

Electronic Exercises for the Metra Potential Method

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Abstract: The metra potential method as a special precedence diagram method is used in many scientific disciplines, e.g. in project management, date- and capacity-planning. It is a combination of graphical modelling and calculations for the duration of projects/processes. In this paper, we introduce an e-learning system that provides exercises concerning the metra potential method. Students can freely model the diagrams without restrictions and do the necessary calculations. Then, their solutions are marked automatically on the basis of a reference solution. The calculations are based on the modelling, thus consecutive faults between modelling and calculation have to be considered as well as consecutive faults only during the calculation.

1 MOTIVATION

Nowadays, though nearly everything can be done via the Internet, students do not want classic lectures to be replaced by electronic ones (Bruns 2002, p. 19); (Glowalla et al., 2004, p. 58). Instead, they prefer that classic lectures be enriched with e-learning aspects, especially with electronic exercises (Glowalla et al., 2004, p. 61). The reason for this is obvious: Students can practice whenever and wherever they want to without being bound to lectures but they still have the opportunity to participate. However, not every kind of exercise is indeed useful. The most popular exercises consist of multiple choice, true-false questions, jumbled sentences and fill-in-the-blank. These kinds of exercises are easy to create, to administer and to mark automatically. But the disadvantage of these kinds of exercises is evident: The questions contain the correct answer in a more or less apparent way so that students who do not know the correct answer are able to guess (König, 2001, p. 112). Instead, e-learning exercises should be sophisticated and interactive (see Haack 2002, p. 129) so that students have to find the answer on their own by using the learned approaches and their own knowledge. Therefore e-learning exercises should not prescribe the problem-solving procedure. Instead, they should allow many degrees of freedom to get to the right answers. Limitations should only appear if they are necessary to implement online exercises. Furthermore, e-learning exer-

cises should be marked automatically, so that the students immediately get feedback concerning their given answer (see Bolliger and Martindale 2004, p. 62); (Issing 2002, p. 162). In summary, e-learning exercises should adhere to the following three requirements (see Siepermann 2005, p. 1751):

- The exercises are more complex than multiple choice, fill-in-the-blank, etc.
- They allow students to really apply their new knowledge.
- They give feedback within a predictable time.

Because there are a huge number of different kinds of exercises, it is impossible to build one system for all kinds. But certain kinds of exercises resemble each other. In different scientific disciplines, graphical modeling is used, like skeletal formulas in chemistry, UML in computer sciences, event-driven process chains in business sciences, etc. Another kind of exercise consists of mathematical calculations that appear in mathematics as well as in physics, business sciences, engineering, etc. The general structure of such exercises is always the same: Concerning the graphical modeling, usually a textual description of the task is given. Then, students have to model with a set of vertices and edges of different kinds. Concerning the mathematical calculations, a textual description is also given. Then students have to calculate a certain number of values. Usually, there is more than one way to come to the correct solution. Thus, the calculation is not necessarily a sequential step-by-step calculation but

possibly a net of several calculation steps where there are several alternative possibilities to arrive at the result.

In this paper, we will present an e-learning system for the so-called metra potential method, a special kind of the precedence diagram method that is often used within project management or date and capacity planning. This method consists of a graphical representation as well as of a calculation scheme so that both kinds of generic exercises mentioned above have to be combined in one e-learning system.

2 LITERATURE REVIEW

Having a look at the vastness of e-learning literature, we can mainly distinguish the following streams:

First, multi-media based e-learning systems were designed that used the rather new concept of hypertext and multimedia elements like videos and animations. Already at this stage, simple exercise forms like multiple-choice, fill-in-the-blank, etc. were implemented and integrated into these systems. The predominant medium was the CD-ROM because Internet connections were too slow and only a few students really used the Internet.

Many authors analysed the success of e-learning when it is used instead of, and in addition to, classic teaching. There are a huge number of empirical studies showing that e-learning, in addition to classic teaching, is a benefit to the learner. In addition, they are working out the key factors of successful and satisfactory e-learning (e.g. Sun et al., 2008).

When the Internet came into the focus of research, many authors designed e-learning systems for the administration of students and classrooms, learning material like lecture notes and recordings, additional material and also exercises, but still exercises on a quite simple level. Often, the technical aspect of integrating new media was in the focus of research. E.g. Higgins et al. 2007 gives an overview of just the literature about whiteboards. Well-known platforms like Moodle, OpenUSS, Blackboard (formerly known as WebCT) emerged from this kind of research. Up to just a few years ago, those platforms were the focus of research (e.g. Brusilovsky et al., 2005).

Thus, creating e-learning systems has a long tradition. Already in 1987, Wenger presented a reference model for intelligent tutoring systems that was used and enlarged by several other authors (e.g. Brusilovsky 1992, p.27 et sqq.). Several authors investigated the design and implementation of mathematical exercises. Patel & Kinshuk 1996 first pre-

sented an e-learning framework for mathematical calculations. They provided exercises for physical equations with multiple possible ways of solving. Siepermann & Lackes 2007 enlarged this approach for the net requirements calculation to a more complex and periodical calculation. Their tool does not prescribe any problem-solving procedure. Students are completely free concerning their calculations. Other applications were designed for the logistics cost accounting and the classic cost accounting (Siepermann and Siepermann, 2008).

Other authors like Higgins et al. 2002, Higgins et al. 2005 or Saikkonen et al. 2002 are concentrating on exercises for programming. This is a very difficult task because already the question as to whether a program stops is impossible to be solved. To check the correctness, those programming exercise tools usually provide black box tests and syntax checks so that many both wrong and correct programs can be identified.

Starting with a framework for e-assessments (Higgins et al., 2002), graphical modeling has also come into the focus of research. Thomas 2004 presented an idea concerning how to mark diagrams for a quite specialised application. Waugh et al. 2004 is based on this approach but does not describe precisely how the method exactly works. Instead, different results of experiments with their system are presented (Thomas et al., 2005). Siepermann 2005 introduced the concept of automatically marking graphical models by covering the student solutions with correct parts of the reference solution and wrong parts of already marked student solutions, so-called patterns. Unrecognised parts of the student solutions have to be corrected by instructors. Then, those parts can be used as part solutions during the marking of other student solutions. Thomas et al. 2006 also mentioned the usage of patterns. In 2008, they switched from ER-diagrams to sequence diagrams (Thomas et al., 2008). In Siepermann et al. 2008, model-checking was used as an alternative method for the marking instead of graph-covering.

For several years now, game-based learning has come into the focus of research. Conferences (e.g. European Conference on Games-Based Learning (ECGBL)) that focused on this special topic now exist. But in game-based learning, usually the didactical approach and the presentation of content are in the main focus, not the technical sophistication of exercises.

What these exercises we discuss above have in common is that they usually focus on one special kind of exercise: The mathematical calculation, the graphical modelling, the programming, the didacti-

cal setting. In the following, we will present an application that is based on graphical modelling, as well as on a mathematical calculation. The mathematical calculation again is based on the structure of the graphical diagram.

3 METRA POTENTIAL METHOD

The metra potential method as a special precedence diagram method is used for planning and scheduling projects or activities with logical relations and interdependencies. The main purpose is to calculate the duration of a project/process, i.e. the minimal and the maximal duration and to identify critical paths and activities that may lead to a delay. During execution, potential delays can be identified so that measures can be taken into account in order to avoid missing a given deadline. For a deeper insight into the method, have a look at Hajdu 1997.

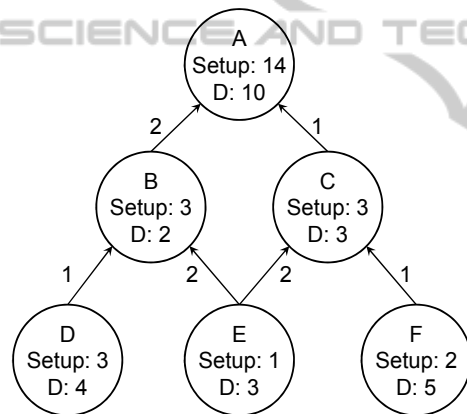


Figure 1: Parts structure diagram.

The general mode of operation is as follows: For explanation, we look at the date and capacity planning of the production planning and control. Let us assume a parts structure as depicted in Figure 1. The figure can be read as follows: Each vertex represents one certain part. The edges represent the relation between the parts. That means, for example, that part B goes into part A. Thus, in order to produce one product A, we need two parts of B and one part of C; to produce B, we need one part of D and two parts of E; and for C we need two parts of E and one of B. Then, concerning the inferior parts D, E and F for one product A, we need all together two parts of D, six parts of E and one part of E. Assuming that every part is produced during one single activity, the parts structure also represents the production process. The time that is needed for the production is given in the

vertices: There is a so-called setup time that is needed in order to prepare the machines in one period. This time consumption is always the same regardless if one or a thousand pieces are produced. In addition, we need time D to produce one piece of each part. Thus, when producing for example three pieces of product A, we need $14 + 3 \times 10 = 44$ time units in total for the last activity in our production process.

Now, this structure has to be modelled with the metra potential method. While the parts structure is more general, the metra potential method can only represent a certain case. That means we have to know the number of pieces to be produced before doing the date planning. In our example, we keep the assumption of three pieces of product A that have to be produced. Assuming that all pieces are produced during one activity before handling them out for the next activity, we get the corresponding diagram as shown in figure 2.

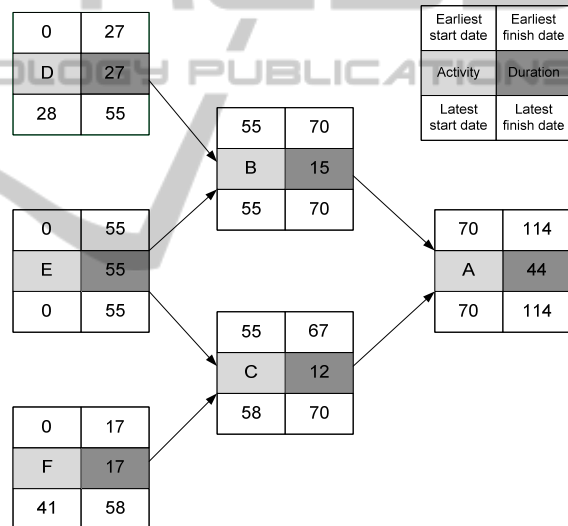


Figure 2: Sample diagram for the metra potential method.

The general structure remains the same. Now each vertex provides the following information: The light grey rectangle indicates the activity and the dark grey rectangle contains the duration of the activity in total. In the upper left, we find the earliest point in time when an activity can start (ESD). In the upper right corner, the earliest possible point in time is displayed when the activity can finish (EFD). In the lower left corner, the latest possible start date is shown (LSD) and in the lower right corner the latest finish date (LFD).

The computation of the duration is not an inherent part of the metra potential method but of the special use case production planning. Within project planning the duration would be given. Nevertheless,

this computation can also be integrated into the e-learning exercises we will present later.

The calculation of the four points in time is an inherent part of the metra potential method. Starting with the current time, the earliest start date of vertices without predecessor is always 0. Let i, j be vertices/activities of the diagram. If there is an edge between i and j , we write (i, j) . Then the four points in time can be computed as follows:

$$ESD_i = \begin{cases} 0 & i \text{ has no predecessor} \\ \max_{(j,i)}\{EFD_j\} & \text{else} \end{cases} \quad (1)$$

$$EFD_i = ESD_i + D \quad (2)$$

$$LFD_i = \begin{cases} \max_j\{EFD_j\} & i \text{ has no successor} \\ \min_{(i,j)}\{LSD_j\} & \text{else} \end{cases} \quad (3)$$

$$LSD_i = LFD_i - D \quad (4)$$

Based on the resulting diagram an analysis can be started concerning the critical path and activities. For each activity, the total buffer (TB) can be computed:

$$TB_i = LSD_i - ESD_i = LFD_i - EFD_i \quad (5)$$

Critical activities are those where the total buffer is 0 because there is no flexibility concerning the time. The path where the total buffer of each activity is 0 is called critical path.

Irrespective of the total buffer, the free buffer indicates the flexibility of an activity with respect to succeeding activities:

$$FB_i = \min_{(i,j)}\{ESD_j\} - EFD_i \quad (6)$$

4 E-LEARNING SYSTEM

4.1 General Design and Architecture

In the following, we will present an e-learning system for the metra potential method. This system is accessible to students via the Internet so that they can practise wherever and whenever they like. Besides this, the following functions are mandatory:

- Definition and provision of interactive, sophisticated exercises of different types,
- Automatic generation of exercises,
- Solving of exercises,
- Automatic marking of exercises,
- Administration of students and exercises,
- Archiving of exercises and student solutions.

The first point deals with the type of exercises.

Students should not be able to guess a solution. For this, the system only provides a graphical editor with a small set of graphical elements. For difficulty level purposes, some elements may not be useful for the metra potential method. Then, students can freely model their diagrams without any restrictions. The captions for the vertices can be derived from the textual description by drag & drop. Once students did the modeling and the calculation part they send their solution to the system that automatically marks the solutions.

For instructors, the system provides a module where exercises can be defined. For this, it is necessary to describe the exercise in textual form. Additionally, it is possible to upload illustrating figures that can also contain necessary information. The description is only for the students. The system itself needs information about the structure itself. For this, instructors model the reference solution for the exercise with the same editor with which students are practicing. With the help of the durations of each activity and the structure of the diagram, the calculation of start and end dates can be done automatically by the system.

In addition to the manual definition, exercises can also be generated automatically. For this purpose, it is only necessary to provide text patterns that can be recomposed to describe an exercise. Necessary numerical values can be easily created with random functions.

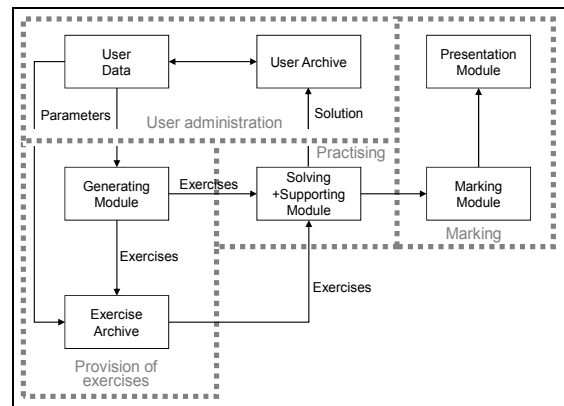


Figure 3: Architecture of the e-learning system.

Besides the practicing part in a narrow sense, the system also provides functions to administer all students and all exercises that have ever been created by instructors or generated automatically. These exercises and also the student solutions are stored so that they can be analysed later by students themselves as well as by instructors so that they can see where there are still problems of understanding.

Figure 3 gives an overview of the e-learning system's architecture.

4.2 Exercise Generation

The general exercise structure for the metra potential method is always the same: Based on the relation structure of activities, start and finish dates have to be computed. The computation of these dates is based on six equations (see equation 1-6) that can easily be realised automatically when the activity structure and the duration of activities is known.

In order to provide an automatic generation of exercises, it is necessary to randomly generate an activity structure and the durations of the activities. Then, based on text patterns, a textual description of an exercise can be generated by using the text patterns and filling out different placeholders with the automatically generated values for the durations.

This general procedure can be refined by implementing special applications. For example, as we could see in the example of the date planning the duration of activities can also be calculated. This does hold not only for this application but also for other applications, such as the project management. There, the duration can be estimated or forecasted with different methods. It follows that for each special application, we just have to implement a method that calculates the duration of activities if some parameters are given. The calculated duration is then the input for the metra potential method while the parameters with which the duration was calculated are given in the generated exercise definition.

Aside from the automatic generation of exercises, three types of exercises can be provided:

- Simple exercises,
- Timed exercises,
- Exam exercises.

Simple exercises are ordinary exercises that can be solved by students. They consist of a description and the editor. Timed exercises additionally provide the target time of the exercise. That helps to prepare for exams because now students know if they are quick enough. Exam exercises also provide the target time, but unlike timed exercises after the target time has run out, students cannot continue with exam exercises anymore.

The calculation of the target time can be done by the system itself. Each vertex and edge of the metra potential diagram usually needs the same time for modelling and, as well, each calculation step needs a certain period of time. If the duration has to be calculated in addition, more time has to be added to the

target time depending on the complexity of the calculation.

In general, exercises should be classified by different levels of difficulty, corresponding to students' level of knowledge. Exercises are much better accepted this way rather than without classification. It is essential that students are able to choose among several difficulty levels. Concerning the metra potential method, the difficulty level mostly depends on the (pre-) calculation of the duration and the complexity of the activity structure. The more parallel paths the diagram has that are interconnected, the more difficult it is to calculate the start and finish dates. In addition, the difficulty increases with the number of activities. Thus, easy exercises already provide the duration and consist only of a maximum of two parallel paths with an interconnection. Medium exercises may either contain the duration or the duration has to be calculated. In addition, there are possibly more than two parallel paths with interconnections. In difficult exercises, the duration has to be calculated for each activity and there are several parallel paths with different interconnections. In addition, the different buffer times of activities can be demanded.

4.3 Automatic Marking

As we have seen, the metra potential method is a mixture of graphical modelling and a calculation scheme. First of all, the structure has to be found before it is possible to calculate the different points in time. When practising, students usually get a textual description that is sometimes illustrated by figures like figure 1 or tables. Then, their task is to model all the elements of the description as exactly as possible and to calculate the different start and finish dates. But as modelling is always a somewhat creative task, it is often possible to model in different ways. That means that a student's solution is not necessarily (completely) similar to the reference solution but is as useful and as correct.

If there was only one possible solution for an exercise, a simple depth first search and comparison between the student solution and the reference solution would be feasible. But it is possible that more than one solution exists such that it is impossible to do just a 1:1-comparison between the reference solution and the student solutions.

The research in this field has created different approaches to mark graphical models where several alternative solutions are possible. In many application fields of the metra potential method, there is only one feasible solution and only a few alterna-

tives that can also be used but that are not as elegant as the single reference solution. The graph covering approach (Siepermann, 2005) with correct and wrong patterns seems to be the best approach to cope with this situation because in most cases, it will be enough to model only one reference solution and only a few additional alternative patterns that are either correct or wrong. For this reason, we decided to use this approach. This approach automatically marks a student solution. If all parts are recognised, the marking algorithm can proceed to check the calculation. If not, the instructor is asked to intervene and to mark only the unrecognised parts. These newly recognised parts are then inserted into the knowledge base of the marking algorithm.

Three different kinds of errors can appear in a student solution (Siepermann and Lackes 2007, p. 16):

- Content faults,
- arithmetical faults and

- caption faults.

Content faults may concern the structure of the diagram and the calculation of some dates. The structure is already checked by graph covering. Thus, only the content faults in the calculation are now in the focus. Arithmetical faults arise when students know about the calculation but do not add up some values in a mathematically correct way, for example. These faults cannot be distinguished from content faults. Caption faults only concern the name of an activity. If the caption can only be done via drag and drop, then only completely wrong captions, doubled captions or interchanged captions can occur. All these faults are also discovered during the graph covering.

This means that only content faults concerning the right or wrong usage of calculation rules for the start and end dates have to be considered after the structure check. The marking of the calculation has

Metra Potential Method - Exercise 3
 Menu Exercise Help About

Description
 In Figure 1 you can see a parts structure of product A. Each part is manufactured in a single activity. The setup time that is needed is given for each activity/part as well as the duration that is needed to manufacture one piece of a part. For example, before manufacturing part B a setup time of 3 time units is needed as setup time. After setup, one piece of part B is manufactured in 2 time units. The production order comprises a total amount of 3 pieces of product A. The execution of activities is not intersecting. That means all parts are given to the next activity in total.

Figure 1: Parts structure of product A

Task

Calculate the earliest and latest end and finish dates of all activities with the metra potential method.

Your Result

What is the earliest finish date of the production?

106

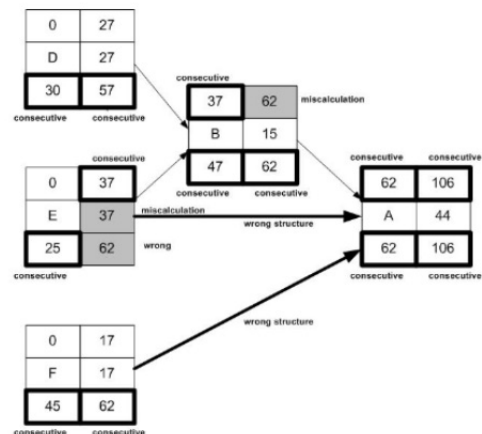
You achieved a score of **50%** in the answers.

Correct with regard to consecutive faults

What is the latest start date of the production?

45

Wrong! It is not the maximal but the minimal LSD!



You achieved a score of **75%** in the modelling.

Your result in detail:

Structure:
 You did not model 1 activity.
 You did not model 3 edges.
 You modelled 2 wrong edges.

Calculation:
 You did not calculate the duration of activity E correctly.
 The correct value is 55. This leads to several consecutive faults.

You did not calculate the earliest finish date of activity B correctly.
 The correct value with regard to your previous errors would be 52.

You did not calculate the latest finish date of activity E correctly.
 It has to be the minimal latest start date of all successors instead of the maximal latest start date.

Figure 4: User Interface of the e-learning system.

to be done on the basis of the diagram of the student solution because if the structure of the diagram is different to the reference solution, different values are calculated that cannot be compared. That means that a possibly faulty value may just be a consecutive fault of the structural modelling.

Within the calculation, many consecutive faults may also arise: If one calculation step is incorrect, all following calculation steps that are based on the faulty value also deviate from the reference solution.

For this, the marking algorithm does not compare the values of the reference solution and the student solution but checks every single calculation step. If the calculation step is correct, the algorithm proceeds with the next value. If not, the algorithm has to mark and memorize the mistake. When proceeding to the next value, the algorithm now has to check this next value considering the previously made mistakes in order to find consecutive faults. There are three possibilities concerning the next value:

- The next value is correct with regard to the reference solution.
- The next value is correct with regard to the previously made mistakes.
- The next value is completely incorrect.

In the first case, the checked value is correct and nothing has to be done. In the second case, the value is a consequence of a previously made mistake and has to be marked as a consecutive fault. In the third case, the value has to be marked as incorrect. After the marking algorithm has finished, the marked solution is displayed to the student. The reference solution that is also calculated automatically can also be viewed by the student.

4.4 User Interface

Figure 4 shows the user interface of the system when a student's solution is already marked. It is the same exercise that we used above. But here, in addition to the modelling, students also have to answer to two questions concerning the earliest starting and latest finish date.

The system has marked all faults red and all consecutive faults with a big red border (both are grey in the figure). The student made a mistake concerning the structure: He forgot to model activity C so that two of his edges are wrong (bold red edges) and one edge is missing. There are also three faults in the calculation. For two faults, the reason cannot be identified. It can be a simple arithmetical fault as well as content fault. But concerning the wrong latest finish date of activity F, it is a content fault because the student has used the maximum starting

date of the successors instead of the minimal date.

All faults are marked in the model and a short description of the marking is given. An overall score for the solution is calculated so that students know their current level of knowledge.

5 CONCLUSIONS

The metra potential method is used in many different scientific disciplines. While the general structure remains the same, the calculation of the duration may vary. In this paper, we presented an e-learning system that provides e-learning exercises for the metra potential method to students. These exercises can be defined manually or generated automatically and they are marked automatically by the system. For each application that should be covered by the system, only a few things have to be done:

- The calculation of the activity duration has to be implemented.
- Text patterns for the exercise generation have to be stored in the system.
- The placeholders in the text patterns have to be assigned to the parameters of the duration calculation.

The e-learning system is used within several lectures by bachelor as well as by master students. Future research should investigate the question as to how the e-learning exercises help students to better understand usage of the metra potential method. Another question is how students accept the system. Initial surveys have shown good acceptance and satisfaction with the system.

The e-learning system itself can also be enlarged: Some of the student faults are the result of a deficit of understanding. When these faults occur, students can be advised to repeat certain lessons.

Another improvement concerns hints during the practicing process. In the current state, the system does not give any hints how to model the activity structure or how to calculate the dates or durations. In the practicing mode, such hints could be implemented so that a student can ask for help if he got stuck.

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