Innovations in Education and Teaching International, 2015
Vol. 52, No. 5, 485–498, http://dx.doi.org/10.1080/14703297.2013.832634

Routledge
Taylor & Francis Group

A navigation pattern analysis of university department's websites using a processing mining approach

Kwan Hee Han, Boram Hwang and Jeonghwan Jeon*

Department of Industrial & Systems Engineering/Engineering Research Institute, Gyeongsang National University, Jinju, Korea

The university's website is a useful tool in disseminating information to current and future college students and is supportive of the university's administrative activities. However, as the university's website began including more and more information and the design of it has become gradually more complex, it has become hard to find desired information and has resulted in low accessibility from current and future students. Therefore, this study aims to analyse the navigation path of the university's website in order to increase its usability and comfort level based on a process mining technique. The design of the proposed approach is comprised of three consecutive steps: data collection and preprocessing of web log, analysing the user navigation path and examining possible improvements. A case study shows that the suggested approach can provide various possible functional improvements to the university's website.

Keywords: university department's websites; navigation path; process mining; web design; usability

1. Introduction

The university's website is a useful tool for disseminating information to current and future college students, and is regarded as a potential tool for improving education and teaching (Saunders, 1997; Yu, She, & Lee, 2010). Various information such as announcements, news, lecture materials, map information, homework assignments and learning forums can be found within the university's website (Herrington, Sparrow, & Herrington, 2000). It supports students as a learning tool that, for example, enables students to discuss group assignments, post work schedules, review peer work, collaborate on their projects anytime and anywhere, and share results of experiments and learning (Flatley, 2005; Richardson, 2006). The operation and utilisation of the university's website have assisted in creating a better learning environment and are essential in the administration of the university (Güzeller, 2012). University managers and policy-makers view internet technology as an integral part of higher education teaching and learning (Eynon, 2008).

However, as the university's website began including more and more information and the design has become gradually more complex, it has become hard to find desired information and has resulted in low accessibility from current and future students. For example, current college students may stumble upon homework announcements on their department's website. Or future college students may find it

*Corresponding author. Email: jhjeon@gnu.ac.kr

inconvenient to find the specific entrance requirements or the desired information owing to the structural complexity of the website. Enticing students who are looking for the gateway to the university's resources is crucial. In particular, college freshmen who are not familiar with the university's activities and organisation may wander around the website. Many universities' websites are not made with user-oriented design in mind, but rather technology-centred design. Furthermore, it is considerably easy to find obsolete elements which have accumulated within the website as time passes. Therefore, navigation pattern analysis of web log is necessary to increase the usability and comfort level of the university's website.

Although many studies have been conducted on the efficiency and effectiveness of e-learning at the university (Chen & Lin, 2008; Mondi, Woods, & Rafi, 2007; Wang, 2008), little research has been undertaken to analyse and improve the usability of the university's website itself. To address this limitation, this research focuses on analysing the navigation path of the university's website and presents a design improvement plan by applying a process mining technique. Process mining is a kind of data mining technique used to analyse event log data accumulated in the information system by extracting common usage patterns and activity sequences of users performing specific tasks (Lee, Ryu, & Song, 2012; Van der Aalst et al., 2007). The university's website can accumulate a large amount of log data for each page (Chang & Chen, 2005). Based on this 'big data', massive paths of navigating the university's website can be analysed and classified. Therefore, process mining can provide various types of model-based analysis and a GUI design improvement to increase the usability of the university's website.

The remainder of this paper is organised as follows. Section 2 briefly reviews the process mining methodology. The research framework is explained in Section 3. Section 4 presents a case study illustrating the proposed approach. Section 5 concludes the study.

2. Literature review

2.1. Process mining

In the past, event log data recorded during the process execution were thrown away or sometimes simple analyses were performed. Recently, however, due to the development of internet and information systems, vast amounts of event log data are being stored in databases. The need for analysing the stored event log data and extracting and utilising useful information has increased greatly and various analytical methods are being studied for this purpose. In this way, process mining is a process for extracting meaningful knowledge from the 'event log' generated when users perform certain tasks, and also is the automated discovery of common usage patterns and process models from event log data (Song, Gunther, & van der Aalst, 2008; Van der Aalst, Schonenberg, & Song, 2011). In general, the process is a structured set of activities designed to produce a specified output for a particular customer.

Process mining technique identifies the structure and sequence of activities that are performed by participants (Van der Aalst, 2011). The purpose of our study is to find the structural pattern of navigation sequence when a user visits the university department's website by applying process mining method to web log data. Therefore, Table 1 shows the mapping of process mining element and corresponding web log elements. The process mining technique consists of three parts: (1) to discover a process model by using the log data; (2) to assess whether the discovered process

Table 1. The relation between process mining element and web log element.

Process mining elements	Web log elements
Case ID	Serial number
Activity	Page request
Event type (start, complete)	Start only
Time stamp	Access time
Originator	IP address

model is appropriate with respect to the intended goal; and (3) to extend the suitability of the discovered process model by modifying it (Lee et al., 2009).

Some research applied data mining technique in the field of education as follows. Jeong and Biswas (2008) built models that categorised student activity from basic behaviour data: students' interactions with a game-like learning environment that uses learning by teaching. A sample student activity discerned from the data was 'map probing'. A model of map probing then was used within a second model of learning strategies and helped researchers study how the strategy varied across different experimental states. Merceron and Yacef (2010) used association rule mining for (1) finding student mistakes that co-occur, (2) associating content with user types to build recommendations for content that is likely to be interesting, and (3) making changes to teaching approaches. Shaeela, Tasleem, Raza, and Inayat (2010) applied the data mining technique named k-means clustering to analyse student's learning behaviour. For more details on data mining in education, see Luan (2002) and Romero and Ventura (2007). Although there have been several attempts to apply data mining to educational fields, little research has been conducted through process mining.

2.2. Design of the university's website

Some research has been conducted on the navigation path of the university's website. Son and Lee (2001) analysed the navigation path of the university's library. Data mining techniques such as association rules were employed to find the most frequent path. Rearrangement of the menu was suggested based on the support and confidence value. Ritter, Freed, and Haskett (2002) provided a task analysis of what each user group (prospective students, current students, parents, staff and alumni) will look for on the university department's websites. This research intended to enhance the clarity and consistency of the procedures used when providing navigational aids. Choi and Ryoo (2005) evaluated and analysed the access points of the university's library homepage to provide directions for a more effective and efficient library service by statistical analysis. However, little research has been conducted on the navigation path of the university's website for the purpose of improving the usability and efficiency of the university's website.

In the non-university field, there have been several studies to analyse user behaviour using process mining techniques. Kim and Kim (2004) presented the method of obtaining web logs from a travel agency's website and then analysing the user's navigation path. Choi, Hwang, and Kim (2010) proposed a model for analysing web documents, which can identify user tendencies and interests from the user query in the web log data. Kim, Byen, Choi, Park, and Park (2012) proposed the usability analysis method of mobile applications using user's behaviour logs. This study

provided the method for continual collection and analysis of the data after the initial distribution of the mobile application.

3. Research framework

In this section, we examine the overall process of the proposed approach, in addition to a brief explanation of each step. As shown in Figure 1, the proposed approach is designed to be executed in three consecutive stages. First, the related event log data of the university's website are collected and preprocessed in electronic text format. Second, the preprocessed event log data are analysed to identify the navigation path of users and the critical path is identified. Finally, possible ways to improve the website's functionality are examined.

3.1. Data collection and preprocessing

Event log data, which have been written about the user's navigational behaviour on the university's website, are collected. One event record in the university's web log indicates which page was assessed from which IP address and at what time. The collected event log data need to be preprocessed since they are unstructured data, which are not appropriately expressed in text format. The detailed procedure for data preprocessing is as follows. First, as a screening process, a log parser is applied to extract event log data successful in connecting to the university's website. Second, event log data possess a lot of meaningless data; for example, those connected by a search engine. Therefore, they are refined by using Microsoft's Excel spread sheet to extract those connected by meaningful users. Finally, event log data are transformed into eXtensible Markup Language (XML) format, which is necessary for analysis by ProM. ProM is an open source process mining tool, originally developed at the Eindhoven University of Technology.

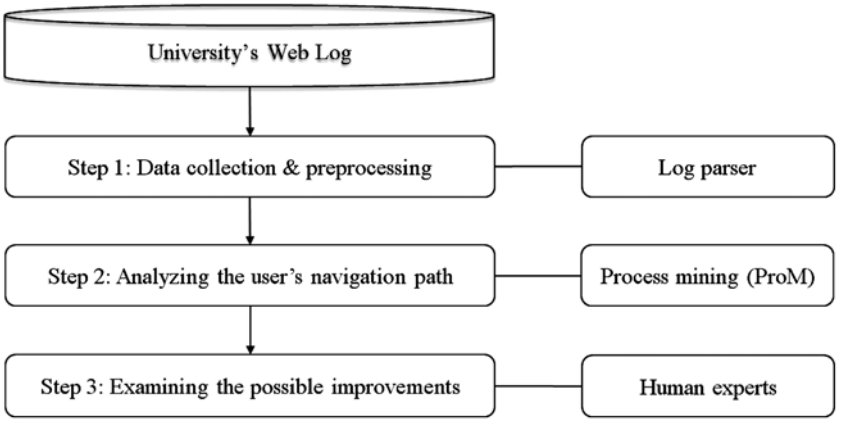


Figure 1. Overall process for analysing the navigation path of the university's website.

3.2. Analysing the user navigation path

The preprocessed event log data are analysed to find the user navigation pattern using ProM. In this study, of the several process mining algorithms available, both heuristic mining and fuzzy mining algorithms were applied. Heuristic mining is a process mining technique used to derive only the major path by calculating the connection frequency between activities based on a heuristic algorithm (Lee et al., 2012). The result of heuristic mining illustrates the whole navigation path. However, it is difficult to interpret the result of heuristic mining since it is highly complicated. For this reason, a fuzzy mining algorithm is used to complement the heuristic mining result. A fuzzy mining technique is usually used in the analysis of complex processes, especially when it is difficult to judge using exact criteria (Gunther & van der Aalst, 2007). Fuzzy mining represents several activities with a high correlation into one cluster by calculating the correlation between activities and integrates unimportant tasks together (Lee et al., 2012).

3.3. Examining possible improvements

The final step is to interpret the process mining results and to provide possible improvements based on the results. For this purpose, students, professors and various experts with extensive experience in the field of web engineering, information technology, and university administration and education are participated.

4. Case study

In this section, the overall process of analysing the navigation pattern of the university's website based on process mining is illustrated. The website of the Department of Industrial & System Engineering (ISE) of the Engineering School of Gyeongsang National University (GNU) in Korea served as the source for the collection of event log data, as shown in Figure 2. The overall structure of ISE's website is comprised of two levels: menu and page.

The Department of ISE website of GNU is appropriate as a case study for the following reasons. First, current and future students as well as professors of the Department of ISE frequently utilise the university department's website. Second, this website has a high enough number of people accessing it so that the pattern of the navigation path of the department's website can be analysed. Third, the complexity of the current structure of the ISE Department's website is suitable for extracting potential design improvements.

4.1. Data collection and preprocessing

The event log data were obtained over an eight-day period from 7 May 2012 to 14 May 2012. Data fields such as access time, IP address, page request and access status were used for the pattern analysis. An example of the data fields of the ISE Department's website is shown in Table 2. The number of collected event log data was 60,935. As the preprocessing stage, a log parser was applied to extract event log data successful in connecting to the ISE website.

Preprocessing by the log parser reduced the number of event log data from 60,935 to 30,881. Then, Microsoft's Excel was utilised to eliminate meaningless event log data which were connected by search engines, other websites, etc. Finally,

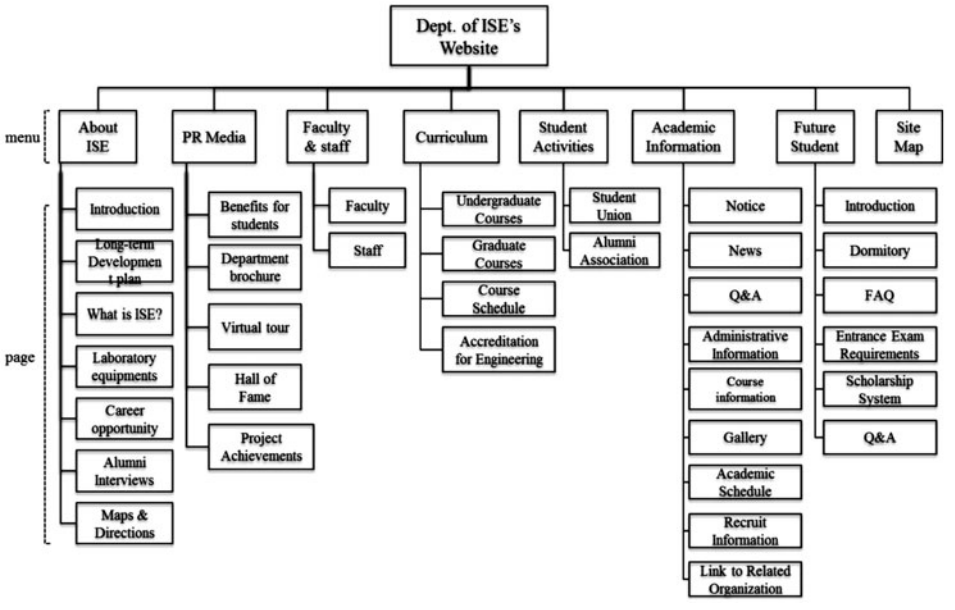


Figure 2. Overall structure of the main website of ISE of GNU.

Table 2. Example of the data fields of the ISE website.

Data field	Example
Access time	7/Dec/2011:00:00:00+0900
IP address	66.249.68.33
Page request	GET/gesipan/view.php?tb=tb_notice&no=946
Access status	4.200.9821

the event log data were transformed into XML format by Nitro since only XML format can be handled in ProM. Nitro is an easy-to-use tool for quickly converting event logs into eXtensible Event Stream format. As a result, the remaining number of event log data was 3963. This means that users clicked 3963 times over eight days. According to the descriptive analysis, 551 users navigated 46 web pages using 3963 clicks.

4.2. Analysing navigation pattern of the ISE website

Based on the 3963 event log data, heuristic mining and fuzzy mining algorithms were employed to find the user navigation pattern of the ISE website. Figure 3 shows the result of heuristic mining. Each node, represented by a square box, stands for a specific website (click action) accessed while navigating the ISE website.

The type of activity carried out and the number of visiting users appear inside the square box. An arrow connecting the nodes represents the activity sequence. There are two numbers on each arrow: the point number and the integer. The point number indicates how much a derived process model matches the given process in the event log. The integer is the frequency of the activities passing along the arrow.

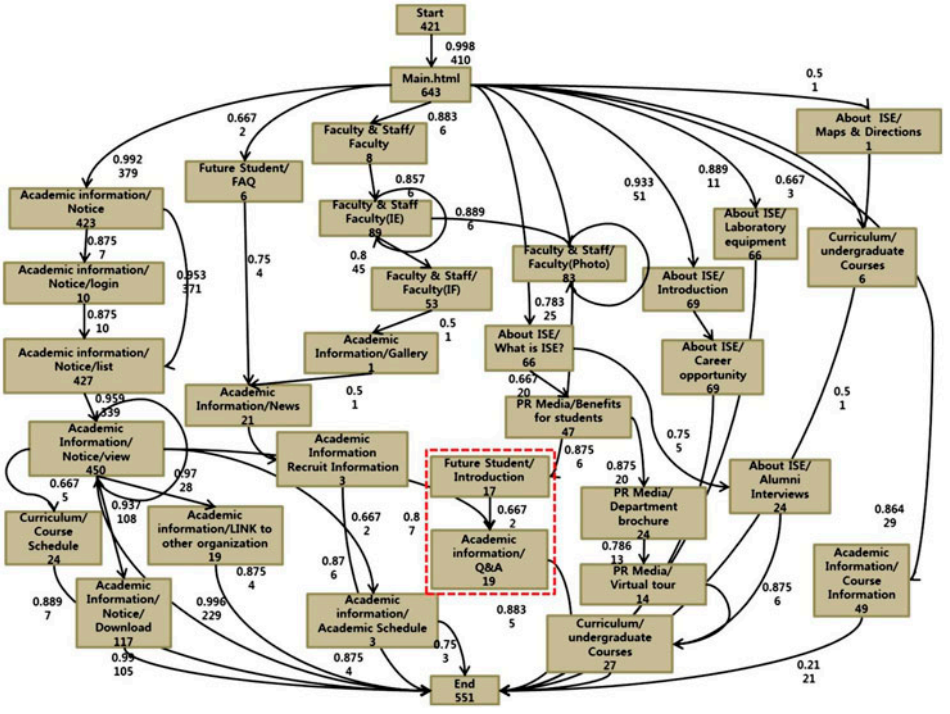


Figure 3. The result of heuristic mining.

For example, between [Future student/introduction] and [Academic information/Q&A] webpages (the dotted box in the lower middle part of Figure 3), the point number is .667 and the integer is 2. This means that the derived process model from [Future student/Introduction] webpage to [Academic information/Q&A] webpage matches the real process to a level of .667 and the frequency of activities that passed from [Future student/Introduction] webpage to [Academic information/Q&A] webpage is 2. Heuristic mining makes it possible to analyse the whole sequence of the navigation path of the users on the ISE website.

Although heuristic mining illustrates the sequence of the whole navigation path of the users, it is difficult to interpret the main route through the nodes and to identify the main access patterns since the network structure is too complex and diversified to understand. Hence, a fuzzy mining technique is utilised in order to make it easy to analyse the sophisticated navigation path. The major navigation path can be observed from the results of fuzzy mining, as shown in Figure 4. The octagonal box is a cluster of nodes with a high correlation. The point number in the octagonal box indicates the significance of the clustered elements. The rounded box represents event classes, and their significance is provided below the event class name within each node. The thickness of the arrow line indicates the frequency of the path. For example, the thickness of the arrow line through cluster 78 is the thickest of the arrow lines. This means that the greatest number of users navigated the path through cluster 78. Based on the results of fuzzy mining, five major navigation patterns were observed. Classification of the five major navigation patterns is summarised in Table 3.

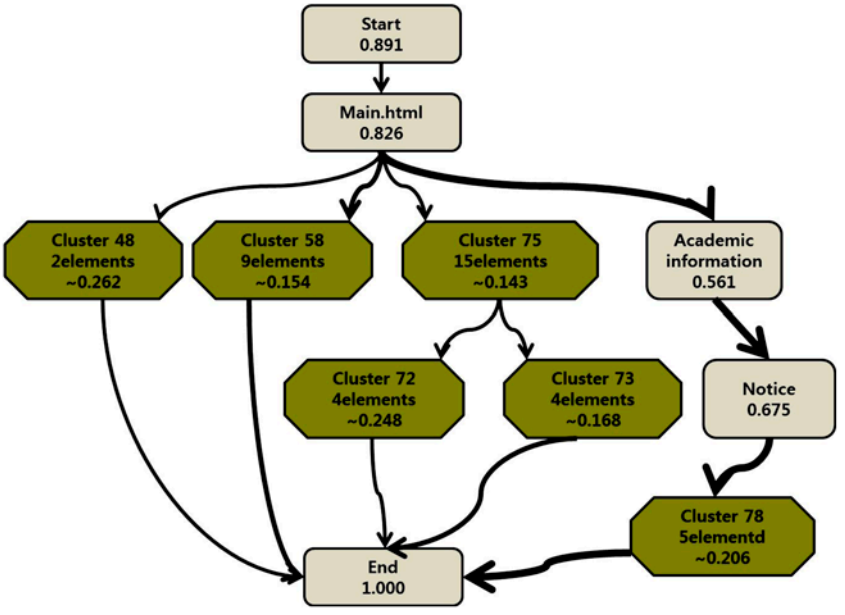


Figure 4. The results of fuzzy mining.

Table 3. Classification of the five major navigation patterns.

Pattern	Path
P1. Finding maps and directions	Main → Cluster48 → End
P2. Confirming academic information	Main → Cluster58 → End
P3. Investigating department information	Main → Cluster75→ Cluster 72 → End
P4. Checking future student information	Main → Cluster75→ Cluster 73 → End
P5. Posting and referring notices and news	Main → Academic information → notice → Cluster 78 → End

Detailed structure of the five navigation patterns is shown in Figure 5 and a brief explanation of each pattern is as follows. Figure 5(a) shows the pattern of navigating [Maps and Directions] webpage to find the route to the GNU campus and ISE department's building. Figure 5(b) shows the pattern of navigating [Academic information] menu. The path is divided into three sub-paths after confirming [Course information] webpage. Three sub-paths are confirming [link to other organisation], [Q&A] and [Recruit information] webpages. Figure 5(c) shows the pattern of investigating department information through [About ISE], [PR Media], [Curriculum] and [Faculty & Staff] menu. Figure 5(d) shows the pattern of navigating [Future student] webpage to check the general information of the ISE. Users who passed this path always clicked the [Site Map] menu firstly. Figure 5(e) shows the navigation pattern for posting and referring in [Notices] and [News] webpages. Right path of Figure 5(e) may be used by staff or assistant for writing and

modifying notices and news of ISE. Left path of Figure 5(e) may be used by students for referring its notices and news.

4.3. Examining possible improvements

As shown in Figure 6, the possible functional improvements of the ISE website are derived from an analysis of the five major navigation patterns as follows:

(1) Suggestion for P1: users usually click the [Maps and Directions] webpage or the link menu on the main website of ISE in order to find the route to

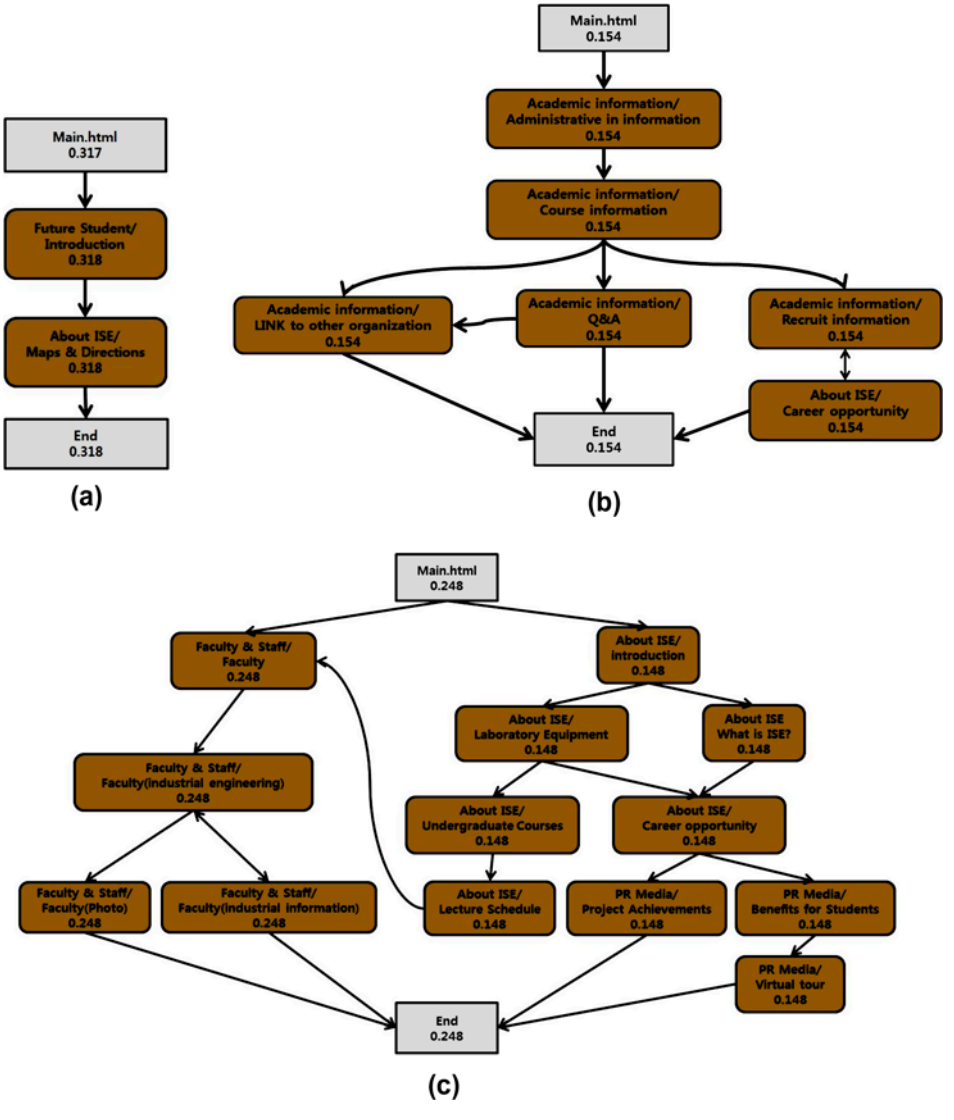
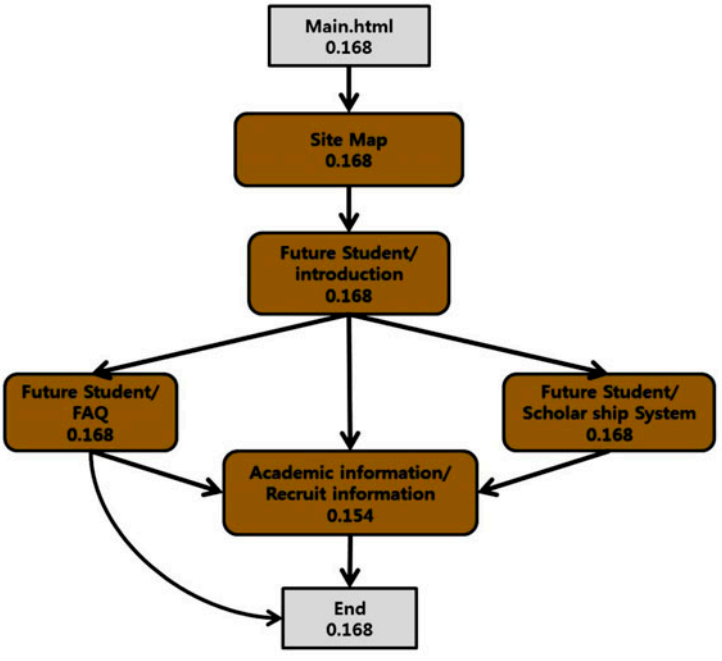
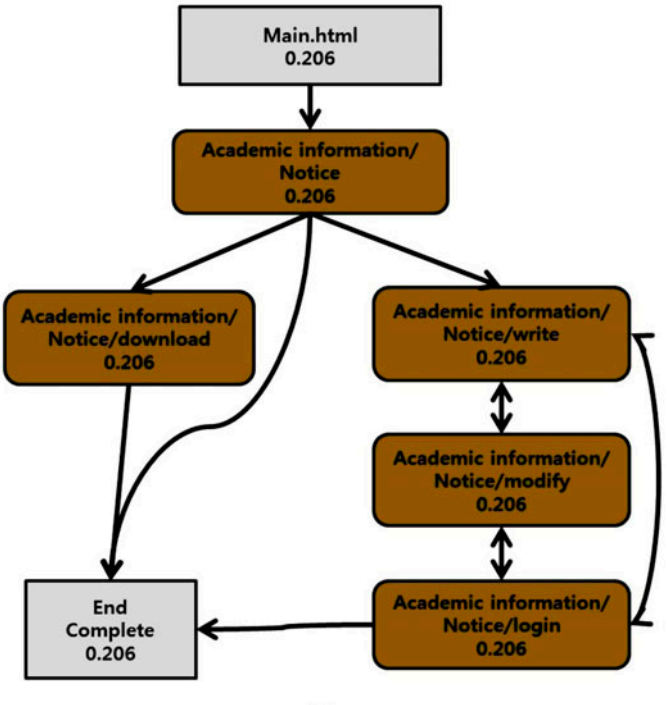


Figure 5. Detailed structure of the five navigation paths. (a) Finding maps and directions. (b) Confirming academic information. (c) Investigating department information. (d) Checking future student information. (e) Posting and referring notices and news.



(d)



(e)

Figure 5. (*Continued*).

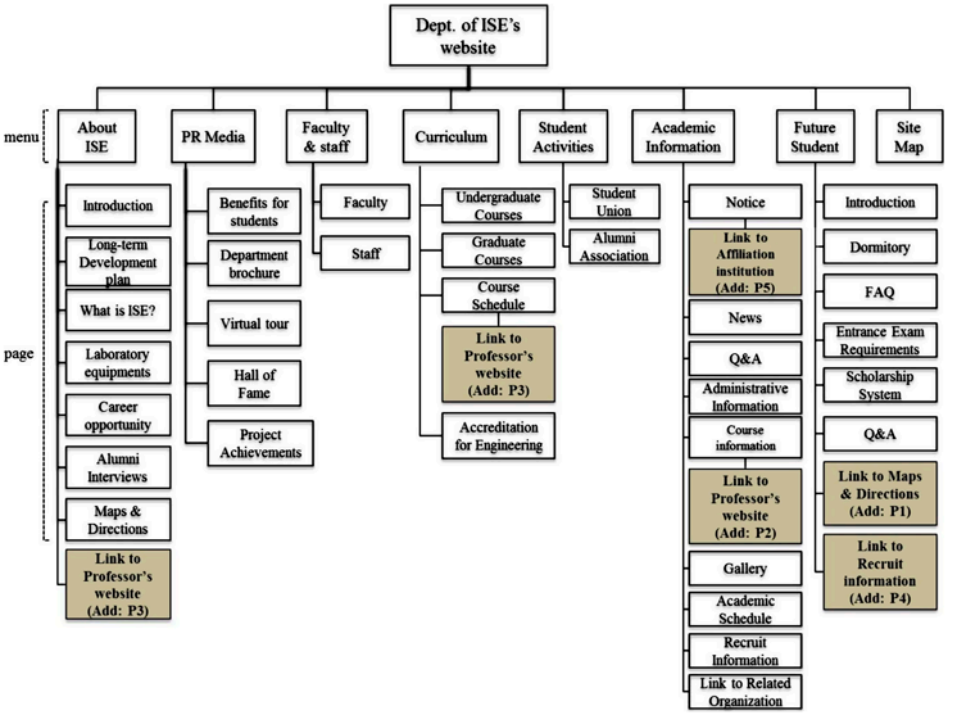


Figure 6. Functional improvements of the ISE website of GNU.

campus. However, from the perspective of future students and their parents who may use this information most often, there is no map information in the [Future student] menu. If a link to [Maps and Directions] webpage is added to the [Future student] menu, future students and their parents looking for a campus map will be able to get the information more conveniently.

(2) Suggestion for P2: the ISE's website has [Course information] webpage to provide lecture information. However, [Course information] webpage just provide general introduction on the lecture and does not provide specific information or lecture materials. On the other hands, most specific information of lecture or lecture materials exists in the personal website or blog of the professor (Churchill, 2011). Therefore, if a link through which users can access the professor's personal website is set up under [Course information] webpage, users will be able to access lecture materials easily.

(3) Suggestion for P3: users who seek [Course schedule] webpage under [Curriculum] menu also access [Faculty] webpage under [Faculty & Staff] menu. The reason why it has many points of access is that the professor's website is linked in [Faculty] webpage. Therefore, if the link to the professor's website is added as a sub-menu under [Course schedule] webpage, users may be able to obtain lecture information with ease. Also, the same link under [About ISE] menu may assist for users to easily access to lecture materials.

(4) Suggestion for P4: Users who check the future student information can be inferred that they are not familiar with the ISE's website because they

always clicked the [Site Map] menu firstly. For that reason, six webpages related to freshman information are positioned under [Future Student] menu as shown in Figure 2. However, these users checked the [Recruit information] webpage under [Academic information] menu at the same time. Therefore, the addition of the link to [Recruit information] webpage under [Future student] menu would be helpful for the users.

(5) Suggestion for P5: Among the various notices in [Academic information], one of the most frequently connected patterns was to access news of the affiliated institution of GNU. To access the affiliated institution from the ISE website after identifying the affiliated institution's notice, it is necessary to click [Academic information] menu → [Link to other organisation] webpage → (the hyperlink of the affiliated institution). Otherwise, it is inevitable to open the university's homepage again and then access sequentially the site-direct-go menu → affiliation category → link of the affiliation institution. To improve this eventful path, if the link to [Affiliation institution] which can directly access the desired affiliated institution's website is added under [Notice] webpage in [Academic information] menu, users will be able to connect easily through a link to the relevant affiliated institution. Figure 6 summarises the results of potential functional improvements of ISE's website.

5. Conclusion

In this paper, navigation pattern analysis of the university's website is proposed in order to increase its usability and efficiency. The proposed approach employs a process mining technique that is executed in consecutive steps: data collection and preprocessing; analysing the user's navigation path; and examining possible improvements. Heuristic mining and fuzzy mining are applied to extract the major navigation pattern of the university's website. A case study using event log data from the ISE Department website of GNU illustrates that the suggested approach is useful. Five major patterns of user navigation paths were found: (a) finding maps and directions; (b) confirming academic information; (c) investigating department information; (d) checking future student information; (e) posting and referring notices and news. The possible functional improvements for each navigation pattern were proposed, which are expected to enable users to find the desired webpage easily and to shorten the navigation route of ISE's website.

The potential contributions of this study can be summarised as follows: First, from a theoretical perspective, this study expanded the scope of data sources to analyse the navigation path of the university's website. Although survey data or an interview was usually formerly utilised, this study employed event log data to analyse the navigation path of the university. Second, from a methodological perspective, this study utilised not just a qualitative method but a quantitative approach in the form of process mining. This provided a systematic and automatic approach for analysing the navigation pattern of the university's website and finding potential design improvements. Third, with respect to its application, the proposed approach can be applied to various teaching and education fields that operate websites. The proposed approach is expected to aid the information system administrator of the university in designing their website and to make it easy for users to use the website of their university.

The proposed approach could be applied to some other fields in education and teaching where the analysis of navigation pattern is necessary for improving the usability of their website such as e-learning website and the university library's website. By analysing the navigation pattern of e-learning website, the design of e-learning website could be improved or the difficulty of the contents might be measured from remaining time. The university library's website could be improved in such fields as finding the most frequent navigation path or suggesting the rearrangement of menu.

Despite the meaningful implications presented here, this research has suffered from some limitations that require further research to overcome. Firstly, although preprocessing of event log data was conducted, both loss of necessary information and the existence of unnecessary information occur since identifying the suitability of all IP addresses was impossible. The method for refining event log data needs to be modified and improved. Secondly, the validity of this approach necessitates testing work by applying the suggestions to the real website of the university. Third, a performance index on the usability and efficiency of the university's website needs to be developed to evaluate the status and improvements quantitatively.

Notes on contributors

Kwan Hee Han is a professor in the Department of Industrial & Systems Engineering, Engineering Research Institute of Gyeongsang National University in Korea.

Boram Hwang is an engineer of AST Co., Ltd. He received BS degree in Industrial Engineering from Gyeongsang National University, Korea in 2012.

Jeong Hwan Jeon is a professor in the Department of Industrial & Systems Engineering, Engineering Research Institute of Gyeongsang National University in Korea.

References

Chang, C. K., & Chen, G. D. (2005). Discovering sequential concept patterns for behavioural diagnosis by interpreting web-page contents. *Innovations in Education and Teaching International, 42*, 27–41.

Chen, N. S., & Lin, K. M. (2008). Analysing users' satisfaction with e-learning using a negative critical incidents approach. *Innovations in Education & Teaching International, 45*, 115–126.

Choi, D. J., Hwang, M. G., & Kim, P. G. (2010, May). *User interests analyzing model using web log data*. Conference of Korea Institute of Information Technology, Gyeongki University, Korea.

Choi, E. J., & Ryoo, J. D. (2005). An evaluative analysis of service accessibility on university library homepage. *Journal of the Korean Society for Library and Information Science, 39*, 245–261.

Churchill, D. (2011). Web 2.0 in education: A study of the explorative use of blogs with a postgraduate class. *Innovations in Education and Teaching International, 48*, 149–158.

Eynon, R. (2008). The use of the world wide web in learning and teaching in higher education: Reality and rhetoric. *Innovations in Education and Teaching International, 45*, 15–23.

Flatley, M. E. (2005). Blogging for enhanced teaching and learning. *Business Communication Quarterly, 68*, 77–80.

Gunther, C. W., & van der Aalst, W. M. P. (2007). Fuzzy mining: Adaptive process simplification based on multi-perspective metrices. *Lecture Notes in Computer Science, 4714*, 328–343.

Güzeller, C. O. (2012). The effect of web-based portfolio use on academic achievement and retention. *Asia Pacific Education Review, 13*, 457–464.

Herrington, J., Sparrow, H., & Herrington, T. (2000, June/July). Instructional design guidelines for authentic activity in online learning units. In J. Bourdeau & R. Heller (Eds.), *Proceedings of ED-MEDIA 2000* (pp. 400–405). Montreal, Canada.

Jeong, H., & Biswas, G. (2008, June). Mining student behavior models in learning-by-teaching environments. In *Proceedings of the 1st International Conference on Educational Data Mining* (pp. 127–136). Montréal, Québec, Canada.

Kim, J. H., & Kim, S. E. (2004). A study of web navigation path in web log analysis of travel agency. *Journal of Tourism and Leisure Research, 16*, 209–226.

Kim, Y. W., Byen, J. W., Choi, S. H., Park, S. H., & Park, S. J. (2012). A usability analysis method of mobile application using user behavior logs. *Journal of Korea Institute of Information Scientists and Engineers, 39*, 91–98.

Lee, S. H., Kim, G. W., Joo, J. W., Lee, D. H., Kim, H. S., & Son, J. H. (2009, June). *BPMN process model extraction through log-based process mining*. Jeju: Korea Computer Congress.

Lee, S. I., Ryu, K. Y., & Song, M. S. (2012). Process improvement for PDM/PLM Systems by using process mining. *Transactions of the society of CAD/CAM Engineers, 17*, 294–302.

Luan, J. (2002). Data mining and its applications in higher education. *New Directions for Institutional Research, 113*, 17–36.

Merceron, A., & Yacef, K. (2010). Measuring correlation of strong symmetric association rules in educational data. In C. Romero, S. Ventura, M. Pechenizkiy, & R. S. J. d. Baker (Eds.), *Handbook of educational data mining* (pp. 245–256). Boca Raton, FL: CRC Press.

Mondi, M., Woods, P., & Rafi, A. (2007). Students' 'uses and gratification expectancy' conceptual framework in relation to E-learning resources. *Asia Pacific Education Review, 8*, 435–449.

Richardson, W. (2006). *Blogs, wikis, podcasts and other powerful web tools for classrooms*. Thousand Oaks, CA: Corwin Press.

Ritter, F. E., Freed, A. R., & Haskett, O. L. (2002). *Discovering user information needs: The case of university department websites*. Retrieved from http://acs.psu.edu/ reports/ ritterFH02.pdf

Romero, C., & Ventura, S. (2007). Educational data mining: A survey from 1995 to 2005. *Expert Systems with Applications, 33*, 135–146.

Saunders, K. (1997). Creating a homepage for classroom use with America online. *Journal of Education for Business, 73*, 69–71.

Shaeela, A., Tasleem, M., Raza, S., & Inayat, K. (2010). Data mining model for higher education system. *European Journal of Scientific Research, 43*, 24–29.

Son, Y. B., & Lee, E. B. (2001, August). *Study on the usability based on web mining in army college library homepage*. Conference of Korea society for information management, Seoul, Korea.

Song, M. S., Gunther, C. W., van der Aalst, W. M. P., & Jung, J. Y. (2008). Improving process mining with trace clustering. *Journal of the Korean Institute of Industrial Engineers, 34*, 460–469.

Van der Aalst, W. M. P. (2011). *Process mining: Discovery, conformance and enhancement of business processes*. Heidelberg: Springer.

Van der Aalst, W. M. P., Reigers, H. A., Weijters, A. J. M. M., van Dongern, B. F., Alves de Medeiros, A. K., Song, M. S., & Verbeek, H. M. W. (2007). Business process mining: An industrial application. *Information System, 32*, 713–732.

Van der Aalst, W. M. P., Schonenberg, M. H., & Song, M. (2011). Time prediction based on process mining. *Information systems, 36*, 450–475.

Wang, Q. (2008). A generic model for guiding the integration of ICT into teaching and learning. *Innovations in Education and Teaching International, 45*, 411–419.

Yu, W. F., She, H. C., & Lee, Y. M. (2010). The effects of web-based/non-web-based problem-solving instruction and high/low achievement on students' problem-solving ability and biology achievement. *Innovations in Education and Teaching International, 47*, 187–199.