill	Schall	scholl	schäl
54	Mist	Most	mußt	meßt	müßt
55	Rist	Rost	Rest	rüst	röst
56	trief	triff	traf	troff	Treff
57	sind	sehnt	Sand	Sund	send
58	Hieb	heb	hob	Hub	hupp
	Auslautteil				
59	reif	reib	reit	Reim	Rhein
60	Muff	muß	Mumm	murr	Mull
61	Mief	mies	miet	mim	mir
62	Weg	wem	wen	Wehr	web
63	nach	Naab	Naht	nag	nahm
64	Ruf	Ruß	Ruch	Ruhm	Ruhr
65	rauf	raus	Rauch	Raub	Raum
66	Los	Lob	Lot	log	Lohn
67	des	Depp	Deck	dämm	denn
68	Saat	sag	sahn	Saar	Saal
69	schief	schieß	schied	schien	schiel
70	Graf	grab	Grat	Gram	Gral
71	weiß	Weib	weit	Wein	weil
72	Hof	hoch	hob	Hohn	hohl

Table 4. The 300 Stimulus Words of the MRT

1		went		sent		bent		dent		tent		rent
2		hold		cold		told		fold		sold		gold
3		pat		pad		pan		path		pack		pass
4		lane		lay		late		lake		lace		lame
5		kit		bit		fit		hit		wit		sit
6		must		bust		gust		rust		dust		just
7		teak		team		teal		teach		tear		tease
8		din		dill		dim		dig		dip		did
9		bed		led		fed		red		wed		shed
10		pin		sin		tin		fin		din		win
11		dug		dung		duck		dud		dub		dun
12		sum		sun		sung		sup		sub		sud
13		seep		seen		seethe		seek		seem		seed
14		not		tot		got		pot		hot		lot
15		vest		test		rest		best		west		nest
16		pig		pill		pin		pip		pit		pick
17		back		bath		bad		bass		bat		ban
18		way		may		say		pay		day		gay
19		pig		big		dig		wig		rig		fig
20		pale		pace		page		pane		pay		pave
21		cane		case		cape		cake		came		cave
22		shop		mop		cop		top		hop		pop
23		coil		oil		soil		toil		boil		foil
24		tan		tang		tap		tack		tam		tab
25		fit		fib		fizz		fill		fig		fin
26		same		name		game		tame		came		fame
27		peel		reel		feel		eel		keel		heel
28		hark		dark		mark		bark		park		lark
29		heave		hear		heat		heal		heap		heath
30		cup		cut		cud		cuff		cuss		cud
31		thaw		law		raw		paw		jaw		saw
32		pen		hen		men		then		den		ten
33		puff		puck		pub		pus		pup		pun
34		bean		beach		beat		beak		bead		beam
35		heat		neat		feat		seat		meat		beat
36		dip		sip		hip		tip		lip		rip
37		kill		kin		kit		kick		king		kid
38		hang		sang		bang		rang		fang		gang
39		took		cook		look		hook		shook		book
40		mass		math		map		mat		man		mad
41		ray		raze		rate		rave		rake		race
42		save		same		sale		sane		sake		safe
43		fill		kill		will		hill		till		bill
44		sill		sick		sip		sing		sit		sin
45		bale		gale		sale		tale		pale		male
46		wick		sick		kick		lick		pick		tick
47		peace		peas		peak		peach		peat		peal
48		bun		bus		but		bug		buck		buff
49		sag		sat		sass		sack		sad		sap
50		fun		sun		bun		gun		run		nun

Table 5. The Hungarian corpus for MRT – 1

1.	bak	rak	lak	jak	csak	(vak, nyak)
2.	far	kar	mar	tar	var	
3.	bab	hab	rab	zab		(tab)
4.	fagy	hagy	nagy	vagy	zagy	
5.	dúl	gyúl	múl	nyúl	túl	(fúl)
6.	bér	dér	fér	kér	mér	(vér)
7.	bor	kor	por	sor	szor	(tor)
8.	bél	cél	dél	fél	szél	(gél, kél, nyél, tél, vél)
9.	bőr	szőr	Győr	tőr	kőr	(csőr)
10.	bal	dal	fal	hal	nyal	
11.	bír	hír	nyír	pír	sír	(szír, zsír)
12.	bók	csók	jók	pók	szók	
13.	hús	bús	dús	szús		(kús)
14.	búr	dúr	fúr	szúr	túr	(zsúr)
15.	bár	cár	már	kár	nyár	(gyár, jár, pár, sár, tár, vár)
16.	bál	tál	sál	hál	nyál	
17.	csűr	kűr	szűr	tűr	zűr	
18.	fát	gát	lát	hát	tát	
19.	búg	húg	lúg	rúg	súg	(zúg)
20.	cser	per	ver	mer	nyer	(szer, jer)
21.	kel	lel	jel	nyel		
22.	kell	mell	Tell	Bell		
23.	hall	vall	gall			
24.	szenny	genny	menny	kenj	menj	
25.	matt	katt	patt	csatt	jatt	
26.	sakk	pakk	cakk	makk	lakk	(fakk, vakk)

Table 6. The Hungarian corpus for MRT – 2

1.	bak	buk	bók	bök	búk	
2.	lap	láp	lep	lép	lop	
3.	kar	kár	kér	kűr	kór	(kör, kőr)
4.	mar	már	mér	mer	mór	
5.	tar	tár	tor	tér	tűr	(tőr)
6.	bár	bér	bor	bór	bőr	
7.	tál	tél	tol	tel	túl	
8.	fal	fel	fél	fúl	fül	
9.	pár	por	per	pír	pér	
10.	rag	rág	rúg	rég	rög	
11.	var	vér	ver	vár		
12.	vaj	váj	vej			

Table 7. The Hungarian corpus for MRT – 3

1.	báb	báj	bál	bán	bár	
2.	gél	gém	gén	gép	géz	
3.	fém	fél	fék	fér	fény	
4.	táv	tán	tár	tál	táp	
5.	tény	tér	tép	tét	tél	
6.	szem	szel	szer	szesz	szenny	
7.	len	les	lesz	lep	lel	(leg, LED)
8.	góc	gój	gól	gót	gór	
9.	szám	szár	száz	szák	száj	(szád, szász)
10.	mák	már	más	máz	máj	(mál)
11.	rám	rád	rác	rák	ráz	(rát, rág)
12.	csak	csal	csat	csap	csaj	
13.	dúc	dúl	dúr	dús		
14.	hab	had	haj	hal	has	
15.	jel	jem	jen	jer	jegy	
16.	kéj	kél	kém	kén	kér	
17.	pék	pép	Pér	pénz	Pécs	
18.	rég	rém	rés	rész	rét	(rév, réz)
19.	vad	vaj	vak	van	var	(vas)
20.	kés	kéz	kép	kész	két	
21.	csel	csen	cser	csepp		

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Abstract: In the paper a heuristic approach is introduced aimed first of all to model supply chains which behavior may depend on many parameters and their analytic description is many times problematic. The proposed approach is based on identifying local vertex models in the parameter space in form of multilayer perceptrons (MLPs). The parameter varying neural system might then be modeled as the convex combination of the identified vertex systems. Depending on the dimension of the parameter space the number of identified vertex models might be large, therefore they reduction is crucial. In order to achieve this goal, first the vertex systems are transformed into HOSVD based polytopic representation followed by complexity reduction.

Keywords: MLP, LPV, modeling, logistics, HOSVD

1. Introduction

In supply chains one can observe that the information demand varies between its certain stages (see 1), i.e. the effective demand forecasting may be crucial from their performance point of view [11][8]. Usually the first stage is represented by the supplier and the last one by the customer. In-between there may be numerous stages, e.g. warehouse, retailer, etc. [14], which behavior might depend on many parameters thus the input-output characteristics of the whole system may reflect strong non-linearity. Each stage may further be divided into sub-stages making the modelling task more difficult. For designing control systems of such logistical processes the service strategy and operational algorithm of the given system must be known. Service strategy is the set of procedures, rules that determine the direction, feature and measure of state transformation of the system and its sub-systems for all possible situations and conditions [2].

Various models have already been developed for supply chains [13][9]. Most of these models are based on the fuzzy set theory, which represents the basis of many models where the handling of the imprecision is of key importance [10]. Various publications are

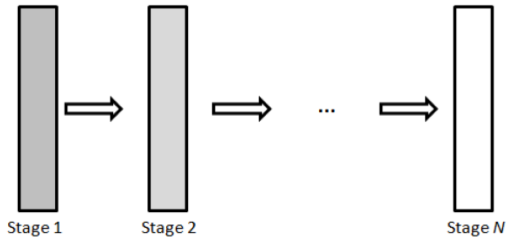

Figure 1. Illustration of state transitions between certain stages of loading system [2]

dealing with the performance of supply chains in connection with the forecasting models [11][12][7]. Most of these techniques belong to the category of heuristic or analytical approaches. Loading systems as subsystems of supply chains may efficiently be modelled by heuristic approaches.

The main contribution of the proposed approach is to identify local heuristic models over a hyper-rectangular grid in the parameter space, reduce their number and blend them together according to the actual value of parameter vector. Since the identification of local models is usually based on noisy measurements and depending on the complexity of the system the number of models to be identified might be significant it is adequate to represent the local models in such a framework in which the number of these models as well as the noise can be reduced efficiently. In other words, we are searching for such a reduced set of MLP models which convex combination approximates the behavior of the system effectively. Similar approaches are used to control non-linear systems on the basis of linear control theories [4], however in our case the models are represented by local MLPs.

The paper is organized as follows: Section 2 gives a brief description of loading systems and their models including the loading processes, in Section 3 a possible approach is described where the loading system is considered as a parameter varying system modeled by locally identified neural networks. Finally Section 4 reports conclusions.

2. Models of Loading Systems

In a loading system numerous state transitions may occur. Since the behavior of such a system is nonlinear and depends on many parameters it can be embedded into an LPV framework and modeled by the above mentioned technique, as well. Numerous measurements are needed to identify the local models in the parameter space. Fig. 3 illustrates the schematic model of the technical and technological process by a complex loading system. There are n types of goods loaded, unloaded and temporary stored in the

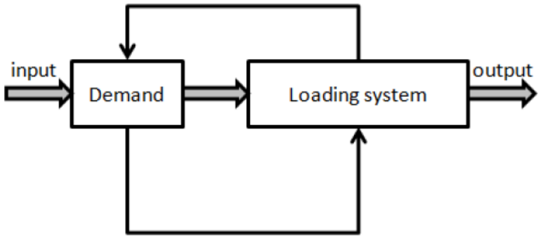

Figure 2. Illustration of the general stochastic demand- adaptive handling system [2]

analysed system. The states of processes running in the system are shown as circles and rectangles, the transitions are represented by directional arrows [2].

In case of stochastic loading systems linking two stochastic processes is causeless to suppose the independency of onset and service, especially the system contains intermittent-duty, mobil, material handling machines. Models developed on that basis are suitable for approximate disquisitions only. In case of a loading system the demand process influences the service process, controls it, accelerates or slows down the executive process. Those loading systems where the input influences the system's processes are referred as adaptive loading systems. Depending on the type of performed changes in the system three cases can be distinguished, namely the spontaneous homothroph and the heterotroph adaptivity. The spontaneous adaptivity is related to intensity changes of services, the homotroph adaptivity considers the number of elements in the system while the heterothroph adaptivity is related to functional change of elements [1],[2].

type of change this case the service intensity, the number of elements in the system

2.0.1. The Input of the Loading System

- LI - Loaded transportation vehicle arriving
- EI - Empty transportation vehicle.

2.0.2. Loading processes

- WU - Transportation vehicle waiting for unloading
- WL - Transportation vehicle waiting for loading
- TS - Temporary storing or warehouse
- SIU - Interrupted state of unloading

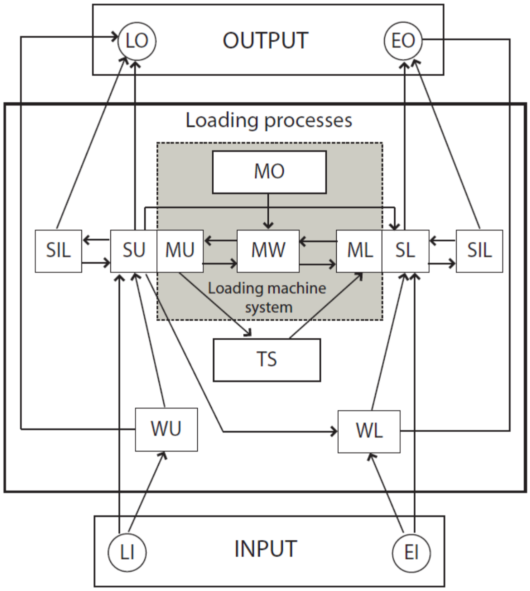

Figure 3. Illustration of loading processes[2]

- SU - State of unloading
- MU - Unloading machine
- MW - Working loading machine waiting for loading
- ML - Loading machine
- SL - State of loading
- SIL - Interrupted state of loading
- MO - Loading machine out of work

2.0.3. The Output of the Loading System

- LO - Transportation vehicle leaving loaded
- EO - Transportation vehicle leaving empty

3. MLPs in HOSVD Based Framework

By monitoring the parameters of the loading system its behavior can numerically be reconstructed and modeled. Since the number of monitored parameters might be large it is reasonable to perform the identification locally and model the whole system by an identified set of simpler models. Although the number of models necessary to accurately describe the dynamics of the whole system might be large (depending on the number of parameters and discretization points), it is reasonable to transform the local models into such a representation in which the models are ordered according to their significance in order to reduce their number. In such a framework the less significant models are responsible for modeling the details and noise, thus by dismissing few from them the noise may also be reduced.

This section deals with the problem of embedding MLPs into HOSVD based framework in order to reduce the number of vertex systems (in our case MLPs). The main advantage of this approach lies in modeling a complex parameter varying system by blending simpler MLP models together. The HOSVD-based framework offers an efficient tool for their reduction.

Let us consider a parameter varying loading system modeled by blending local multilayer perceptron (MLP) models which correspond to different parameter vectors. Let us further suppose that these local MLP models are identical in structure. Their architecture is depicted by Fig. 4. The output of such a local model can be expressed as follows [15]:

$$\mathbf{a}_3 = \varphi_3\left(\mathbf{W}^{(3)}\varphi_2\left(\mathbf{W}^{(2)}\varphi_1\left(\mathbf{W}^{(1)}\mathbf{h}\right)\right)\right) \tag{1}$$

where

$$\mathbf{W}^{(\mathbf{j})} = \begin{pmatrix} w_{11}^{(j)} & w_{12}^{(j)} & \cdots & w_{1S_{j-1}}^{(j)} & b_{j1} \\ w_{21}^{(j)} & w_{22}^{(j)} & & w_{2S_{j-1}}^{(j)} & b_{j2} \\ \vdots & & & & \\ w_{S_j1}^{(j)} & w_{S_j2}^{(j)} & & w_{S_jS_{j-1}}^{(j)} & b_{jS_j} \end{pmatrix},$$

$j = 1..N_L$ (Number of layers (N_L) in our example represented by Fig. 4 is 3),

$$\mathbf{h} = \begin{pmatrix} h_1 & h_2 & \cdots & h_R & 1 \end{pmatrix}^T$$

stand for the input vector, while vector

$$\mathbf{a}_3 = \begin{pmatrix} a_{31} & a_{31} & \cdots & a_{3S_3} \end{pmatrix}^T$$

represents the output of the NN in Fig. 4.

In order to identify the vertex MLP-based models - corresponding to the nodes of a hyper-rectangular grid in the parameter space - measurements are needed. The nodes of

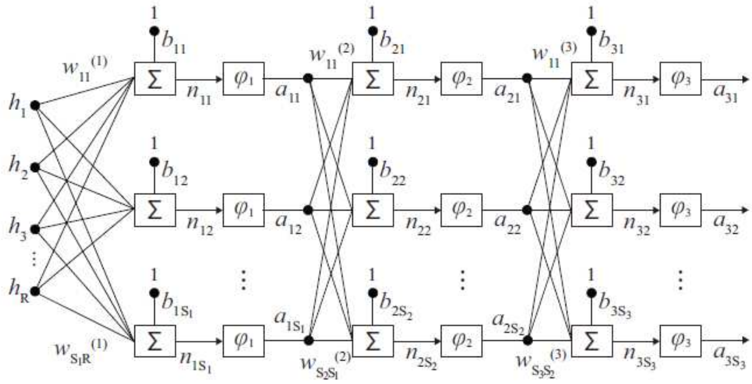

Figure 4. Architecture of vertex neural models [15]. ($R = S_0$)

the hyper-rectangular grid stand for those parameter vector values for which the local behavior of the system has to be identified. Let us denote the number of discretization points for the jth dimension as I_j. Based on such measurements (input-output pairs) the proper weights of the vertex MLP-based models are determined. From the weight matrices of corresponding layers of vertex MLP models an N+2 dimensional tensor $\mathcal{B}_i \in \Re^{I_1 \times I_2 \times \cdots \times I_N \times S_j \times (1+S_{j-1})}$ can be constructed [15]. Index i indicates the layer index of the MLP. Since in case of a loading system the number of parameters N and the number of identified vertex models corresponding to the certain dimensions may be large it is reasonable to reduce the complexity, i.e. the number of considered vertex models. The reduction can be performed efficiently by decomposing $\mathcal{B}_i$ (containing the weight matrices of corresponding layers) to a set of orthonormal components by HOSVD. Since the approximation is performed in the parameter space, the HOSVD is performed only for the 1st N dimensions of $\mathcal{B}_i$. The decomposition will result a core tensor $\mathcal{D}_i$ having the same size as $\mathcal{B}_i$ and N pieces of orthonormal matrices in which the columns stand for the components ordered according to their significance. From such a form the less significant components can be dismissed, thus the number of vertex models can be reduced [5],[15]:

$$\mathbf{a}_3(\mathbf{p}) = \varphi_3\left(\mathbf{W}^{(3)}(\mathbf{p})\varphi_2\left(\mathbf{W}^{(2)}(\mathbf{p})\varphi_1\left(\mathbf{W}^{(1)}(\mathbf{p})\mathbf{h}\right)\right)\right), \tag{2}$$

where

$$\mathbf{W}^{(1)}(\mathbf{p}) = \mathcal{D}_1 \boxtimes_{n=1}^{N} \xi_n^{(1)}(p_n), \tag{3}$$

$$\mathbf{W}^{(2)}(\mathbf{p}) = \mathcal{D}_2 \boxtimes_{n=1}^{N} \xi_n^{(2)}(p_n), \tag{4}$$

$$\mathbf{W}^{(3)}(\mathbf{p}) = \mathcal{D}_3 \boxtimes_{n=1}^{N} \xi_n^{(3)}(p_n), \tag{5}$$

where $\mathbf{p}$ stands for the vector of parameters, $\mathcal{D}_i$ the core tensor corresponding to the ith layer and the elements of vector valued functions

$$\xi_n^{(i)}(p_n) = \begin{pmatrix} \xi_{n1}^{(i)}(p_n) & \xi_{n2}^{(i)}(p_n) & \cdots & \xi_{nI_n}^{(i)}(p_n) \end{pmatrix}$$

are the function values of components (corresponding to the nth dimension of $\mathcal{D}_i$) at parameter value p_n.

3.1. Complexity Reduction

Let us express equations (3)-(5) in the following form:

$$\mathbf{W}^{(1)}(\mathbf{p}) = \sum_{i_1=1}^{I_1}\sum_{i_2=1}^{I_2}\cdots\sum_{i_N=1}^{I_N}\prod_{n=1}^{N}\xi_{ni_n}^{(1)}(p_n)\mathbf{d}_{i_1,i_2,\ldots,i_N}^{(1)} \tag{6}$$

$$\mathbf{W}^{(2)}(\mathbf{p}) = \sum_{i_1=1}^{I_1}\sum_{i_2=1}^{I_2}\cdots\sum_{i_N=1}^{I_N}\prod_{n=1}^{N}\xi_{ni_n}^{(2)}(p_n)\mathbf{d}_{i_1,i_2,\ldots,i_N}^{(2)} \tag{7}$$

$$\mathbf{W}^{(3)}(\mathbf{p}) = \sum_{i_1=1}^{I_1}\sum_{i_2=1}^{I_2}\cdots\sum_{i_N=1}^{I_N}\prod_{n=1}^{N}\xi_{ni_n}^{(3)}(p_n)\mathbf{d}_{i_1,i_2,\ldots,i_N}^{(3)} \tag{8}$$

It follows from the properties of the HOSVD, that the rightmost columns of singular matrices in each dimension represent those weighting functions which are responsible for describing the details involved in the measurement data. According to the above indexing the ξ_{ni_n} functions with larger i_n index are of less significance, thus by dismissing them the number of local models can be reduced by keeping the approximation error at lower level. It is the best low rank approximation of the original tensor, i.e. giving the minimal Frobenius norm $\left\|\mathbf{W}^{(\mathbf{i})} - \widetilde{\mathbf{W}}^{(i)}\right\|$, where i denotes the layer index and $\widetilde{\mathbf{W}}^{(i)}$ stands for the approximation of $\mathbf{W}^{(\mathbf{i})}$ as follows:

$$\widetilde{\mathbf{W}}^{(1)}(\mathbf{p}) = \sum_{i_1=1}^{I_{1_r}}\sum_{i_2=1}^{I_{2_r}}\cdots\sum_{i_N=1}^{I_{N_r}}\prod_{n=1}^{N}\xi_{ni_n}^{(1)}(p_n)\mathbf{d}_{i_1,i_2,\ldots,i_N}^{(1)} \tag{9}$$

$$\widetilde{\mathbf{W}}^{(2)}(\mathbf{p}) = \sum_{i_1=1}^{I_{1_r}}\sum_{i_2=1}^{I_{2_r}}\cdots\sum_{i_N=1}^{I_{N_r}}\prod_{n=1}^{N}\xi_{ni_n}^{(2)}(p_n)\mathbf{d}_{i_1,i_2,\ldots,i_N}^{(2)} \tag{10}$$

$$\widetilde{\mathbf{W}}^{(3)}(\mathbf{p}) = \sum_{i_1=1}^{I_{1_r}}\sum_{i_2=1}^{I_{2_r}}\cdots\sum_{i_N=1}^{I_{N_r}}\prod_{n=1}^{N}\xi_{ni_n}^{(3)}(p_n)\mathbf{d}_{i_1,i_2,\ldots,i_N}^{(3)}, \tag{11}$$

where $0 < I_{j_r} < I_j$, $j = 1..N$, matrices $\mathbf{d}^{(i)}_{i_1,i_2,\ldots,i_N}$ stand for the weight matrices of vertex models for the ith layer. The output of the approximated MLP can then be expressed as:

$$\widetilde{\mathbf{a}}_3 = \varphi_3\left(\widetilde{\mathbf{W}}^{(3)}\varphi_2\left(\widetilde{\mathbf{W}}^{(2)}\varphi_1\left(\widetilde{\mathbf{W}}^{(1)}\mathbf{h}\right)\right)\right) \tag{12}$$

4. Conclusions

In the paper a theoretical approach has been introduced for modeling loading systems having various parameters. Instead of looking onto the system as a unit, we proposed to model it by the combination of simpler models identified in the parameter space. As simpler models local MLPs have been considered and transformed into polytopic representation in order to blend them efficiently together according to the actual parameter vector as well as to reduce the number of identified models according to their significance. As future work we are going to test the suitability of the approach on real word data.

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A Fourth Order Finite Difference Method for Numerical Solution of the Goursat Problem

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Abstract: In this article, we consider the finite difference method for numerically solving the Goursat Problem, using uniform Cartesian grids on the square region. Numerical examples are considered to ensure accuracy of the developed method on both linear and nonlinear Goursat Problems of second order partial differential equations. The results obtained for these numerical examples validate the efficiency and expected fourth order accuracy of the method.

Keywords: finite difference method, fourth order method, Goursat problem, maximum absolute error, numerical method, stability

1. Introduction

The mathematical formulation of physical phenomena in natural sciences and engineering often leads to an initial value problem of partial differential equations. This type of problem can be formulated either in terms of first order PDEs or higher order PDEs. The Goursat problem arises in the study of wave phenomena. The solutions are frequently required in many applications such as accoustic scattering[1], Sine Gordon [2], electromagnetic theory [3] and wave equation [4]. Finite difference methods are commonly used to solve the Goursat problem. In addition to finite difference methods, other methods may be applied to numerically solve the Goursat problem; for example, heronian mean averaging method [5], cubature method [6], nonlinear trapezoidal method [7], adomian decomposition method [8], variational iteration method and references therein.

Developing an efficient and accurate numerical method for solutions for the Goursat problem is an active research topic. A new fourth order compact finite difference method for solving the Goursat problem was reported in [9], following the ideas therein.

In this article we consider a novel exponential finite difference approach which precisely satisfies the initial conditions. The present work is organised as follows. In section 2, we consider the development and derivation of novel exponential finite difference approximation for the Goursat problem. A novel finite difference method is presented so that the resulting difference equation need satisfies the initial conditions exactly. A local truncation error,convergence and stability of the present method discussed in section 3 and finally, the application of the developed method presented together with illustrative numerical results have been produced to show the efficiency of the method in section 4. A discussion and conclusion on the performance of the method are presented in section 5.

2. Derivation of Method

The subject of the present paper is to develop a finite difference method for the numerical solution of linear and nonlinear Goursat problem which arise in physical phenomena and applied sciences. For this purpose, we consider the Goursat problem [8],

$$\frac{\partial^2 u}{\partial x \partial y} = f(x,y,u), \qquad 0 \leq x,y \leq 1 \tag{1}$$

subject to boundary conditions

$$\begin{aligned} &u(x,0) = g(x), \quad and \quad u(0,y) = h(y) \\ &g(0) = \ h(0) \end{aligned} \tag{2}$$

This problem with a different source function $f(x,y,u,u_x,u_y)$ has been examined by several numerical methods such as cubature method [6], adomian decomposition method [8], nonlinear trapezoidal [7], Runge-Kutta method [10], finite difference method [9] and references therein.

The existence and uniqueness of the solution of the problem (1) is assumed. The specific assumption on $f(x,y,u)$ to ensure existence and uniqueness will not be considered.

We superimpose on the region of interest a mesh by lines $x_m = mh$, $y_m = mh$, $m = 0,1,2,.....N$, with mesh size $h = 1/N$ in x and y directions respectively. For convenience of notation the following symbolism is used. We denote the nodal point (x_i,y_j) as (i,j) and value of the source function f evaluated at the mesh point (x_i,y_j,u_{ij}) by f_{ij} and similarly we can define other notations in this article. Suppose we have to determine a number $u_{i+1,j+1}$, which is a numerical approximation of the theoretical value of $u(x_i + h,y_j + h)$, a solution of the problem (1) at the mesh point $(x_i + h,y_j + h)$.

To derive the method, we consider 9-points (i,j), $(i \pm 1,j)$, $(i,j \pm 1)$ and $(i \pm 1,j \pm 1)$. Following the idea in [11], we propose an approximation to theoretical solution $u(x_i +$

$h, y_j + h)$ of the problem (1) as an exponential difference method

$$u(x_i + h, y_j + h) - u(x_i + h, y_j - h) - u(x_i - h, y_j + h) + u(x_i - h, y_j - h) = b_0 h^2 f(x_i, y_j, u(x_i, y_j)) e^{\phi(x_i+h, y_j+h)} \quad (3)$$

where b_0 is the unknown constant, $\phi(x_i + h, y_j + h)$ an unknown sufficiently differentiable function.

Let us define a function $F(x_i, y_j, u(x_i, y_j), h)$ as

$$F(x_i, y_j, u(x_i, y_j), h) \equiv u(x_i + h, y_j + h) - u(x_i + h, y_j - h) - u(x_i - h, y_j + h) + u(x_i - h, y_j - h) - b_0 h^2 f(x_i, y_j, u(x_i, y_j)) e^{\phi(x_i+h, y_j+h)} = 0 \quad (4)$$

By Taylor series expansion of $\phi(x_i + h, y_j + h)$ about mesh point (x_i, y_j), we have

$$\phi(x_i + h, y_j + h) = \phi_{ij} + h(\phi_{xij} + \phi_{yij}) + \frac{h^2}{2}(\phi_{xxij} + 2\phi_{xyij} + \phi_{yyij}) + O(h^3) \quad (5)$$

where $\phi(x_i, y_j) = \phi_{ij}$, $(\frac{\partial \phi}{\partial x})_{ij} = \phi_{xij}$,......etc.. The expression (5) will provide an $O(h^3)$ approximation for the function $e^{\phi(x_i+h, y_j+h)}$.
So, we have

$$e^{\phi(x_i+h, y_j+h)} = 1 + \phi_{ij} + h(\phi_{xij} + \phi_{yij}) + \frac{h^2}{2}(\phi_{xxij} + 2\phi_{xyij} + \phi_{yyij}) + \frac{1}{2}\{\phi_{ij}^2 + h^2(\phi_{xij} + \phi_{yij})^2 + 2h\phi_{ij}(\phi_{xij} + \phi_{yij}) + h^2\phi_{ij}(\phi_{xxij} + 2\phi_{xyij} + \phi_{yyij})\} + O(h^3) \quad (6)$$

In order to determine a constant and $\phi(x_i + h, y_j + h)$, by the Taylor series expansion of the function $u(x, y)$ about the mesh point(x_i, y_j) and using notations defined above, from(4) we will write the expansion as

$$F_{ij}(x, y, u, h) \equiv h^2(4(u_{xy})_{ij} - b_0(1 + \phi_{ij} + \frac{1}{2}\phi_{ij}^2)f_{ij}) - b_0 h^3(1 + \phi_{ij})(\phi_{xij} + \phi_{yij})f_{ij} + h^4(\frac{2}{3}(u_{xxxy} + u_{xyyy})_{ij} - \frac{1}{2}b_0((\phi_{xij} + \phi_{yij})^2 + (1 + \phi_{ij})(\phi_{xxij} + 2\phi_{xyij} + \phi_{yyij}))f_{ij} = 0 \quad (7)$$

where $\frac{\partial^2 u}{\partial x \partial y} = u_{xy}$, $\frac{\partial^4 u}{\partial x^3 \partial y} = u_{xxxy}$, etc...

Comparing the coefficients of h^p, $p = 2,3,4$ in (7) and using the fact that $u_{xyij} = f_{ij}$ from (1), we will have following system of nonlinear equations

$$\begin{aligned} b_0(1+\phi_{ij}+\frac{1}{2}\phi_{ij}^2) &= 4 \\ b_0(1+\phi_{ij})(\phi_{xij}+\phi_{yij})f_{ij} &= 0 \\ \frac{1}{2}b_0((\phi_{xij}+\phi_{yij})^2+(1+\phi_{ij})(\phi_{xxij}+2\phi_{xyij}+\phi_{yyij}))f_{ij} & \\ = \frac{2}{3}(u_{xxxyij}+u_{xyyyij}) & \end{aligned} \tag{8}$$

To simplify the calculation and solving the system of equations (8), let us assume $\phi_{ij} = 0$, $\phi_{xij} = 0$ and $\phi_{yij} = 0$. So we will get

$$b_0 = 4 \tag{9}$$

$$\phi_{xxij} + 2\phi_{xyij} + \phi_{yyij} = \frac{1}{3f_{ij}}(u_{xxxy} + u_{xyyy})_{ij} \tag{10}$$

On Substitution of the values of ϕ_{ij} , ϕ_{xij} , ϕ_{yij} and $\phi_{xxij} + 2\phi_{xyij} + \phi_{yyij}$ in (5), and assuming the negligible contribution of the terms with $O(h^3)$, we have

$$\phi(x_i + h,y_j + h) = \frac{h^2}{6f_{ij}}(u_{xxxy} + u_{xyyy})_{ij} \tag{11}$$

Finally substituting the values of b_0 and $\phi(x_i + h,y_j + h)$ from (9-10) in (4), we will obtain the expression

$$\begin{aligned} u(x_i+h,y_j+h) - u(x_i+h,y_j-h) - u(x_i-h,y_j+h) + u(x_i-h,y_j-h) & \\ = 4h^2 f(x_i,y_j,u(x_i,y_j))e^{\frac{h^2(u_{xxxy}+u_{xyyy})_{ij}}{6f_{ij}}} & \end{aligned} \tag{12}$$

This is an explicit method which is at least $O(h^4)$ accurate. The source function f plays an important role in approximation of the terms u_{xxxy} and u_{xyyy} in (11). However, we have used only a discrete approximation for these terms. First we have substituted f_{xx} and f_{yy} for the terms u_{xxxy} and u_{xyyy} respectively. Thus we have obtained our compact exponential finite difference method

$$u_{i+1,j+1} - u_{i+1,j-1} - u_{i-1,j+1} + u_{i-1,j-1} = 4h^2 f_{ij} e^{\frac{h^2(f_{xx}+f_{yy})_{ij}}{6f_{ij}}} \tag{13}$$

where $u_{i+1,j+1}$ is an approximate value of the theoretical value of $u(x_i + h,y_j + h)$,..etc. For the computational purpose reported in section 4, we have used second order finite difference approximations for the terms f_{xx} and f_{yy} i.e.

$$\begin{aligned}(f_{xx})_{ij} &= \frac{f_{i+1,j} - 2f_{ij} + f_{i-1,j}}{h^2} \\ (f_{yy})_{ij} &= \frac{f_{i,j+1} - 2f_{ij} + f_{i,j-1}}{h^2}\end{aligned} \tag{14}$$

To compute initial values in (13), we have the following algorithm reported in [9],

$$u_{i,j} = u_{i,j-1} + u_{i-1,j} - u_{i-1,j-1} + \frac{h^2}{4}(f_{i,j} + f_{i,j-1} + f_{i-1,j} + f_{i-1,j-1}) \tag{15}$$

3. The Local truncation error , Convergence and Stability Analysis

In this section, we consider the error associated with the proposed method (12. Let $u(x,y)$ be the solution of problem (1) six times continuously differentiable in the domain $[0,a] \times [0,a]$. Let T_{ij} be the truncation error in the proposed difference method (12) at mesh point (i,j) which may be defined as in [12] and we can write as

$$\begin{aligned}T_{ij} &= u_{i+1,j+1} - u_{i+1,j-1} - u_{i-1,j+1} + u_{i-1,j-1} - 4h^2 f_{ij} e^{\frac{h^2(f_{xx}+f_{yy})_{ij}}{6f_{ij}}} \\ &= \frac{h^6}{90}(3\frac{\partial^6 u}{\partial x^5 \partial y} + 10\frac{\partial^6 u}{\partial x^3 \partial y^3} + 3\frac{\partial^6 u}{\partial x \partial y^5} - \frac{5}{f}(\frac{\partial^4 u}{\partial x^3 \partial y} + \frac{\partial^4 u}{\partial x \partial y^3})^2)_{ij}\end{aligned} \tag{16}$$

Thus the order of the method (12) is four. Let us define error equation for difference method (12) as

$$\begin{aligned}&\epsilon_{i+1,j+1} - \epsilon_{i+1,j-1} - \epsilon_{i-1,j+1} + \epsilon_{i-1,j-1} \\ &\qquad = 4h^2(f(x_i,y_j,u(x_i,y_j)) - f(x_i,y_j,u_{ij})) + O(h^6)\end{aligned}$$

where $\epsilon_{ij} = u(x_i,y_j) - u_{ij}$. Using mean value theorem we have

$$\epsilon_{i+1,j+1} + \epsilon_{i-1,j-1} = \epsilon_{i+1,j-1} + \epsilon_{i-1,j+1} + 4h^2\epsilon_{ij}(\frac{\partial f}{\partial u})_{ij} + O(h^6) \tag{17}$$

Let us define E_{j+1}, the maximal error on the $(j+1)^{th}$ level i.e.

$$E_{j+1} = \max_i |\epsilon_{i,j+1}|$$

Thus from (16), we have

$$\max_i |E_{j+1} + E_{j-1}| \leq \max_i |E_{j+1} + E_{j-1}| + 4h^2|E_j|\left|(\frac{\partial f}{\partial u})_{ij}\right| + O(h^6)$$

Thus as $h \to 0$

$$4h^2|E_j|\left|(\frac{\partial f}{\partial u})_{ij}\right| = 0$$

Thus the method (12) converges. The numerical solution will contain roundoff error and let $\bar{\epsilon}_{ij}$ be the roundoff error defined as

$$\bar{u}_{ij} = u_{ij} + \bar{\epsilon}_{ij}$$

Since a difference equation governs the prorogation of errors, it is possible to write (16) as

$$\bar{\epsilon}_{i+1,j+1} + \bar{\epsilon}_{i-1,j-1} = \bar{\epsilon}_{i+1,j-1} + \bar{\epsilon}_{i-1,j+1} + 4h^2\bar{\epsilon}_{ij}(\frac{\partial f}{\partial u})_{ij} \tag{18}$$

For the difference equations with constant coefficients, the error may be expanded in a finite Fourier series [12]. Thus if the source function, f is linear and defined $\bar{\epsilon}_{m,n}$, as in [12].

$$\bar{\epsilon}_{m,n} = Ae^{(i\beta mh)}\xi^n$$

where β is real number and A is an arbitrary constant. So the equation (17) may be written as

$$\xi^2(e^{(2i\beta h)} - 1) - 4h^2e^{(i\beta h)}\frac{\partial f}{\partial u}\xi - (e^{(2i\beta h)} - 1) = 0 \tag{19}$$

To simplify the equation (18), we have

$$\xi^2 + 2h^2 \csc(\beta h)\cot(\beta h)\frac{\partial f}{\partial u}\xi - 1 = 0 \tag{20}$$

$$\xi^2 - 2h^2 \sec(\beta h)\frac{\partial f}{\partial u}\xi - 1 = 0$$

The number ξ is called the amplification factor of the difference method. The method is stable iff $|\xi| \leq 1$. If source function f has arguments x and y only, then we see that the method is stable for all β. On solving (19), we conclude that the difference method (12) is stable if $\frac{\partial f}{\partial u} > 0$ then $\beta \in (\frac{\pi}{2}, \frac{3\pi}{2})$ and if $\frac{\partial f}{\partial u} < 0$ then $\beta < \frac{\pi}{2}$.

4. Numerical experiment

To illustrate our method and demonstrate its computational efficiency, we will consider the examples discussed in [8, 10], in which the errors taken to be the maximum absolute error i.e.

$$MAU = \max_{2\leq i,j\leq N} |u(x_i,y_j) - u_{ij}|$$

We have used Newton-Raphson iteration method to compute the values in (14). All computations in the experiment were performed on MS Window 2007 professional operating system in the GNU FORTRAN environment version -99 compiler(2.95 of gcc) running on Intel Duo core 2.20 Ghz PC. The solutions are computed on $(N-1)^2$ nodes, in computation of initial value iterations continued until either maximum difference between two iterates is less than 10^{-9} or number of iterations reached 10^3.

Problem 1. Consider a nonlinear problem discussed in [10]which,when solving consists of

$$u_{xy} = e^{(2u)}$$

in the region $[0,1] \times [0,1]$ with the boundary conditions $u(x,0) = x/2 - \log(1 + e^x)$, $u(0,y) = y/2 - \log(1 + e^y)$, for which the analytical solution is found to be $u(x,y) = (x + y)/2 - \log(e^x + e^y)$. For sake of comparison, we have computed the solution by the method in [13]. We have presented MAU by the present method (12) and method in [13], for different values of N in Table 1.

Problem 2. Consider a linear problem discussed in [8]which,when solving consists of

$$u_{xy} = u$$

in the region $[0,2] \times [0,2]$ with the boundary conditions $u(x,0) = e^x$, $u(0,y) = e^y$, for which the analytical solution is found to be $u(x,y) = e^{(x+y)}$. We have computed MAU by the present method (12) and the method in [13]. The computed MAU for both methods, for different values of N presented in Table 2.

Table 1. Maximum absolute error in $u(x,y) = (x + y)/2 - log(e^x/2 + e^y/2)$ for problem 1.

MAU	N			
	4	8	16	32
(12)	.36221743(-3)	.53644180(-4)	.67353249(-5)	.15497208(-5)
[13]	.61531067(-1)	.74501038(-2)	.11291504(-2)	.37765503(-3)

Table 2. Maximum absolute error in $u(x,y) = e^{(x+y)}$ for problem 2 .

MAU	N					
	4	8	16	32	64	128
(12)	.24116898(0)	.31757355(-1)	.41389465(-2)	.52642822(-3)	.80108643(-4)	.53405762(-4)
[13]	.57629776(0)	.61531067(-1)	.74501038(-2)	.11291504(-2)	.37765503(-3)	.72517395(-2)

5. Conclusion

In general, each numerical method has its own advantages and disadvantages of use. The present method is therefore good for use under the initial conditions. The major disadvantage of this method is in computation of nonlinear initial values.Our fourth order exponential finite difference method seems competitive with other finite difference methods.The decision to use a certain difference method does not depend on the given order of the method but also its computational efficiency. The numerical results for problems show that method is computational efficient. Also it is observed from the results that method has higher accuracy i.e smaller concretization error.

In the present article a different form of a high order method has been derived on the basis of exponential function. We have studied the accuracy and theoretical aspect of a developed finite difference method for numerical solutions of the Goursat problem.The development of this exponential method will lead to a possibility to approximate higher order derivatives in term of the power of lower order derivatives of solutions, to raise the order and accuracy of the method. Work in this direction is in progress.

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