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Editor’s Introduction

In this MISR issue, we are delighted to present four research papers. The summary of the four papers is as follows.

Iryna Pentina, Oksana Basmanova, Lixuan Zhang and Yuliya Ukis in their paper “Exploring the Role of Culture in eWOM Adoption” argue that given the explosive growth of customer review sites, the questions of why and how individuals use these services in different cultures, as well as whether eWOM exerts comparable influence in different cultures, warrant comprehensive research. The majority of studies in this emerging stream are conducted in a single-country context, and do not consider the impact of cultural environment on consumers’ eWOM dissemination, usage, or outcomes. To address this gap, their study compares eWOM attitudes and usage in the US (an established eWOM tradition within a developed market economy) and Ukraine (reflecting a relatively recent eWOM adoption in transitional political and institutional circumstances). They apply content analysis to in-depth interview transcripts obtained from 14 Ukrainian and 10 American consumers and compare differences in their usage and perceptions of online product reviews.

Chian-Son Yu in his paper “Antecedents and Consequences of Trust in Using Mobile Banking” states that because large amount of literature identifies trust as a crucial factor in the success of mobile banking, his study aims to illuminate the link from trust’s precursors, itself, to its outcome in the context of mobile banking. After surveying 356 potential customers and 247 current customers, the empirical results indicate that trust significantly influences potential users’ intention of current users’ commitment to use mobile banking. Regarding current customers, the results reveal that situational normality, structural assurance, knowledge-incurred trust, personal-incurred trust, and calculative-incurred trust, in that order of relative power, considerably affect trust belief in mobile banking. As for potential customers, the results reveal that personal-incurred trust, knowledge-incurred trust, structural assurance, and situational normality, in that order of relative influences, considerably affect trust belief in mobile banking. Given that the level of influence of trust’s antecedents in generating consumers trust varies across potential customers and current customers, banks are advised to strengthen different trust resources to meet the main concerns of different customer groups.

Olawale S. Adebayo, Morufu Olalere and Joel N. Ugwu in their paper “Implementation of N-Cryptographic Multilevel Cryptography Using RSA and Substitution Cryptosystem” explore that the purpose of cryptography is to ensure information is made in such a way that
an unintended individual will not have access to it or does not understand what it means when intercepted on a communication network. Some people try to defeat the purpose by using an extra ordinary means to harm the algorithmic construct of the system. The effort required for the purpose depends on the complexity of the algorithm and the number of cryptographic-ciphers used. Given that effort required to cryptanalyze ciphertext in making one-algorithmic transformation is $x$-effort, then the effort required when $n$-algorithmic transformation was done is $nx$-effort. Their paper implements multilevel encryption algorithm using two ciphers; RSA and Substitution ciphers with one transformation each. It presents an algorithmic paradigm which can be implemented using any programming language. It simplifies the stages used for both encryption and decryption, presenting each stage in a sequential order.

Harshadkumar B. Prajapati and Vipul A. Shah in their paper “Development of an In-House Grid Testbed Supporting Scheduling and Execution of Scientific Workflows” argue that researchers working in Grid workflow scheduling need a real Grid environment to produce the results of experiments. However, many interested researchers of academic institutes may not be able to produce experimental results due to unavailability of a required testbed at their institutes. Their article addresses an important challenge of developing an in-house Grid testbed that supports workflow scheduling and execution. The article proposes the architectural design of the in-house testbed and then concisely presents chosen software tools, their understanding, installation, configuration, and the testing related to the implementation of the testbed. Furthermore, the article presents the methodology of performing experiments on the testbed. The in-house Grid testbed is implemented using open-source, freely available, and widely used software components. In addition, the testbed allows one to produce a real Grid scenario of varying bandwidth values by emulating the network characteristics among the Grid-sites of the testbed. The article addresses testing of all the internal components of the testbed and the integrations for their proper inner working. The article also provides testing and demonstration of workflow scheduling and execution. The presented Grid testbed can easily be replicated or adapted and its deployment can guide researchers in carrying out real experimentation for their research purposes.

As the final note, we would like to thank all the authors and reviewers for their collaborative efforts to make this issue possible. It is our sincere wish that this journal become an attractive knowledge exchange platform among information systems researchers. Last but not least, to our loyal readers around the world, we hope you find the contents of the papers useful to your work or research.
Dr. Eldon Y. Li
Editor-in-Chief and University Chair Professor

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Exploring the Role of Culture in eWOM Adoption

Iryna Pentina¹, Oksana Basmanova², Lixuan Zhang³, Yuliya Ukis⁴

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ABSTRACT: Given the explosive growth of customer review sites, the questions of why and how individuals use these services in different cultures, as well as whether eWOM exerts comparable influence in different cultures, warrant comprehensive research. The majority of studies in this emerging stream are conducted in a single-country context, and do not consider the impact of cultural environment on consumers’ eWOM dissemination, usage, or outcomes. To address this gap, this study compares eWOM attitudes and usage in the US (an established eWOM tradition within a developed market economy) and Ukraine (reflecting a relatively recent eWOM adoption in transitional political and institutional circumstances). We apply content analysis to in-depth interview transcripts obtained from 14 Ukrainian and 10 American consumers and compare differences in their usage and perceptions of online product reviews.


1. Introduction

The importance of social influence in the process of shopping and in the consequent purchase-related decision-making has been firmly established in the marketing literature (Bearden & Etzel, 1982). It is rooted in the socially prominent role of possessions, long recognized as symbols of status (Veblen, 1898) and as material representations of a person’s identity (Belk, 2010). Involving peers in the process of purchase selection boosts consumer self-confidence (Bearden et al., 2001) and provides greater legitimacy to the choices made (Burnkrant & Cousineau, 1975). The persuasive superiority of word-of-mouth (WOM) in comparison to paid marketing communications is largely attributed to the trust and/or liking experienced by customers towards their friend and family (Katz & Lazarsfeld, 1965).

In addition to utilizing product and brand information from these strong-tie connections, shoppers increasingly rely on the opinions of unfamiliar fellow consumers in
the digital space (electronic WOM or eWOM) (Ludwig et al., 2013). According to a recent industry report, 90% of global consumers read and rely on online product reviews for their decision-making (Channel Advisor, 2011). The growing popularity and influence of online customer reviews stems from their perceived objectivity due to apparent independence from commercial communication sources, and from their potential to represent multiple and diverse perspectives (Godes & Mayzlin, 2004). Other advantages to consumers who utilize eWOM include its instant, ubiquitous and nearly permanent availability, amenability to search, interactivity (encouraging content co-creation), and transparency (Lindgreen et al., 2013).

Given the mounting impact of eWOM on sales revenues and corporate reputations (Griffith, 2011), companies are raising their expenditures on eWOM campaigns and paid review and rating postings. Gartner estimates that by 2014, 10-15% of all reviews posted online will be paid for, either by cash, coupons, or promotions (Gartner, 2012). This practice can potentially lead to damaged reputations and litigations and undermine customer reliance on online reviews and ratings, reducing their access to objective product information and increasing information asymmetry. Therefore, better understanding of what factors affect the adoption and credibility of eWOM information, and ultimately influence shopping outcomes, is imperative for marketers designing communication strategies for the digital age.

An emergent stream of research in the areas of eWOM and online consumer reviews has addressed consumer motivations to post (Alexandrov et al., 2013; Hennig-Thurau et al., 2004) and seek (Goldsmith and Horowitz, 2006) online reviews. Considerable attention has also been given to the source and message characteristics that affect online reviews’ perceived usefulness and credibility (Cheung et al., 2009; Li & Zhan, 2011; Park & Lee, 2008; Purnawirawan et al., 2012). Additionally, several recent studies have assessed the effects of eWOM on new product adoption (López & Sicilia, 2013) and sales (Davis & Khazanchi, 2008; Zhang et al., 2013). Other issues that received attention in the extant literature include the moderating roles of product (Sen & Lerman, 2007), social (Steffes & Burgee, 2009), and personality (Gupta & Harris, 2010) factors in the eWOM’s influence on purchasing decisions. Typically, the majority of studies in this emerging stream are conducted in a single-country (mostly economically developed) context, and do not consider the potential impact of cultural environment on consumers’ eWOM dissemination, usage, or outcomes (Kim et al., 2011). However, the role of culture in affecting inter-personal communication cannot be underestimated (Hall, 1976). Existing marketing literature has documented cultural influences on consumers’ beliefs and attitudes towards traditional (Durvasula et al., 2001) and online advertising (Roberts & Ko, 2001), cautiousness in shopping behaviors (Marinov et al., 2002), patterns of online media use (Chau et al., 2002), and word-of-mouth activities (Lam et al., 2009). These
significant findings imply that cross-cultural differences may exist in consumers’ eWOM-related behaviors and attitudes, pointing at an important research gap unaddressed by previous studies.

Given the explosive world-wide growth of customer review sites and their potential use for global marketing, the questions of why and how individuals use these services in different cultures, as well as whether eWOM exerts comparable influence in different cultures and economic conditions, warrant comprehensive research. To address this gap, the current study compares eWOM attitudes and use behaviors in the US (an established eWOM tradition within a developed market economy) and Ukraine (reflecting a relatively recent eWOM adoption in transitional political and institutional circumstances). We apply the qualitative method of content analysis to in-depth interview transcripts obtained from 14 Ukrainian and 10 American consumers and compare differences in their usage and perceptions of online product reviews.

In the remainder of the paper, we describe prior relevant research, identify the gaps addressed by the current study, report the study’s methods and discuss its results. Further, managerial implications are derived from the findings, and directions for future research in the area are proposed.

2. Related literature

The existing literature on the role of online product reviews in affecting consumer attitudes and purchase intentions has mainly focused on the following issues:

- motivations to use reviews in the process of online product information;
- message characteristics affecting persuasiveness and helpfulness of online reviews;
- product, user and source characteristics as moderating variables in the relationship between message characteristics and online shopping outcomes.

A number of existing studies address characteristics of online shoppers who adopt eWOM. As a result of surveying 220 US marketing students, Bailey (2005) proposed that consumers seek eWOM to obtain additional product information, to seek assurance or reassurance in product choice, as a primary source of information, because they came across it by chance, and because they were referred to it by others. Goldsmith and Horowitz (2006) also investigated motivations for seeking others’ opinions online. After surveying 309 undergraduate business students in the US they identified the following eight factors that prompt consumers to use eWOM: risk reduction, “because others do
it”, to secure lower prices, to easily access information, by accident, “because it is cool”, because of offline (e.g., TV) stimulation, and to get pre-purchase information.

The previous studies on the role of message-related attributes have focused on the usefulness, credibility and persuasiveness effects of positive/negative framing of a single review (Park & Lee, 2009), ratios of positive to negative reviews in a set (Doh and Hwang, 2009; Purnawirawan et al., 2012), star rating valence (Cheung et al., 2009; Yang et al., 2012), emotional vs. factual presentation modes (Park & Lee, 2008), message sidedness (Cheung et al., 2009), and number, volume, order, and sequence of differently valenced reviews (Park & Lee, 2008; Purnawirawan et al., 2012; Yang et al., 2012).

In terms of message characteristics, comprehensiveness and relevance were identified as the most important factors affecting eWOM adoption in the US (Cheung et al., 2008). A survey of Chinese consumers found that argument strength, source credibility, and confirming users’ prior product beliefs positively affected eWOM message credibility (Cheung et al., 2009). Additionally, recommendation consistency and aggregate ratings were found to increase eWOM credibility, with greater effect of recommendation consistency for low-involvement consumers. No valence or message sidedness effects, however, were identified (Cheung et al., 2009). Recently, Siering and Muntermann (2013) examined Amazon.com’s product reviews for different categories of search and experience goods and identified message factors that affect their perceived helpfulness. According to the authors, review depth, statements of product quality and number of total votes on its helpfulness are positively related to review helpfulness. Review extremity and experiential product classification are negatively related to review helpfulness rating. In addition, positive review sentiment increases helpfulness for search goods, while negative review sentiment increases perceived helpfulness of reviews about experience goods.

In an experiment involving Korean students, Doh and Hwang (2009) manipulated ratios of positive and negative messages in message sets. They found that, in general, more positive sets showed greater eWOM effects than negative sets. However, customer involvement and prior product knowledge moderated the relationships, with high-involvement and high-knowledge consumers showing lower outcomes for all positive sets. Purnawirawan et al. (2012) conducted an experiment with Belgian university students, in which ratios of positive-negative-neutral reviews of a resort and their sequence in eight-review sets were manipulated. The results showed that unbalanced (positive or negative) review sets are perceived as more useful than balanced sets. In addition, positive wrapping in positively balanced sets and negative wrapping in negatively balanced sets improved their perceived usefulness. Park and Lee (2009) found that negative messages have greater effect on eWOM persuasion than positive messages. Yang, Kim, and Amblee (2012) used secondary data from Korean movie box office revenue to show that eWOM
valence is significantly related to revenue only in the case of non-mainstream movies. For mainstream movies, only the volume of eWOM had positive effect on revenues.

Through an observational study and two experiments, Sen and Lerman (2007) showed that product type moderates the effect of review valence, with review readers exhibiting a negativity bias for utilitarian products only. Readers of negative utilitarian product reviews attribute them to product-related attributes and consider them more useful than positive product reviews. On the contrary, users of negative hedonic product reviews are more likely to attribute the negative opinions expressed to the reviewer’s internal (and not product-related) motives, finding these reviews less useful than positive reviews. Park and Lee (2009), in an experiment involving Korean undergraduate students, found that the impact of negative eWOM is greater for experience vs search goods and the website reputation has a stronger impact on eWOM effects for experience vs search products. Davis and Khazanchi (2008) used data from a multi-product e-commerce firm and found that product category and the volume of postings moderated the relationship between eWOM and sales. Senecal and Nantel (2004) considered the impact of product (search vs. experience), source (personal vs. impersonal) and website (seller vs. shopping engine vs. opinion site) characteristics on consumers’ online choices in an experiment. They concluded that reviews by impersonal recommender systems and those for experience products were more influential in consumer product choice. The type of the website did not make a significant influence on this choice.

Park and Lee (2008) reported that low-involvement consumers use the number of reviews offered as the product’s popularity measure and rely on it as a heuristic to increase purchase decision-making. On the other hand, high-involvement consumers who are willing to elaborately process all information, when exposed to large numbers of reviews experience information overload and decreased purchase intentions. Gupta and Harris (2010), in an experiment with 198 US students, discovered that users with lower Need for Cognition (NFC) used eWOM as a decision-making heuristic and were influenced more by the number of recommendations than by their arguments, which led to suboptimal product choices. Those high in NFC, on the contrary, paid more attention to the review arguments and were more motivated to process the message, which resulted in more optimal product selections. Zhu and Zhang (2010) used ratings data from the video game industry to examine how product and consumer characteristics moderate the influence of online consumer reviews on product sales. They found that online reviews are more influential for less popular games and for consumers who have greater experience with the product.

Li and Zhan (2011) considered combined effects of message and source characteristics on eWOM adoption using data from 1,793 Amazon Kindle reviews. They
identified message comprehensiveness, argument strength, positive valence and source expertise as significant influencers of eWOM adoption. In a follow-up experimental study, they noted that the positive message valence increased eWOM adoption only for consumers with prior positive product attitude and for those with prior negative product attitude, but high product involvement.

In summary, the reported findings identify a great number of variables that play a role in utilizing eWOM and in increasing its persuasiveness. However, the majority of reported results lack consistency and comprehensiveness, probably due to wide diversity of the contexts of the investigations, including product types and categories, sample composition, and different cultural environments. In an attempt to explore the role of cultural context in addressing some of the mentioned inconsistencies, the current study utilizes a qualitative approach and compares in-depth interview transcripts with broad range of online consumers in different cultures.

2.1 The role of culture

Defined as “shared perceptions of the social environment” (Triandis, 1972), culture incorporates language, art, customs, habits, knowledge, morals, and beliefs acquired by a person in the process of socialization (Tylor, 1958). It affects information processing and evaluation and has an influence on each individual’s self-construal and group identification (Markus & Kitayama, 1991). It also has an impact on the mechanism of cognitive stereotyping that leads to classification and evaluation of self and others in terms of personality traits and similarity, shaping trust, credibility, attitudes, and behaviors of individuals. People from different cultures choose different messages and channels to communicate (Kale, 1991). Additionally, several prior studies identified differences in social relationships and trust antecedents among cultures (Kim, 2005; Pavlou & Chai, 2002; Smith et al., 2007).

Research in online communication contexts suggests possible influence of value orientations on online shoppers’ motives and usage patterns, which underscores the possibility of unique findings in the Ukrainian context. For example, a comparative study of motives to join the online social network Facebook found that Korean students were “seeking social support” and “seeking information” (Kim et al., 2011), while students in the US joined Facebook for “entertainment” and “convenience”. The authors suggested that in low-context cultures (like the US), users join social networks for superficial impression management and casual relationships, while in high-context cultures (like Korea), the motives are based on the needs to form long-term relationships and define one’s group identity. Another comparative Korean-American study (Lewis & George, 2008) identified a positive effect of cultural trait of masculinity on deceptive behavior in online social networks.
While no studies to date have compared eWOM motivations and usage patterns in different cultures, existing findings confirm important role of culture in the frequency and intensity of traditional WOM (Money et al., 1998). In particular, individualism is likely to facilitate the spread of positive WOM to out-groups (weak ties), masculinity intensifies WOM sharing with in-groups, and uncertainty avoidance is negatively associated with in-group (strong-tie) WOM. Additionally, customers in high uncertainty-avoidance cultures were found less likely to complain or engage in negative WOM (Liu et al., 2001).

Boasting a high level of education and literacy and classified as an emerging market by the World Trade Organization, the United Nations, and the World Bank, Ukraine is representative of other former Soviet countries in economic transition. With the GDP per capita estimated at $3,867 in 2012 (World Bank, 2012) and the human development index of 0.740 in 2012 (United Nations Development Programme, 2012), Ukraine is undergoing a prolonged complex transition to a free-market, consumption-based economic model. While numerous business and marketing practices effective in Western economies are being implemented by businesses in Ukraine, the low Internet penetration (34% in Ukraine and 81% in US) prevents a mass scale use of Internet for shopping (International Telecommunication Union, 2012). However, the emerging middle class exhibits great interest and involvement with the Internet as both informational and commercial communication channel. The few existing research studies of Ukrainian marketing and marketing in former Soviet countries focus on the specifics of advertising perceptions (Wells, 1994), stages and managerial approaches to adopting marketing in Eastern Europe (Akimova, 1997; Marinov et al., 1993), as well as the effect of marketing adoption on firm performance (e.g., Akimova, 2000; Brooksbank, 1991). Done more than a decade ago they can’t be a reliable source for characteristics of consumers’ online behavior in post-Soviet-Union countries as they underwent great institutional and infrastructure changes since that time. E.g., Internet penetration rate in Ukraine has grown almost 50 times -- from 0.72% in 2000 to 33.7% in 2012 (International Telecommunication Union, 2012).

Contemporary Ukrainian culture has been influenced by both the traditional communal values of the 17~19th centuries, quasi-collectivist features of the oppressive Soviet regime, and the growing individualistic tendencies borrowed from Western pluralism (Badan, 2011). As a result, it can be presently characterized as “tribal”, where loyalty and interdependence are concentrated at the family (or small in-group) level and competition and hedonism are practiced in the society in general (Leaptrott, 2003). Dominated by the Russian communal culture through the 17~19th centuries and by the Soviet ideology for a large part of the 20th century, Ukrainian population has distinctive preferences for the personality traits desirable in communication (Badan, 2011). According to Katz (2006), Ukrainians are “generally serious people who rarely smile and may seem stern.” They appreciate sincerity, firmness and dependability in their counterparts (Katz, 2006). Based
on this, the message and source characteristics affecting Ukrainians’ perception of trust
and credibility of online reviews may differ from those in the US (Robins et al., 2000).

Since communication media patterns and motives are shaped by cultural contexts
(Kim et al., 2011), and cultural dimensions of individualism, masculinity, uncertainty
avoidance and high/low communication context influence WOM patterns (Lam et al.,
2009), we anticipate that Ukrainian eWOM users are driven by a somewhat different
set of motivations and exhibit different use patterns than those in the developed Western
countries. The present research endeavors to explore motivations to use eWOM, its usage
and persuasiveness factors in Ukraine, and to compare them to those in the US.

3. Method

This paper employed qualitative interviews and the content analysis methods,
designed to explore potential attitudinal and behavioral differences among online review
users in different cultural environments. This approach follows the grounded methodology
method (Strauss & Corbin, 1998), seeking insights for little researched phenomena at the
initial research stages. The total sample was comprised of twenty-four respondents from
a wide range of backgrounds and demographic segments (Tables 1 and 2). While the
demographic and socio-economic spread of respondents was large, the data were analyzed
without the regard to these individual characteristics, keeping in line with the purpose of
discovery (Zaltman et al., 1982).

Fourteen in-depth interviews (15 to 30 minutes each) with Ukrainian online review
users and ten interviews with online opinion users in the US were conducted with the
goal to elicit information about the respondents’ motivations, uses and perceptions of the
eWOM process. An interview guide, developed from existing empirical studies, was used
to ensure consistency across all the interviews. The interview scripts were identical for
both countries but done in the native language of respondents to avoid language-related
errors. Correct English-Ukrainian translation was assured by two bilingual authors. All
interviews were recorded without objection. Two trained graduate students (in the US)
and professor and two trained graduate students (in Ukraine) conducted the interviews and
applied probing questions to complement the interview guide and uncover rich insights
and unexpected examples.

The Ukrainian sample was 57% male and ranged in age from 17 to 57 years old,
with the average age of 33.3 years old. 86% of respondents had a bachelor’s or higher
degrees. Table 1 shows the respondents’ demographic information. Ukrainians spend on
the Internet a median of 5 hours per day (min = 1.5, max = 9), 64% of them named home
as the major place of Internet access, 43% named work, 21% of respondents use mobile
devices for online access. In terms of annual household income, the sample was equally split into $7,500 to $11,250 range and $3,750 to $7,500 range, reflecting the average Ukrainian annual of $4,537 in 2012. The sample characteristics are representative of the Ukrainian Internet user who is characterized by younger age and higher socio-economic status that facilitates access to wireless and mobile communications (Kostenko, 2011).

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Age</th>
<th>Education</th>
<th>Occupation</th>
<th>Income, $ Per Year</th>
<th>Access to the Internet</th>
<th>Time Spent in the Internet, Hours Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alona</td>
<td>21</td>
<td>B.A.</td>
<td>Student</td>
<td>7,500 ~ 11,250</td>
<td>Home, mobile</td>
<td>3</td>
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<tr>
<td>Svetlana</td>
<td>22</td>
<td>B.A.</td>
<td>Accountant</td>
<td>3,750 ~ 7,500</td>
<td>Work, mobile</td>
<td>8</td>
</tr>
<tr>
<td>Anna</td>
<td>27</td>
<td>M.A.</td>
<td>Marketing associate</td>
<td>3,750 ~ 7,500</td>
<td>Work</td>
<td>8</td>
</tr>
<tr>
<td>Helen</td>
<td>32</td>
<td>M.A.</td>
<td>Sales manager</td>
<td>3,750 ~ 7,500</td>
<td>Work</td>
<td>2.5</td>
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<tr>
<td>Natalia</td>
<td>41</td>
<td>Ph.D.</td>
<td>Professor</td>
<td>7,500 ~ 11,250</td>
<td>Home</td>
<td>7</td>
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<tr>
<td>Nataly</td>
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<td>M.S.</td>
<td>Retired economist</td>
<td>3,750 ~ 7,500</td>
<td>Home</td>
<td>3.5</td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roman</td>
<td>17</td>
<td>High school</td>
<td>Schoolboy</td>
<td>3,750 ~ 7,500</td>
<td>Home</td>
<td>3</td>
</tr>
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<td>Maxim</td>
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<td>Some college</td>
<td>Student</td>
<td>3,750 ~ 7,500</td>
<td>Home, mobile</td>
<td>6</td>
</tr>
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<td>Vlad</td>
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<td>B.A.</td>
<td>Student</td>
<td>3,750 ~ 7,500</td>
<td>Home</td>
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<tr>
<td>Igor</td>
<td>28</td>
<td>M.S.</td>
<td>Technical support</td>
<td>7,500 ~ 11,250</td>
<td>Work</td>
<td>9</td>
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<tr>
<td>Alexey</td>
<td>36</td>
<td>Ph.D.</td>
<td>Professor, IT consultant</td>
<td>7,500 ~ 11,250</td>
<td>Home, work</td>
<td>6</td>
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<td>7,500 ~ 11,250</td>
<td>Home</td>
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<td>50</td>
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<td>Home</td>
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<tr>
<td>Ivan</td>
<td>54</td>
<td>Ph.D.</td>
<td>Research director</td>
<td>7,500 ~ 11,250</td>
<td>Work</td>
<td>1.5</td>
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</tbody>
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### Table 2  Participant Profile: US

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Age</th>
<th>Education</th>
<th>Occupation</th>
<th>Income, $ Per Year</th>
<th>Access to the Internet</th>
<th>Time Spent in the Internet, Hours Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Francine</td>
<td>22</td>
<td>Vocational school</td>
<td>Cosmetology &amp; retail</td>
<td>$65,000</td>
<td>Home</td>
<td>5</td>
</tr>
<tr>
<td>Jennifer</td>
<td>30</td>
<td>Associates degree</td>
<td>Banking procurement</td>
<td>$78,000</td>
<td>Work</td>
<td>5</td>
</tr>
<tr>
<td>Patricia</td>
<td>57</td>
<td>B.A.</td>
<td>Finance</td>
<td>$85,000</td>
<td>Home</td>
<td>4</td>
</tr>
<tr>
<td>Susan</td>
<td>24</td>
<td>B.A., almost MBA</td>
<td>Student, photography</td>
<td>$25,000</td>
<td>Mobile</td>
<td>16</td>
</tr>
<tr>
<td>Donna</td>
<td>31</td>
<td>Some college</td>
<td>Operator, engineer</td>
<td>$150,000</td>
<td>Home, mobile</td>
<td>3</td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wesley</td>
<td>33</td>
<td>MBA</td>
<td>Student, software sales</td>
<td>$50,000</td>
<td>Home, work, school</td>
<td>4</td>
</tr>
<tr>
<td>Daniel</td>
<td>27</td>
<td>BFA</td>
<td>Graphic designer</td>
<td>$45,000</td>
<td>Home, work, mobile</td>
<td>6</td>
</tr>
<tr>
<td>James</td>
<td>23</td>
<td>Some college</td>
<td>Retail</td>
<td>$30,000</td>
<td>Home</td>
<td>9</td>
</tr>
<tr>
<td>Eric</td>
<td>58</td>
<td>B.A.</td>
<td>Engineering</td>
<td>$80,000</td>
<td>Home</td>
<td>2</td>
</tr>
<tr>
<td>Jacob</td>
<td>60</td>
<td>M.A.</td>
<td>Engineering manager</td>
<td>$120,000</td>
<td>Work</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The US sample was 50% male, ranging in age from 22 to 60 years old, with the average age of 37 years old. 60% of respondents reported having a bachelor’s or higher degrees. Table 2 shows the respondents’ demographic information. US participants spent online a median of 5.5 hours per day (min = 0.5, max = 16), with 70% naming home as their major place of Internet access, 40% indicating work, and 30% predominantly using mobile devices for online access. US respondents’ median annual income is $72,800 (min = $25,000, max = $150,000). These demographics reflect the characteristics of an average American online shopper, with equal proportion of males and females, higher educational level, and the diverse age and income spread as identified by Pew Research Center (Pew Research Center, 2013).
4. Results

The interview recordings were transcribed verbatim as soon as possible by paid transcribers in each country. One coder was assigned in each country to identify emergent themes, using both fully inductive and based on preliminary work classification (Brown et al., 2007). Two bi-lingual authors (inter-judge reliability index 89%) then compared the results in both countries. Table 3 summarizes the differences in eWOM motivations, usage, and persuasiveness drivers between the two cultures.

Table 3 Comparing eWOM Motivations and Usage Patterns in the US and Ukraine

<table>
<thead>
<tr>
<th>Emerging Themes</th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>eWOM motivations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product-related</td>
<td>Product price, importance, significance</td>
<td>Product price, importance, significance</td>
</tr>
<tr>
<td>Consumer-related</td>
<td>Need to validate preexisting wants, needs and desires</td>
<td>Need for information (add to information available from salespeople, little prior knowledge, others may know more)</td>
</tr>
<tr>
<td></td>
<td>Personal relevance, product interest, involvement</td>
<td></td>
</tr>
<tr>
<td>Search process-related</td>
<td>Need to find best option (fit)</td>
<td>To reduce consideration set</td>
</tr>
<tr>
<td></td>
<td>Easy availability, convenience</td>
<td>Ease of getting eWOM info compared to traditional WOM</td>
</tr>
<tr>
<td></td>
<td>Habitual use</td>
<td></td>
</tr>
<tr>
<td><strong>eWOM information sought</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product categories</td>
<td>All products and services</td>
<td>Home appliances, electronics, cell phones</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Apparel and cosmetics</td>
</tr>
<tr>
<td>Subjective opinions</td>
<td>Ratings, opinions, points of view</td>
<td>Travel</td>
</tr>
<tr>
<td></td>
<td>Common themes among reviewers</td>
<td>Ratings, opinions, points of view</td>
</tr>
<tr>
<td></td>
<td>Majority opinions from those who experienced the products</td>
<td>Common themes among reviewers</td>
</tr>
<tr>
<td>Objective facts, specifications and details</td>
<td>Store locations (online and retail)</td>
<td>Majority opinions from those who experienced the products</td>
</tr>
<tr>
<td></td>
<td>Customer service</td>
<td>Customer service quality</td>
</tr>
<tr>
<td></td>
<td>Product/service quality</td>
<td>Product/service quality</td>
</tr>
<tr>
<td></td>
<td>Product pictures</td>
<td>Advantages and drawbacks of product, problems encountered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technical specifications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Usability, length of service</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Effectiveness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warranty, size, delivery options</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assortments, prices, contacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Model comparison</td>
</tr>
</tbody>
</table>
### Table 3  Comparing eWOM Motivations and Usage Patterns in the US and Ukraine (continued)

<table>
<thead>
<tr>
<th>Categories of eWOM sources</th>
<th>US motives</th>
<th>Ukraine motives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Search engines</strong></td>
<td>- To broaden range of opinions</td>
<td>- To broaden range of opinions</td>
</tr>
<tr>
<td></td>
<td>- To compare prices</td>
<td>- To compare prices</td>
</tr>
<tr>
<td><strong>Category specific review sites (e.g., Yelp)</strong></td>
<td>- Due to great number of users</td>
<td>- Due to great number of users</td>
</tr>
<tr>
<td></td>
<td>- Access to expert reviews</td>
<td>- Access to expert reviews</td>
</tr>
<tr>
<td></td>
<td>- Narrow focus on product category</td>
<td>- Narrow focus on product category</td>
</tr>
<tr>
<td></td>
<td>- More objective (more perspectives represented) than selling sites</td>
<td>- More objective (more perspectives represented) than selling sites</td>
</tr>
<tr>
<td></td>
<td>- More frequent and recent updates</td>
<td>- More frequent and recent updates</td>
</tr>
<tr>
<td><strong>Selling sites (e-retail and manufacturing)</strong></td>
<td>- Ability to compare prices</td>
<td>- Ability to compare prices</td>
</tr>
<tr>
<td></td>
<td>- Large reviewer base</td>
<td>- Large reviewer base</td>
</tr>
<tr>
<td></td>
<td>- Prior buying experience, familiarity with the site</td>
<td>- Prior buying experience, familiarity with the site</td>
</tr>
<tr>
<td></td>
<td>- High traffic and number of users</td>
<td>- High traffic and number of users</td>
</tr>
<tr>
<td></td>
<td>- Convenience and simplicity (located near the product)</td>
<td>- Convenience and simplicity (located near the product)</td>
</tr>
<tr>
<td></td>
<td>- Good established reputation</td>
<td>- Good established reputation</td>
</tr>
<tr>
<td><strong>Discussion sites (blogs, forums, communities)</strong></td>
<td>- Objectivity</td>
<td>- Objectivity</td>
</tr>
<tr>
<td></td>
<td>- No links to businesses</td>
<td>- No links to businesses</td>
</tr>
</tbody>
</table>

### Determinants of website trustworthiness

<table>
<thead>
<tr>
<th>Trust criteria</th>
<th>US reasons</th>
<th>Ukraine reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Prior usage (by self or friends)</td>
<td>- Prior usage (by self or friends)</td>
<td></td>
</tr>
<tr>
<td>- Objectivity (diversity, number of reviews, no connection to seller)</td>
<td>- Objectivity (diversity, number of reviews, no connection to seller)</td>
<td></td>
</tr>
<tr>
<td>- Expertise and narrow focus</td>
<td>- Expertise and narrow focus</td>
<td></td>
</tr>
<tr>
<td>- Reputation (size, traffic)</td>
<td>- Reputation (size, traffic)</td>
<td></td>
</tr>
<tr>
<td>- Convenience, simplicity</td>
<td>- Convenience, simplicity</td>
<td></td>
</tr>
<tr>
<td>- Frequent and current updates</td>
<td>- Frequent and current updates</td>
<td></td>
</tr>
<tr>
<td>- Objective and trusted</td>
<td>- Objective and trusted</td>
<td></td>
</tr>
<tr>
<td>- Relevant (product category focus)</td>
<td>- Relevant (product category focus)</td>
<td></td>
</tr>
</tbody>
</table>

### Determinants of reviewer credibility
Table 3  Comparing eWOM Motivations and Usage Patterns in the US and Ukraine

(continued)

<table>
<thead>
<tr>
<th><strong>Style</strong></th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Readable, knowledgeable</td>
<td>- Readable, knowledgeable</td>
<td>- Readable, knowledgeable</td>
</tr>
<tr>
<td>- Few or no mistakes (grammar, vocabulary)</td>
<td>- Few or no mistakes (grammar, vocabulary)</td>
<td>- Few or no mistakes (grammar, vocabulary)</td>
</tr>
<tr>
<td>- Punctuation, paragraph structure</td>
<td>- Punctuation, paragraph structure</td>
<td>- Punctuation, paragraph structure</td>
</tr>
<tr>
<td>- Educated (expert) language</td>
<td>- Educated (expert) language</td>
<td>- Educated (expert) language</td>
</tr>
<tr>
<td>- Length and presence of details</td>
<td>- Length and presence of details</td>
<td>- Length and presence of details</td>
</tr>
<tr>
<td>- Non-standard, not template-based</td>
<td>- Non-standard, not template-based</td>
<td>- Non-standard, not template-based</td>
</tr>
<tr>
<td>- Two-sided (positive and negative)</td>
<td>- Two-sided (positive and negative)</td>
<td>- Two-sided (positive and negative)</td>
</tr>
<tr>
<td>- Logical and competent</td>
<td>- Logical and competent</td>
<td>- Logical and competent</td>
</tr>
<tr>
<td>- “whining” vs legitimate complaints</td>
<td>- “whining” vs legitimate complaints</td>
<td>- “whining” vs legitimate complaints</td>
</tr>
<tr>
<td>- Similar experience in usage, buying, preferences</td>
<td>- Similar experience in usage, buying, preferences</td>
<td>- Similar experience in usage, buying, preferences</td>
</tr>
<tr>
<td>- Unemotional, objective</td>
<td>- Unemotional, objective</td>
<td>- Unemotional, objective</td>
</tr>
<tr>
<td>- Not related to wrong product use or individual service issues</td>
<td>- Not related to wrong product use or individual service issues</td>
<td>- Not related to wrong product use or individual service issues</td>
</tr>
<tr>
<td>- Not abstract: need details and analysis</td>
<td>- Not abstract: need details and analysis</td>
<td>- Not abstract: need details and analysis</td>
</tr>
</tbody>
</table>

**Drivers of persuasiveness**

<table>
<thead>
<tr>
<th><strong>Valence</strong></th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Positive majority for reassurance</td>
<td>- Positive majority for reassurance: need 70 ~ 72% of positive reviews</td>
<td>- Positive majority for reassurance: need 70 ~ 72% of positive reviews</td>
</tr>
<tr>
<td>- Would not consider products with majority of negative reviews</td>
<td>- Would not consider products with majority of negative reviews: if 50% or more negative -- would not buy</td>
<td>- Would not consider products with majority of negative reviews: if 50% or more negative -- would not buy</td>
</tr>
<tr>
<td>- Valence is contingent on issues and their importance for buyer</td>
<td>- Valence is contingent on issues and their importance for buyer</td>
<td>- Valence is contingent on issues and their importance for buyer</td>
</tr>
</tbody>
</table>

**Order of reading reviews**

<table>
<thead>
<tr>
<th><strong>Valence</strong></th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>- First read most recent or most helpful, or in the order posted, then move to negative only</td>
<td>- First read most recent or most helpful, or in the order posted, then move to negative only</td>
<td>- First read most recent or most helpful, or in the order posted, then move to negative only</td>
</tr>
<tr>
<td>- If inconsistent: focus on negative, mainly whether negative evaluations concern important issues</td>
<td>- If inconsistent: focus on negative, mainly whether negative evaluations concern important issues</td>
<td>- If inconsistent: focus on negative, mainly whether negative evaluations concern important issues</td>
</tr>
</tbody>
</table>

**Number of reviews read**

<table>
<thead>
<tr>
<th><strong>Valence</strong></th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Up to 20 (lack of time, involvement, interest, boredom); if inconsistent: read more</td>
<td>- Up to 20 (lack of time, involvement, interest, boredom); if inconsistent: read more</td>
<td>- Up to 20 (lack of time, involvement, interest, boredom); if inconsistent: read more</td>
</tr>
<tr>
<td>- Contingent on price</td>
<td>- Contingent on price</td>
<td>- Contingent on price</td>
</tr>
</tbody>
</table>

**Content**

<table>
<thead>
<tr>
<th><strong>Valence</strong></th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Positive majority for reassurance</td>
<td>- Positive majority for reassurance: need 70 ~ 72% of positive reviews</td>
<td>- Positive majority for reassurance: need 70 ~ 72% of positive reviews</td>
</tr>
<tr>
<td>- Would not consider products with majority of negative reviews</td>
<td>- Would not consider products with majority of negative reviews: if 50% or more negative -- would not buy</td>
<td>- Would not consider products with majority of negative reviews: if 50% or more negative -- would not buy</td>
</tr>
<tr>
<td>- Valence is contingent on issues and their importance for buyer</td>
<td>- Valence is contingent on issues and their importance for buyer</td>
<td>- Valence is contingent on issues and their importance for buyer</td>
</tr>
<tr>
<td>- First read most recent or most helpful, or in the order posted, then move to negative only</td>
<td>- First read most recent or most helpful, or in the order posted, then move to negative only</td>
<td>- First read most recent or most helpful, or in the order posted, then move to negative only</td>
</tr>
<tr>
<td>- If inconsistent: focus on negative, mainly whether negative evaluations concern important issues</td>
<td>- If inconsistent: focus on negative, mainly whether negative evaluations concern important issues</td>
<td>- If inconsistent: focus on negative, mainly whether negative evaluations concern important issues</td>
</tr>
</tbody>
</table>

**Number of reviews read**

<table>
<thead>
<tr>
<th><strong>Valence</strong></th>
<th>US</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Up to 20 (lack of time, involvement, interest, boredom); if inconsistent: read more</td>
<td>- Up to 20 (lack of time, involvement, interest, boredom); if inconsistent: read more</td>
<td>- Up to 20 (lack of time, involvement, interest, boredom); if inconsistent: read more</td>
</tr>
<tr>
<td>- Contingent on price</td>
<td>- Contingent on price</td>
<td>- Contingent on price</td>
</tr>
</tbody>
</table>
4.1 Motivations to utilize eWOM, information sources and content sought

From the interviews, the product categories for which a representative Ukrainian consumer seeks online reviews include home appliances and electronics, cell phones, travel, apparel and cosmetics. While a few American respondents specifically mentioned electronics, the majority did not specify individual product categories, implying virtually unlimited use of available online opinions for a broad range of product and service categories.

The most frequently cited motivation to search for and read the opinions of other consumers online for both the Ukrainian and the US samples was the perceived significance of the purchase manifested through its high price or personal importance. Respondents used phrases like “big purchase”, “expensive”, and “not a trivial or low price item” to describe what would prompt them to read online customer reviews. Interestingly, other reasons mentioned for consulting the reviews differed between the two cultural samples. Such personal reasons as the need for validation or confirmation of preexisting wants, needs and desires, and personal interest (involvement) in the product category were only mentioned by the US respondents. The need for information, on the other hand, was only indicated by the Ukrainian shoppers. They explained that the reviews posted by others added to the product information provided by salespeople, and that they consulted the reviews because others may know more, or when they had little prior knowledge of the product in question. Finally, task-related motivations for referring to online reviews were also different for each sample. Ukrainian consumers mentioned the need for help with decision making and with reducing their product consideration set, they also stated that ease of obtaining eWOM compared to requesting product information from friends and acquaintances was a driver for their eWOM use. American consumers pointed out the need to find the best product option (fit), habitual use of review sites, and easy and convenient availability of customer reviews as reasons for utilizing eWOM.

The kind of information sought about the products was generally similar for both samples. It contained a) subjective emotions and opinions of other people about the product/service, including points of view, ratings, common themes, and majority opinions among the reviewers and b) objective details about the products. The latter category comprised product/service quality, customer service levels, store locations (US only) and pictures (US only). In addition, the objective information for Ukrainian consumers also included problems encountered, advantages and drawbacks of the product, technical specifications, usability and length of service, effectiveness, warranty, delivery, model comparison, assortments, prices, and sizes.

Generally, respondents in both countries looked for eWOM information on a wide range of websites and did their best to obtain reviews from multiple sources. These
websites can be classified into: category-specific review sites (e.g., cnet.com, yelp.com, tripadvisor.com for the US consumers), selling sites (e-retailers and manufacturers), and discussion sites (forums, blogs, and communities unaffiliated with commercial entities). Frequently, the starting point for these websites was a search portal (Google for the US and Yandex.ru for Ukrainian consumers).

Respondents in both countries stated that they utilize a wide variety of sources to obtain a more objective picture representing multiple perspectives. The incentives for utilizing category-specific sites included perceived expertise of reviewers, great number of users, narrow product focus, and greater perceived objectivity compared to seller sites, as well as frequent and more recent updates. It should be noted that the number of such sites mentioned by Ukrainian consumers was significantly lower compared to those identified by the US respondents. The reasons mentioned for using eWOM on selling sites were: the possibility to compare prices, large reviewer base, customer prior experience buying from the site and familiarity with it, high traffic and number of users, convenience and simplicity of reviews located near the products, and good reputation. Finally, user groups and discussion sites were considered superior due to their perceived independence from businesses. Search engines were used by both samples as a gateway to the review sites to obtain exposure to more diverse available opinion outlets, and for price comparisons. In general, the criteria for utilizing a particular eWOM website coincided for both samples and included: convenience/simplicity, frequent and current updates, trustworthiness and objectivity, as well as relevance to the product.

4.2 Website trustworthiness and reviewer credibility

As a major criterion used in selecting review websites and adopting individual reviewer postings, trust and credibility were discussed in depth by respondents in both countries. Surprisingly, we found no differences in the determinants of trust in review websites or credibility of individual reviews between Ukrainian and American responses. Respondents trusted the websites that were: previously used by them or their friends (for purchasing or reading reviews), objective (either due to the high volume and diversity of posted reviews, or independence from sellers), expert or narrowly focused, and/or those with proven reputation (because of their size, traffic volume, or prior use).

The credibility of individual review postings was judged by their style and content. In particular, respondents in both samples indicated that they trusted reviews that were intelligible, readable, with fewer mistakes, well-structured and punctuated. They preferred reviews from the sources that were “well spoken,” educated, expert, competent, knowledgeable and smart. They considered reviews more credible if they were meaningful, logical, reasonably long, containing details, not based on standard templates, “not too flowery”, and presenting both negative and positive sides. Review users in both
countries differentiated between reviewers who were “whiners” from those who had legitimate complaints, and preferred to receive information from those who were similar to them in experience, buying preferences and usage behaviors. They favored unemotional and objective messages, containing details and analysis instead of abstract descriptions, and did not consider negative opinions related to customer service problems or failures due to wrong usage.

4.3 Drivers of online review persuasiveness

Three major variables appeared to influence the persuasiveness of online reviews in both countries, although to a different extent. Specifically, message valence, order in which reviews were read, and the number of reviews read were mentioned as important determinants of eWOM influence. Greater part of respondents favored products, for which the majority of reviews were positive. According to them, it provided “reassurance,” with some respondents not even willing to consider products for which the majority of reviews were negative. Several Ukrainian respondents gave more specific details on acceptable valence proportions: they stated that they would buy products with $70 \sim 72\%$ of positive reviews. A lower weight of positive reviews would alert them to consider specific product attributes receiving negative opinions in more detail. If 50% of reviews or more are negative, Ukrainian consumers would most likely not buy the product at all.

In terms of the review order, respondents in both countries read reviews either in the order they are posted on the site, or preferred to start with most recent or most helpful reviews. After reading a few reviews in any of the above orders, the majority of respondents would focus on negative reviews to identify specific issues warranting attention. Customers paid more attention to identifying individual problems when they encountered inconsistencies among the reviews. In particular, they attempted to identify whether the negative evaluations pertain to the delivery, product, seller, or price. Based on the priority of the negatively reviewed issues for their purchase, customers used or discarded the reviews in subsequent decision-making.

Finally, the number of reviews sufficient to affect a shopping decision differs between the samples. American respondents on average read up to 20 reviews before making a decision to buy or abandon the product. They cite lack of time, boredom, lack of interest/involvement, and lower cost as factors reducing the number of reviews consulted. However, if the reviews appear inconsistent, they would read more reviews and/or visit other review websites. Ukrainian respondents report visiting several sites and reading on average 40-70 reviews before making a decision, although this number is also contingent on the price of the product.
5. Discussion

The findings of this study reveal that while online shoppers in Ukraine and the US exhibit similar behavioral patterns in using and evaluating the credibility of eWOM, important differences exist between the two samples in (1) the dominant reasons to read others’ reviews, (2) the information sought in these reviews, and (3) the number of total, positive, and negative reviews sufficient to influence purchasing decisions. Whereas these differences may be explained by the relatively recent availability of eWOM in Ukraine, it is also possible that such cultural characteristics as high-context communication tradition and higher degree of uncertainty avoidance can affect usage patterns and attitudes to eWOM in Ukraine.

While representatives of both cultures admit that they are more likely to refer to others’ opinions online for expensive and personally important items, there are differences in their motivations to utilize eWOM.

Specifically, the social aspect of shopping (confirmation and validation of one’s product selection) is only prominent among American respondents, while the need for functional product information is predominant in the Ukrainian responses. This finding is corroborated by the differences in the depth of information sought, with Ukrainians naming many more functional and performance-related evaluation aspects they want to see in online reviews than the American respondents. This greater focus on factual, product performance-related aspect of eWOM use can tentatively be explained by differences in the cultural communication context dominating each country. It is possible that a higher-context culture in Ukraine does not encourage extensive sharing of subjective, non-factual information with strangers in a transparent manner, limiting the available information to technical specifications of the product and its performance. It is also possible that more tribal and closed social structure discourages trust in the subjective opinions of unknown others, resulting in greater reliance on factual information. An alternative explanation may be the greater abundance of product information in sources other than consumer-generated content sites in the US compared to Ukraine due to Ukraine’s later entrance in the area of internet shopping. In this case, American consumers would be more interested in the valence of others’ experiences with the product, and less -- with the objective specifications that could be easily obtained elsewhere. However, this reasoning alone does not account for the absence of the need for social validation by other online consumers in the Ukrainian data.

Another eWOM use motivation mentioned by the American, but not Ukrainian, respondents was involvement with and personal interest in the product category (e.g., golf clubs). This motivation was not recorded for the Ukrainian sample. A possible
explanation can be lack of specialized in-depth product information in the Ukrainian internet space that has not achieved full scale of content marketing and co-creation due to low internet penetration rates. This is supported by very few mentions of the available category-specific websites offering product information. It is also possible that Ukrainian consumers mostly use online reviews in the initial stages of their shopping process, and use other communication sources (such as strong-tie personal connections) to share their interests and validate their opinions for the product categories of special interest, reflecting the high-context communication tradition.

The finding that Ukrainians utilize eWOM to help with such functional tasks as reducing consideration set and purchase decision-making, while American respondents seek to identify a better fitting option (model) of the product, may also signal that each sample uses eWOM at different stages of online shopping. It is possible that Ukrainian consumers turn to online opinions at the initial stage of their shopping process, when they have less information about the product and find it difficult to obtain such information from the strong-tie connections. American shoppers, on the other hand, may turn to online reviews after they have located the product in several outlets and compared the prices before making a final narrow selection among available models.

While the criteria for the review website trustworthiness (prior use, objectivity, diversity, no commercial affiliation, expertise and reputation) and individual review credibility (readability, competence, two-sidedness, objectivity, focus on detail, and source similarity) were similar for both samples, drivers of review persuasiveness were more specific in the Ukrainian interviews. Respondents in both samples preferred products with the majority of positive reviews. However, for Ukrainians, 70% or more of the available reviews had to be positive to influence a purchase decision. Several respondents indicated that 50% or more of negative reviews would most likely determine their decision not to buy the product. No specific proportions were indicated by the American consumers. Indicating more specific cut-off points for the reviews to influence purchase decisions may reflect lower uncertainty tolerance by the Ukrainian sample, implying a possibility of the underlying uncertainty avoidance cultural trait. This desire to react to the majority opinion was also evident in the greater number of reviews the Ukrainian consumers had to read on average before making a decision (40-70) compared to the American respondents (up to 20).

Both samples reported similar behaviors in selecting the order in which they read the reviews. The respondents were equally likely to start reading the reviews, regardless of their valence (or star ratings), in one of the three patterns: in the order they were posted, newest first, or most helpful first. After getting the initial impression, both American and Ukrainian consumers moved on to the negatively valenced reviews to identify specific
product issues that were considered problematic. After weighing the importance of the problematic issues, they decided to include or exclude the negative reviews in their decision process.

6. Conclusion and implications

This study contributes to the existing literature on consumer attitudes towards eWOM and its usage patterns by identifying a potential impact of culture on the dominant motivations to utilize online product reviews, the type of information sought for in these reviews, and the amount of reviews sufficient for affecting a purchase decision. The qualitative content analysis of in-depth interviews with a broad cross-section of Ukrainian and American online shoppers reveals that online product reviews exert significant influence on shopping processes and buying decisions in both countries. However, Ukrainian consumers utilize eWOM mainly to receive objective product information that includes technical specifications and performance reports, while American respondents rely on others’ opinions mainly to validate their pre-existing preferences and to satisfy curiosity about product categories of interest. Additionally, online shoppers in Ukraine need online reviews to reduce their shopping consideration set and assist in decision-making, while American consumers use eWOM to help with finding a better fit (option) of the selected product. Further, a greater number of positive/negative reviews are required for a Ukrainian consumer to make a purchase decision compared to a US online shopper, although the trustworthiness and credibility criteria are very similar for each country.

These findings imply that in cultures, characterized by the dominance of high-context communication tradition, weak-tie eWOM environments (where participants are unknown) encourage sharing of objective information. On the contrary, both objective and subjective information is exchanged in low-context cultures, with subjective information being more clearly articulated and therefore better capable of performing a diagnostic role. It is also possible that consumer online review websites are used in high-context cultures only at the initial stages of the shopping process, with strong-tie connections becoming more influential closer to the purchase decision. This can explain the dominance of information-related motivation for eWOM use, as well as the task of consideration set reduction in the Ukrainian sample, compared to the needs for social validation and more focused option selection in the US sample. The fact that a greater number of positive or negative reviews is necessary for Ukrainian consumers to consider or reject the purchase compared to the US respondents may be a manifestation of greater uncertainty avoidance and lower tolerance for ambiguity that has traditionally characterized societies with extensive social programs and safety nets.
These initial findings imply that companies employing eWOM marketing techniques should utilize different strategies in diverse cultures and at different stages of the online shopping process. For example, companies operating in high-context cultures should encourage consumers to post product reviews with more objective product information, possibly providing a list of decision criteria to help reduce the number of available products and brands, and solicit greater numbers of online opinions. Based on a qualitative analysis of a small sample of cross-cultural consumers, the results of this study should be generalized with caution. Future research should rigorously test the potential explanations of differential eWOM attitudes and behaviors for different cultural traditions offered in this paper.

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Exploring the Role of Culture in eWOM Adoption


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Antecedents and Consequences of Trust in Using Mobile Banking

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ABSTRACT: Because large amount of literature identifies trust as a crucial factor in the success of mobile banking, this study aims to illuminate the link from trust’s precursors, itself, to its outcome in the context of mobile banking. After surveying 356 potential customers and 247 current customers, the empirical results indicate that trust significantly influences potential users’ intention to use mobile banking and current users’ commitment to use mobile banking. Regarding current customers, the results reveal that situational normality, structural assurance, knowledge-incurred trust, personal-incurred trust, and calculative-incurred trust, in that order of relative power, considerably affect trust belief in mobile banking. As for potential customers, the results reveal that personal-incurred trust, knowledge-incurred trust, structural assurance and situational normality, in that order of relative influences, considerably affect trust belief in mobile banking. Given that the level of influence of trust’s antecedents in generating consumers trust varies across potential customers and current customers, banks are advised to strengthen different trust resources to meet the main concerns of different customer groups.

KEYWORDS: Trust, Mobile Banking, Trust Antecedents, Trust Consequences, Mobile Services.

1. Introduction

With the rapid growth and advances in smartphone, tablet computer, and telecommunication technology, businesses have forged substantial commercial opportunities by offering mobile financial services to customers. Motivated by such trends, banks have committed large investment to providing mobile banking services for their customers in recent years. However, the growth and usage of mobile banking services depends not only on technological advances but also on consumer confidence in the provided services (Weber and Darbellay, 2010). This requisite confidence explains why many academic studies and industry reports have discussed and determined the essential of trust for people considering the use of mobile banking (Akhlap & Ahmed, 2013; Dimitriadis & Kyrezis, 2008; Grabner-Krauter & Faullant, 2008; Luo et al., 2010; Munoz-Leiva et al., 2010; Sanchez-Franco, 2009; Yap et al., 2010; Yousafzai et al., 2005, 2009; Zhao et al., 2010; Zhou, 2012a, 2012b).
An extensive review of the literature indicated that current research predominantly uses technology adoption theories such as technology acceptance model (TAM), innovation diffusion theory (IDT), and the unified theory of acceptance and use of technology (UTAUT) to examine the adoption of mobile banking (Zhou, 2011). By contrast, studies focusing on trust to explore the usage of mobile banking are relatively few. Based on literature review, only seven papers focusing on trust in the context of mobile banking. In other words, although considerable research has identified trust as a crucial factor that affects individual willingness to use mobile banking (Akhlap & Ahmed, 2013; Munoz-Leiva et al., 2010; Yousafzai et al., 2005, 2009; Zhao et al., 2010; Zhou, 2012a, 2012b), relevant research mostly focuses on the consumer’s adoption of mobile banking rather than on the consumer’s trust for using mobile banking. Moreover, these few studies focusing on consumer trust in mobile banking examined the precursors, outcomes, and dimensions of trust, separately, without taking a holistic view.

Therefore, to address this deficiency, the study investigated the connection amongst antecedents, dimensions, and consequences of trust within a single research structure. This deficiency exists not only in mobile banking but also within the wider context of e-commerce, making the findings culled from this empirical study applicable to other e-commerce services. The remainder of the paper is organized as follows: Section 2 reviews the related literature; Section 3 presents hypothesis proceeding from the literature review; Section 4 describes the survey design and sampling; Section 5 is dedicated to data analysis and hypothesis testing; Section 6 discusses the academic and practical implications derived from the study; and, finally, Section 7 presents the conclusion and addresses the limitations of this study.

2. Literature review

Through reviewing challenges associated with mobile banking development in Korea, Kim et al. (2009) hypothesized that trust will significantly affect individual intention to use mobile banking and a person’s trust is significantly shaped by four types of trust-inducing forces: structural assurances, perceived relative benefits, personal propensity to trust, and firm reputation. Kim et al. (2009) considered the level of initial trust is a function of diverse forces. After gathering 192 valid samples from cellular-phone users of three large mobile telecoms in South Korea, Kim et al. (2009) performed a two-step analysis and discovered that relative benefits, personal propensity to trust and structural assurances significantly influence initial trust, which in turn considerably affects usage intention in mobile banking.

Considering that extensive literature used technology adoption model (TAM) to
explain a consumer’s acceptance of new information technology and services, Gu et al. (2009) reviewed TAM-based research and trust-based TAM research. By referring to the study of Gefen et al. (2003), they then integrated the extended TAM and the trust-based TAM to construct a theoretical framework. Using a web-based survey to collect 910 usable samples from a private Bank in South Korea, Gu et al. (2009) empirically identified situational normality, structural assurances, and calculative-based trust as salient predecessors of trust, and found that trust significantly affects both the perceived usefulness and intention to use mobile banking.

By incorporating the integral role of trust and risk into TAM and theory of planned behavior (TPB), Luo et al. (2010) followed up on the work of McKnight et al. (2002) to present a theory-based research structure in which trust was distinguished from antecedents of trust. They considered disposition to trust as an antecedent of structural assurance, structural assurance is an antecedent of perceived risk, and trust is an antecedent of perceived risk, performance expectancy, and behavioral intention. By surveying 122 undergraduate students at an U.S. university in 2008, they empirically concluded that disposition to trust considerably influences structural assurance, which in turn significantly affects perceived risk. Notably, their empirical results revealed that trust have not a positive effect on consumer intention to adopt mobile banking, which is inconsistent to other literature.

Considering that mobile banking is a technological innovation and relatively new electronic delivery channel, Lin (2011) presented a research structure based on IDT and trust research. After obtaining 368 respondents from a questionnaire-based survey, Lin (2011) divided them into two groups: potential customers and repeat customers. For both types of customers, her study empirically revealed that two of three aspects of knowledge-based trust significantly affect consumer attitudes toward mobile banking. These two aspects are perceived competence and perceived integrity. Another aspect, named perceived benevolence, not significantly influences consumer attitudes. Notably, Lin (2011) simply considered knowledge-based trust as trust itself rather than its predecessors. That is, in contrast to other literature that deems knowledge-based trust as an antecedent of trust which contains perceived competence, integrity and benevolence, Lin (2011) did not distinguish trust itself from its antecedents. Additionally, her study relied heavily on IDT rather than on an investigation of the links between trust’s antecedents and its consequences regarding the adoption of mobile banking.

Concerning previous research not solely highlighting on trust, Zhou (2011) conducted a study focusing on the effect of trust in the adoption of mobile banking. Through literature review, Zhou (2011) discovered that predecessors of initial trust regarding electronic commerce can be grouped into three categories. The first category
is related to mobile banking website (i.e., information quality and system quality), the second category is associated with the consumers (i.e., their propensities to trust), and the third category is associated with the bank itself (i.e., reputation, image, and the scale). By adopting the concept of Siau and Shen (2003), who divided mobile trust into initial trust and continuous trust, Zhou (2011) posited that antecedents of initial trust on mobile banking consist of information quality, system quality, trust propensity, and structural assurance, and that the consequences of initial trust are perceived usefulness and usage intention. Zhou (2011) then collected 210 valid responses at two service halls of China Mobile and empirically concluded that hypotheses in his study are all supported.

In addition to considering the factor of trust, Zhou (2012a) argued that people may be reluctant to adopt mobile banking because it does not possess a flow experience. In his study, flow experience is defined as a holistic sensation that people feel when they are completely involved in an activity. Thus, even when customers believe that mobile banking is safe, they may still be unwilling to use mobile banking due to lacking of an engaging experience (Zhou, 2012a). Thus, by integrating both a trust and flow experience, Zhou (2012a) posited that antecedents of trust are structural assurance, ubiquity, perceived ease of use, and personal innovativeness, whereas the outcomes of trust are flow experience and usage intention, in which flow experience impacts usage intention. Through randomly collecting 200 valid responses at two service halls of two main mobile telecom operators in China, Zhou (2012a) identified that, among four antecedents of trust, only personal innovativeness does not significantly impact trust. Additionally, trust considerably influences flow experience and the intention to use mobile banking. By adapting research from Lee et al. (2007), Zhou (2012a) characterized the flow experience in terms of focus, control, and pleasure.

Through reviewing extant research on mobile banking, Zhou (2012b) found that existing research is often based on information technology adoption theories and the process of trust development has seldom been explored. Considering the high perceived risk on mobile banking, Zhou (2012b) contended that trust is crucial to facilitate the adoption and usage of mobile banking. Accordingly, Zhou (2012b) put efforts on studied trust and hypothesized six factors as the antecedents of trust. By collecting 240 student respondents from a university located in an eastern China city, Zhou (2012b) empirically concluded that information quality, service quality, system quality, reputation, structural assurance, and self-efficacy considerably influence the trust development.

Building on the above literature review, this study discovered that to date only seven studies related to trust in mobile banking exist, and each study investigated trust from different disciplines and no consistent research structure existed among them. The
literature review also indicated that the findings of some studies were inconsistent with those of others, and the antecedents of trust were posited in different ways. However, five of seven studies consistently considered usage intention as a consequence of trust. Table 1 summarizes the empirical findings of seven mobile banking studies on precursors and outcomes of trust.

**Table 1** The Summary of Trust Research on Mobile Banking

<table>
<thead>
<tr>
<th>Authors (Study in which Country)</th>
<th>Sample Size</th>
<th>Empirically Verified Antecedents of Trust</th>
<th>Empirically Verified Consequences of Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim et al. (2009) (South Korea)</td>
<td>192</td>
<td>Perceived Relative Benefits, Propensity to Trust, Structural Assurance</td>
<td>Perceived Usefulness, Usage Intention</td>
</tr>
<tr>
<td>Gu et al. (2009) (South Korea)</td>
<td>910</td>
<td>Situational Normality, Structural Assurance, Calculative-based Trust</td>
<td>Usage Intention</td>
</tr>
<tr>
<td>Luo et al. (2010) (U. S.)</td>
<td>122</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Lin (2011) (Taiwan)</td>
<td>368</td>
<td>None</td>
<td>Attitude toward Using mobile banking</td>
</tr>
<tr>
<td>Zhou (2011) (China)</td>
<td>210</td>
<td>Information Quality, System Quality, Propensity to Trust, Structural Assurance</td>
<td>Perceived Usefulness, Usage Intention</td>
</tr>
<tr>
<td>Zhou (2012a) (China)</td>
<td>200</td>
<td>Structural Assurance, Ubiquity, Flow, Usage Intention</td>
<td>None</td>
</tr>
<tr>
<td>Zhou (2012b) (China)</td>
<td>240</td>
<td>Information Quality, Service Quality, System Quality, Reputation, Structural Assurance, and Self-efficacy</td>
<td>None</td>
</tr>
</tbody>
</table>

In contrast to mobile banking that enables users to access banking services by using mobile devices without temporal and spatial constraints, online banking, also known as Internet banking, enables users to access banking services by logging on to a bank Web site via an Internet network without time limitation. Accordingly, both mobile banking and online banking are regarded as subsets of e-banking (Maroofi et al., 2013), both achieve similar purposes and provide similar functions (Laforet & Li, 2005; Laukkanen, 2007; Sripalawat et al., 2011; Suoranta & Mattila, 2004), and mobile banking is typically considered as an extension of online banking (Maroofi et al., 2013; Yao & Zhong, 2011). Given that trust research on mobile banking is limited, this study further reviewed such research on Internet banking. Table 2 summarizes the empirical findings of 17 online banking studies on precursors and outcomes of trust.
### Table 2  The Summary of Trust Research on Internet Banking

<table>
<thead>
<tr>
<th>Authors (Study in which Country)</th>
<th>Sample Size</th>
<th>Empirically Verified Antecedents of Trust</th>
<th>Empirically Verified Consequences of Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mukherjee and Nath (2003) (India)</td>
<td>510</td>
<td>Shared Values, Communication, Opportunistic Behavior</td>
<td>Commitment</td>
</tr>
<tr>
<td>Kim and Prabhakar (2004) (U. S.)</td>
<td>266</td>
<td>Propensity to Trust, Structural Assurance, Word-of-mouth Referrals</td>
<td>Adoption of Internet Banking</td>
</tr>
<tr>
<td>Yousafzai et al. (2005) (U. K.)</td>
<td>64</td>
<td>Structural Assurance</td>
<td>None</td>
</tr>
<tr>
<td>Kassim and Abdulla (2006) (Qatar)</td>
<td>276</td>
<td>Shared Values, Communication, Opportunistic Behavior</td>
<td>Commitment</td>
</tr>
<tr>
<td>Flavian et al. (2006) (Spain)</td>
<td>633</td>
<td>Bank image</td>
<td>Adoption of Internet Banking</td>
</tr>
<tr>
<td>Vatanasombut et al. (2008) (U.S.)</td>
<td>4,667</td>
<td>Shared values, communication, perceived security, perceived quality</td>
<td>Customer Retention</td>
</tr>
<tr>
<td>Grabner-Krauter and Faullant (2008) (Austria)</td>
<td>381</td>
<td>Propensity to trust, Familiarity with the Internet</td>
<td>Consumer Attitude to Use e-banking</td>
</tr>
<tr>
<td>Dimitriadis and Kyrezis (2008) (Greece)</td>
<td>762</td>
<td>Disposition to Trust, and Reputation</td>
<td>None</td>
</tr>
<tr>
<td>Sanchez-Franco (2009) (Spain)</td>
<td>456</td>
<td>Satisfaction</td>
<td>Commitment</td>
</tr>
<tr>
<td>Zhao et al. (2010) (China)</td>
<td>540</td>
<td>None</td>
<td>Perceived Risk Perceived Competence</td>
</tr>
<tr>
<td>Munoz-Leiva et al. (2010) (Spain)</td>
<td>1,983</td>
<td>Institution-based Trust, Situational Normality</td>
<td>None</td>
</tr>
<tr>
<td>Yap et al. (2010) (Australia)</td>
<td>202</td>
<td>Bank Reputation, Website Quality and Security</td>
<td>Willingness to Use e-banking</td>
</tr>
<tr>
<td>Kantsperger and Kunz (2010) (Germany)</td>
<td>232</td>
<td>Propensity to Trust, Satisfaction</td>
<td>Loyalty</td>
</tr>
<tr>
<td>Aldas-Manzano et al. (2011) (Spain)</td>
<td>330</td>
<td>None</td>
<td>Loyalty</td>
</tr>
</tbody>
</table>
3. Hypothesis development

The previous literature review reveals that a variety of terms are used as trust’s antecedents shown in Tables 1 and 2, different studies used different names and perspectives to define the antecedents of trust, and no consistent research structure exists. By contrast, the common points among literature are that precursors of trust can be categorized on the basis of consumers and banks. Table 1 shows that precursors related to the bank comprise structural assurance, situational normality, information quality, system quality, service quality, and bank reputation. Table 2 shows that antecedents of trust related to the bank involve opportunistic behavior, structural assurance, bank image, institution-based trust, situational normality, and website quality and security.

As for the antecedents related to consumers, Table 1 reveals perceived relative benefits, propensity to trust, calculative-based trust, perceived ubiquity, and perceived ease-of-use; and Table 2 reveals shared values, communication, word-of-mouth referrals, perceived security and quality, propensity to trust, familiarity with the Internet, disposition to trust, satisfaction, and intrinsic motivation. As noted, regarding the consequences of trust, both Tables 1 and 2 indicate that commitment, adoption, and intention to use have often been verified as the outcomes of trust. Building in the above, the following eight hypotheses are developed.

3.1 Knowledge-incurred trust

Knowledge-incurred trust, also known as familiarity-based trust, means that trust is created when one party has sufficient knowledge about the other to allow him or her to predict the behavior of that other party. Robert, Dennis and Hung (2009) contended that knowledge-incurred trust derives from personal knowledge of an individual’s past behavior. In other words, trust develops over time with the accumulation of trust-relevant knowledge resulting from experiences with the other party. Previous literature review has revealed that a bank’s reputation; a customer’s familiarity with the Internet or mobile device; a customer’s perceptions of website attributes such as security, privacy, and ease-of-use; and the communication experience between customers and the bank considerably influences consumers’ trust belief in mobile banking. Therefore, familiarity-based trust requires time and interaction between parties.
Grabner-Krauter and Faullant (2008) showed that familiarity with the Internet exerted a marked effect on consumer attitude toward using Internet banking. Dimitriadis and Kyeris (2008) and Yap et al. (2010) concluded that consumer perception of a bank’s reputation significantly influenced their willingness to use the bank’s e-banking services. Moreover, Sanchez-Franco (2009) and Yap et al. (2010) also found that the satisfaction or quality learning from consumers’ past experience exerts a considerable influence on their commitment to use e-banking services. Given that trust develops gradually over time based on how two parties assess each other, customers might not adopt mobile banking because they lack knowledge-based trust regarding mobile banking. Accordingly, this study operationalized Knowledge-incurred trust by requesting the respondents to indicate their level of trust based on their past experiences in communicating with their banks and using mobile phones or mobile services. The following hypothesis is posited:

\[ H_1: \text{Knowledge-incurred trust considerably affects customers’ trust in using mobile banking.} \]

3.2 Calculative-incurred trust

Calculative-incurred trust is based on rational choice (Kim & Prabhakar, 2004). Rousseau et al. (1998) and Kim and Prabhakar (2004) considered that trust emerges from a calculated weighting of expected gains and losses. In line of this thinking, trust is derived from an economic analysis of ongoing relationships and is based on the assumption that people are rational and calculative, act in their own best self-interest, and refrain from inflicting harm upon themselves. Therefore, calculative-incurred trust results from the rational calculation of costs and benefits when individuals make trust-based choices (Gefen et al., 2003; Williamson, 1993).

In a study involving 910 respondents, Gu et al. (2009) showed that calculative-incurred trust has a considerable effect on consumer trust in the context of mobile banking. Skandrani et al. (2011) contended that calculative-based trust expresses a sense of calculation and rational optimization. Hence, calculative-based logic posits that consumers evaluate their potential losses and damages that could from using mobile banking. Therefore, this study assumed that customers trust mobile banking services when they believe that the bank would lose more than it would gain by cheating customers or by violating their trust. Accordingly, we operationalized calculative-incurred trust by asking respondents to indicate the level at which their bank could benefit them or cause injury by violating consumer trust in the context of mobile banking. The following hypothesis is thus posited:

\[ H_2: \text{Calculative-incurred trust considerably affects customers’ trust in using mobile banking.} \]
3.3 Cognition-incurred trust

In contrast to the previous two types of trust, cognition-incurred trust states that trust is built on first impressions rather than through personal interactions (Gefen et al., 2003; Meyerson et al., 1996). Cognition-incurred trust is grounded in individual beliefs about peer reliability and is formed through the two dimensions of categorization processes and illusion of control. Categorization processes are based on the idea that individuals place more trust in people who are similar to themselves and assess trustworthiness based on second-hand information and on stereotypes (Gefen et al., 2003; Morgan & Hunt, 1994). Illusion of control describes how, in the absence of first-hand information, trusting beliefs can be over-inflated.

Considering that trust and distrust exist objectively in the process of user adoption of mobile banking services, Yao et al. (2013) contended that cognition-incurred trust is critical for individual interests in mobile banking. Previous literature on online banking (Kassim & Abdulla, 2006; Kim & Prabhakar, 2004; Mukherjee & Nath, 2003; Vatanasombut et al., 2008) has revealed that shared values, word-of-mouth referrals, and perceived ease-of-use are salient factors affecting trust. By operationalizing cognition-incurred trust, we asked the respondents indicate the extent to which they agreed with their friends and peers, positive or negative comments from experienced mobile banking users, and their impression or expectation about using mobile banking. This study assumed that when consumers deciding whether to use mobile banking services, they are influenced considerably by cognition-incurred trust. Accordingly, the hypothesis $H_3$ is posited as follows:

$H_3$: Cognition-incurred trust considerably affects customers’ trust in using mobile banking.

3.4 Personality-incurred trust

Since the study by Mayer et al. (1995), many researches explicitly separated trust antecedents from trust itself. By considering trust within these different perspectives, psychologists tend to believe that trust develops during childhood when an infant seeks and receives help from a parent (Kim & Prabhakar, 2004), thus resulting in a general tendency to believe or not to believe in others. This is called personality-incurred trust (Gefen et al., 2003; Mayer et al., 1995; McKnight et al., 1998, 2002). Personality-incurred trust, also known as a disposition to trust, propensity to trust, or emotion-based trust, has been reveals as a noticeable factor that influences trust in online banking (Dimitriadis & Kyrezis, 2008; Grabner-Krauter & Faullant, 2008; Kantsperger & Kunz, 2010) and mobile banking (Kim et al., 2009; Zhou, 2011).

Through 192 valid samples from three large mobile telecommunications companies in South Korea, Kim et al. (2009) showed that personal propensity to trust influence initial trust considerably, which subsequently immensely affects usage intention in mobile
banking. By dividing mobile trust into initial trust and continuous trust, Zhou (2011) showed that individual trust propensity markedly affects whether consumers use mobile banking based on the response of 210 China Mobile users. Similarly, previous literature review on online banking (Dimitriadis & Kyrezis, 2008; Grabner-Krauter & Faullant, 2008; Kantsperger & Kunz, 2010) indicated that propensity to trust considerably impacts the consumer willingness to use e-banking. Accordingly, this study operationalized personality-incurred trust by requesting respondents to express the extent to which they agreed with trust statements related to banks, people, and new mobile services. The following hypothesis is thus posited.

\[ \text{H}_4: \text{Personality-incurred trust considerably affects customers' trust in using mobile banking.} \]

3.5 institution-incurred trust

By contrast to that psychologists' preference for personality-incurred trust, sociologists generally prefer to an institution-incurred trust and analyze how it creates an environment in which a person feels safe and secure to participate in its activities (Pavlou & Gefen, 2004; Yousafzai et al., 2005). Structural assurance is one of types of institution-incurred trust that originates from sociological theory and is defined as the willingness of individuals to conduct online transactions based on rules and regulations. Structural assurance, also known as structural safeguards, involves legal protections, regulations, and third-party certifications (Gefen et al., 2003; McKnight et al., 2002). As examined in previous literature on both mobile and online banking, structural assurance is commonly deemed as a critical antecedent of forming trust belief (Gu et al., 2009; Kim & Prabhakar, 2004; Kim et al., 2009; Yousafzai et al., 2005; Zhou, 2011, 2012a).

The literature on online banking (Kim & Prabhakar, 2004; Yousafzai et al., 2005) empirically showed that structure assurance substantially affects the adoption of Internet banking. Moreover, the literature on mobile banking (Gu et al., 2009; Kim et al., 2009; Zhou, 2011, 2012a) consistently revealed that structure assurance plays a salient role in determining consumer intentions to use mobile banking. Therefore, we operationalized structure assurance by asking the respondents to indicate the extent to which they agreed with statements related to security mechanism, mobile technologies, and legal commitment. The hypothesis \[ \text{H}_5: \text{Structural assurance considerably affects customers' trust in using mobile banking.} \]

\[ \text{Situational normality is another type of institution-incurred trust. McKnight et al. (1998) described situational normality as an appropriately ordered setting that appears likely to facilitate successful interactions. In this study, situational normality is defined as} \]
the notion that a banking environment is trustworthy because the “situation” (e.g., a mobile banking interface) looks and behaves in a normal and appropriate manner. Yousafzai et al. (2005) conducted a field experiment and discovered that situational normality significantly affected consumer perceptions of trustworthiness. In a survey of 910 respondents, Gu et al. (2009) suggested that the presence of any abnormal icons, symbols or information, as well as any awkward interface, unusual procedures, or requirements could markedly influence customer trust when using mobile banking services. Munoz-Leiva et al. (2010) identified situational normality as a major antecedents of forming trust. If a banking environment process features an awkward or suspicious interface and customers are required to perform unexpected or unwanted procedures or to provide atypical information, they (based on experience) typically do not trust the banking environment. Therefore, we operationalized situational normality by asking respondents to indicate the extent to which they agreed with the steps, information, and interactions they were required to perform when using mobile banking services. The hypothesis $H_6$ is then presented as follows:

$H_6$: Situational normality considerably affects customers’ trust in using mobile banking.

### 3.6 Consequences of trust

By reviewing prior research on trust, Mayer et al. (1995) distinguished the trust’s consequences from the trust. They considered that the consequence of trust involves, on the one hand, a willingness to be vulnerable and, on the other hand, an actual action that puts oneself in a possible vulnerable situation (Kim & Prabhakar, 2004). As shown in Table 1, four out of seven studies on mobile banking conclude that usage intention is the consequence of trust (Gu et al., 2009; Kim et al., 2009; Zhou, 2011, 2012a). As shown in Table 2, six out of 17 works concluded that trust significantly influences usage intention. As for other studies in Tables 1 and 2, researchers have employed different terms, such as attitude toward using mobile banking, adoption of online banking, attitude to use, intention to use and willingness to use. Although these terms are different, the meaning behind these terms is very similar. Therefore, based on the prior literature and the concept of Mayer et al. (1995), this study assumed that customers intend to use mobile banking once they have trust beliefs regarding mobile banking. Therefore, the following hypothesis is posited:

$H_7$: Trust considerably affects potential customers’ intention to use mobile banking.

Mukherjee and Nath (2003) provided both the earliest theory-based research on trust in e-banking and the first study on the consequence of trust in e-banking. By surveying 510 banking clients in India, they discovered that trust considerably affects commitment. Based on the literature review and two focus group interviews in Qatar, Kassim and Abdulla (2006) hypothesized that trust positively and considerably influences
commitment. After sampling 276 respondents, they empirically uncovered that trust positively influences consumer commitment at the significant level of $p$-value $< .01$. As shown in Table 2, four of 17 studies indicate that commitment is a salient outcome of trust (Kassim & Abdulla, 2006; Mukherjee & Nath, 2003; Saeednia & Abdollahi, 2012; Sanchez-Franco, 2009).

Referring to Oliver (1999), who defined loyalty as a deeply commitment, Sanchez-Franco (2009) considered customer loyalty and commitment as having a very similar meaning, and defined customer commitment as an enduring desire to maintain a valued relationship. By surveying 456 e-banking users in Spain and using the satisfaction-trust-commitment model, Sanchez-Franco (2009) empirically showed that commitment is a consequence of trust. Therefore, considering that the commitment, loyalty, and customer retention have similar meaning, Vatanasombut et al. (2008), Kantsperger and Kunz (2010), and Aldas-Manzano et al. (2011) consistently supported that commitment is a considerable consequence of trust. Hypothesis 8 is therefore proposed as follows:

H$_8$: Trust considerably affects current customers’ commitment to use mobile banking

4. Survey design and sampling

A review of the literature has indicated that trust is a cross-disciplinary concept and the construct of trust has been defined in various ways (Kantsperger & Kunz, 2010). Since the literature describes a different aspect of trust (Grabner-Krauter & Faullant, 2008) across a variety of fields including philosophy, psychology, sociology, economics, management, marketing, communication, organization behavior, and information systems (Du et al., 2010; Mukherjee & Nath, 2003), numerous definitions for trust exist in literature (Dimitriadis et al., 2011; Kim & Prabhakar, 2004) and no universal definition of trust exists (Dimitriadis et al., 2011). Referring to Kantsperger and Kunz (2010), who tabulated the trust definition during 1985-2009, this study defines trust in mobile banking as a belief that a bank can be relied on through the use of mobile devices and that a variety of financial services can be obtained through a mobile interface.

Based on 32 articles and books on trust, McKnight et al. (2002) conceptually summarized prior findings and categorized 15 types of trusting beliefs from the findings. They then grouped 15 types into four constructs: integrity, benevolence, competence, and an indefinable “other”. By examining the role of trust in 504 university students, Zhao et al. (2010) defined trust as a concept composing of three elements: integrity, benevolence, and competence, and used these three elements to assess trust. Likewise, Sanchez-Franco
(2009) and Luo et al. (2010) also used the three dimensions of integrity, benevolence, and competence to measure trust. Building in the above, this study applied integrity, benevolence and competence to assess the construct of trust.

Items used to assess integrity, benevolence, competence, knowledge-incurred trust, calculative-incurred trust, cognition-incurred trust, personality-incurred trust, structural assurance, situational normality, intention to use mobile banking, and commitment to mobile banking in the survey instrument were adapted from literature and converted to fit the context of mobile banking. Two pretests were performed to ensure that the questionnaire was verified and that it effectively reflected the research purpose and design. In the first pre-test, three scholars were invited to review the research structure, hypotheses, and methodology. Following their suggestions, some items, terms and sentences have been revised. The final items were summarized in Table 3. All the variables were measured on a 5-point Likert scale ranging from 1 (strong disagree) to 5 (strong agree).

<table>
<thead>
<tr>
<th>Construct</th>
<th>Items</th>
<th>Item Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence</td>
<td>CPT1: I believe that the mobile banking provides me required services</td>
<td>Adapted from Yousafzai et al. (2005), Dimitriadis and Kyrezis (2008), Sanchez-Franco (2009), Luo et al. (2010), Zhao et al. (2010), and Dimitriadis et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>CPT2: I believe that the mobile banking processes my transactions accurately</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CPT3: I believe that the mobile banking fulfills my needs on time</td>
<td></td>
</tr>
<tr>
<td>Integrit</td>
<td>INT1: I believe that the mobile banking has consistent practices and policies as the bank does in its physical branch office;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>INT2: I believe that the mobile banking provides me same quality services as the bank does in its physical branch office;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>INT3: I believe that the mobile banking fairly treats customers as the bank does in its physical branch office.</td>
<td></td>
</tr>
<tr>
<td>Benevolence</td>
<td>BEN1: I believe that the mobile banking has policies that respect the customer;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BEN2: I believe that the mobile banking has policies that favor the customer’s best interest;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BEN3: I believe that the mobile banking has policies that act in the customer’s needs.</td>
<td></td>
</tr>
<tr>
<td>Constructs and Corresponding Items (continued)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Knowledge-Incurred Trust</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KNO_Trust1: My past experience with the bank is trustworthy;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KNO_Trust2: My past experience with the mobile phone is trustworthy;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KNO_Trust3: My past experience with the mobile service is trustworthy.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapted from Gefen et al. (2003) and Dimitriadis et al. (2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Calculative-Incurred Trust</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAL_Trust1: The bank has nothing gain by being dishonest when I am using mobile banking;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAL_Trust2: The bank have something lose by not caring about me when I am using mobile banking;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAL_Trust3: The bank has a penalty if it violates customer trust.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapted from Gefen et al. (2003) and Gu et al. (2009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cognition-incurred trust</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COG_Trust1: I feel trust about using mobile banking;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COG_Trust2: I feel trust since most of my peers have used mobile banking;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COG_Trust3: I feel trust since I have heard many positive comments about using mobile banking.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapted from Gefen et al. (2003) and Dimitriadis et al. (2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Personality-Incurred Trust</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PER_Trust1: I usually trust people until they prove I should not trust them.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PER_Trust2: I usually trust banks until they prove I should not trust them.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PER_Trust3: I usually trust new mobile services until they prove I should not trust them.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapted from McKnight et al. (2002), Gefen et al. (2003), Kim and Prabhakar (2004), Dimitriadis et al. (2011), and Zhou (2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Assurance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR_Trust1: I feel safe using mobile banking services because the bank has sufficient security mechanism to protect me</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR_Trust2: I feel safe using mobile banking services because the advances on communication technologies can adequately protect me.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR_Trust3: I feel safe using mobile banking services because the legal and bank will commit their obligation to protect me.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapted from McKnight et al. (2002), Gefen et al. (2003), Kim and Prabhakar (2004), and Zhou (2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Situational Normality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIT_Trust1: I feel safe using mobile banking services because the steps required in mobile banking are typical of most mobile websites;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIT_Trust2: I feel safe using mobile banking services because the information requested in mobile banking is typical information of most mobile websites request;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIT_Trust3: I feel safe using mobile banking services because the interaction with mobile banking is typical of most mobile websites.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapted from Gefen et al. (2003) and Munoz-Leiva et al. (2010)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3  Constructs and Corresponding Items (continued)

<table>
<thead>
<tr>
<th>Intention to Use Mobile Banking</th>
<th>Trust_INT1: I intend to use banking services via mobile banking</th>
<th>Adapted from Lee (2005), Kim et al. (2009), Gu et al. (2009), and Zhou (2011, 2012a, 2012b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trust_INT2: I intend to check account, conduct payment or transfer money via mobile banking;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trust_INT3: Given the chance, I intend to use mobile banking.</td>
<td></td>
</tr>
<tr>
<td>Commitment to Mobile Banking</td>
<td>Trust_COM1: I am very committed to continuously use mobile banking;</td>
<td>Adapted from Sanchez-Franco (2009)</td>
</tr>
<tr>
<td></td>
<td>Trust_COM2: I will recommend others to use mobile banking;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trust_COM3: Mobile banking is very important to me.</td>
<td></td>
</tr>
</tbody>
</table>

Based on the above, the questionnaire contains two sections with a total of 43 questions. In the first section, the first question asks respondents “Have you used mobile banking?” Based on their self-reported use of mobile banking, the respondents were split between potential customers and current customers. Potential customers were those who have not yet used mobile banking, whereas current customers were those who have used mobile banking. The following five questions in the first section were used to collect basic data such as the gender, age, occupation, education level and annual income of the respondents. The second section contains 36 questions, as shown in Table 3, used to assess respondents’ constructs related to mobile banking. Notably, both potential and current customers were asked the same questions except with respect to the last three questions in the second section. For potential customers, these last three questions were used to assess the construct of their intention to use mobile banking, whereas current customers were asked to evaluate their commitment to mobile banking.

Because respondents in most online surveys are young students possessing low income, this study tried to diversify the population of respondents through using the mall intercept method. The mall intercept method has emerged as one of popular survey methods and can be used to collect more representative respondents than online surveys by intercepting respondents in shopping malls or other public space. The research assistants first screened potential respondents for appropriateness (i.e., age distribution and gender ratio), and then invited them to fill out the paper-based questionnaires with prize incentives. To remove potential sampling biases in accordance with previous research suggestions (De Bruwer & Haydam, 1996), four part-time research assistants were trained and dispatched to interview the respondents in several urban areas during the morning, afternoon, and evening of ten weekdays and three weekends. The profile of respondents is summarized in Table 4.
<table>
<thead>
<tr>
<th>Categories</th>
<th>Number and Percentage for Potential Users</th>
<th>Number and Percentage for Current Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>173</td>
<td>134</td>
</tr>
<tr>
<td>Female</td>
<td>183</td>
<td>113</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 20-year-old</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>20 ~ 25 years old</td>
<td>121</td>
<td>26</td>
</tr>
<tr>
<td>25 ~ 30 years old</td>
<td>68</td>
<td>61</td>
</tr>
<tr>
<td>30 ~ 35 years old</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>35 ~ 40 years old</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>40 ~ 45 years old</td>
<td>22</td>
<td>32</td>
</tr>
<tr>
<td>45 ~ 50 years old</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>50 ~ 55 years old</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>55 ~ 60 years old</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>60 ~ 65 years old</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>above 65 years old</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Occupation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banking/Finance/Insurance</td>
<td>8</td>
<td>43</td>
</tr>
<tr>
<td>ICT/Electronics</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>Biomedical/Hospital</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Construction/Real Estate</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Culture/Media/Tourism</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>General Manufacturing</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>General Service</td>
<td>49</td>
<td>13</td>
</tr>
<tr>
<td>Education</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>Police/Military Service</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>Government Employees</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Student</td>
<td>78</td>
<td>26</td>
</tr>
<tr>
<td>House Keeper</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>Others or Self-Employed (i.e., lawyer, accountant, designer)</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior High Diploma or Below</td>
<td>30</td>
<td>13</td>
</tr>
<tr>
<td>Associate Bachelor Degree</td>
<td>53</td>
<td>37</td>
</tr>
<tr>
<td>Bachelor Degree</td>
<td>211</td>
<td>133</td>
</tr>
<tr>
<td>Master Degree</td>
<td>55</td>
<td>52</td>
</tr>
<tr>
<td>Ph.D. Degree</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4 The Profile of Sample (continued)

<table>
<thead>
<tr>
<th>Annual Income</th>
<th>Less than NT$ 250,000</th>
<th>86</th>
<th>24.2%</th>
<th>39</th>
<th>15.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT$ 250,000 ~ 500,000</td>
<td>131</td>
<td></td>
<td>36.8%</td>
<td>73</td>
<td>29.6%</td>
</tr>
<tr>
<td>NT$ 500,000 ~ 750,000</td>
<td>68</td>
<td></td>
<td>19.1%</td>
<td>82</td>
<td>33.2%</td>
</tr>
<tr>
<td>NT$ 750,000 ~ 1,000,000</td>
<td>48</td>
<td></td>
<td>13.5%</td>
<td>37</td>
<td>15.0%</td>
</tr>
<tr>
<td>Over NT$ 1,000,000</td>
<td>23</td>
<td></td>
<td>6.5%</td>
<td>16</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

Among a total of 687 participants, 356 potential customers and 247 current customers were interviewed during the summer of 2013. For respondents who have not used mobile banking, Table 4 shows that 173 (48.6%) were men and 183 (51.4%) were women, and approximately 76.6% of respondents had a bachelor degree or higher. The top five occupations of those respondents were student (21.9%), general service (13.8%), education (9.8%), general manufacturing (9.1%), and government employees (7.6%). Of the total respondents, who not yet use mobile banking, 39.9% were younger than 25 years, 30.3% were 25 ~ 35 years of age, and 29.8% were older than 35. By the contrast, of the total respondents who have used mobile banking, 11.3% were younger than 25 years, 46.6% were 25 ~ 35 years of age, and 42.1% were older than 35. For respondents who have used mobile banking, Table 4 shows that 134 (54.3%) were men and 113 (45.7%) were women, and approximately 79.8% of respondents had a bachelor degree or higher. The top five occupations were 17.4% in the banking/finance/insurance sector, 14.2% in the ICT/electronics sector, 10.5% were students, 9.7% were government employees, and 8.5% in the culture/media/tourism sector.

5. Data analysis and hypothesis testing

By following the concept of Lin (2011), this study separated the respondents into potential customers and current customers based on their self-reported use of mobile banking. After running the partial least squares (PLS) regression, the data was generated and summarized in Tables 5 ~ 6 and depicted graphically in Figures 1 ~ 2. The advantages and limitation of the PLS regression were examined by literature (Geladi & Kowalski, 1986). As suggested by Yu (2011) and Zhou (2012b), factor loadings, composite reliability, and the average variance extracted (AVE) were used to assess the reliability and convergent validities, whereas the discriminant validity was assessed by examining whether or not the squared roots of AVE exceeded the correlations between constructs, as suggested by Venkataesh and Zhang (2010) and Zhou (2012b). As Table 5 shows, all factors in the measurement model possessed adequate reliability and convergent validity.
because all factor loadings were greater than 0.7, the composite reliabilities exceeded acceptable criteria of 0.6, and the AVEs were greater than the threshold value of 0.5 in all cases. Table 6 is constructed to show that the diagonal elements are the square roots of AVE and off-diagonal elements are correlations between constructs. Because Table 6 indicates that all diagonal elements were higher than the off-diagonal elements in the corresponding rows and columns, the discriminant validity was supported.

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Items</th>
<th>Factor Loading</th>
<th>Composite Reliability</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge-incurred Trust</td>
<td>KNO_Trust1</td>
<td>0.827</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KNO_Trust2</td>
<td>0.908</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KNO_Trust3</td>
<td>0.869</td>
<td>0.874</td>
<td>0.850</td>
</tr>
<tr>
<td>Calculative-incurred Trust</td>
<td>CAL_Trust1</td>
<td>0.853</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAL_Trust2</td>
<td>0.867</td>
<td></td>
<td>0.909</td>
</tr>
<tr>
<td></td>
<td>CAL_Trust3</td>
<td>0.857</td>
<td></td>
<td>0.811</td>
</tr>
<tr>
<td>Cognitive-incurred Trust</td>
<td>COG_Trust1</td>
<td>0.841</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COG_Trust2</td>
<td>0.825</td>
<td></td>
<td>0.834</td>
</tr>
<tr>
<td></td>
<td>COG_Trust3</td>
<td>0.755</td>
<td></td>
<td>0.753</td>
</tr>
<tr>
<td>Personal-incurred Trust</td>
<td>PER_Trust1</td>
<td>0.893</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PER_Trust2</td>
<td>0.840</td>
<td></td>
<td>0.850</td>
</tr>
<tr>
<td></td>
<td>PER_Trust3</td>
<td>0.762</td>
<td></td>
<td>0.777</td>
</tr>
<tr>
<td>Structural Assurance</td>
<td>STR_Trust1</td>
<td>0.816</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STR_Trust2</td>
<td>0.865</td>
<td></td>
<td>0.812</td>
</tr>
<tr>
<td></td>
<td>STR_Trust3</td>
<td>0.770</td>
<td></td>
<td>0.783</td>
</tr>
<tr>
<td>Situational Normality</td>
<td>SIT_Trust1</td>
<td>0.774</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SIT_Trust2</td>
<td>0.816</td>
<td></td>
<td>0.824</td>
</tr>
<tr>
<td></td>
<td>SIT_Trust3</td>
<td>0.801</td>
<td></td>
<td>0.795</td>
</tr>
<tr>
<td>Competence</td>
<td>Com1</td>
<td>0.862</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Com2</td>
<td>0.828</td>
<td></td>
<td>0.862</td>
</tr>
<tr>
<td></td>
<td>Com3</td>
<td>0.802</td>
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<td></td>
</tr>
<tr>
<td>Trust</td>
<td>Int1</td>
<td>0.800</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Int2</td>
<td>0.816</td>
<td></td>
<td>0.838</td>
</tr>
<tr>
<td></td>
<td>Int3</td>
<td>0.743</td>
<td></td>
<td>0.836</td>
</tr>
<tr>
<td>Benevolence</td>
<td>Ben1</td>
<td>0.719</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ben2</td>
<td>0.840</td>
<td></td>
<td>0.815</td>
</tr>
<tr>
<td></td>
<td>Ben3</td>
<td>0.789</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intention to Use Mobile Banking</td>
<td>Trust_INT1</td>
<td>0.798</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trust_INT2</td>
<td>0.759</td>
<td></td>
<td>0.853</td>
</tr>
<tr>
<td></td>
<td>Trust_INT3</td>
<td>0.784</td>
<td></td>
<td>0.784</td>
</tr>
</tbody>
</table>
Table 5  Reliability and Convergent Validity Examination of the Constructs (continued)

<table>
<thead>
<tr>
<th>Commitment to Mobile Banking</th>
<th>Trust_COM1</th>
<th>Trust_COM2</th>
<th>Trust_COM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust_COM1</td>
<td>0.814</td>
<td>0.757</td>
<td>0.775</td>
</tr>
<tr>
<td>Trust_COM2</td>
<td>0.743</td>
<td>0.814</td>
<td>0.757</td>
</tr>
<tr>
<td>Trust_COM3</td>
<td>0.748</td>
<td>0.743</td>
<td>0.775</td>
</tr>
</tbody>
</table>

Table 6  Discriminant Examination of the Constructs

<table>
<thead>
<tr>
<th></th>
<th>KNO</th>
<th>CAL</th>
<th>COL</th>
<th>PER</th>
<th>STR</th>
<th>SIT</th>
<th>Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNO</td>
<td>0.922</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAL</td>
<td>0.304</td>
<td>0.901</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>COL</td>
<td>0.570</td>
<td>0.463</td>
<td>0.868</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PER</td>
<td>0.509</td>
<td>0.269</td>
<td>0.421</td>
<td>0.881</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR</td>
<td>0.552</td>
<td>0.412</td>
<td>0.674</td>
<td>0.461</td>
<td>0.885</td>
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</tr>
<tr>
<td>SIT</td>
<td>0.577</td>
<td>0.380</td>
<td>0.608</td>
<td>0.563</td>
<td>0.758</td>
<td>0.892</td>
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<tr>
<td>Trust</td>
<td>0.664</td>
<td>0.398</td>
<td>0.607</td>
<td>0.544</td>
<td>0.680</td>
<td>0.699</td>
<td>0.914</td>
</tr>
</tbody>
</table>

Figure 1 shows that the generated $R^2_{adjusted}$ values of .673 and .532 accounted for the variances explained in trust and intention to use mobile banking, respectively, among the potential customers. Figure 2 shows that the generated $R^2_{adjusted}$ values of .678 and .624 accounted for the variances explained in trust and commitment to mobile banking, respectively, among the current customers. Given that * stands for $p$-value < .05, ** stands for $p$-value < .01, and *** stands for $p$-value < .001, Figure 1 illustrates that trust extremely significantly influences intention to use mobile banking for nonusers, and Figure 2 demonstrates that trust extremely significantly influences commitment to mobile banking among users.

Regarding antecedents of trust, the empirical results of potential customers reveal that personal-incurred trust, knowledge-incurred trust, structural assurance and situational normality, in that order of relative influences, considerably affect trust belief in mobile banking. By contrast, the empirical results of current customers reveal that situational normality, structural assurance, knowledge-incurred trust, personal-incurred trust, and calculative-incurred trust, in that order of relative power, considerably affect trust belief in mobile banking. The knowledge-incurred trust, personal-incurred trust, structural assurance and situational normality are four commonly major antecedents of trust for both potential and current customers, although some differences regarding the order of relative strength exist. The major difference between potential and current users lies in calculative-incurred trust, which is a significant factor ($p$-value < .05) in creating current customers’ trust, whereas it is not significant in generating potential customers’ trust.
Antecedents of Trust | Trust Belief | Consequences of Trust
---|---|---
Consumer side
| Knowledge-incurred trust | .246*** |  
| Calculative-incurred trust | .062 |  
| Cognitive-incurred trust | .075 |  
| Personal-incurred trust | .277*** |  
Bank side
| Structural Assurance | .210*** |  
| Situational Normality | .204*** |  

\[ R^2_{\text{adjust}} = .673 \]
\[ R^2_{\text{adjust}} = .532 \]

Trust

Intention to use Mobile Banking

Figure 1 The Results of PLS for Potential Customers

Antecedents of Trust | Trust Belief | Consequences of Trust
---|---|---
Consumer side
| Knowledge-incurred trust | .194*** |  
| Calculative-incurred trust | .090* |  
| Cognitive-incurred trust | .072 |  
| Personal-incurred trust | .173** |  
Bank side
| Structural Assurance | .213*** |  
| Situational Normality | .299*** |  

\[ R^2_{\text{adjust}} = .678 \]
\[ R^2_{\text{adjust}} = .624 \]

Commitment to Mobile Banking

Trust

Figure 2 The Results of PLS for Current Customers
In summary, after performing a survey of 603 respondents (356 potential users and 247 current users), this study used the PLS regression to examine the posited hypothesis. The empirical results indicate, firstly, that not all the antecedents considerably influence the generation of consumers' trust beliefs and, secondly, that the level of influence of these antecedents of trust vary across potential customers and current customers. Regarding the consequences of trust, trust significantly influences potential customers' intention to use mobile banking, and considerably affects current customers’ commitment to mobile banking. Therefore, Hypotheses 1, 4, 5, 6, 7 and 8 were empirically supported, whereas Hypothesis 3 was rejected. Hypothesis 2 was rejected for potential customers but supported for current customers.

6. Implication and discussion

Figures 1 and 2 show consistent results with respect to knowledge-incurred trust, personal-incurred trust, structural assurance, and situational normality, and these factors significantly influence the formation of consumer trust, whereas cognition-incurred trust does not yield considerable influence. Knowledge-incurred trust is also called familiarity-based trust because it is based on the accumulation of trust-relevant knowledge over time. Because knowledge-incurred trust highly correlates with the ability to predict behavior based on previous experience (Lin, 2011) or personal knowledge (Robert et al., 2009), familiarity-based trust captures the customer’s knowledge and experience in mobile banking. Thus, for current users, their positive experience with the mobile banking is extremely important for forming their trust, which subsequently causes them to commit to using mobile banking. For potential users, their positive knowledge about the mobile banking is extremely important for generating their trust, which in turn affects their intention to use mobile banking. The following implications can therefore be derived.

First, knowledge-incurred trust requires time and interaction between parties. Thus, for current customers, increasing trust requires long-term care for their using experience and immediate response for their feedback. Banks are advised to give current customers considerably truthful and reliable interactions whenever they use mobile banking services. By contrast, people may choose not to use mobile banking because of a lack of knowledge-incurred trust about mobile banking, especially once those people have established more traditional banking practices. Hence, for potential customers, experiential marketing is useful for building their trust because it offers customers opportunities to gain experience and knowledge on using mobile banking. Similarly, incentive programs are useful because such programs offer customers incentives to use mobile banking. Once they have used mobile banking, their experience and knowledge increase. Additionally, to increase potential users’ trust, banks are advised to demonstrate the advantages of
mobile banking through advertisements and marketing events. Such efforts can enhance customers’ positive impression, which can motivate potential customers to try mobile banking. Once they have a successful experience, their trust beliefs increase.

Both Figures 1 and 2 also show that cognition-incurred trust does not possess significant influence. Because cognition-based trust is grounded in individual beliefs about peer comments for the strengthening or weakening of trust, executing testimonial strategy is ineffective in building customer trust on mobile banking. The reason may be attributed to the fact that using mobile banking is a private interest and an unobserved personal behavior. Therefore, although noted figure and customer testimonials are popular and have been widely used in the advertisements of many brands (i.e., Nokia and Samsung) or product recommendation (i.e., healthy food and organic drinks), testimonial strategy does not exert a significant effect on building trust in the use of mobile banking.

Personal-incurred trust has been studied in a variety of technological context and is one of the most studied precursors related to trust in Internet and mobile banking studies (Zhou, 2011). Given that this study has identified personality-incurred trust as an important source of trust, which is also concluded in other literature (Castelfranchi & Falcone, 2010; Du et al., 2010), banks must place attention on those people who possess a personal propensity to trust. For example, banks may cluster potential consumers by their personal characteristics in term of disposition to trust, and then divide them into first priority potential users, second priority potential users, and so on, based on the level of their personality-incurred trust. Thereafter, banks may execute different strategies that favor different consumer clusters. Because the empirical results illustrate that personal-based trust considerably influences the trust of both potential and current consumers, banks may also cluster current customers by their level of disposition to trust. In this respect, banks are advised to offer advanced and profitable services to those users who have a higher disposition to trust.

The generated figures also show that not all factors related to consumers hold statistical significance and the level of influence of these factors in generating consumers trust varies across potential customers and current customers. Accordingly, instead of a single trust building strategy, banks are advised to strengthen different trust resources to meet the main concerns of different customer groups (such as current users vs. potential users, young consumers vs. old consumers, and nonusers vs. heavily users). For example, calculative-incurred trust is a salient factor for current customers, but not a significant factor for potential customers. As previous literature reveals, calculative-incurred trust is the result of a rational calculation of the cost and benefit when individuals make trust choices (Gefen et al., 2003; Williamson, 1993). Because current users’ trust are considerably affected by calculative-incurred trust, banks may execute a trust-building strategy based on economic calculation (for instance, customers can receive rewards if
they discover the bank is cheating them, the bank incurs a penalty if it violates customer trust, and the like). Based on the above, the derived implication is that banks are better to execute different trust-building strategies to appropriately reduce main concerns of different customer groups rather than single trust-building strategy.

After discussing the implications from the consumer-side constructs, this study now shift to a discussion for the bank-side constructs. Because structural assurance is a salient factor, it is critical for banks to provide reliable, state-of-the-art technology for mobile banking platforms to enhance people’s trust in mobile banking. Hence, the implication is that communications and advertisements must emphasize that banks have sufficient security mechanisms and are committed to protecting mobile banking users, which further enhance both the willingness of potential customers and the commitment of current customers to use mobile banking. Additionally, given that situational normality is an extremely significant factor influencing consumers’ trust belief (regardless of whether they are potential or current consumers), banks should pay their greatest attentions to situational normality. In other words, procedures and policies required to deliver services and information to complete banking transactions should be reasonable and expected. The derived implication is that customer trust can be enhanced by offering benchmarking practices and standardizing banking processes through mobile devices.

Because both structural assurance and situational normality are aspects of institution-incurred trust, another implication derived from the study is that banks should focus on building institution-incurred trust when delivering innovative services (i.e., mobile banking services). In other words, before banks shift their focus to trust resources on consumer side, banks are advised to create customer trust from the mobile banking side such as situational normality and structural assurance. Accordingly, the following points are provided for bank managers:

(1) Banks should convince consumers that the mobile banking services they offered are strictly protected by the government and laws.

(2) Banks should clearly display and demonstrate security mechanisms (such as laws of data privacy protection, secure socket layer protocol, secure infrastructure, and the like) related to mobile banking.

(3) Banks should deliver and communicate accurate and reliable information though the mobile interface to bank clients.

(4) Banks should ensure that all procedures related to mobile banking are seen as normal and logical.
7. Concluding remarks

Although the adoption of mobile banking has been extensively studied based on technology adoption theories as commented by Zhou (2011), current literature indicates that research focusing on trust into mobile banking is rare. Although banks invest heavily in mobile banking services that allow people to conduct daily business and financial tasks anytime, anywhere, and faster compared to traditional banking, the adoption rate of mobile banking is rising slowly and lower than the expected. Considerable literature has indicated that mobile banking operates in an impersonal and technology-enabled environment that might cause customers to feel uncertainty and risk which create a lack of trust for using mobile banking. Consequently, investigating the links from trust’s antecedents to trust and from trust to trust’s consequences on mobile banking becomes necessary and very important, which can assist banks to devise trust-building strategies. Therefore, this study attempted to rectify this deficiency.

After surveying 356 nonusers (potential customers) and 247 users (current customers), the empirical results of current customers reveal that situational normality, structural assurance, knowledge-incurred trust, personal-incurred trust, and calculative-incurred trust, in that order of relative power, considerably affect trust belief in mobile banking. The empirical results of potential customers reveal that personal-incurred trust, knowledge-incurred trust, structural assurance and situational normality, in that order of relative influences, considerably affect trust belief in mobile banking. Trust significantly influences nonuser intention to use mobile banking, and trust considerably influences user commitment to use mobile banking. Anyway, this study merely represents a pioneer work. To provide banks with more useful clues, further elaborate research is required.

Numerous trust determinants and consequences were identified and empirically tested, but current research on trust lacks clarity, remains fragmented, and is context specific (Sirdeshmukh et al., 2002; Skandrani et al., 2011). None of the studies adopted a holistic viewpoint to investigate the link among antecedents of trust, trust itself, and consequences of trust in a single research framework. Therefore, this study may not only advance current knowledge on trust in the context of mobile banking, but also contribute to pave a way of understanding how the trust incurs, develops, and fosters. Particularly, mobile banking is an application of mobile commerce, which a subset of e-commerce (Kim et al., 2009). Therefore, the findings of this study may be applicable to other mobile commerce and e-commerce. However, caution is still necessary when generating the results to other mobile service or e-commerce fields.

Besides, Table 4 shows that age and occupation may have positive correlation with consumer willingness to use mobile banking. However, only using physiological
and sociological variables may yield cursory findings and simplistic profile (Yu, 2011).

As literature suggests that trust is an accumulated belief and considered as a strategic variable in marketing practices (Flavian et al., 2005; Selnes, 1998), the future research is encouraged to incorporate trust with marketing theories. Since the level of telecom infrastructure, the level of maturity of cell phone usage, culture, and governmental regulation may differ across countries, generalizing the findings and implications to other countries must be executed cautiously.

As with most research, some limitations exist in this study. First, because the respondents were surveyed in Taiwan, future studies are encouraged to conduct in different countries to compare the results. Second, this study merely represents a preliminary work. Therefore, to verify and generalize the methodology, more elaborated researches are necessary. Third, because of limited manpower and resources, this study used the mall intercept method to collect respondent data. Bias naturally exists in any questionnaire-based survey. Banks could conduct face-to-face interviews to collect more in-depth data that is more comprehensive to find effective trust strategies for different customers.

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**References**


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Implementation of N-Cryptographic Multilevel Cryptography Using RSA and Substitution Cryptosystem

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Department of Cyber Security Science, Federal University of Technology, Nigeria

ABSTRACT: The purpose of cryptography is to ensure information is made in such a way that an unintended individual will not have access to it or does not understand what it means when intercepted on a communication network. Some people try to defeat this purpose by using an extra ordinary means to harm the algorithmic construct of the system. The effort required for this purpose depends on the complexity of the algorithm and the number of cryptographic-ciphers used. Given that effort required to cryptanalyze ciphertext when one-algorithmic transformation was made is x-effort, then the effort required when n-algorithmic transformation was done is nx-effort. This paper implements multilevel encryption algorithm using two cryptosystem; RSA and Substitution cryptosystem with one transformation per each. It presents an algorithmic paradigm which can be implemented using any programming language. It simplifies the stages used for both encryption and decryption, presenting each stage in a sequential order.

KEYWORDS: Cryptography, n-Cryptographic, Ciphertext, Cryptosystem, Cryptanalysis, Multilevel Encryption, RSA Cryptosystem, Substitution Cryptosystem.

1. Introduction

The effect of information attacks and their exposure on the present day communication media has been alarming. Much research work has been devoted to this area, while people continue to work against the progress of this effort thereby making the field of information security an ever more demanding research area (Ugwu, 2014). Many algorithms have been developed, while many are still in the pipeline, as it is a highly dynamic area. Using multiple transformations could be seen as a better option compared to a single one thereby making the process a multiple transformed output. This multiple transformation could either be of the same algorithm with the same key, or of the same algorithm with different keys, or even different algorithms. As multiple transformed ciphertext will require multiple computational efforts, it is clear that it requires more effort and time to be cryptanalyzed; hence making the ciphertext better secured.

While the security of a multilevel process depends on the security of its component
algorithms, it is better practice to use either the same algorithm with different keys or different algorithms for multilevel processes. The choice of which strategy to use depends on the individual and on the application purpose. The RSA cryptosystem together with Substitution cryptosystem is adopted in this research to realize a given multilevel algorithm, presenting all steps involved in the process, and also simplifying the construct in such a manner that it can easily be implemented using any programming language.

The RSA cryptosystem is made in such a way that it cannot be easily factored; this is done by using a high value prime number during the computation and selection of the exponent. This should be done as if it were to be used alone and after which the substitution operation is used against its output (Bruce, 1996). The substitution table should be an agreement within both ends, if it were not to be implemented within an application interface; both ends should have the knowledge of the substitution table as it will be used for reverse computation by each other when a message is received from another individual that has an RSA public key of the receiver.

Just as algorithms are essential in securing information prior to dispatching the documents on the communication network (Adebayo et al., 2012), the sequence of the algorithmic applications also matters a lot, since it determines how its encryption and decryption transformation will occur. The process that comes first during encryption will often come last during decryption. The transformation process occurs in reverse manner, to realize the original clear text at the other end, but it all depends on the agreement between the parties involved or the implementation used.

2. Literature review

Harn and Lin (1990) proposed a key generation scheme for multilevel data security using bottom-up approach. The term multilevel was used to mean variable securities at different access levels with many users of a single system having different keys at each different access level. This approach was formed modifying the approach proposed by Akl and Taylor (1982) using a top-down model. Usha Devi and Wahida Banu (2012) proposed a multilevel encryption-decryption of text into cipher data in which its characters are encoded uniquely into its corresponding cipher and eliminating the possibility of any pattern as described in their paper titled “Secure Multilevel Cryptography Using Graceful Codes.” It uses more than one level of security by employing many ciphers to disguise any pattern.

Gawande et al. (2012) introduced the culture of securing images using chaotic
mapping and elliptic curve cryptography in a network environment. The dependency of stream ciphers on pseudo-stochastic sequences was noted as it can produce a pseudo-random sequence with good randomness. Hardjono and Seberry (1989) discovered a system that makes use of hierarchical keys used to encrypt and decrypt data stored in databases using the RSA cryptosystem with additional restriction of encrypted information to the public. The base of the systems security is discrete logarithms and the term “multilevel” used in this context means multiple users with different securities.

“Multi-Level Crypto Disk: A Secondary Storage with Improved Performance” was introduced by Chaitanya et al. (2006). They discussed the issue of hard disks becoming increasingly vulnerable to security attacks as they are now accessed remotely, either with mobile devices or in other unanticipated operating environments. They highlighted the demerits of using single data encryption on storage devices, proposing a secure disk using multiple crypto levels. “Multi-Level Cryptographic Functions for the Functionalities of Open Database System” was designed and implemented by Adio et al. (2011). This is a secure open database system for an organization that can open their information system for access by different users. The implementation does not require input to be hidden from anyone or converted to place holder characters for security reasons, but the user only needs to study the sequence of codes and active boxes that describe his password and uses it in place of his active boxes.

A secure information transmission using Multilevel Steganography and Dynamic Cryptography was proposed by Sikarwar (2012) in his paper titled “An Integrated Synchronized Protocol for Secure Information Transmission Derived from Multilevel Steganography and Dynamic Cryptography.” He juxtaposed the use of both simple steganography and cryptography proposing that multiple and dynamic codes give more security. Maruti and Subhash (2009) present a practical implementation of a quasigroup based multilevel encryption for data and speech. It makes use of an indexed scrambling transformation for signal authentication, encryption, and broadcasting applications in secrete-key cryptography. The results presented shows that a quasigroup transformation is very effective in destroying the structure of the input signal, and hence can be a good encryption technique.

2.1 RSA cryptosystem

RSA is a cryptosystem named after the founders’ initials; Ronald Rivest, Adi Shamir, and Leonard Adleman in the 1970s (Judy, 2002). Its method of application and the computations of its keys as well as the encryption and decryption procedures are presented with examples below:
2.2 Key generation

2.2.1 Step i. Primes selection

Two numbers that are co-prime are selected randomly.

Say P and Q are chosen and their product \((P \times Q)\) is computed to be “n.” This value is kept to be used as a modulus for encryption and decryption of plaintext and ciphertext respectively.

2.2.2 Step ii. Euler-Totient computation, \(\phi(n)\)

The prime numbers chosen in 2.2.1 above are used for the computation of Totient Function. “1” is subtracted from each of the primes as \((P – 1)\) and \((Q – 1)\) and their product is determined. This value \(((P – 1) \times (Q – 1))\) is used for the determination of the encryption key and the decryption key as well.

2.2.3 Step iii. Totient co-prime selection

After the Totient function has been computed, we determine the Lowest Common Multiple LCM of the Totient value in order to know the list of values that are relative primes to the Totient value.

From these values, a number is chosen to be used as an encryption key. Let this chosen value be denoted as \(e\). The Greatest Common Divisor (gcd) of Totient function, \(\text{gcd}(e, \phi(n)) = 1\).

2.2.4 Step iv. Totient co-prime inverse computation

An inverse of \(e\), \(e^{-1}\) is computed using Euclidean algorithm as described below. The Extended Euclidean algorithm is used to determine the value \(e \times d + \phi(n) \times y = 1\).

Where \(d = e^{-1}\) (Ugwu, 2014).

2.3 Encryption and decryption

RSA encryption involves the transformation of plain information using a private key into ciphertext in such a manner that the message on arrival at the destination will be retransformed back to the original plaintext using the public key of the Sender by the Receiver (Ugwu, 2014). Someone can equally write to the owner of an RSA key using his public key that is published to the public. The message will be retransformed to the plain information by the owner using his private key. The plain message has to be transformed to the numerical equivalent, which then allows the enciphering function to be applied in other to get the required numerical equivalent of the ciphertext, and thus substituted with the ciphertext symbol equivalent to get the ciphertext. For instance,
Let \( m \) be the plaintext message

Let \( f \) be the enciphering function and \( f^{-1} \) be the deciphering function.

Let \( c \) be the ciphertext

To encrypt a message using RSA algorithm, the sender computes the following (Simmons, 1979):

\[
c = f(m) = m^e \tag{1}
\]

After this computation, the ciphertext, \( c \) will be sent along the unsecure medium to the destination.

While to decrypt the ciphertext, the receiver will first map the numerical equivalent of the ciphertext before the application of deciphering function, as follows:

\[
m = f^{-1}(c) = c^d \tag{2}
\]

### 3. Implementation of RSA cryptosystem

#### 3.1 Key generation

We shall exemplify the implementation of the RSA cryptosystem using small prime integer values in order to depict what exactly happens within the system. The value shall be small in order to permit the computation of the encrypting and decrypting functions using a scientific calculator, otherwise it will not be computable (Ugwu, 2014).

Let \( P = 11 \), and \( Q = 5 \),

Computing the value of \( n \),

\[
n = 11 \times 5
\]

\[
= 55
\]

Computing the Euler Totient Function \( \phi(n) \),

\[
\phi(n) = (11 - 1) \times (5 - 1)
\]

\[
= 10 \times 4
\]

\[
= 40
\]

Selecting the encryption exponent, \( e \):

Let \( e = 7 \);

Checking whether the \( \phi(n) \) and \( e \) are relatively prime
Finding the LCM of 40 and 7

LCM of 40 = $2^3 \times 5^1$ and LCM of 7 = $7^1$

From the computation above, you could understand that there is no similarity with the components that make up $\phi(n)$ and $e$,

$$\text{gcd}(e, \phi(n)) = 1$$

Hence, they are relatively prime to each other.

To compute the value of $d$, we shall invoke the use of extended Euclidian algorithm, which shall accurately give us the value of the inverse function of $e$, $(e^{-1})$

$$40 = 7 \times 5 + 5$$
$$7 = 5 \times 1 + 2$$
$$5 = 2 \times 2 + 1$$
$$2 = 1 \times 2 + 0$$

Where the computations are in the order of:

Dividend = Divisor $\times$ Quotient + Remainder,

For the Iterating values, the former Divisor will become the new Dividend, as the former Remainder will become the new Divisor, this continues until the remainder becomes 0,

Then, we work back to get the extended Euclidian value,

$$1 = 5 - (2 \times 2)$$
$$= 5 - 2 \times (7 - 5)$$
$$= 5 - 2 \times 7 + 2 \times 5$$
$$= 3 \times 5 - 7 \times 2$$
$$= 3 (40 - (7 \times 5)) - 7 \times 2$$
$$= 40 \times 3 - 7 \times 17$$, therefore

$$1 = 40 \times 3 + 7 \times (-17)$$

Hence the inverse function of the $e$ value is:

$$-17 \mod 40$$

$$= 40 - 17$$
\[ d = 23. \]

The private keys which are \( n \), \( \phi(n) \), \( P \), \( Q \), \( e \), and \( d \) are:

55, 40, 11, 5, 7, 23

The public keys which are \( n \) and \( e \) are:

55 and 7.

### 3.2 Encryption and decryption

If one wants to send a message ABA to a friend living at a far distance, but would want to encrypt it manually using the above keys as already computed.

Taking the English alphabetical-number equivalent as written in Table 1:

<table>
<thead>
<tr>
<th>Table 1 Alphabetic Equivalence Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>, .</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>+</td>
</tr>
<tr>
<td>28</td>
</tr>
<tr>
<td>(</td>
</tr>
<tr>
<td>42</td>
</tr>
</tbody>
</table>

\( m = A \ B \ A \), so, from the alphabetical equivalence table above,

\( m = 2 \ 3 \ 2 \)

The encryption function as stated in Equation (1) above is

\[ c = m^e \pmod{n} \]

Where \( c \) = the ciphertext message; \( m \) = the plaintext message; \( e \) = the encrypting exponent; \( n \) = the modulus.

\( c = 2^7 \ 3^7 \ 2^7 \) all in \( \pmod{55} \)

\( c = 128 \pmod{55} \ 2187 \pmod{55} \ 128 \pmod{55} \)

\( c = 18 \ 42 \ 18 \)

From the alphabetical equivalence table, you could infer that:
Then the sender will now send:

\[ c = Q \ (Q \text{ to the destination owner of the public key}). \]

The owner of the public key will decrypt the ciphertext using the private keys, \( n \) and \( d \) as stated in Equation (2) above.

\[ m = c^d \mod n \]
\[ m = 18^{23} \times 42^{23} \times 18^{23} \text{ all in } \mod 55 \]
\[ m = 74347713614021927913318776832 \mod 55 \]
\[ 2.1613926941579800829422581272845e + 37 \mod 55 \]
\[ 74347713614021927913318776832 \mod 55 \]
\[ m = 232 \]

The receiver will look back from the alphabetical equivalence table to get their values, hence

\[ m = ABA \]

The receiver, and owner of the key will also understand that the message was meant for him.

Therefore, \( c = 8278 \)

\[ m = 8^7 \times 27^7 \times 8^7 \text{ all in } \mod 55 \]
\[ m = 2097152 \mod 55 \]
\[ 10460353203 \mod 55 \]
\[ 2097152 \mod 55 \]
\[ m = 232 \]

From the alphabetical table equivalence:

\[ 2 \text{ = A, and } 3 \text{ = B.} \]

Hence the message sent is:

ABA

3.3 Substitution cryptosystem

The substitution cryptosystem involves the use of substitution encryption and decryption table to encrypt and decrypt a message based on its equivalences. We shall exemplify what happens within the Multilevel Offline Cryptography Support System using Table 2 (Simmons, 1979):
Table 2  Substitution Cryptosystem Table

| Pi  | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
| Ci  | # | + | - | Z | Y | * | / | ! | ~ | W | X | \ | $ | % | ^ | A | C | B | ( | ) | < | > | D | F | E |
| Pi  | - | * | / | \ | ] | [ | ; | : | } | { | = | _ | ) | ( | ) | * | % | $ | # | @ | ! | ~ | ` | < | > | “ |

Where Pi indicates the Plaintext character and Ci indicates the Ciphertext character.

A substitution cipher involves direct changing of the plaintext messages with the ciphertext equivalent.

One might wish to encrypt and send a message joeljupiter@yahoo.com. Before sending this message, he or she must first of all take the direct ciphertext representation to compute the ciphertext from the substitution table before sending it. It is computed as below:

Plaintext = joeljupiter@yahoo.com

From the ciphertext table, the ciphertext equivalence is:

Ciphertext = xa*$x<cw)*(|f+~aa#za% 

The ciphertext message above will now be sent to the receiver who then decrypts the message using the substitution cipher table.

4. Multilevel paradigm (RSA-substitution cryptosystem)

N-Cryptography Multilevel ciphers shown in Figure 1 combined the features of RSA and Substitution cipher. In the multilevel cryptographic example here, we will employ the use of RSA and Substitution cryptosystems which produces several layers in the specified prototype algorithm. The encryption layers are:

(1) The upper layer: this layer maps the plaintext letters to their numeric equivalents;

(2) The middle upper layer: this layer involve the transformation of the numeric values using the RSA encryption

(3) The middle lower layer: this layer takes the values from RSA transformation and subsequently maps numeric values to their letter equivalents, and

(4) The terminal layer: this layer involves taking the RSA ciphertext letters’ equivalent values from the substitution table.
For instance using the keys in 2.2 and Tables 1 and 2 specified above, one might wish to send a message “ABA” to a friend using the RSA and Substitution multilevel paradigm. The computation is done as follows:

The plaintext, \( m = ABA \)

From the RSA alphabetical-number equivalent in Table 1 above, the numbers equivalence are:
Encryption function as stated in Equation (1) above is $c = m^e \pmod{n}$

Where $c =$ the ciphertext message; $m =$ the plaintext message; $e =$ the encrypting exponent; $n =$ the modulus.

$m = 232$

$n = 55$, $e = 7$,

c = $2^7 \cdot 3^7 \cdot 2^7$ all in $\text{mod} 55$

c = $128 \pmod{55}$ $2187 \pmod{55}$ $128 \pmod{55}$

c = $18 \cdot 42 \cdot 18$

From the alphabetical-number equivalence table above, you could infer that:

18 = Q, and 42 = (  

Then the sender will now have the RSA ciphertext as:

$c = Q(Q$

The sender will also go to the substitution-encryption-decryption table above to take the ciphertext equivalence value of the RSA ciphertext as follows:

Q = B

( = U

Then the final ciphertext message will now become BUB

The sender will now send $c = BUB$ to the destination of the message.

 Decryption of ciphertext involves many layers, but is arranged as reverse of the encryption above. These layers are:

(1) The upper layer which involves the decryption of the substitution ciphertext using the substitution encryption-decryption table above to get the RSA ciphertext,

(2) The middle upper layer involves the mapping of the RSA ciphertext with the number equivalent using the letter-number equivalent table.

(3) The middle lower layer which involves the decryption of the numeric equivalence using RSA decryption formula

(4) The lower layer involves subsequent mapping of the numeric values with its letter equivalence from the RSA number-letter equivalence table.
We shall exemplify the steps above using the ciphertext obtained from the computation above.

The ciphertext is BUB

Converting the BUB to the substitution plaintext to get the RSA ciphertext using Table 2 above,

Pi = BUB

Ci = Q(Q

Then, the RSA ciphertext value Q(Q will be mapped with its alphabet-number equivalence in Table 1 above to get 18 42 18

Using the formula $m = c^d \pmod{n}$ from Equation (2) and the keys specified in 2.2 above.

$m = 18^{23} \times 42^{23} \times 18^{23}$ all in mod 55

$m = 74347713614021927913318776832 \pmod{55}$

$2.1613926941579800829422581272845e + 37 \pmod{55}$

$74347713614021927913318776832 \pmod{55}$

$m = 232$

The receiver will look back from the number-alphabetical equivalence table in Table 1 above to get their values, hence

$m = ABA$

The receiver, which is the owner of the key, will also understand that the message was meant for him.

5. RSA and substitution ciphers multilevel algorithm

Start

//Input the plaintext message, m or ciphertext, c

//Is it to encrypt

If YES

//Request for key,

//Do you have keys
If YES

//Insert the encryption keys

//Is encryption key public

If yes

//Encrypt with public key

Else

//Encrypt with private key

//Encrypt with Substitution table

//Display Ciphertext

Else,

//Generate Keys

//Move back “Insert plaintext or ciphertext”

Else,

//Insert the decryption keys

//Decrypt with Substitution table

//Is text Encrypted with public key?

If yes

//Decrypt with private key

Else

//Decrypt with public key

//Display the Plaintext

Stop

6. Performance evaluation

The researchers adopt ISO/IEC 27004 (Figure 2) (International Organization for Standardization and International Electrotechnical Commission, 2009) and the methodology proposed in NIST SP 800-55 (National Institute of Standards and Technology, 2000) in order to measure the performance of new RSA-Substitution
cryptosystem. The ISO/IEC 27004 identifies four major processes for quality assessment which are listed below:

(1) Measures and Measurement Development.

(2) Measurement Operation.

(3) Data Analysis and Measurement Results Reporting.

(4) ISMP Evaluation and Improvement.

Figure 2  ISO/IEC 27004:2009 Model
6.1 Variable definition

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robustness</td>
<td></td>
</tr>
<tr>
<td>Very robust</td>
<td>1</td>
</tr>
<tr>
<td>Weak</td>
<td>0</td>
</tr>
<tr>
<td>Timeliness</td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td>1</td>
</tr>
<tr>
<td>Slow</td>
<td>0</td>
</tr>
<tr>
<td>Operation result</td>
<td></td>
</tr>
<tr>
<td>Maximal</td>
<td>1</td>
</tr>
<tr>
<td>Minimal</td>
<td>0</td>
</tr>
<tr>
<td>Goal &amp; Objectives</td>
<td></td>
</tr>
<tr>
<td>Achieved</td>
<td>1</td>
</tr>
<tr>
<td>Not achieved</td>
<td>0</td>
</tr>
<tr>
<td>Security standard, policies and procedures</td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>1</td>
</tr>
<tr>
<td>Not observed</td>
<td>0</td>
</tr>
</tbody>
</table>

6.2 Data analysis

Binary values have been assigned in Table 3 to make a preliminary analysis of the combined effect of the two ciphers. This shows the joint system has the robustness of the RSA system, the speed of a substitution cipher and an optimized operational result. A full ISO/IEC 27004 analysis would require baseline measurements on a practical implementation, followed by comparative measurements using the same methodology over time.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Robustness</th>
<th>Timeliness</th>
<th>Operation Result</th>
<th>Goals and Objectives</th>
<th>Implementation Level of Established Security Standard, Policies and Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSA</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Substitution</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RSA+ Substitution</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3 Data Analysis of RSA, Substitution, and RSA-Substitution Cryptosystem
7. Benefits of multilevel RSA-substitution cryptosystem

The implementation of RSA-Substitution Cryptosystem shows that it has the followings benefits:

1. It is robust and highly secure than single cryptosystem.
2. It is cost effective.
3. It is efficient in terms of implementation processing time.

8. Future research

The researchers aim to measure and enhance the performance of the RSA-Substitution multilevel cryptosystem in order to improve its robustness and other benefits.

9. Conclusion

This research has successfully implemented a multilevel algorithm using the combination of RSA and Substitution ciphers. Implementing the substitution cipher with RSA encryption realized a high level of information security assurance as the RSA cipher will ensure the authenticity of the message. Implementing this algorithm in the application layer gives a great advantage to the computation of RSA keys because of the factorization of large prime numbers. In the overall implementation of the RSA cipher, using large primes could be seen as a great security additive and hence we are encouraged to use this. The multilevel paradigm presented above is very simple and can be implemented using any programming language. The output of the RSA transformation is taken as the input of the Substitution transformation, after which, the required ciphertext is obtained. The decryption process as indicated by the flowchart above can be seen as the reverse of the encryption process. The substitution transformation that was done last during the encryption process was first to be deciphered, while the RSA step was done last.

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References


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Development of an In-House Grid Testbed Supporting Scheduling and Execution of Scientific Workflows

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Abstract: Researchers working in Grid workflow scheduling need a real Grid environment to produce the results of experiments. However, many interested researchers of academic institutes may not be able to produce experimental results due to unavailability of a required testbed at their institutes. This article addresses an important challenge of developing an in-house Grid testbed that supports workflow scheduling and execution. This article proposes the architectural design of the in-house testbed and then concisely presents chosen software tools, their understanding, installation, configuration, and the testing related to the implementation of the testbed. Furthermore, the article also presents the methodology of performing experiments on the testbed. The in-house Grid testbed is implemented using open-source, freely available, and widely used software components. In addition, the testbed allows to produce a real Grid scenario of varying bandwidth values by emulating the network characteristics among the Grid-sites of the testbed. This article addresses testing of all the internal components of the testbed and their integrations for their proper working. This article also provides testing and demonstration of workflow scheduling and execution. We believe that this article can educate novice users about developing a Grid testbed. The presented Grid testbed can easily be replicated or adapted; furthermore, the presented deployment of the Grid testbed can guide to researchers for carrying out real experimentation for their research purposes.

Keywords: Grid Testbed, Grid Deployment, Grid Software Integration, Workflow Scheduling, Workflow Execution.

1. Introduction

Grid computing (Foster & Kesselman, 2003; Foster et al., 2001) enables to execute performance demanding scientific applications efficiently by exploiting distributed resources in a collaborative manner. Many research projects, a few examples include (Blaha et al., 2014; Exon, n.d.; LIGO, n.d.; Montage, n.d.), try to solve their computing problems by making computation demanding applications composed of reusable batch-executables. Various systems (Altintas et al., 2004; Deelman et al., 2005; Fahringer et al., 2005) have been used by such projects to execute computation demanding applications
efficiently. Moreover, the systems that are open-source, freely available, well documented, and actively updated attract attention of many researchers and users.

A Grid application having data dependencies among its jobs is called workflow application (Taylor et al., 2007), which can be represented as a Directed Acyclic Graph (DAG). A workflow scheduler respects the dependencies among the tasks of a workflow in the prepared output schedule and a workflow executor executes these tasks as per the arranged order on the chosen resources. The scheduling (Pinedo, 2008) aspect in Grid computing (Dong & Akl, 2006; Prajapati & Shah, 2014c) is involved in two different entities: a local resource scheduler and an application scheduler. Workflow scheduling (Yu et al., 2008), an application scheduling, in Grid is complex and challenging (Deelman et al., 2005; Wieczorek et al., 2005), as the workflow scheduler has to decide about which resources will execute which tasks, what will be the order of the tasks, how to respect the data dependencies, and how to minimize the makespan of the workflow application.

A Grid computing architecture is complex to build and configure, as the Grid environment is generally implemented by using more than one software and with more than one physical computing resources. Readers may find how-to guide for installation and configuration of an individual software from software vendor. However, integrating various Grid related software is a big challenge for novice users. As a solution to this problem, in big organizations specialized system administrators are responsible for building the Grid testbed; however, in small organizations, it may not be the case. Many researchers working in academic institutes may not have budget to acquire specialized system administrators. Consequently, such researchers have no option other than deploying needed environment themselves. Because a Grid computing architecture involves use of various software in order to develop an environment with desired functionalities, the beginners need to spend a lot of time in understanding various topics related to Grid computing. Furthermore, many tools and software are available to solve the same purpose, which increases the complexity of building a Grid computing architecture.

Three major categories of Grid environment related software are (1) Local Resource Manager, (2) Grid middleware, and (3) higher level software and services. However, to perform workflow scheduling of scientific workflows requires integrations of appropriate software. Building and configuring of a required Grid environment involves the understanding of various software and their proper configuration. Therefore, the new researchers, specifically academic researchers, happen to stay away from Grid computing topic, or instead rely on simulation based approach. Moreover, if researchers want to embed new functionalities or new algorithms, then they need to take right decision about various software. Therefore, this article addresses the problem of design and implementation of the required Grid testbed supporting workflow scheduling and
execution with the minimal physical resources available. The article discusses the development in a logical way rather than showing the commands that are found in how-to guides.

Pegasus WMS is a widely used workflow management system for scheduling of scientific workflows; it is open-source and freely available. Therefore, we choose it as a WMS and integrate it in the testbed for scheduling and execution of scientific workflows. However, Pegasus WMS cannot run standalone; Pegasus WMS requires that Grid infrastructure is available and the infrastructure is exposed to itself in a specific way. Our testbed is implemented using Globus 5.2.3 (Globus Toolkit, n.d.), Condor 7.8.7 (HTCondor, n.d.), Pegasus WMS 4.1.0 (Pegasus WMS, n.d.), Network Time Protocol, and Dummynet (Dummynet, n.d.). The Globus software is used as a Grid middleware and Condor is used to implement Local Resource Manager. Moreover, Condor-g component of Condor is used for submitting jobs to the Grid-sites, and DAGMan of Condor is used to execute the concrete workflow that is prepared by Pegasus WMS. Pegasus WMS is used for workflow planning and workflow monitoring. Dummynet is used to control bandwidth among the Grid-sites in order to emulate a real network of Grid-sites, say the Grid-sites present in different countries. NTP is used for synchronizing clocks of Grid-sites.

**Our Contributions:** To carry out research on workflow scheduling aspect, we needed a Grid testbed supporting desired functionalities and administrative control. However, such Grid testbed was not available at our institute. Therefore, we develop a Grid testbed made of open-source and freely available software components. We attempt an important research challenge: many researchers interested in workflow scheduling can not perform experiments on a real Grid due to either unavailability or access of Grid testbed at their institutes or organizations.

Our major contributions in this article are as follows:

- Design a Grid testbed that uses minimal number of resources and still allows the execution of workflow scheduling.

- Discuss constituent software components and their roles in the development of the Grid testbed.

- Present preparation of a real Grid network scenario through network emulation.

- Discuss installation, configuration, integration, and testing of various software in a concise and logical way, rather than showing commands found in how-to guides, to allow beginners to reproduce a similar testbed.

- Demonstrate the applicability of the prepared testbed by scheduling and executing black-diamond workflow of Pegasus WMS; show the effect of data
communication size on makespan by scheduling and executing two workflows having the structure of Molecular dynamics code.

The interested researchers can use or replicate the ready-made design architecture presented in this article for their research purposes. Moreover, all the important details pertaining to the development of the Grid testbed are concisely discussed to enable its replication or customization needed by the interested researchers. To summarize, the article can help to researchers in two significant ways. First, it can help in understanding overall Grid architecture with roles and responsibilities of various involved software. Second, it guides to researchers in implementing a real Grid testbed with minimal hardware resources available with them.

2. Related work and motivations for this work

Some large scale Grid testbeds are available in certain countries, a few examples include Grid’5000 for users of France, EUROGRID for users of Europe region, and Open Science Grid for users of United States and few other countries. The work in (Lai & Yang, 2003) demonstrates building a Grid computing environment on Linux clusters, an in-house Grid testbed. The mentioned work (Lai & Yang, 2003) uses Globus toolkit (Foster & Kesselman, 1997) as a Grid middleware and Sun Grid Engine (Gentzsch, 2001) as a clustering software. Their work demonstrates performance achievement using Grid infrastructure for parallel applications; however, their work does not focus on workflow applications and the workflow scheduling aspect. Similarly, the work in Introduction to Grid Computing with Globus (Ferreira et al., 2003) provides the installation steps of building a Grid infrastructure using GT 4; however, it does not focus on workflow scheduling aspect. A recent work in (Sajat et al., 2012) focuses on the implementation steps of achieving security in Grid through Grid Security Infrastructure (GSI). Specifically, their work focuses on installation and testing of host certificates and client certificates and their testing. As compared to (Sajat et al., 2012), our work has wider scope, not just the security in Grid.

Workflow concept allows reusing data analysis operations to solve higher-level analysis problems in various domains; for example, the work in (Turner & Lambert, 2014) addresses use of workflows in social sciences. A Workflow Management System (WMS) can integrate various operations related to workflow modeling, scheduling, execution, and result gathering. Various WMSs support either Directed Acyclic Graph based workflow or Control Flow Graph based workflow or both. Triana (Taylor et al., 2004), GridAnt (Amin et al., 2004) or Karajan (von Laszewski and Hategan, 2005), UNICORE (Erwin & Snelling, 2001), Askalon (Fahringer et al., 2005), and ICENI (Furmento et al., 2002) are
Control Flow Graph based WMSs, and DAGMan (Frey, 2002), Taverna (Hull et al., 2006), GrADS (Berman et al., 2001), GridFlow (Cao et al., 2003), Gridbus (Buyya & Venugopal, 2004) are DAG based WMSs. Most of the mentioned systems are Globus based except Taverna, GridFlow, and UNICORE. Furthermore, a few systems also support web-services. However, only a few systems are active in further development of WMSs and in providing help or support to their users, and Pegasus WMS is one of them. Moreover, Pegasus WMS is open-source and freely-available. Therefore, we choose Pegasus WMS, a widely used workflow management system, for performing scheduling of scientific workflows.

Performing workflow scheduling and execution on a real Grid computing environment requires that the needed infrastructure is available. Moreover, performing experiments on a real system takes time and efforts and requires sound understanding of the system. If researchers require the results of workflow scheduling quickly and there is no need to develop a real Grid environment, then simulation based workflow scheduling and execution can become useful. The work in (Pop et al., 2008) provides MONARC based simulation solution for performing decentralized dynamic resource assignment for large scale workflow applications. Their work provides fault tolerant dynamic scheduling, which allows re-scheduling of remaining workflow when some allocated resources fail. The work in (Simion et al., 2007) proposes ICPDP (Improved Critical Path using Descendant Prediction) workflow scheduling algorithm. Moreover, their work adds facility of dependent tasks scheduling in DIOGENES, which was not available in DIOGENES. Their work implements the proposed algorithm in DIOGENES and compares its performance with HLFET, ETF, and MCP algorithms based on total scheduling time, schedule length, and normalized schedule length. SimGrid (Casanova et al., 2008) framework, which is a versatile framework supporting generic functionalities needed for simulating parallel and distributed applications, has been used by many researchers for performing workflow scheduling. Another popular simulation framework is GridSim (Buyya & Murshed, 2002). A workflow scheduling simulator called WorkflowSim (Chen & Deelman, 2012) is available for performing simulation of workflow overhead analysis, job clustering, and job failure analysis in addition to support of optimization of workflow execution. WorkflowSim mainly focuses on job clustering based workflow scheduling.

The following reasons motivated us to work on the development work presented in this article. First, we have worked on a simulation based evaluation of workflow scheduling algorithm (Prajapati & Shah, 2013). However, to validate the practical applicability and to evaluate various workflow scheduling algorithms, a real test environment is needed. As we did not have a real Grid testbed at our institute, we needed to develop a small, representative testbed to experiment with various workflow scheduling algorithms. Second, it is possible to get deployed the needed Grid testbed by
acquiring specialized system administrators; however, for an academic institute it is not a viable solution. Third, we felt that researchers who do not have access to a Grid testbed should not refrain themselves from research in Grid computing. Fourth, certain research projects (European Grid Infrastructure, n.d.; FutureSystems, n.d.; Pordes et al., 2007; SHIWA, n.d.) provide access to their Grid testbeds freely; however, the access is country specific due to their own limitations and policies. Finally, the most important one, though somehow researchers get access to an external Grid testbed, they do not get any freedom of changing any part of any component of the testbed, e.g., changing workflow scheduling algorithm. To evaluate a new algorithm, researchers require to do changes in the system, which is possible only if they own or get control of the testbed.

3. Architecture of the testbed and constituent components

Figure 1 shows a generalized architecture of Grid computing environment with focus on LRMs and connecting them using Grid computing mechanism. A Grid computing environment involves various Grid-sites, generally one organization is considered as one Grid-site. Each organization generally contains a batch-queue controlled cluster, which is exposed to external organizations through Grid computing services and protocols. Each Grid-site contains a Head node, which is accessible through network, generally Internet.

We attempt to implement this Grid computing architecture, shown in Figure 1, consisting of four Grid-sites using four machines, in which each machine represents one Grid-site. The architectural diagram of a Grid testbed supporting workflow scheduling is presented in Figure 2. In a real Grid system, each Grid-site generally involves many computing nodes, as shown in Figure 1. However, we use only one computing node under each Grid-site in our testbed to build the required computing infrastructure with minimal resources. Moreover, a real Grid computing architecture can involve Grid-sites of various countries. Therefore, to have such real network scenario in the prepared Grid testbed, we emulate the bandwidth and latency characteristics of network using dummynet (Carbone & Rizzo, 2010).

Next, we describe each component that we use in our testbed in brief.

3.1 Dummynet as a network emulator

Dummynet (Carbone & Rizzo, 2010) is a link emulator, which supports emulating configurable network environments. It is a kernel level bandwidth shaper, which can work without modifying an existing OS. It is easy to use, as once it is installed into OS, it can be configured using `ipfw` commands. Dummynet can be used to emulate network topologies also, including the emulation of a router device. Dummynet also supports
Development of an In-House Grid Testbed Supporting Scheduling and Execution of Scientific Workflows

packet classification, various queue management policies, and loss generation. Dummynet has two components: emulation engine, which works at kernel level, and packet classifier command (ipfw), which instructs the emulation engine. Readers are directed to Section 4.2 for further details.

3.2 HTCondor as an LRM

HTCondor (HTCondor, n.d.), which is formerly known as Condor (Litzkow et al., 1988), is a set of daemons and commands that enable to implement concept of Cluster computing (Buway, 1999). In this article, the words Condor and HTCondor are used to refer to the same thing. In Condor terminology, the batch queue controlled cluster prepared using Condor is referred by the word Condor Pool. The interaction with Condor system

Figure 1  An Architectural Diagram Showing Four Grid-Sites, Each Having Its Own LRM of Computing Nodes under Its Control
for various activities is done through command interface; the internal working of Condor system involves various daemons: Condor master, Condor startd, Condor collector, Condor schedd, Condor negotiator, Condor shadow, and Condor starter (Litzkow et al., 1988). Condor allows job submission, job execution, job monitoring, and input-output data transfer for batch jobs. In our testbed, we expose HTCondor LRMs to grid users through Globus middleware.

### 3.3 Globus toolkit as a grid middleware

To implement Grid computing (Foster & Kesselman, 2003), a Grid middleware software, which glues different local resources of organization, is needed. We use
Globus toolkit (Foster & Kesselman, 1997), which is a de-facto standard software for implementing Grid computing, as a Grid middleware. The testbed uses Globus for following activities.

- Grid Security (Certificate based authentication, authorization, and single signon) and Simple CA certificate authority for signing host and user certificates.
- GSI (Certificate) based GridFTP (Alcock et al., 2003) (client and server) for transferring data (files) on Grid-sites (machines)
- GRAM client and GRAM server to allow remote job submission using standard protocol -- GRAM.

3.4 Globus to LRM adapter

Each Local Resource Manager, e.g., Condor (Litzkow et al., 1988), SGE (Gentzsch, 2001), or PBS (Henderson, 1995), has its own interface of performing various job management related activities. GRAM (Foster & Kesselman, 2003) is a standard way of accessing a Globus Grid resource. A GRAM-LRM adapter enables usage of any LRM using GRAM. The GRAM-LRM adapter translates GRAM messages into LRM specific messages. Therefore, to access any LRM in a Globus based Grid, the installation of GRAM-LRM adapter is required. We use Globus to Condor adapter for accessing the Grid-sites of the testbed, which are running Condor LRM.

3.5 NTP for time synchronization

Network Time Protocol (NTP) (NTP, n.d.) is used to synchronize the time of a computer (client or server) to another reliable computer or a reference computer. NTP is a networking protocol for clock synchronization. NTP uses a hierarchy of clock sources. We use NTP in our testbed to have the clocks of all the computers in sync. NTP is needed in the testbed because due to the clock mismatch it is quite possible to send a certificate from one computer to the another on which the start validity period of the certificate has not yet come.

3.6 Condor-g and DAGMan as pre-requisites for Pegasus WMS

Condor-g (Frey et al., 2002) provides an ability to access Grid resources in the Condor way. Therefore, using Condor-g it is possible to use non-Condor Grid resources, such as PBS, SGE, for execution of the jobs that are submitted to a Condor queue. Moreover, Condor-g also enables exploiting job management related features of Condor for the jobs submitted to non-Condor remote Grid resources. Pegasus WMS uses Condor-g for submitting jobs to remote Grid resources. Condor-g communicates with resources and transfers files from and to these Grid resources. Condor-g uses GRAM protocol for job
submission to Grid resources and a local *Global Access to Secondary Storage* (GASS) (Bester et al., 1999) server for file transfers.

DAGMan (Frey, 2002) is HTCondor technology supporting execution of the jobs of a DAG on a Condor pool. It can utilize non-Condor Grid resources such as SGE, PBS, and LSF using Condor-g and can utilize the facility of flocking to get more resources in the pool. DAGMan submits a DAG job as a Condor job to a Condor scheduler. However, a data movement from one Grid-site to another Grid-site is not automatically handled by DAGMan, for which pre-script and post-script need to be associated with the jobs. DAGMan provides fault tolerance through generating a rescue DAG, which can be restarted from the failure point without redoing the earlier computed work.

3.7 *Pegasus WMS as a workflow management system*

Pegasus WMS (Deelman et al., 2005) is a workflow execution and management software for workflow jobs, which are represented as Directed Acyclic Graph in DAX format. It manages the dependencies of the jobs of a workflow. Pegasus WMS can allow use of one or more Grid resources for execution of the jobs of a particular workflow application. Pegasus WMS uses DAGMan (Frey, 2002) for execution of dependent jobs and Condor-g for job submission. A separate section is devoted to Pegasus WMS, see Section 6 for further details.

4. Deployment of the grid testbed: network configuration and network emulation

The Grid middleware software and other related services/software are available for Linux OSes. Therefore, we use Ubuntu OS for the machines of the Grid testbed, though the details presented on the deployment are applicable to other Linux variants with minor differences in the installation steps or in the OS specific configuration files.

4.1 *Network configuration*

The testbed includes four personal dual-core computers having Ubuntu 12.04LTS operating system and a networking switch to make a LAN environment. The configuration of the host names and the IP addresses is shown in Table 1. For each machine, the configuration of IP address is done using GUI based Network settings utility available in Ubuntu. The host name of a machine is configured in the `/etc/hostname` file and the mapping of host name to IP address is configured in the `/etc/hosts` file.
Table 1  The Host Names and IP Addresses of Four Computers Used for Deployment of the Grid Testbed

<table>
<thead>
<tr>
<th>Host Name</th>
<th>IP Address</th>
<th>Fully Qualified Hostname</th>
</tr>
</thead>
<tbody>
<tr>
<td>ca</td>
<td>192.168.31.230</td>
<td>ca.it2.ddu.ac.in</td>
</tr>
<tr>
<td>grid-b</td>
<td>192.168.31.203</td>
<td>grid-b.it2.ddu.ac.in</td>
</tr>
<tr>
<td>grid-v</td>
<td>192.168.31.231</td>
<td>grid-v.it2.ddu.ac.in</td>
</tr>
<tr>
<td>grid-m</td>
<td>192.168.31.232</td>
<td>grid-m.it2.ddu.ac.in</td>
</tr>
</tbody>
</table>

4.2 Network emulation

We use dummynet (Carbone & Rizzo, 2010) to emulate network links. The dummynet emulator is available in source code form (Dummynet, n.d.); therefore it needs to be compiled into binary before installation. We used 20120812-ipfw3.tgz file, which is available on its web-site. We uncompress this file using the tar command, and we build binary files by running the make command. The installation of dummynet includes placing the ipfw executable in the /usr/local/sbin directory and the ipfw_mod kernel module in the directory: /lib/modules/`uname-r`. We install dummynet on each computer of the Grid testbed, but we configure each machine with different bandwidth values. Figure 3 shows the additional steps of configuring dummynet in the Grid testbed.

To emulate different bandwidth values among the four machines of the testbed, we configure each machine with different bandwidth value. The grid-b has 1,024 kbit/s, grid-v has 512 kbit/s, grid-m has 256 kbit/s, and ca has 128 kbit/s as bandwidth values. Figure 4 shows how to configure bandwidth control on the grid-b machine through the install-bandwidth-limiter.sh file, which we create and is not an available configuration file. The bandwidth control uses two pipes: one for the upload bandwidth and the second for the download bandwidth. For other machines, the install-bandwidth-limiter.sh file is similar, except for the value of bandwidth and the source and the destination IP addresses. The pipe 101 is used to control the bandwidth on the traffic that travels from the machine itself to the other three machines of the testbed. Similarly, the pipe 102 is used to control the bandwidth on the traffic that arrives from

Figure 3  Additional Steps of Configuration Dummynet in the Grid Testbed
any other machine of the testbed to the machine itself. When bandwidth control is not
needed, the network emulation can be disabled by running the `ipfw -q flush` and `ipfw
-q pipe flush` commands.

5. Deployment of the grid testbed: LRM and grid middleware

5.1 Our common procedure for installation of software on Ubuntu

In Ubuntu OS, software that are maintained by various Ubuntu repositories are
installed on a computer by connecting the computer to Internet and then running `sudo
apt-get install` command. We first installed, without doing any configuration, all the
required software and their dependencies on one computer using `sudo apt-get install`.
As part of any software installation on a Ubuntu machine using apt tool, all the needed
.deb files with dependencies are downloaded into the `/var/cache/apt/archives`
directory. Using these downloaded .deb files, for each software we create the required
package repository and package indexing, i.e., `Packages.gz` file, using the `dpkg-
scanpackages` command. Then, we modify the `/etc/apt/sources.list` file to reflect
the locations of various local repositories created in the earlier step. Next, we update the
package repository using the `sudo apt-get update` command. Finally, we install a
particular software using the `sudo apt-get install <package-name>` command,
where `<package-name>` is the name of the chosen software, as if you are connected to
Internet.

Installation of non-Ubuntu maintained software on Ubuntu OS involves one
additional step of configuring vendor’s repository on the computer. Installation using
either the `sudo apt-get install <package-name>` command or through searching in
Ubuntu Software Center will not succeed, as such software are not maintained by Ubuntu
repositories. For non-Ubuntu maintained software, the required repository files (*.deb) for
various supported platforms are provided by its software vendor. For configuring the local
repository of a computer, first we need to choose appropriate repository file depending

```bash
ipfw -q flush
ipfw -q pipe flush
echo "setting delay 100ms and bandwidth 1024kbit/s"
ipfw pipe 101 config delay 100ms bw 1024kbit/s
ipfw pipe 102 config delay 100ms bw 1024kbit/s
ipfw pipe show
```

**Figure 4** Content of the Additional File: install-bandwidth-limiter.sh on the grid-b Machine for Controlling Bandwidth in the Grid Testbed
upon the target platform of the computer, characterized by operating system and hardware architecture (32 bit or 64 bit); next, we need to download the chosen repository file to the computer; then, we need to install the repository file using the `sudo dpkg -i <repository-file.deb>` command to update the local repository configuration of the machine.

5.2 Globus installation and configuration

Globus requires Java and Ant as prerequisites. Therefore, we install Java from `jdk-7u9-linux-i586.gz` file and Apache Ant from `apache-ant-1.8.4-bin.tar.gz` file on all the four machines of the testbed. We present the installation and configuration of globus components next.

5.2.1 Roles and corresponding machines

In our testbed, the ca machine, which works as a Certificate Authority using SimpleCA, issues host certificates and user certificates to other machines. The other three machines: `grid-b`, `grid-v`, and `grid-m`, and `ca` play roles of Grid nodes. The Grid node role indicates that a particular machine is a compute node, which allows the execution of a remotely submitted job.

5.2.2 Installation of globus components on the ca machine

We install the `globus-gram5` and `globus-gridftp` packages as per the procedure discussed in Section 5.1. Similarly, on CA, i.e., the `ca.it2.ddu.ac.in` machine, we install `globus-gsi` and `globus-simple-ca` Globus packages. As part of the above installation on CA, the following steps are done automatically by the installer: (1) install Grid Security Infrastructure and Simple CA, (2) create the `simpleca` user automatically, (3) create the self-signed host-certificate, and (4) the `simpleca` user gets `globus`, default one, as the pass-phrase to sign requests of signing host-certificates and user-certificates. We create a user with the name `gtuser` on all the machines, including ca as it also plays role of a Grid node.

5.2.3 Configuration of grid user on the ca machine

On the ca machine, as the `gtuser` user we send a request for user certificate using the `grid-cert-request` command. The command prompts the requesting user to enter its name and choose PEM pass-phrase, and generates the following three files: `usercert_request.pem`, `userkey.pem`, and an empty `usercert.pem`. Then, we send the user certificate request (`usercert_request.pem`) file to the `simpleca` user for signing, which the `simpleca` user signs using the `grid-ca-sign` command and sends the generated file back to the `gtuser` user. We as the `gtuser` user store the received signed certificate file under its `/home/gtuser/.globus` directory with the name `usercert.pem`. The `gtuser`
user can verify the installation and configuration using the grid-proxy-init -debug -verify command. Next, we do a mapping from a user certificate to a local Linux user account by running the grid-mapfile-add-entry command as the root user. Finally, we verify working of all components by running globus-job-run ca.it2.ddu.ac.in/jobmanager-fork/bin/hostname -f command as the gtuser user.

5.2.4 Preparing GSI configuration file on CA for distribution

On the ca machine, we as the simpleca user create a .deb file containing GSI configuration using the grid-ca-package command. The generated .deb file is used to setup GSI on other (Non-CA) machines which will work as Grid nodes. Other Grid nodes install GSI configuration using the dpkg command and the generated .deb file.

5.2.5 Installation and configuration on other grid nodes

In this paragraph, we discuss about how we install and configure Globus components on the remaining Grid nodes, i.e., grid-b, grid-v, and grid-m. We install GRAM and GridFTP Globus components using the procedure discussed in Section 5.2.2. Next, as the root user, we install CA certificates and signing policy, using the distribution file generated by simpleca user on the ca machine in Section 5.2.4, on the grid-b, grid-v, and grid-m machines. Next, on each machine we generate a request for a host certificate and get it signed from SimpleCA. This step is similar to getting a signed user certificate, except that the host certificate request is generated as the user being root user. Next, we do the configuration of the Grid user on each machine, for which the used procedure is similar to as discussed in Section 5.2.3.

5.3 Installation and configuration of NTP

We use the grid-b machine as a local NTP server and other machines as NTP clients to grid-b. After installing NTP on each machine of the testbed, we configure the /etc/ntp.conf file. We put following configuration line: server 127.127.1.0, on the grid-b machine in its /etc/ntp.conf file. On the other machines, we put server 192.168.31.203 as the configuration line in their /etc/ntp.conf files, where 192.168.31.203 is the IP address of the grid-b machine.

5.4 Installation and configuration of condor components

We use Condor 7.8.7 as a LRM. In the testbed, as each machine is to work as a Grid-site, we install personal Condor on each machine. We install condor using sudo apt-get install condor command by following the procedure discussed in Section 5.1. Next, we verify the installation of Condor by submitting a Condor submit file containing a Vanilla universe job using condor_submit command.
To allow submission and execution of remotely submitted jobs, we install GRAM-Condor adapter on each Grid-site of the Grid testbed. We install the adapter using `sudo apt-get install globus-gram-job-manager-condor` command. For each Grid-site, we do testing of GRAM-Condor adapter by submitting a GRAM job from any other machine of the testbed. For example, to test working of GRAM-Condor adapter on the grid-v machine, we perform following steps: (1) login on grid-b as the gtuser user, (2) create proxy credentials using `grid-proxy-init`, and (3) submit a job to grid-v using `globus-job-run`.

Pegasus WMS uses the Grid universe for a job to allow its execution and monitoring on remote Grid-site in the condor way. Condor-g component of HTCondor allows the Grid universe job to be submitted using `condor_submit`. The condor-g component gets automatically installed when HTCondor is installed. Though a Condor job can be submitted to a remote Condor LRM using `globus-job-run`, the Pegasus WMS uses Condor-g for submission of remote jobs to avail facilities of job monitoring and fault tolerance for the submitted jobs on the submit site in the unified way -- the Condor way.

6. Deployment of the grid testbed: Pegasus WMS and its configuration for the grid testbed

Pegasus WMS was developed by University of Southern California in collaboration with the Condor team of University of Wisconsin Madison. Pegasus WMS is maintained by the Pegasus team. Pegasus WMS is available freely in binary form for different platforms; moreover, it is open source and it relies on other open source software. Pegasus WMS is made available for use since 2001. We use Pegasus WMS version 4.1 for preparing the Grid testbed supporting workflow scheduling. In this section, we first concisely describe Pegasus WMS and then present the configuration that we do in the Grid testbed to achieve scheduling of scientific workflow application.

6.1 Pegasus WMS as a workflow planner and DAGMan as a workflow executor

Pegasus WMS is a workflow execution and management software for workflow jobs that are represented as Directed Acyclic Graph. It manages dependencies of jobs. It can allow use of one or more Grid-sites for execution of the jobs of a workflow application. Pegasus WMS can use any Grid resource or a Grid-site that can be accessed using GRAM. Pegasus WMS uses, on the workflow submit site, Condor-g for job submission and Condor DAGMan for execution of a DAG. Pegasus WMS does planning of the jobs of a workflow, represented in .dax format, and generates a concrete workflow in form of .dag file and Condor-g submit files, and passes them to DAGMan for execution.
DAGMan itself cannot decide about which Grid-site runs which jobs, though the site can utilize any available machine of the cluster once the job is submitted to a particular Grid-site. DAGMan can not take decision about which Grid-site is best to run a particular job. Therefore, Pegasus WMS complements DAGMan for supporting scheduling and execution of the jobs of a workflow on Grid resources. Pegasus WMS chooses appropriate Grid resources for execution of jobs, which is done by a site-selector algorithm, and generates codes for file movement, data cleanup, data registration, etc. Moreover, Pegasus WMS provides the monitoring of a running workflow and also provides the provenance and performance related information.

6.2 Working of Pegasus WMS

We briefly highlight on working of Pegasus WMS. Pegasus WMS’s **pegasus-plan** command takes an abstract workflow (DAX) as an input and does planning (deciding which task runs on which Grid-site) of tasks of the workflow based on the information provided in catalogs. This selection decision is taken by a site-selector algorithm, which we configure in the property file — **.pegasusrc** file in our testbed, of Pegasus WMS. The **pegasus-plan** command uses physical locations specified for input files from the replica catalog. The **pegasus-plan** command prepares the DAGMan .dag file and Condor job submit files based on the information provided in the transformation catalog. The prepared Condor submit files are in fact Condor-G submit files having Grid as Universe. The **pegasus-plan** command adds the additional jobs for creating a workflow directory, transferring intermediate files, registering the final data and intermediate data in replica catalog, and cleanup activities. Pegasus WMS’s **pegasus-run** command runs the jobs of the planned workflow on the chosen Grid-sites. The **pegasus-run** command itself does not run the jobs of the workflow, rather Pegasus WMS relies on DAGMan, which is a workflow executor for Pegasus WMS.

When a workflow is started using the **pegasus-run** command, the command starts the monitoring daemon (**pegasus-monitord**) in the directory (called workflow directory and is created by **pegasus-plan**) containing the condor submit files. The **pegasus-monitord** daemon parses the condor output files and updates the status of the workflow to a database and to the **jobstate.log** text file.

6.3 Installation and configuration of Pegasus WMS in the grid testbed

6.3.1 Installation of Pegasus WMS

As the root user, we install Pegasus WMS on the machines, which are having 32-bit Ubuntu OS, using **pegasus 4.1.0-2 i386.deb** file, which we generated from .rpm file using alien tool, as .deb file for 32-bit, Intel architecture was not available. As discussed earlier, we use the four Grid nodes as four Grid-sites. We assign the names of these sites
as ddu_grid-b, ddu_grid-v, ddu_grid-m, and ddu_ca, and configure these names in the *Site Catalog*. All these four Grid-sites play role of an Executor and ddu_grid-b plays role of a Submit and an Output site, in addition to Executor.

### 6.3.2 Configuration of directory structure and files

The Pegasus WMS needs a *scratch* directory and a *storage* directory on each Gridsite. The `pegasus-plan` creates create dir jobs, one per Grid-site, which will create a workflow directory under *scratch* directory on each Grid-site that will run jobs of the workflow. The *storage* directory is used to hold output data of workflows. We create `/scratch` as a *scratch* directory and `/storage` as a *storage* directory, both having all permissions, on each Grid-site of the testbed. We configure the locations of these directories in *Site Catalog*.

We configure Pegasus WMS for the *gtuser* user on the submit Grid-site, as we have configured the *gtuser* user as the user of the Grid testbed. Under the home directory of the *gtuser* user, i.e., `/home/gtuser`, we create the `.pegasusrc` file containing initialization of various properties. The `.pegasusrc` property file contains the configuration of locations of Replica Catalog, Site Catalog, and Transformation Catalog. Furthermore, we also specify the `pegasus.selector.site` property indicating which site-selector algorithm is used for mapping the jobs of a workflow in this file.

Figure 5 shows the directory structure used for keeping the configuration files, the input files to Pegasus WMS, and the output files generated by Pegasus WMS. The `rc.data` file under the directory `/home/gtuser/pegasus-wms/config` is a text based *Replica Catalog*. The `sites.xml` file under `/home/gtuser/pegasus-s-wms/config` is an XML based *Site Catalog*. The `tc.data.text` file under `/home/gtuser/pegasus-wms/config` is a text based *Transformation Catalog*. The `/home/gtuser/pegasus-wms/local-scratch` is the directory to hold temporary files created for the local site and the directory `/home/gtuser/pegasus-wms/local-storage` is used to store data files. When we use the `pegasus-plan` command to do planning of an abstract workflow, we make the `/home/gtuser/pegasus-wms/` directory as the current working directory so that the paths to the `.dax` file and the workflow run directory can be specified relative to this directory. The `/home/gtuser/pegasus-wms/dax` directory is used to keep abstract workflow files in DAX (XML) format. The `workflow-run` directory is used, specified using `--dir` option to `pegasus-plan`, by the `pegasus-plan` to store generated submit files produced by planning of the workflow. The `pegasus-plan` creates a separate directory for each planning done by it under `workflow-run` directory, which `pegasus-run` uses for executing the planned concrete workflow. The `input-data` directory is used to hold data files of workflows, whose locations are specified in *Replica Catalog*. 
7. Testing and use of the testbed

7.1 Methodology of experimentations

Figure 6 shows the steps of the methodology used to carry out experiments on the Grid testbed supporting workflow scheduling, which includes four major phases of performing experimentation. These phases in sequence are as follows: (1) experiment configuration, (2) workflow planning, (3) workflow execution, and (4) result generation. During experiment configuration in Pegasus WMS, the steps of computations of a scientific workflow are specified as an abstract workflow in DAX, an XML file. Next, site catalog, transformation catalog, and replica catalog are set up. Next, the site-selector algorithm is chosen by assigning appropriate name of siteselector class, i.e., workflow scheduling algorithm, to the \texttt{pegasus.selector.site} property in \texttt{.pegasusrc} file. The next two steps are related to planning of a workflow.

Once the concrete workflow is generated at the end of workflow planning, the execution and monitoring of the workflow can be started. For workflow execution, first, the Grid user, in our testbed the \texttt{gtuser} user, needs to create proxy credentials to allow access of Grid resources to the jobs submitted by \texttt{pegasus-run} on behalf of the user. Next, the \texttt{pegasus-run} command is executed to start execution of the jobs of the planned workflow on the Grid-sites. The execution of the workflow can be monitored by running the \texttt{pegasus-status} command under control of watch command. An optional step of using \texttt{pegasus-analyzer}, which is not shown in the diagram, can be used to debug a failed workflow. If the execution of the workflow is completed, various plots are generated using the \texttt{pegasus-plots} command and statistics of the workflow run is collected using the \texttt{pegasus-statistics} command.

7.2 Testing of various components and workflow scheduling and execution

The complete testing of the whole testbed includes testing of many constituent
components and their functionalities. We list out various testings that we carried out for our testbed. Then, we provide testing of workflow scheduling and workflow execution. The work in (Prajapati & Shah, 2014b) addresses remote job submission to LRM using Grid computing mechanisms. We have performed following testings on each Grid-site to test working of various components.

- Testing of GSI for proxy credential generation using `grid-proxy-init` and `grid-proxy-info`
- Testing of Condor LRM for job execution using `condor_submit` and monitoring using `condor_q`
- Testing of gridftp using `globus-url-copy` for file transfer
- Testing of fork job manager using `globus-job-run`
- Testing of Condor job manager (Globus-Condor adapter) for job execution using `globus-job-run`
- Testing of Condor-g for remote job submission using `condor_submit` and `Universe=Globus` in condor submit file

We perform testing of Pegasus WMS by scheduling and running the blackdiamond workflow on the four Grid-sites: `ddu_grid-b`, `ddu_grid-v`, `ddu_grid-m`, and `ddu_ca`. We create the concrete workflow for RoundRobin site-selector algorithm using `pegasus-plan` by passing the four Grid-sites to `--sites` option. If the planning is successful,
pegasus-plan will concretize the workflow and will create a unique directory, for which time-stamp value is used as the name of the directory, containing job submit files and DAGMan submit file. To start execution of the planned workflow, we run the workflow using the pegasus-run command. While the workflow is executing, we can see status of executing workflow using pegasus-status. To check status of activities the four Grid-sites are doing for black diamond workflow at particular instant of time, we log on to three other machines (grid-v, grid-m, and ca) using ssh from the grid-b machine.

Next, we generate various charts using the pegasus-plots command. The pegasus-plots command will generate various plots under the plots sub-directory under the workflow run-directory. Figure 7 shows Gantt chart showing the assignment of the workflow jobs on the four Grid-sites using RoundRobin site-selector algorithm.

7.3 Workflow scheduling and execution of molecular dynamics code workflow

Using the way of creating the black-diamond workflow, we prepare two workflows of 41 tasks based on the structure of the task-graph of Molecular dynamics code, which is available in (Topcuouglu et al., 2002). For both the test workflows, we choose the runtime of each task randomly in the range 243 ~ 357 seconds. For both the workflows, the cumulative runtime of all the tasks is 12,219 seconds and the average runtime is 298.02 seconds. However, we keep different amount of data communication among the tasks of these two test workflows to observe their effect on makespan. For the first test workflow, the amount of data communication between two tasks is chosen randomly in the range 9,879,000 ~ 15,698,940 Bytes; the Communication to Computation Ratio (CCR) for this workflow is $CCR \approx 0.65$. For the second test workflow, the amount of data communication between each pair of tasks is small, specifically, it is in the range 987,900 ~ 1,569,894 Bytes.
Bytes. Thus, the CCR for the second workflow is $CCR \approx 0.065$. We schedule and execute both the test workflows using Random site-selector algorithm in the similar way, as discussed earlier. For the first test workflow, the makespan of 23,261 seconds is observed. However, for the second test workflow, having small data communication, the makespan of 6,308 seconds is observed. Figure 8 shows the Gantt chart showing the assignment of the jobs of the second test workflow on the four Grid-sites using Random site-selector algorithm. From the experimental results, we can understand that by increasing the amount of data communication among the workflow tasks, the makespan of workflow execution increases due to relatively higher time spent in data communication. Thus, the prepared testbed can allow experimentation of workflow scheduling and execution on a real Grid environment.

This testbed was used in (Prajapati & Shah, 2014a) for performing bandwidth-aware workflow scheduling of scientific workflow.

7.4 Scalability and failure handling in the testbed

Two important problems: scalability of a testbed and failure of resources in the testbed can affect to workflow scheduling and execution. In our testbed, we have added a single node under each Grid site, as show in Figure 2, for demonstration purpose; however, it is possible to add many nodes under each Grid site to make the testbed more scalable. Workflow scheduling time depends on the number of Grid sites, not on the number of computing nodes. Therefore adding computing nodes under a Grid-site will not affect to workflow scheduling time. Moreover, adding Grid-sites will affect workflow scheduling time polynomially depending upon the workflow scheduling algorithm. Failure

![Timeline in seconds ->](image)

**Figure 8** Host over Time Chart for Molecular Dynamics Code Workflow Having Small Data Communication Using Random Site-Selector Algorithm
of resources can happen at two levels: (1) failure of a computing node and (2) failure of a Grid-site. The failure of a computing node does not affect to workflow execution, as the failed job can be handled by the LRM by restarting it on some other available computing node under its control. However, failure of a Grid-site can affect to workflow execution depending upon how the used WMS deal with the Grid-site failure. In case of Pegasus WMS, the failure of a job is detected by the monitoring daemon (pegasus-monitord). The user can debug the failed workflow execution using pegasus-analyzer, which provides information related to the failure.

8. Conclusion

Our work designed and developed an in-house Grid testbed using widely used open-source software packages/tools, including Globus toolkit 5.2.3, HTCondor 7.8.7, NTP, and Pegasus WMS 4.1.0, to experiment workflow scheduling and execution. Furthermore, the testbed emulated a real Grid scenario of bandwidth variation among various Grid-sites using dummynet. Building a Grid environment requires the understanding of the concepts related to network, protocols, services, etc. However, due to proper study and experimentation with individual software components, we are able to produce a usable Grid testbed, having minimal physical resources, for carrying workflow scheduling and execution. Furthermore, through the experimental work, we are able to provide concise understanding of various involved software, their installation, their configuration, and their testing.

Our testbed has only four computing machines, in which each machine works as a Grid-site as well as a computing node. It is possible to add additional computing nodes in each Grid-site. The added computing machines need to become part of the batch-queue cluster that is under control of a particular Grid-site. For example, in our testbed we need to install Condor on each additional computing machine and we need to make each added computing machine to respond to the central manager of a particular Grid-site. Thus, the presented Grid testbed can easily be replicated or adapted, as the work concisely included all important details pertaining to the development and the deployment of the Grid architecture supporting workflow scheduling. Moreover, we can easily include a large number of computing nodes under each Grid-site to achieve better reliability. There are other WMSs, e.g., Askalon (Fahringer et al., 2005), Kepler (Altintas et al., 2004), and Karajan (von Laszewski & Hategan, 2005), for which similar deployment and testing of a Grid testbed can provide substantial help to novice researchers.
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References


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