



# Trustworthiness for personal lending on Blockchain

Wisnu Uriawan

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**Trustworthiness for Personal Lending on Blockchain**

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# Abstract

Individual borrowers request loans for personal projects or urgent requirements. Small and medium-sized enterprises (SMEs) need loans to scale up their businesses [1]. Most loans given by traditional banks are secured loans, which have terms and conditions that are sometimes not easy for borrowers to fulfill. Banks require collateral or guarantors to guarantee that borrowers return their loans. Collateral can be in the form of assets (i.e., houses, vehicles, savings, deposits, and securities) [2]–[4]. A guarantor is a person who gives some guarantee for the person or SME applying for loans [5], [6]. With a secured loan, the lender can take over an asset provided as collateral if the customer cannot make the loan payments. In addition, many documents may be needed during the loan application process. Administrative costs may be required at the time of application submission as well. There is also little visibility in the centralized process, so the borrower does not know the clear reasons for being accepted or rejected. Moreover, the traditional loan application process is time-consuming.

On the other hand, Blockchain technology is emerging and is successfully applied in many financial applications [7], including Peer-to-Peer lending [8], [9]. In 2020, peer-to-peer consumer lending in Europe (excluding the U.K.) reached 2.9 billion U.S. dollars [10]. P2P lending platforms allow lenders and borrowers to connect without going through a bank. Some of the problems of traditional lending such as burdensome administrative processes can be avoided in P2P lending. A significant increase in P2P lending is estimated to be close to one trillion U.S. dollars by 2050. Today many lending platforms are available supported by Blockchain technology (such as, SALT, BlockFi, ETHLend, etc.), however, they still require collateral [11], which does not help borrowers avoid this burden.

In this thesis, we propose that borrowers' trustworthiness be used as an alternative in lending applications so that borrowers are no longer burdened with collateral or guarantors. The problem is how to reliably calculate trustworthiness. Another problem is how to enforce the conditions of lending and borrowing in a P2P environment. In this thesis, we make several contributions in these areas, which are summarized below.

As a first contribution, we build a borrower trustworthiness scoring model called LAPS. The LAPS formula computes the borrowers' trustworthiness score based on variables such as loan risk, user activity, user profile, and social recommendations. In the LAPS model, we introduce social recommendations in support of a borrower. The advantage of the LAPS score is that it may help to convince the lenders/investors to provide loans with minimal or no collateral. They get assurance that the borrowers are able to pay back the loans, and the recommender bridges the gap between the borrower and the lender.

Our second contribution is to develop smart contracts that enforce the conditions of lending and borrowing in a P2P environment. The smart contracts are program codes powered by Solidity and Ethereum blockchain that can be realized in a decentralized P2P manner. They



can replace the intermediary process between users (borrowers, recommenders, and lenders/investors) and eliminate the third party. We use these smart contracts to enable interactions between users (borrowers, recommenders, and lenders/investors) in a secure way where all agreed upon rules are enforced. The smart contracts implement the LAPS trustworthiness score formula.

As the third contribution, we introduce TrustLend as a personal lending platform and present its design and implementation details. We develop a fully functional prototype of TrustLend as a decentralized application (DApp). The prototype shows the features required by borrowers, recommenders, and lenders/investors to rely on trustworthiness by implementing trustworthiness scores with Ethereum smart contracts. TrustLend deploys the smart contracts and applies the LAPS formula to compute the borrowers' trustworthiness scores. We describe the prototype architecture and conduct various personal loan simulations.

TrustLend presents architectural designs that meet the needs of borrowers, recommenders, and lenders/investors, such as permissionless access, integrity, and security. In addition, the platform aims for several other properties: Transparency: all system transactions are traceable and accountable. Automatic enforcement of terms: autonomous transactions by smart contracts are binding for all participants. Reduced costs: we attempt to minimize gas costs for feasible economics.

**Keywords:** Blockchain, Collateral, DApp, Decentralization, Ethereum, Lending, Smart Contracts, Social Recommendation, Trustworthiness, P2P.

## Résumé

Les emprunteurs individuels demandent des prêts pour des projets personnels ou des besoins urgents. Les Petites et Moyennes Entreprises (PMEs) ont besoin de prêts pour développer leurs activités [1]. La plupart des prêts accordés par les banques traditionnelles sont des prêts garantis, dont les termes et conditions ne sont parfois pas faciles à remplir pour les emprunteurs. Les banques exigent des garanties ou des garants pour garantir que les emprunteurs remboursent leurs prêts. La garantie peut prendre la forme d'actifs (c'est-à-dire des maisons, des véhicules, des économies, des dépôts et des titres) [2]–[4]. Un garant est une personne qui donne une garantie pour la personne ou la PMEs qui demande un prêt [5], [6]. Avec un prêt garanti, le prêteur peut reprendre un actif fourni en garantie si le client ne peut pas effectuer les remboursements du prêt. De plus, de nombreux documents peuvent être nécessaires lors du processus de demande de prêt. Des frais administratifs peuvent également être exigés au moment de la soumission de la demande. Il y a également peu de visibilité dans le processus centralisé, de sorte que l'emprunteur ne connaît pas les raisons claires pour lesquelles il a été accepté ou rejeté. De plus, le processus de demande de prêt traditionnel prend du temps.

D'autre part, la technologie Blockchain émerge et est appliquée avec succès dans de nombreuses applications financières [7], y compris les prêts Peer-to-Peer [8], [9]. En 2020, les prêts à la consommation peer-to-peer en Europe (hors Royaume-Uni) ont atteint 2,9 milliards de dollars américains [10]. Les plateformes de prêt P2P permettent aux prêteurs et aux emprunteurs de se connecter sans passer par une banque. Certains des problèmes des prêts traditionnels, tels que les processus administratifs fastidieux, peuvent être évités dans les prêts P2P. Une augmentation significative des prêts P2P est estimée à près d'un billion de dollars américains d'ici 2050. Aujourd'hui, de nombreuses plateformes de prêt sont disponibles, prises en charge par la technologie Blockchain (telles que SALT, BlockFi, ETH-Lend, etc.), mais elles nécessitent toujours des garanties [Norta2019], qui n'aide pas les emprunteurs à éviter ce fardeau.

Dans cette thèse, nous proposons que la fiabilité des emprunteurs soit utilisée comme alternative dans les demandes de prêt afin que les emprunteurs ne soient plus surchargés de garanties ou de garants. Le problème est de savoir comment calculer de manière fiable la fiabilité. Un autre problème est de savoir comment faire respecter les conditions de prêt et d'emprunt dans un environnement P2P. Dans cette thèse, nous apportons plusieurs contributions dans ces domaines, qui sont résumées ci-dessous.

Comme première contribution, nous construisons un modèle de notation de la fiabilité des emprunteurs appelé LAPS. La formule LAPS calcule le score de fiabilité des emprunteurs en fonction de variables telles que le risque de prêt, l'activité de l'utilisateur, le profil de l'utilisateur et les recommandations sociales. Dans le modèle LAPS, nous introduisons des recommandations sociales en soutien à un emprunteur. L'avantage du score LAPS est qu'il

peut aider à convaincre les prêteurs/investisseurs d'accorder des prêts avec peu ou pas de garantie. Ils obtiennent l'assurance que les emprunteurs sont en mesure de rembourser les prêts, et le recommandeur comble le fossé entre l'emprunteur et le prêteur.

Notre deuxième contribution est de développer des contrats intelligents qui imposent les conditions de prêt et d'emprunt dans un environnement P2P. Les contrats intelligents sont des codes de programme alimentés par la blockchain Solidity et Ethereum qui peuvent être réalisés de manière P2P décentralisée. Ils peuvent remplacer le processus d'intermédiaire entre les utilisateurs (emprunteurs, recommandataires et prêteurs/investisseurs) et éliminer le tiers. Nous utilisons ces contrats intelligents pour permettre des interactions entre les utilisateurs (emprunteurs, recommandataires et prêteurs/investisseurs) de manière sécurisée où toutes les règles convenues sont appliquées. Les contrats intelligents implémentent la formule de score de fiabilité LAPS.

En tant que troisième contribution, nous présentons TrustLend en tant que plateforme de prêt personnel et présentons ses détails de conception et de mise en œuvre. Nous développons un prototype entièrement fonctionnel de TrustLend en tant qu'application décentralisée (DApp). Le prototype montre les fonctionnalités requises par les emprunteurs, les recommandataires et les prêteurs/investisseurs pour s'appuyer sur la fiabilité en mettant en œuvre des scores de fiabilité avec les contrats intelligents Ethereum. TrustLend déploie les contrats intelligents et applique la formule LAPS pour calculer les scores de fiabilité des emprunteurs. Nous décrivons l'architecture du prototype et réalisons différentes simulations de prêt personnel.

TrustLend présente des conceptions architecturales qui répondent aux besoins des emprunteurs, des recommandataires et des prêteurs/investisseurs, tels que l'accès sans autorisation, l'intégrité et la sécurité. De plus, la plateforme vise plusieurs autres propriétés: Transparence: toutes les transactions du système sont traçables et responsables. Application automatique des conditions: les transactions autonomes par contrats intelligents sont contraignantes pour tous les participants. Coûts réduits: nous essayons de minimiser les coûts de gaz pour des économies réalisables.

**Mots-clés:** Blockchain, Garantie, DApp, Décentralisation, Ethereum, Prêt, Contrats intelligents, Recommandation sociale, Fiabilité, P2P.

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## **Part I**

# **Introduction and State of The Art**



# Chapter 1

## Introduction

Today, traditional banks or financial institutions offer financial services to customers, including savings, insurance, investments, and loans. In banks, customers are able to save their money and apply for loans as well. However, banks or financial institutions traditionally give services. When applying for loans, customers go through the banks and prepare the necessary documents, guarantors, and collateral or assets. These requirements are burdensome for to the customer.

In this thesis, we propose solutions in order to alleviate the above mentioned burden on the borrowers. For this purpose, the thesis presents the borrower's trustworthiness score, a LAPS (Loan risk, Activity, Profile, and Social recommendation score) formula, and designing a lending platform. A Decentralized applications (DApp) architecture is able to simplify the process of applying for loans. We also introduce an Ethereum blockchain-based lending platform to incorporate distributed trustworthiness scores and peer-to-peer lending scenarios (TrustLend). Trustlend is supported by smart contracts in a peer-to-peer (P2P) manner and secure transactions. Our lending platform allows borrowers to apply for loans without providing collateral replaced by social recommendations. This research proposes a trustworthiness score to assist borrowers in getting a loan with a reliable score evaluation associated with loan approvals.

### 1.1 Traditional Lending System

Figure 1.1 shows the traditional lending process. Five actors are involved: personal customers, Small and Medium-sized Enterprises (SMEs)<sup>1</sup>, guarantors, banks/financial institutions, and the central bank. 1) personal customers and 2) SMEs client applying for a loan. 3) Both (personal and SMEs) clients require a guarantor/collateral when they apply for loans. 4), 5) branches of banks/financial institutions will coordinate with the central bank to decide. Both clients would be accepted their loans when meeting the terms and conditions.

In addition, many documents are necessary and administrative costs are required during the loan application process. The banks may offer interest rates that are high making it burdensome for the borrower [12]. In decision-making, there is no transparency because of a centralized process (black box). The borrower may not know the loan status, and there may not be precise time information. The bank manager makes decisions after coordination with the central bank, which takes time. In general, SMEs debtors easily get loans with

<sup>1</sup>[https://ec.europa.eu/regional\\_policy/sources/conferences/state-aid/sme/smedefinitionguide\\_en.pdf](https://ec.europa.eu/regional_policy/sources/conferences/state-aid/sme/smedefinitionguide_en.pdf)



their assets as guarantors or collateral [4]. Borrower assets are taken by the bank or financial institutions for the default borrowers when they cannot fulfill the payments, or there are delays in payments [5], [13], [14].

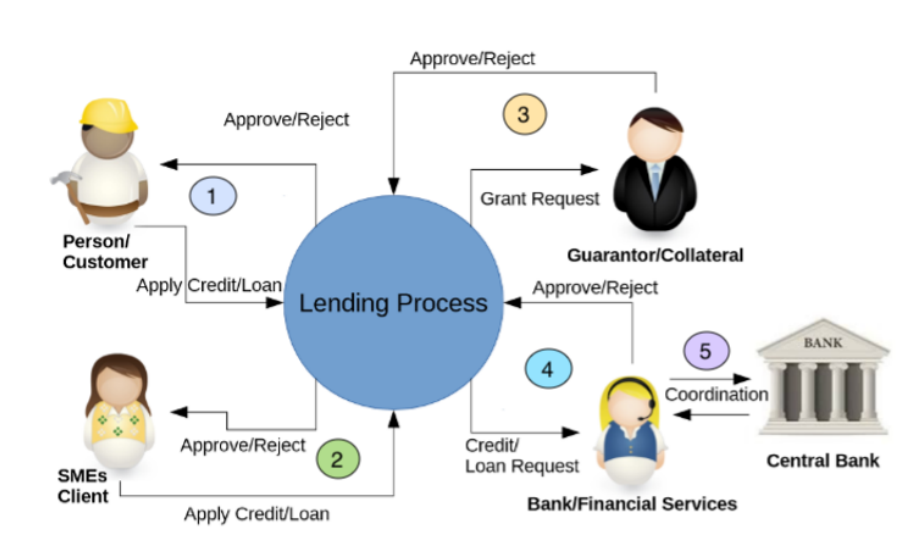


FIGURE 1.1: A traditional lending system.

## 1.2 Banks and Financial Institutions

Banks or financial institutions provide loans with terms and conditions that are sometimes difficult to fulfill [1]. It corresponds with the risk and the collateral required. The borrowers request loans for personal projects, and SMEs need loan to increase their enterprise's capacity and market. Banks or financial institutions require collateral to guarantee that the borrowers can return their loans [5], [6]. Collateral is able to be in the form of valuable assets such as houses, vehicles, savings, deposits, and securities [3], [4], [15]. The collateral is the key for borrowers to get a loan from banks or financial institutions as a guarantee that borrowers are able to pay back their loans.

TABLE 1.1: Types, Rates, Terms, and Speed of Funding [15], [16]

Type of Lender	Rates (%)	Terms (years)	Funding (days)
Bank	6-10	3-7	14-30
SBA (Small Business Administration)	6-10	3-7	10-30
Line of Credit	5-15	1-3	7-30
Alternative	6-25	1-5	5-7
Cash Advance	1.16-1.55	3-24 months	1-3
Invoice Finance	1-2 (weekly)	1 – 90 (days)	1-3

Source: <https://gudcapital.com/types-of-business-loans/>

In Table 1.1 and Table 1.2 are shown the estimation of funding speed (days) and approval rates. The approval rate of a Cash Advance Lenders of 90% is greater because of fast processing with 1-3 days approval. The Alternative Lenders reach 70% loan processing with 5-7

days approval, the Traditional Banks average 45%, and Large Banks about 25% with 14-30 days processing.

TABLE 1.2: Approval Rates [15], [16]

Types of Debt	Percentage (%)
Traditional Banks	45
Cash Advance Lenders	90
Alternative Lenders	70
Large Banks	25

Source: <https://gudcapital.com/types-of-business-loans/>

On the other hand, Table 1.2 shows the difficulty for borrowers to get a loan from banks or financial institutions. Borrowers' approval corresponds with the type of banks or financial institutions. The Large Banks system, 25% are approved, and 75% are denied in proposed loans. For Traditional Banks will support 45% borrowers, whereas 55% borrowers are left out. For Alternatives Lenders, 70% were accepted, and 30% declined. For Cash Advance Lenders, 90% agreed, and 10% rejected [14].

## 1.3 Lending Marketplace

Peer-to-Peer (P2P) lending worldwide was close to 3.5 billion U.S. dollars in the year 2013 [17]. In the United States, the value of mobile P2P payments was close to \$86 billion in 2018, and trending payments for daily activity came to 26% of the people who have admitted used P2P. [17]. In 2020, peer-to-peer consumer lending in Europe (excluding the U.K.) reached 2.9 billion U.S. dollars [10]. An exponential increase in the P2P market share is expected and it is estimated to reach one trillion U.S. dollars in 2050 [10], [18].

In 2016, the number of P2P online platforms in China reached 2448, with a turnover of up to 2,063 billion RMB. It has increased by about 110% from the previous year [19]. In 2024, Transparency Market Research predicts the global P2P market will reach \$897.85 billion with a Compound Annual Growth Rate (CAGR) of 48% from \$26.16 billion in 2015 [20].

### 1.3.1 P2P Lending

P2P lending is part of the new economic paradigm of the "sharing economy". P2P lending platforms allow borrowers and lenders/investors to meet without a third party. The P2P lending marketplace became the world trend with advantages such as fast transactions and efficiency. P2P lending platforms were initially introduced in the United States, and the United Kingdom [21]. They provide an alternative concept of low-cost financing that effectively connects potential investors directly with borrowers. Similar ideas were done in the Czech Republic [4]. For example, [lendingclub.com](https://www.lendingclub.com)<sup>2</sup> offers making loans directly to the borrower

<sup>2</sup><https://www.lendingclub.com>

[22], [23]. In addition, users would be able to invest in the Securities and Exchange Commission (SEC) registered instruments. SEC-registered securities are called member payment-dependent notes, which correspond to fractions of loans. The portion corresponding to users' messages will deposit into their account if borrowers make their monthly loan payments of principal and interest. The lendingclub.com takes out applicable fees, and deposits [24].

The P2P lending marketplaces offer loans with instant process [13], [22]. However, they provide loans with higher interest and hidden costs (e.g., administrative costs) [25]. The borrowers are still attracted to propose loans even if they offer higher interest with administrative costs added. However, they may be rejected at the end. There is no precise information, so the borrower does not know why the decision is accepted or rejected.

In P2P lending, the borrowers have direct access to communicate efficiently to get financing from lenders/investors [22], [26]. P2P lending also allows individual users to transact with other users in the network. However, the growth of the lending platform is not only profitable and also creates risks for lenders when the borrower cannot make payments according to the agreement [19].

Credit risk is the possible loss of lenders/investors after offering a loan to a defaulting borrower. They include not only the actual risk of the borrower cannot pay back the loan but also the potential risk of default due to a decrease in a credit score or a reduction in the borrower's ability to repay so [27]. For example, the borrower cannot repay the loan even with a high credit score. The lenders'/investors' perspective would be interesting because it could generate higher commissions and be associated with the lenders' credit risk estimation [28].

Evaluating risk is a bottleneck challenge for lenders because it simultaneously attempts to reduce the default risk rate when the borrowers loan their money. The lenders assist and maximize the chance of borrowers who expect to get loan approval. As for loan cost reduction, recent peer-to-peer lending platforms have become an alternative solution to bank loans and lending companies. They offer sustainable marketplaces for borrowers and lenders to interact directly, reduce commissions, and competitive interest rates.

On the other hand, some investors invest their funds to help borrowers. They expect the benefits of their investment [29]. In this case, investors will usually be more careful in investment, especially on lending platforms. They risk losing their funds if the borrowers do not repay their loans.

### 1.3.2 Ethereum Blockchain-Based Lending Platforms

Blockchain technology is emerging and successfully applied in many fields, motivating us to explore the potential of blockchain. Blockchain technology has been used for fintech, and crowdfunding [9], [23], [29], [30]. They provide alternative money lending services without proposing a loan to the bank or financial institution.

Blockchain technology has supported the lending platform with features such as ledger and smart contracts to record and manage all transactions on the network. The P2P has unique access to a digital wallet (e.g., MetaMask) with the privilege. The smart contracts manage transactions, the primary processes with immutability and anonymous [7], [31], [32].

Fintech encompasses blockchain technology applied to peer-to-peer (P2P) lending [7]–[9]. However, some terms and conditions, such as personal information and collateral in the saving funds or crypto assets, are still required. The borrowers with a guarantee as collateral, making it easier to be granted. The lenders/investors will consider the valuable collateral to provide the proposed loan amount. Probably, the collateral value is more significant than the loan amount. The borrowers will be taking a risk when they cannot repay the loan. Finally, the collateral will become lenders’ property after the judgment of “Fiducia”<sup>3</sup>. Fiducia essentially constitutes a contract of sale to a person, usually agreeing that the purchaser should sell the property back upon fulfilling certain conditions [14].

In addition, they provide or serve the application of fiat money and cryptocurrency. Blockchain has been utilized by developing countries in Africa [33] and Asia [34], which still have a market share in online lending [35]. These loans help meet daily needs at certain community levels, such as support education fees, allowing family members, home renovation, buying a car, renting a house, and even buying a house. With the facility of ease, applying for loans on more accessible terms is of great interest. It’s an opportunity for lending platform development in the future [6], [36].

## 1.4 Research Questions

Our research questions can be summarized as follows:

1. How can we compute the trustworthiness score of a user borrower who applies for a loan? The trustworthiness score is used to evaluate whether the user will return the amount according to the stipulated loan conditions.
2. Existing lending platforms are based on requiring the borrower to submit collateral. Can we establish a lending platform where user borrowers can get a loan without or minimal collateral? For example, by using trustworthiness score as an alternative.
3. How to build a decentralized lending platform that enables the evaluation of the default risk of borrowers and achieves low cost in lending transactions?

## 1.5 Contributions and Outcomes

This section describes the contributions and outcomes of our research.

### 1.5.1 Contributions

The contributions of this thesis are as follows:

1. **Minimization of Collateral.** Borrowers’ trustworthiness based on social recommendations is used for getting a loan without collateral. Most banks or financial institutions still require collateral from borrowers when they propose loans. Recommenders

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<sup>3</sup><https://www.merriam-webster.com/dictionary/fiducia>

provide social recommendations as guarantees for a borrower who submits the loan application to replace collateral on our lending platform. The lenders can therefore achieve confidence in making the lending transaction.

2. **LAPS (Loan Risk, Activity, Profile, and Social Recommendation)** is the borrowers' trustworthiness score that supports the lending platform to compute each borrower's trustworthiness score. The trustworthiness score is a dynamic value that increases automatically if the borrower has promising activity in lending (e.g., installment payment on time) and decreases if the borrower is unwilling to pay their loan.
3. **Smart Contract Development**, which enforces the conditions of lending and borrowing in a P2P environment and can be realized in a decentralized manner. The smart contracts are program codes powered by Solidity and Ethereum blockchain. Smart contracts can replace the intermediary process between users (borrowers, recommenders, and lenders/investors) and eliminate third parties. We use these smart contracts to implement the LAPS trustworthiness score formula. They enable interactions between users (borrowers, recommenders, and lenders/investors) in a secure way where all agreed-upon rules are enforced.
4. Our lending platform is built on the Ethereum blockchain. It is called **TrustLend**. We provide the borrowers, recommenders, and lenders/investors with a dashboard to make lending transactions and an admin board to monitor the lending activity. IPFS supports our lending platform for blockchain storage. The interface of our lending platform is straightforward for borrowers to apply for loans, the recommender to give some recommendations, and lenders/investors to grant the loan.

## 1.5.2 Outcomes

### Publications

1. **2022**, *Decentralized Trustworthiness Score Management with Smart Contracts on the TrustLend Platform*. **Wisnu Uriawan**, Youakim Badr, Omar Hasan, Lionel Brunie. IET Blockchain journal <https://ietresearch.onlinelibrary.wiley.com/journal/26341573>. (Received first round of reviews, revised and resubmitted for review, extended version of SECUREPT 2022 conference)
2. **2022**, *TrustLend: Using Borrower Trustworthiness for Lending on Ethereum*. **Wisnu Uriawan**, Youakim Badr, Omar Hasan, Lionel Brunie. The 19th International Conference on Security and Cryptography (SECUREPT). July 11-13, 2022, Lisbon, Portugal.
3. **2022**, *Implementing the Business Logic of Financial Services using Smart Contracts*. **Wisnu Uriawan**, Omar Hasan, Youakim Badr, Lionel Brunie. (Under Submission)
4. **2022**, *LAPS: Computing Loan Default Risk from User Activity, Profile, and Recommendations*. **W. Uriawan**, O. Hasan, Y. Badr and L. Brunie. Fourth International

Conference on Blockchain Computing and Applications (BCCA) 2022, San Antonio, Texas, USA, pp. 167-172, doi: 10.1109/BCCA55292.2022.9922034.

5. **2021**, *Collateral-Free Trustworthiness-based Personal Lending on a Decentralized Application (DApp)*. **Wisnu Uriawan**, Omar Hasan, Youakim Badr, Lionel Brunie. Proceedings of the 18th International Conference on Security and Cryptography (SE-CRYPT), 839-844.
6. **2020**, *SWOT Analysis of Lending Platform from Blockchain Technology Perspectives*. **Wisnu Uriawan**. International Journal of Informatics, Information System and Science Engineering (INJIISCOM), vol. 1, no. 1, pp. 103-116, Dec. 2020.

#### **Presented at the following Workshops and Seminars**

1. **October 3–8th, 2022**. IRIXYS Workshop, *LAPS: Computing Loan Default Risk from User Activity, Profile, and Recommendations*, Unimi, Milan, Italy.
2. **May 30th–June 3rd, 2022**. IRIXYS Workshop, *TrustLend: Using Borrower Trustworthiness for Lending on Ethereum*, Passau University, Germany. (Online)
3. **November 29th–December 3rd, 2021**. IRIXYS Workshop, *Collateral-free Trustworthiness-based Personal Lending on a Decentralized Application (DApp)*, INSA Lyon, France.
4. **October 29–30th, 2021**. *Seminar Kemajuan Studi PNS/P3K 2021*, Trustworthiness for Personal Lending on Blockchain, Attaché pour l'éducation et la culture de l'ambassade d'Indonésie, Paris, France.
5. **September 25–26th, 2021**. Journée des Doctorants Indonésiens, "Bangkit", *Collateral-free Trustworthiness-based Personal Lending on a Decentralized Application (DApp)*, Paris, France.
6. **November 16th, 2020–January 18th, 2021**. IRIXYS Workshop, *Toward A Trustworthy DApp Architecture for Personal Lending on Blockchain*, Milan, Italy. (Online)
7. **October 9–10th, 2020**. *Seminar Kemajuan Studi dan Riset PNS/P3K Tugas Belajar di Prancis Tahun 2020*, *Trustworthiness for Personal Lending on Blockchain*. Attaché pour l'éducation et la culture de l'ambassade d'Indonésie, Grenoble, France.
8. **June 12th–July 10th, 2020**. IRIXYS Workshop, *Trustworthy Blockchain-Based Architecture for Personal Lending*, Milan, Italy. (Online)
9. **December 2–5th, 2019**. IRIXYS Workshop, *Borrower Trustworthiness for Personal Lending on Blockchain*, Passau, Germany.
10. **October 26th, 2019**. Journée des Doctorants Indonésiens, *Penguatan Sumber Daya Manusia dan Kualitas Riset guna Meningkatkan Daya Saing Bangsa di Era Industri 4.0*, Paris, France.

11. **June 17–21st, 2019.** IRIXYS Workshop, *Trustworthiness for Personal Lending on Blockchain*, INSA Lyon, France.

### Seminars Attended

1. **November 5th, 2019.** *Journée Blockchain Workshop du Projet Européen BLISS*, Université Lyon 1, Lyon, France.
2. **March 26th, 2019.** *Introduction à la Blockchain Ethereum et la Programmation de Smart Contract (Jean-Patrick Gelas)*, Maître de Conférences de l'UCB, Lyon, France.

## 1.6 Developed Software

The following software prototype of the personal lending platforms was developed during this thesis:

- **Trustlend:** *Uncollateralized Crypto Loans Based on The Trustworthiness Score*, available at : <https://github.com/ethereum-app/LoanProtocol><sup>4</sup>
- We provide to use this DApp, navigate to <https://trustlend.netlify.app/> and connect with MetaMask wallet. Next, make sure to choose Optimism Testnet Network<sup>5</sup> and ensure the users have some testnet tokens KOVANETH in order to be able to pay fees for the transactions. To get some testnet tokens<sup>6</sup>, the users can request them on this application.
- In order to test it in localhost, use the Hardhat tool. Hardhat<sup>7</sup> is a tool to develop environments, compile, deploy, test, and debug Ethereum applications.

## 1.7 Outline of the Thesis

- In **Chapter 1**, we provide a general introduction to the traditional lending system, Banks and Financial Institutions, and the Ethereum blockchain-based lending platform.
- In **Chapter 2**, we describe a State of the Art, including credit scores, P2P Lending Platforms, Technologies for enabling P2P Lending, and Public Dataset.
- In **Chapter 3**, we present the first contributions of our research. In particular, we provide the concepts of Decentralized Application (DApp). We describe the architecture application and introduce a trustworthiness score formula, user management, functionality, and lending management to minimize collateral. The last section briefly describes sidechains, Ethereum, and smart contracts.

<sup>4</sup>Lending platform still close for public

<sup>5</sup><https://chainlist.org/>

<sup>6</sup><https://app.mycrypto.com/faucet>

<sup>7</sup><https://hardhat.org>

- In **Chapter 4**, we present the following contributions of our research. In particular, we provide the concepts of the LAPS (Loan risk, Activity, Profile, and Social recommendation) formula for borrowers' trustworthiness score.
- In **Chapter 5**, the following is a contributions of our research. We provide the smart contracts implementation of the LAPS formula for borrowers' trustworthiness scores. We proposed a prototype lending platform and how to minimize collateral.
- In **Chapter 6**, we present the last contributions of our research. We describe the design and implementation of the lending platform (TrustLend). We implement and test the LAPS formula for borrowers' trustworthiness score and lending transaction mechanism.
- In **Chapter 7**, we discuss the regulation and governance of the lending platforms. It also discusses the lending platforms' scalability scenario and critical factors affecting their scalability.
- In **Chapter 8**, a conclusion and possible future works describe in this thesis manuscript. We offer an opportunity and potential for future implementation of our lending platform (TrustLend).





## Chapter 2

# State of The Art

This chapter presents the current and existing research related to our contributions. We review some lending platforms' advantages, disadvantages, and issues established lending platforms. We also analyze and combine some credit scoring methods from several perspectives.

They study mentioned how the BLockchain-Enabled Social Credit System (BLESS) applied in the system leverages the decentralized architecture of the blockchain network. The BLESS allows grassroots individuals to participate in the rating process of a social credit system (SCS)<sup>1</sup>. They provide tamper-proof of transaction data in a trustless network environment. The anonymity in blockchain records also protects individuals from being targeted in the fight against powerful enterprises [37]. A smart contract-enabled authentication and authorization strategy. It prevents unauthorized entities from accessing the credit system. The BLESS scheme offers a secure, transparent, and decentralized SCS. However, they have difficulty implementing technology in social aspects such as public acceptance and mass adoption [38].

Next, they develop a credit-scoring model using logistic regression and multivariate discriminant analysis applied in Moroccan Financial Institutions (MFIs). The model combines behavioral and descriptive data related to the borrowers, including age, activity, level of education, number of unpaid debts, and number of loans. In addition, they also collect information on the amount of credit, duration of credit, and the number of concluded loans per portfolio manager. The weaknesses require a more extensive data sample and a deep enough history of the customer's behavior. Also, more information about variables related to the client's activity and its performance to predict the default better [39], [40].

Other research reviews we found in the literature related to smart contracts. The research mentioned how smart contracts could provide such an alternative mechanism of contract governance. While the impact of smart contracts is potentially broader and confined argument solely affects contracting and relations with contract law [41]. Their research aims to fill this gap by conceptualizing a model of blockchain-mediated trust in peer-to-peer transactions in the sharing economy. They build on existing trust research in e-commerce and conceptualize an advanced trust model that can apply blockchain technology to increase trust among peers in the sharing economy, decrease intermediation and reduce transaction costs [31]. Another research proposed solution utilizes smart contracts to have code that automates the version control logic and workflow of digital documents to facilitate controlled or restricted data-sharing mechanisms. The smart contract code orchestrates all the interactions among

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<sup>1</sup><https://www.igi-global.com/dictionary/social-credit-system/83145>

multiple participants (including those approvers and developers) in an entirely decentralized way [42].

The fundamental mission of blockchain is to build a trustworthy ecosystem among independent participants in an untrustworthy distributed environment. The autonomous blockchain is a secure system based on chained blocks, peer-peer nodes, consensus-based ledger mechanisms, anonymous accounts, self-regulated data ownership, and programmable smart contracts. Minimal blockchain effort is required, feasible, efficient, and enduring. In addition, unique credit mechanisms are necessary to make blockchain systems creditworthy, although blockchains provide a credit-worthy infrastructure for data-level storage and operations [43]. We are interested in the existing solutions that could improve some weaknesses by detailing implementation to be enhanced.

## 2.1 Credit Scores

This section describes the provider credit scoring analysis, including the FICO and FIVE scores.

### 2.1.1 FICO Scoring

The FICO [44] is popular scoring credit in the U.S. They have a formulation to measure the ability of borrowers who propose a loan. There is no open formula calculation, but we can analyze supported indicator variables. They have three prominent credit report companies: Experian, Equifax, and Transunion. They use the five variables evaluated for borrowers: payment history, credit report, credit limit, credit consumed, and another loan. These categories have weights, which are as follows [45]:

1. **Payment history:** The payment history category gets a percentage reach 35%, considering whether the borrowers consistently have on-time installment payments and credit accounts. The borrowers' payment history will impact their credit score. It also times preference factors in previous defaults and delinquencies.
2. **Amount owed:** The following significant variable is the amount owed to the borrowers' credit and gets a percentage of about 30%. This scoring component focuses on the borrowers' existing debt and analyzes the other loan account to calculate their charges. This situation informs the lenders to risk borrowers' when they act in spending upper than the credit limit. The credit score reminds the ratio of borrowers to availability used under 30%. However, the sizeable amount owed will decrease the credit score trend.
3. **Length of credit history:** The borrowers' credit accounts that have been a long time and in regular activity will positively impact their credit scores. It gets a percentage of 15%. The rationality is that the borrower who has never been late in installment payments after 20 years is better than the borrower in a few years.

4. **New credit:** The more frequently the borrowers apply for loans, it indicates the more financial problem and a new credit account, which causes a lower credit score. The lenders/investors use it to measure the borrowers' activity, and their scores will decrease; this variable gets a percentage of 10%.
5. **Credit mix:** The lenders/investors analyze multiple credits, such as credit cards, housing, gas station cards, credit company membership, and installment record that the borrowers have. It is an indicator of the borrowers' ability to manage their credit. When the borrowers successfully manage all credit, the lenders/investors recognize their ability to pay. This variable gets a percentage of 10%. The credit history declared, such as housing, car, and education loans.

### FICO Credit Score Ranges

A FICO credit score is shown in Table 2.1, which indicates the scoring range based on the borrowers' financial condition. The FICO score supports the lenders/investors in deciding when the borrowers apply for loans. For example, for borrowers who have a credit score below 600 is challenging to get a loan. Banks or financial institutions usually charge high interest and short-term installments to cover the risk [45].

TABLE 2.1: FICO Credit Scoring Range

Range	Values
Excellent	800-850
Very Good	740-799
Good	670-739
Fair	580-669
Poor	300-579

Source: [https://www.investopedia.com/terms/c/credit\\_score.asp](https://www.investopedia.com/terms/c/credit_score.asp)

In contrast, borrowers with a credit score of 700 or above are the better entry-level. These results impact their loan will get more negotiated in interest rate. The excellent scores are more significant than 800. At the same time, every lender defines its range of credit scores. The illustration of all of these categories is considered in the overall score, starting from 300 to 850. In this section, borrowers are able to evaluate their credit scores. The borrowers ensure their email addresses or phone numbers are valid. They were checking up regularly to ensure no fraudulent activity since borrowers had not used it. Set up notifications for them for at least three months or a year to update information. Then, no activation of the automatic payment system that borrowers have. The borrowers with many credit cards and closings have possibly impacted their credit scores.

### Improving the FICO Credit Score

The borrowers should update their credit history to raise credit scores. The borrowers are able to improve credit scores as follows [44]:

- **Regularly payment:** The borrowers with a minimum of three months regularly of payments are essential to analyze differences in their scores.
- **Upgrading credit limit:** If the borrowers have a credit card, they are able to required to increase the credit plan. Borrowers with a good payment record can scale up the credit limit. It is essential not to spend this credit limit to guard the credit score based on the borrowers' spending activity.
- **Work with the best credit repair companies:** When borrowers have problems with their loans, it could be helpful to discuss with the credit repair company to keep the borrowers' information secure and credit scores. The company will guide the borrowers to improve their credit scores and manage their loans. They will propose some advice to the borrowers and intermediary to several credit agencies to use the borrowers' accounts to compensate a monthly fee.
- **Keeping a credit card:** An illustration is when the borrowers have €2,00 in debt with a €6,00 credit limit between credit cards. In this case, the borrowers' credit utilization is good between 20-30%. However, the borrowers will be negatively affected by their credit scores. Closing the credit card will increase the borrowers' spending rate by 40% the other cards, impacting their credit scores. Ideally, the borrowers can stop using the credit card rather than closing it, depending on the functionality and credit limit. It can increase a credit score.

### The FICO Precision Score

The Fair Isaac Corporation is one of the precision credit score companies called FICO. Many lenders/investors use FICO scores to look for potential borrowers. It helps both sides (lenders and borrowers) to meet the lending requirements. The credit score company provides the credit report of borrowers using the precision score and borrowers' personal information. Credit scores are functional in financial services to help lenders decide for the potential borrower. Credit scores reduce the transaction time for lenders/investors and minimize the risk for new borrowers [45].

Almost credit scoring systems use a scale integrated between lower and high scores. It shows the level of credibility of borrowers and minimizing of default. The lenders' emphasis on low scores indicates low potential for the borrowers. The lenders will offer high-interest rates with terms and conditions that are not easy for borrowers, and collateral is required. Borrowers without a credit score are difficulty accessing loans. Some borrowers with low credit scores commit to being willing to pay back the loan. The credit score helps to minimize the dependence on collateral and interest rates. Generally, the high impact factors are the borrowers' payment record and level of owed.

### 2.1.2 FIVE Cs Scoring

The FIVE Cs<sup>2</sup> is another credit score system used by lenders/investors to identify potential borrowers. The FIVE Cs of credit evaluating a borrower incorporates qualitative and quantitative measures. The FIVE Cs score aims to maximize the potential borrowers in the lending system. The credit score system has five characteristics of the borrower conditions such as the character of borrowers, capacity in payment, good capital, asset/collateral, and condition of the borrowers, as follows [46], [47]:

1. **The first C is character:** The reputation of borrowers shows in payments and information related to the borrower's credit history. Some companies, such as Experian, TransUnion, and Equifax, provide credit histories. These reports also include information on the borrowers' loan history, defaulting, and personal information recorded over the five years. The credit history contains information on the borrowers' transactions in paying the loans on time.
2. **The second C is capacity:** The capacity evaluates the borrower's ability to pay back the loan by the ratio of income to expenses. Lenders/investors measure the balance by the borrower's total monthly income divided by the loan payment. The result shows the capacity of the borrowers, and the excellent result is probably a chance to get a loan from lenders/investors. Some lenders/investors are different types, but most prefer a borrower with a ratio of 35% or less before granting the loan.
3. **The third C is capital:** Lenders/investors measure the capital of the borrower as a potential investment. The borrowers with significant wealth are minimized from defaulting on loan payments. For example, borrowers who are able to make a down payment to buy a car typically find it easier to receive a loan. Down payments indicate that borrowers have the ability to make installment payments. Some countries have a different standard for a down payment of about 2-3.5%.
4. **The fourth C is collateral:** The collateral is the key to the borrowers getting a secure loan with reduced interest rates. The lender/investors are more confident if the borrower offers some collateral to protect their loan. The lenders/investors can get advantages by acquiring the collateral. Usually, the collateral is a valuable object that becomes money, such as a House, Car, savings, or Securities.
5. **The fifth C is conditions:** The borrower's financial conditions, such as savings, deposits, and securities, are required when applying for a loan. The lenders/investors look for potential borrowers and minimize the risk of default borrowers. Interest rates and collateral terms and conditions which the lenders/investors to the borrowers. The lenders/investors choose the borrowers with a specific purpose, such as a student loan, housing, and car easier to approve. Those loans may consider outside the borrower's conditions, such as the banking system, trend industry, or monetary.

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<sup>2</sup><https://www.navyfederal.org/makingcents/business/the-5-cs-of-credit.html>

### 2.1.3 Evaluation of FICO and FIVE Cs Scoring

This section compares the credit scoring method between the FICO score and FIVE Cs to provide a reliable borrower trustworthiness score. The result obtained from the selected methods has advantages and disadvantages. The features of FICO are more precise in capturing the eligible borrowers. The FIVE Cs more significantly describe the borrowers' profiles. Both show all borrowers' activity by referring to their identity and lending activity. Lenders can use credit scoring to decide the eligible borrowers' candidates. The lenders/investors have instantly assessed the creditworthiness of borrowers who proposes a loan. Credit scores help lenders decide and reduce the risk associated and inefficiency. Credit scores are essential in financial services, particularly in the lending system. The FICO scores are more precision a credit scoring system, but FIVE Cs are more significant to coverage risk. Almost all credit companies use credit scoring from third-party like FICO and FIVE Cs.

Borrowers with low credit scoring indicate a low potential to get the loan. It is signaling to the lenders not to approve their loans. Borrowers with low credit scores are able to be rejected until they are favorable in terms and conditions, such as having collateral and the ability to pay. The loans will be approved if there is additional collateral or a guarantee. The credit history and the scoring are used to determine the borrowers. The borrowers and lenders are subject to an agreement to set up the lending process, such as interest, time, terms, and conditions. Although the methodology uses precise calculation in the credit scoring evaluation, risk scores, high or low, are not mentioned. Some companies claim credit scoring is associated with lower default rates than the conventional lending system without credit scoring.

### 2.1.4 Credit Scoring Analysis

Lenders still use some criteria to decide whether the borrowers are eligible for loans and offer the credit limit with an effective interest rate. The lenders determine a borrower's default if the loan's principal and interest cannot be returned in full and on time [44]. The credit scoring systems and their assigned scores have emerged as a crucial element in this context [12]. Presently, Credit scores and traditional banking systems are two of the most variables required in this space, although the two objects have substantial differences. The emerging blockchain technology has propelled the growth of sharing financial solutions, bringing under their fold many included segments [48]. For example, blockchain has brought secure trading, lending, and identity services to unbanked populations, thus enabling their access to financial services.

The following paragraphs describe to advantages of the applicability of Credit Scoring methods. It shall implement the specific lending platform, credit identity, and borrowers' information. This research approach is to fulfill numerous credit scoring methods. The lending platform [16], along with monitoring the value of crypto assets listed on exchanges, also connects with individual users' wallets directly. The lending platform allows them to build credit scoring information. The assessment of credit scoring evaluation creates an incentive to generate a rationale for decision-making. The cryptocurrency-based lending platform [49] for

individuals is the first extensive step for lenders to get eligible borrowers based on personal identity, credit history, collaterals, and terms and conditions.

Traditional banks [50] and lending platforms provide lending systems that put a model of information gathering and technological support to create a credit scoring information system. The credit scoring information includes personal details that are primary to credit reports which form the basis for identification, such as personal information (name, email, address, date of birth, phone number, and social security number). It also includes public records like bankruptcies, bad records acquired from court records, and socially available information. Lenders' identification has other criteria, such as the willingness to return the loan, collateral, and credit history. The element of the overall credit decision applied to some decision frameworks is the lenders' decision system framework that a lender or credit granter would have.

Trustworthiness [27], [51], [52] is based on the necessary credit reports before any financial transaction, standing as protection against risky and fraudulent finances. The credit reports [53] reveal financial backgrounds, including the history of loans, debts, repayments, and public records like bankruptcies and bad records. This comprehensive information was helpful as proof of creditworthiness. Positive information on a credit report is the qualifier for approval of loans and associated benefits. The information on credit reports, both traditional and cryptocurrency-based, is identical. It becomes crucial for individuals to be informed about what lenders look for in a credit report. It is especially true of the lending platform developer, given the challenge in this sector and the essential involvement variables. In this

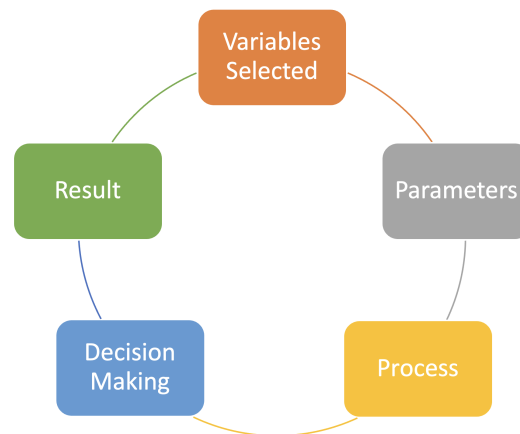


FIGURE 2.1: Methodology

context, the survey describes the input features for the accepted samples' credit scoring. The steps in the proposed framework analysis include a variables selection, parameters identification, processing, decision making, and result. We describe the methodology shown in Figure 2.1 of comparatives credit scoring models, as follows:

1. **Variables Selected:** Describes the methods and how they selected corresponding variables.
2. **Parameters:** What parameters when the variables are selected.



3. **Process:** How to implement the selected variables to the scoring method.
4. **Decision-Making:** How to use the scoring method.
5. **Result:** Which models are more suitable to implement in the blockchain-based lending platform?

## 2.2 P2P Lending Platforms

Over the years, traditional banks have established their reference market only for specific regions and business-to-business activities and maintain market segmentation. The P2P platform is based on a general banking model, fully inclusive, without limitations on space and certain types of business that result in faster development. P2P platforms have better data collection on the network where borrowers come from existing businesses and social relationships between clients. This research suggests improving the predictive performance of the risk measurement model used by the P2P platform through the correlation network model, given the main characteristics of the correlation network model in finance as a tool for understanding financial flows and risk management in the global market [54].

Their research on peer-to-peer (P2P) lending platforms uses scorecards and machine learning methods to create loan evaluation models. Their result is satisfaction with the random forest method that maximizes their accuracy, reduces the error rate, and ignores the role of lender profits. The performance of Random Forest used in loan evaluation is better than other methods in P2P lending. A healthy P2P lending platform is newly proposed using model evaluation criteria by maximizing the profit score and accuracy and reducing the error rate by adding a Genetic Algorithm (RFoGAPS) to minimize the risk of loss [55], [56].

The majority of the P2P lending platforms offer to focus on finding the factors influencing successful funding and the default rate in P2P lending. The borrower's financial strength is crucial in obtaining secured and unsecured credit from financial institutions and the P2P lending marketplace. This article describes the risk of investing in P2P loans and proposes eliminating the risks [57]. Focus on the benefits and risks of P2P lending, P2P lending developments, and online lending's advantages and disadvantages. The point of view, as well as credit evaluation risk from the investors, is essential. This section evaluates the lending platforms and observes their essential features. The parameters of lending platform services include registering required, interest rate, lending or borrowing provided, using own token, and loan to value (required collateral). These parameters correspond with several existing lending platform features are shown in Table 2.2.

### 2.2.1 Everex

Everex is a financial technology that creates decentralized, global credit histories and scorings for individuals and SMEs. The Everex supports transfers, borrowing/lending, and trading. They still transact in any fiat currency from anywhere in the world. Everex uses Crypto cash Ethereum ERC20 tokens, as well as fiat currencies. The Everex is implemented on the

TABLE 2.2: Ethereum Lending platforms [58]

Lending Platform	Registration Req.	Interest Rate (Min.)	Lend or Borrow	Own Token	Req. Collateral
Everex	Yes	Market	Both	Yes	Yes
ETHLend	Yes	Market	Both	Yes	Yes
WeTrust	Yes	Market	Both	Yes	Yes
SALT	Yes	5.99%	Borrow	Yes	Yes
BlockFi	Yes	4.5%	Both	No	Yes
Dharma	Yes	Market	Both	No	Yes
Compound	No	Market	Both	No	Yes
MakerDAO	No	3.5%	Borrow	Yes	Yes
LendingClub	Yes	Market	Both	No	Yes

Ethereum blockchain and uses Solidity as a smart contract language. Similar to the traditional lending system, the Everex environment still involves fiat money and requires collateral [11].

### 2.2.2 ETHLend

ETHLend is an Ethereum-based decentralized lending platform connecting borrowers and lenders. It allows anyone to lend or borrow with an Ethereum address. ETHLend is decentralized lending on the Ethereum network using ERC-20 compatible tokens or Ethereum Name Service (ENS) domains as collateral. ETHLend reduces the loss of loan capital on default. Some features allow the marketplace to manage, such as interest rate and collateral value. However, the pseudo-anonymous nature of the Ethereum blockchain network opens the possibility of avoiding repayment of the loan since the lender might not have all the necessary details of the borrower to enforce the debt in the borrower's jurisdiction [59].

### 2.2.3 WeTrust

WeTrust is an Ethereum blockchain that provides mutual aid on equal footing to borrowers with existing social capital and trust networks. Trusted Lending Circles are proposed to create a Rotating Savings and Credit Association (ROSCA) powered by smart contracts. It eliminates the need for a trusted third party, which cuts fees, improves incentive structures, and decentralizes risks. It will eventually incorporate mutual insurance, voting within reciprocal aid organizations, and P2P lending. However, WeTrust may not be suitable for personal users because it still requires collateral [60].

### 2.2.4 SALT

The SALT Lending platform is an Ethereum blockchain-based, distributed ledger and supports multi currencies (USD, EUR, GBP, JPY, and RMB). The SALT Lending is supported by the SALT platform, Secure Automated Lending Technology, Automatic Collateral Management, Secure Collateral Storage, and Credit Agreement Terms Enforcement. The countries implemented include Europe and Africa. The collateral is still required [6].

### 2.2.5 BlockFi

BlockFi is a lending platform ready for profiling, registering, and supporting Ethereum and Bitcoin. Available exchange in the U.S. Dollar. Gemini supports loan security with the crypto asset as collateral. BlockFi is a lending platform with U.S. Dollar, profiling, register, Ethereum, and Bitcoin support. Loans security by Gemini, a New York trust company regulated by the New York Department of Financial Services, requires cryptocurrencies as collateral. Darma Lever is a P2P Ethereum-based lending, open marketplace, lending system, and borrowing terms. Crypto as collateral, alpha mode, and does not have its token. ETHLend is an Ethereum token platform ready for registration or profiling, which supports over 180 Ethereum tokens, Ethereum, Bitcoin, and LEND tokens as collateral. MakerDAO is Ethereum-based [58].

### 2.2.6 Darma Lever

Darma Lever is available in the marketplace. A P2P lending Ethereum-based. The service provides for lending and borrowing with crypto assets as collateral and does not have tokens [58].

### 2.2.7 MakerDAO

MakerDAO is a stablecoin that provides lending and borrowing systems with collateral more significant than the loan proposed. They support multi tokens, decentralized, and main exchange in U.S. dollar. The Ethereum-based DAI supports Ethereum and Bitcoin [58].

### 2.2.8 Compound

The Compound is a MakerDAO-supported, decentralized lending application with a smart contract system with accessibility without permission or registration. Users are able to propose rates when offering loans to borrowers. Supports multi-tokens [58].

### 2.2.9 LendingClub.com

LendingClub.com is a lending platform popular in the U.S. that provides lending and investment. Multi-product for personal, business loans, and investments support by FICO credit score as a third-party. The application is available on desktop and mobile and has fiat money support. The portfolio and collateral are required for insurance members and United States citizens with valid long-term visas. The user has a verifiable bank account and is at least 18 years old [23].

## 2.3 Technologies for enabling P2P Lending

The financial sector is widely regarded as a critical user of the blockchain concept, and Bitcoin is the most popular implementation of this technology. However, it still has significant weaknesses process of maximizing the business [61].

### 2.3.1 Blockchain Technology

The blockchain shown in Figure 2.2 is a distributed, decentralized database shared among nodes in a computer network and saving data in blocks, each containing multiple transactions. Each block adds to the blockchain's length and generates a ledger of the transaction history. The network is able to validate blocks using cryptography. Each block contains a timestamp, the previous block's hash value, nonce, and a random number for hash verification [62]. A Blockchain is a simplified representation of blocks linked together. Each block contains a header and a record of transactions with a fixed-length hash output added to the block header. The first block follows the formation for each subsequent valid block with the previous block header's hash output. The last block header is linked by the hash of the following block header, which is contained in every block. Finally, a blockchain is created with connected blocks [63].

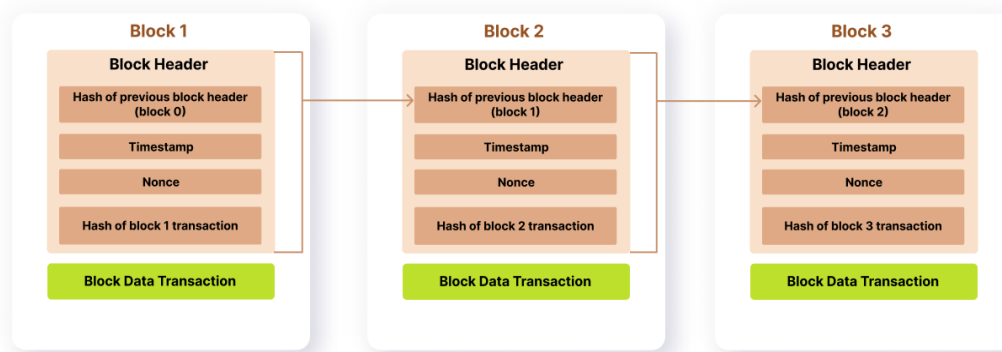


FIGURE 2.2: Blockchain Technology

A new record is added to a blockchain after the computed hash is broadcast to everyone interested and keeps their transactions. Each node does not need to keep a copy of the transaction. The latest hash will broadcast to every node and verify that the data hasn't been changed. They are able to update with a different hash and valid. Most decentralized networks would have to agree to validate any additional entries or records to a block [64].

Blockchain features are secure consensus mechanisms with proof of work (PoW) or proof of stake (PoS) to prevent malicious actors from validating fraudulent transactions or double-spending. The consensus supports that a single node is in charge. The Byzantine Generals' problem is obtaining a consensus among untrustworthy blockchain nodes. On the other hand, It isn't easy to achieve a consensus in a distributed system. It is also an issue for blockchain due to the decentralized blockchain network characteristic. There is no central node in the blockchain to ensure that distributed node ledgers are equal. Consensus algorithms are protocol sets that allow humans or machines to collaborate in a distributed and decentralized environment. One of the first examples of consensus mechanisms is designed to reward node operators or so-called miners with native network tokens like Bitcoin tokens only if and when they contribute to the network's security [65].

One of Bitcoin's consensus mechanisms is PoW. In a decentralized network, someone must be authorized to record transactions. The simplest method is to use random selection.

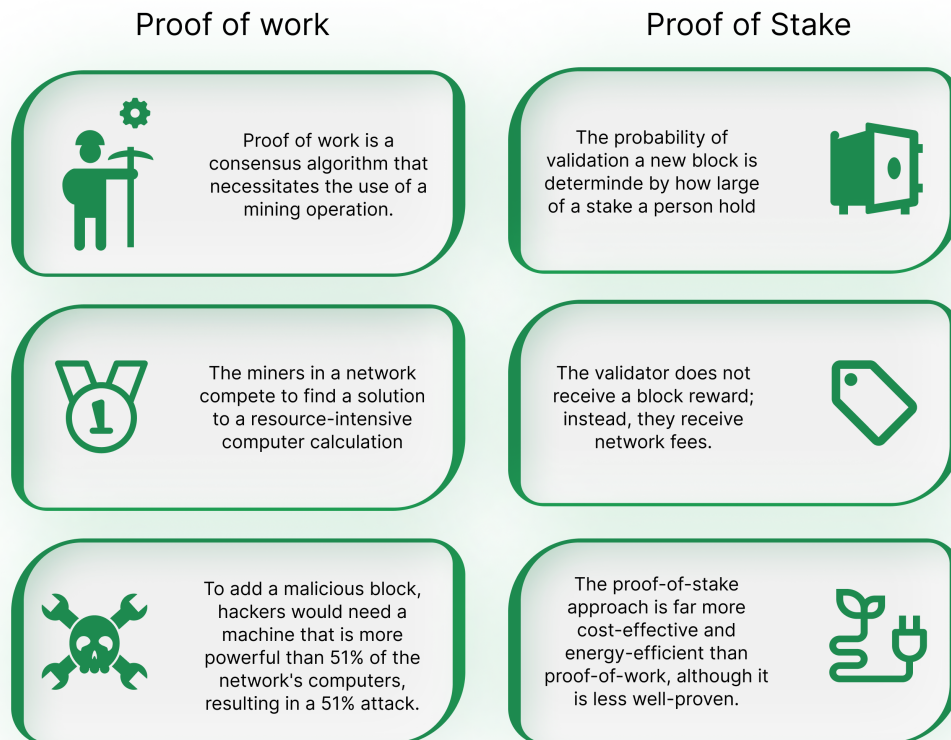


FIGURE 2.3: Proof of Work (PoW) and Proof of Stake (PoS)

Random selection, on the other hand, is open to assault. Suppose a node is required to publish a block of transactions. In that case, it must provide a service to protect it from network attackers. PoW aims to solve the complex arithmetic problem, yet it's relatively simple to verify. As a result, once a hash is established, it can be easily validated, and a consensus can be reached quickly [66]. Transactions are bundled in blocks in digital currency frameworks. The miner identifies a node in the network of cryptocurrency verified. PoW mining with complex computationally processes is challenging to increase over time as the processing capability of hardware devices. The nodes create mining pools to complete the mining task under the direction of pool managers. By computing complex mathematical problems, miners create blocks on the blockchain network. This problem can be solved by costly guesswork, and the process is known as the PoW Challenge [67].

Meanwhile, to cover the weakness of PoW in energy consumption, another consensus mechanism that is more energy-efficient is called PoS. Miners in PoS must demonstrate ownership of the quantity of currency. Those with more coins are less inclined to assault the network. The possibility of a node being chosen to forge the next block as the validator is proportional to the size of its stake so that the node's chances of winning the subsequent block rise as its stake increases. However, these selection criteria are distorted because the network would be dominated by a single node with the maximum stake. More ways are added to the selection process to tackle this issue: "randomized block selection" and "coinage selection". The randomized block selection helps choose the next forger with a combination of hash and

node with the highest and lowest value.

The nodes are able to predict the next forger based on the size of the stake owned in the public network. The next forger is elected using the coinage selection technique, which considers how long the stake has been held and the size. It's calculated by multiplying the total amount of staked coins by the days they've been held at stake. The coinage of a block is reset to zero once the node has forged it. To prevent substantial stake nodes from dominating the blockchain after generating a block. The node must wait a certain amount before developing another block [66]. The efficiency of PoW is shown in Figure 2.3 than PoS. Blockchains begin with PoW, and close transition to PoS [65].

Blockchain provides confidentiality and immutability to store credential data. Identifying trends in many industries, such as financial services and healthcare, is required. Blockchain helps open the AI black box by tracing the algorithms' work and input-output supplies to machine learning. Blockchain-AI is able to improve efficiency better than human or conventional computing. Blockchain applications transcend across industries by utilizing blockchain's advantages, offering tremendous prospects and significant benefits. There is a slew of other applications that aren't covered in this work because they've already been covered elsewhere [68].

### 2.3.2 Interplanetary File System (IPFS)

Interplanetary File System (IPFS)<sup>3</sup> is able to store and access files, websites, applications, and data in a distributed network<sup>4</sup>. For example, an application is able to keep some information, such as the projected image, the image description, etc. The other users are able to access it in many places. CID (Content Identifier)<sup>5</sup> is a unique address derived from a hash of the file's content. It points to the information uploaded during the loan creation and stored. This means files stored on IPFS are resistant to tampering and censorship. Any changes to a file don't overwrite the original, and common chunks across files can be reused [69].

### 2.3.3 Oracles, APIs, and DIDs

Oracles<sup>6</sup>, such as Chainlink, could be used to perform off-chain calculations and data provisioning. It can be used to import users' scores from trusted third parties (TTPs)<sup>7</sup> (e.g. loan risk scores from bank APIs), or social network APIs<sup>8</sup> to bring users' profile scores on-chain (see Figure 2.4). Oracles could also be helpful to automatize smart contracts and trigger smart contract execution when conditions are met [70]. For example, perform automatic repayments from the borrower's wallet or refund lenders if the borrower doesn't return the borrowed money after the deadline. A decentralized identifier (DIDs)<sup>9</sup> is a new digital identity identification model that enables verification and decentralization. The DID can control

<sup>3</sup><https://ipfs.io>

<sup>4</sup><https://docs.ipfs.tech/concepts/what-is-ipfs/>

<sup>5</sup><https://docs.ipfs.io/concepts/content-addressing/>

<sup>6</sup><https://chain.link/education/blockchain-oracles>

<sup>7</sup>[https://csrc.nist.gov/glossary/term/trusted\\_third\\_party](https://csrc.nist.gov/glossary/term/trusted_third_party)

<sup>8</sup><https://www.mulesoft.com/resources/api/what-is-an-api>

<sup>9</sup><https://www.w3.org/TR/did-core/>

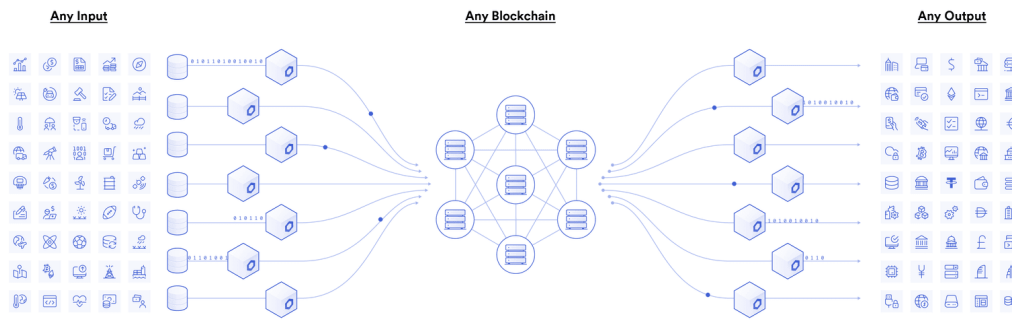


FIGURE 2.4: Blockchain oracles connect blockchains to inputs and outputs in the real world<sup>10</sup>

any subject, such as an individual, organization, thing, data model, or abstract entity. This protocol could be used to verify persons or organizations applying for loans in order to make the lending process more secure [71].

### 2.3.4 Smart Contracts

The blockchain features smart contracts that are able to implement the logic and verify that the users in the network meet all conditions. They allow replacement trusted third parties and automation processes. Smart contracts provide executable instructions that run on the blockchain. It accommodated the performance of untrustworthy parties such as a third party. In a distributed architecture, smart contracts support the programming of values and run their self-procedures (autonomous). Smart contracts differ from traditional contracts that allow users to make legal agreements and trustworthy relationships to enable automated transactions without central authority [72].

A smart contract running logic transaction protocol autonomously, the contract's provisions and find to bind between numerous parties is shown in Figure 2.5. Smart contracts are decentralized and transparent, offering business efficiency, low transaction costs, and anonymity. These characteristics make blockchain technologies necessary, particularly in financial services. It reduces the risk of fraud and improves the quality of financial contract transactions without relying on the third-party [73]. The provisions of a smart contract are conducted without depending on a responsible third party. A smart contract is a programming language that may enable users to transact the crypto assets such as Bitcoin and Ethereum units in a blockchain setting. It is visible to all other users in the network (transparency) [74]. Smart contracts minimize dependencies on the lawyers and banks to participate in purchasing contracts as a legal agreement. It is a means for transferring such property directly, peer-to-peer, without a centralized intermediary. The second attribute has a variety of implications. Consumers will be able to make decentralized property or money trades once they can establish decentralized contractual agreements. Consumers can enforce contracts without going to court if they can hold money without going to a bank. Consumers may be able to overcome the severe disenfranchisement of consumers in online contractual environments if they can provide their standardized contractual arrangements [75].

<sup>10</sup>Source: <https://chain.link/education/blockchain-oracles>

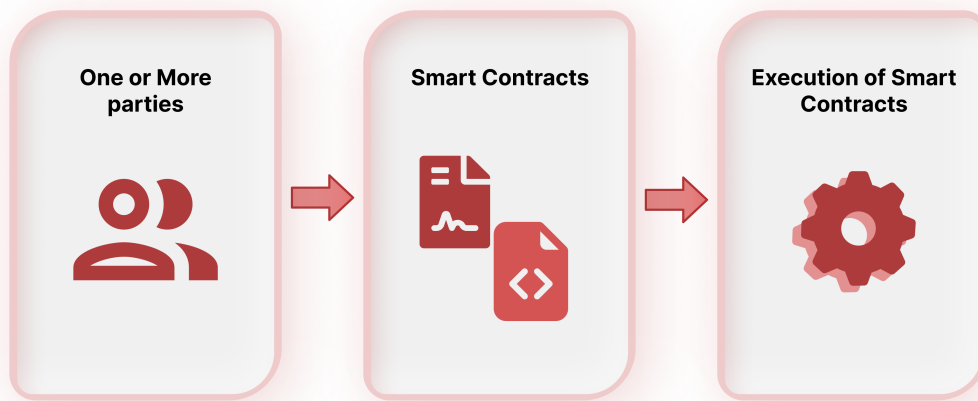


FIGURE 2.5: Smart Contracts concepts

A smart contract can manage property ownership, such as tangible and intangible assets, including houses, automobiles, and intellectual property. For example, crypto assets such as Ethereum and Bitcoin are decentralized as an implementation of blockchain technology that smart contracts as a programming logic [76]. Smart contracts can be applied in informal and formal business fields with autonomous contracts. Smart contracts are highly customizable, as well as a wide range of ways to develop, administer, and perform smart contracts [77]. It uses to store information, inputs, and outputs. For example, the smart contract defines a constructor that allows being created. The sender should invoke the host a new smart contract and the constructor in smart contracts. Self-destructor is the advantage of a smart contract when the system is closed. The smart contract proprietor has the authority to destroy the contracts [78].

Conversion of legal documents to smart contract code manually or automatically. It is also possible that artificial intelligence techniques will be applied. The translation from legal documentation to code for tiny, non-standard, loosely-regulated contracts will likely be done anew for each deal. Automating the translation may be practicable and advantageous if the legal documents are brief and straightforward. Not all legal documents will be represented in computer code as a percentage is likely to be encoded [77]. The importance of ensuring that the smart contract code follows the legal agreement has been highlighted in that the gap between the lawyer's and smart contract semantics code operation may pose unacceptably high operational and regulatory issues [79]. When evaluating a smart contract, the challenge is how the code is legal and correct. The manual or automatic execution uses a tool to assess the compliance process. The solutions integrated the code and the legal provisions so that the smart contract implementation corresponds to the interpretation of the human language [80], [81].

Ethereum is based on the smart contract developed to cover Bitcoin's insufficiency. The basic concept behind it is to run program users on the blockchain. The result is expressive



smart contracts written in the programming language. The stack runs on the EVM (Ethereum Virtual Machine) with the byte code of the smart contract. Solidity<sup>11</sup> and Serpent<sup>12</sup> are the programming languages in Ethereum development. The benefit of smart contracts is establishing a consensus. Smart contracts' functionality by precisely encoding specified rules and performing relevant activities when they meet requirements. Furthermore, smart contracts are utilized to arrange digital property management (e.g., ujomusic<sup>13</sup>, and supply chain<sup>14</sup>). The financial sector is even considering whether the blockchain will be able to replace substantial portions of its current operations. The payment process is an excellent example, and the transaction takes a few days when customers pay with their credit cards. Blockchain is the solution to reduce the delay in real-time by updating the ledger [61], [73].

### 2.3.5 Annual Percentage Yield (APY)

This research proposes the interest rate calculated using the Annual Percentage Yield (APY). The APY<sup>15</sup> is the standard interest rate that is possible to apply in a blockchain lending platform considering compounding interest, is shown in Equation 2.1. The amount of calculation is directly added to the balance of lenders/investors. That is integral to evaluating a lender/investor fees withdrawal from an overall investment return [45].

$$APY = (1 + r/n)^n - 1 \quad (2.1)$$

where:

$APY$  = Annual Percentage Yield

$r$  = Period rate

$n$  = Number of compounding periods

For example, if lenders/investors invest 100 ETH for a year at 5% interest and the deposit is compound added, then evaluated every four-month, at the end of the year, the lenders/investors would have 105.09 ETH. In contrast, if the lenders/investors had invested in effective interest rates, they would get only 105 ETH [45].

$$\text{The APY } (1 + 0.05/4) \times 4 - 1 = 0.05095 = 5.095\%$$

Description:

For 5% a year, interest compounded for four months would get 5.095%, that is, in normal conditions. However, if the lenders/investors invest 100 ETH for four years and use compound interest rates in Equation 2.2, the deposit amount would be 121.99 ETH. The

<sup>11</sup><https://docs.soliditylang.org/en/v0.8.13/>

<sup>12</sup><https://www.cs.cmu.edu/music/serpent/doc/serpent.htm>

<sup>13</sup><https://blog.ujomusic.com>

<sup>14</sup><https://www.ibm.com/blockchain/supply-chain>

<sup>15</sup><https://www.investopedia.com/terms/a/apr.asp>

lenders/investors would only get 120 ETH compared to the effective rates [45].

$$X = D(1 + r/n)n \times y \quad (2.2)$$

$$\begin{aligned} &= 100(1 + 0.05/4)4 \times 4 \\ &= 100(1.21989) \\ &= 121.99 \text{ ETH} \end{aligned}$$

where:

$X$  = Final amount

$D$  = Initial Deposit

$r$  = Period rate

$n$  = Number of compounding periods per year

$y$  = Number of years

## 2.4 Public Dataset

In this Section, we present the datasets that we have Bank Marketing datasets. We get from UCI public datasets [82]. It contains more than four thousand records of customers, and twenty-one columns represent dataset features. Datasets in Figure 2.6 contain essential data,

	age	job	marital	education	default	housing	loan	contact	month	day_of_week	...	campaign	pdays	previous	poutcome	emp.var.rate	cons.price.idx	cons.conf.idx	euribor3m	nr.employed	y	
	0	30	blue-collar	married	basic.9y	no	yes	no	cellular	may	fri	...	2	999	0	nonexistent	-1.8	92.893	-46.2	1.313	5099.1	no
	1	39	services	single	high.school	no	no	no	telephone	may	fri	...	4	999	0	nonexistent	1.1	93.994	-36.4	4.855	5191.0	no
	2	25	services	married	high.school	no	yes	no	telephone	jun	wed	...	1	999	0	nonexistent	1.4	94.465	-41.8	4.962	5228.1	no
	3	38	services	married	basic.9y	no	unknown	unknown	telephone	jun	fri	...	3	999	0	nonexistent	1.4	94.465	-41.8	4.959	5228.1	no
	4	47	admin.	married	university.degree	no	yes	no	cellular	nov	mon	...	1	999	0	nonexistent	-0.1	93.200	-42.0	4.191	5195.8	no
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
4114	30	admin.	married	basic.9y	no	yes	yes	cellular	jul	thu	...	1	999	0	nonexistent	1.4	93.918	-42.7	4.958	5228.1	no	
4115	39	admin.	married	high.school	no	yes	no	telephone	jul	fri	...	1	999	0	nonexistent	1.4	93.918	-42.7	4.959	5228.1	no	
4116	27	student	single	high.school	no	no	no	cellular	may	mon	...	2	999	1	failure	-1.8	92.893	-46.2	1.354	5099.1	no	
4117	58	admin.	married	high.school	no	no	no	cellular	aug	fri	...	1	999	0	nonexistent	1.4	93.444	-36.1	4.966	5228.1	no	
4118	34	management	single	high.school	no	yes	no	cellular	nov	wed	...	1	999	0	nonexistent	-0.1	93.200	-42.0	4.120	5195.8	no	
4119 rows × 21 columns																						

FIGURE 2.6: Bank Marketing dataset

such as age, marital status, job, etc. These feature collections and row data should be analyzed. We selected the features that are suitable to apply to our research. Some features are selected to represent variables the reliable candidate of borrowers. Features selection is an essential phase to define the best variable for supporting personal lending. The phase of analysis is shown in Figure 2.7.

### 2.4.1 Features Selection

The process started with features collection from datasets is shown in Figure 2.7, then continued with features prediction. In this phase, we predict the features closely related to our research. Next, we try to phase the feature selection by applying a random sample of convenient features, including age, job, marital status, education, housing, and loan. For further research, we are able to apply some methods, such as association rules or decision trees. When we get the features selected, we can observe that all the feature records are complete

[83]–[85]. We applied these features to a borrower’s candidate profile in the last phase. The

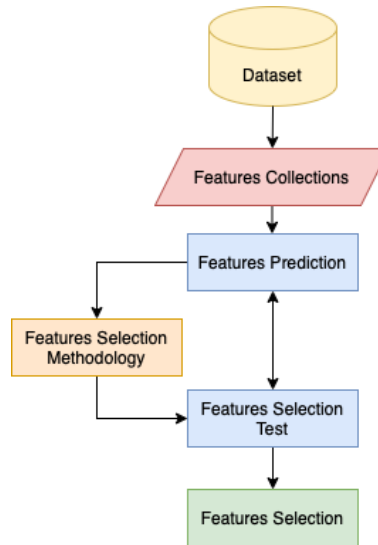


FIGURE 2.7: Model process of Features Selection

features selection sequences and we obtained the selected features, including age, job, marital, education, housing, and loan, are shown in Figure 2.8.

	age	job	marital	education	housing	loan
0	30	blue-collar	married	basic.9y	yes	no
1	39	services	single	high.school	no	no
2	25	services	married	high.school	yes	no
3	38	services	married	basic.9y	unknown	unknown
4	47	admin.	married	university.degree	yes	no
...	...	...	...	...	...	...
4114	30	admin.	married	basic.6y	yes	yes
4115	39	admin.	married	high.school	yes	no
4116	27	student	single	high.school	no	no
4117	58	admin.	married	high.school	no	no
4118	34	management	single	high.school	yes	no

4119 rows × 6 columns

FIGURE 2.8: UCI Bank Marketing dataset

# **Part II**

## **Contributions**



## Chapter 3

# Collateral-Free Trustworthiness-Based Personal Lending

Most loans given by banks are secured loans and require the borrower to provide collateral as a guarantee for returning the loan principal and interest. With a secured loan, the lender can take over an asset provided as collateral if the customer cannot make the loan payments. This chapter proposes a peer-to-peer personal lending platform that minimizes the collateral requirement. The trustworthiness of borrowers is considered an indicator of whether the borrowers will pay the installments on time. Borrowers' reliability is viewed as a function of their reputation and relationships. The lending platform is designed as a Blockchain Decentralized Application (DApp).

This chapter is based on a published conference paper. The complete reference of the paper is as follows: Collateral-Free Trustworthiness-based Personal Lending on a Decentralized Application (DApp). Uriawan, W.; Hasan, O.; Badr, Y. and Brunie, L. (2021). In *Proceedings of the 18th International Conference on Security and Cryptography - SECRYPT*. Lieusaint - Paris, France. pages 839-844. DOI: 10.5220/0010605108390844 [16].

### 3.1 Introduction

The traditional loan application process is shown in Figure 1.1 in chapter 1. Many loan applicants are rejected because they do not meet the terms and conditions [4], [9], [13], [23], [30], [86]–[88]. Banks and non-bank entities provide loans with terms and conditions that are sometimes not easy for borrowers to fulfill. Individual borrowers request loans for personal projects or urgent requirements. Small and medium-sized enterprises (SMEs) need loans to scale up their businesses [1]. Banks or financial institutions require collateral or guarantors to guarantee that borrowers return their loans. Collateral can be in the form of assets (i.e., houses, vehicles, savings, deposits, and securities) [3], [4], [15]. A guarantor is a person who gives some guarantee for the person or SME applying for loans [5], [6].

In addition, many documents may be needed during the loan application process. Administrative costs may be required at the time of submission. The required interest rates can also be more significant, making it burdensome for the borrower [89]. There is also little visibility in the centralized process, so the borrower does not know the precise reasons for being accepted or rejected. Moreover, the traditional loan application is time-consuming. Lending marketplaces offer loans that can speed up the lending process [13], [22]. However, they

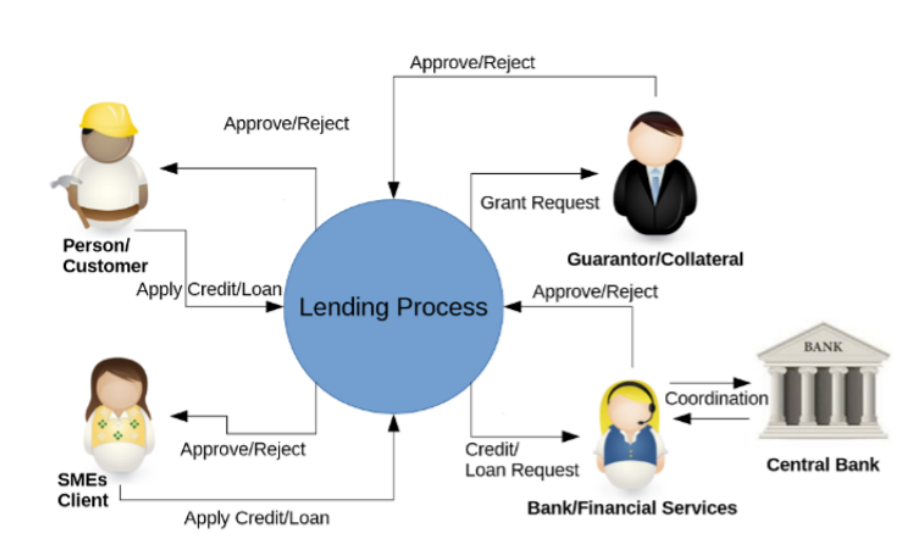


FIGURE 3.1: A traditional lending system.

still require similar terms and conditions. The types of debt financing and estimated times for funding are shown in Table 1.1 in chapter 1. The percentage of approval studied for 100 borrowers showed that 45 were approved and 55 were rejected in the traditional bank system. For cash advance lenders, 90 are approved, and 10 are rejected. For alternative lenders, 70 are approved, and 30 are declined. For large banks, 25 are approved, and 75 are denied [15]. It is difficult to obtain loans from traditional lending systems.

TABLE 3.1: Types, Rates, Terms, and Speed of Funding [15]

Types	Rates (%)	Terms (years)	Funding (days)
Bank	6-10	3-7	14-30
SBA (Small Business Administration)	6-10	3-7	10-30
Line of Credit	5-15	1-3	7-30
Alternative	6-25	1-5	5-7
Cash Advance	1.16-1.55	3-24 months	1-3
Invoice Finance	1-2 (weekly)	1 – 90 (days)	1-3

On the other hand, Blockchain technology is emerging and successfully applied in many business applications, such as banking and financial services. Recently, Blockchain technology [8] has been applied to Peer-to-Peer lending [9] and fintech [7]. In 2013, peer-to-peer lending worldwide reached 3.5 billion U.S. dollars [17]. In 2020, peer-to-peer consumer lending in Europe (excluding the U.K.) reached 2.9 billion U.S. dollars [10]. Peer-to-peer lending is a new trend in the “sharing economy”. P2P lending platforms allow lenders and borrowers to meet without going through a bank. A significant increase is estimated to be close to one trillion U.S. dollars by 2050. In 2018, mobile P2P payments’ value reached U.S. \$86 billion and continued to increase [10].

Today many lending platforms are supported by Blockchain technology, but they still require collateral [11]. ETHLend provides secured lending with the use of ERC-20 compatible tokens as collateral. Borrowers’ trustworthiness [90] is an alternative in a lending application

so borrowers are no longer burdened with collateral or guarantor since not every borrower can provide collateral. The problem is how to calculate trustworthiness. The evaluation for borrowers is only based on credit scores until the present. Borrowers can apply for a loan in a lending platform with a credit score [91]. In this section, we summarize our contributions as follows. We design a lending platform, a completely decentralized and Ethereum-based platform on the blockchain. The trustworthiness score is calculated from collected information such as borrower profile, business activities, recommendations, and loan risk to minimize collateral. In addition, the platform aims for several other properties: Scalability: our lending platform should provide accessibility for borrowers, lenders, and investors in a large community. Cost-effectiveness: enable low-cost transactions. Transparency: all transactions of the system should be traceable and accountable. Automatic enforcement of terms: autonomous transactions by smart contracts as a legal agreement. Efficient: reduce the latency time for the transactions. Security: every user must be protected from unauthorized access.

## 3.2 Related Work

The WeTrust lending platform provides a user dashboard system with a trust lending circle and support by ROSCA. Ethereum is Blockchain-based, autonomous, frictionless, and decentralized. Sybill Attack Prevention, product (Mutual Insurance, Trusted Lending Circles), Country implementation (India, Latin America, China, USA). However, the weaknesses are that collateral (deposit on WeTrust wallet) is still needed and the involvement of a foreperson [60]. SALT Lending, supported by Automated Lending Technology. Ethereum Blockchain-based, distributed ledger (Decentralized), Multi-Currency Support (USD, EUR, GBP, JPY, and RMB). In the countries implemented (Europe and current African Expansion), collateral is still required with automatic collateral technology, and high deposit multi-variant product [6].

TABLE 3.2: Ethereum Lending platform [58]

Lending Platform	SALT	BlockFi	ETHLend	Dharma	Compound	MakerDAO
Registration Required	Yes	Yes	Yes	Yes	No	No
Interest Rate for Loans (Min.)	5.99%	4.5%	Market	Market	Market	3.5%
Lend or Borrow	Borrow	Both	Both	Both	Both	Borrow
Loan-to-Value (Max.)	70%	50%	50%	Market	66%	66%
Own Token	Yes	No	Yes	No	No	Yes

BlockFi is a lending platform with U.S. Dollar, profiling, register, Ethereum, and Bitcoin support. Loans security by Gemini, a New York trust company regulated by the New York Department of Financial Services, requires cryptocurrencies as collateral. Dharma Lever is a P2P Ethereum-based lending, open marketplace, lending system, and borrowing terms. Crypto as collateral, alpha mode, and does not have its token. ETHLend is an Ethereum token platform ready for registration or profiling, which supports over 180 Ethereum tokens, Ethereum, Bitcoin, and LEND tokens as collateral. MakerDAO is Ethereum based. DAI stablecoin decentralized finance application U.S. dollar support. The compound, decentralized



lending application behind MakerDAO relies on a wholly decentralized smart contracts system that can be accessed without permission or registration. Users can customize the rates they want to lend out or pick which loans they are willing to accept and support Ether and multiple ERC20 tokens. MakerDAO lending and borrowing support borrowers need to maintain a collateral value that is 150% of what they borrow [58]. A comparison of lending platforms is shown in Table 3.2.

### 3.3 Our Lending Platform

To address the challenges above, we propose a DApp platform for Ethereum blockchain-based personal lending to assist borrowers in proposing and receiving loans. To this end, we reduce or eliminate the need for collateral by assessing the borrower's trustworthiness for the loan's repayment, as shown in Figure 3.2.

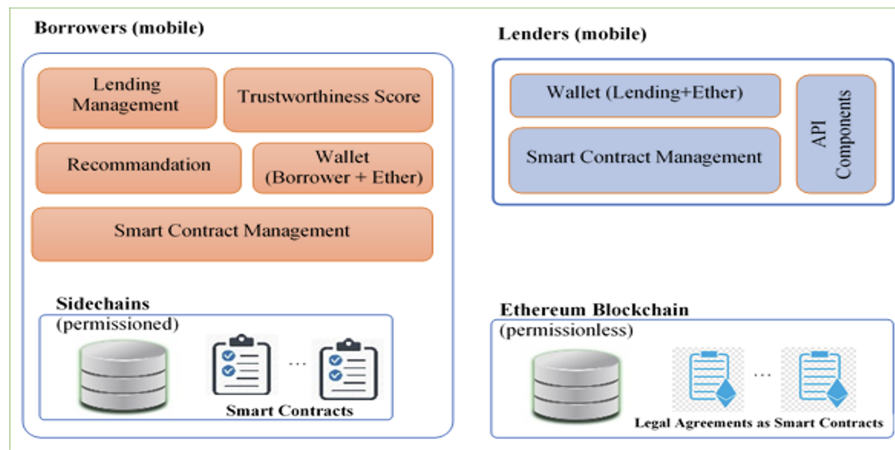


FIGURE 3.2: DApp platform for blockchain-based personal lending.

#### 3.3.1 Trustworthiness Score

Underlying beliefs or personality factors contribute to credit scores. Four factors include impatience, impulsivity, risk tolerance, and trustworthiness [52]. It seems reasonable to expect a lower credit score associated with the payments process if there is evidence of impatience with current and future consumptive activity with borrowing. A higher loan application risk implies the possibility of not being able to pay the installments. Impulsive individuals who have difficulty resisting the temptation to borrow for consumptive needs will increase their debt.

A lack of trust can also cause a bad credit score due to a lack of trustworthiness and failure to meet obligations. And finally, financial risk-taking can significantly affect credit scores because those who accumulate debt will experience repayment difficulties. Credit score using a third party based on information reported by the applicant, such as the FICO score. This credit score estimation uses measuring tools: risky attitude, trustworthiness, time preference, and impulsive survey measures so that it can be used to determine the correlation of behavior of creditors as reflected in the credit score. The standards of impatience, trustworthiness, and

impulsivity affected credit scores, as reported in [91]. We define the trustworthiness score in terms of four variables, namely *profile\_score*, *activity\_score*, *social\_recommendation\_score*, and *loan\_risk\_score*, as follows Equation 3.1:

$$\begin{aligned} \text{Trustworthiness}_{\text{Score}} = & \text{Profile}_{\text{score}} + \text{Activity}_{\text{score}} \\ & + \text{SocialRecommendation}_{\text{score}} \\ & + \text{LoanRisk}_{\text{score}} \end{aligned} \quad (3.1)$$

Where:

*Trustworthiness\_Score*: Borrower credit score.

*Profile\_score*: Personal information of Borrower.

*Activity\_score*: Business activity or job information of Borrower.

*SocialRecommendation\_score*: The recommendation value of Borrower from Recommender.

*LoanRisk\_score*: Information of the record from another loan of Borrower.

### 3.3.2 User Management

The public key creates account addresses similar to bank identities or account numbers in traditional banking. When signing transactions from the account, the private key will be required (Figure 3.3). Each node on the network can verify its signature [92], [93].

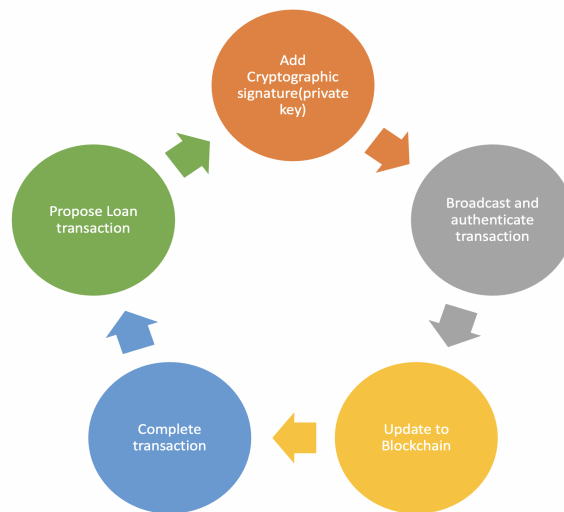


FIGURE 3.3: User management process.

### 3.3.3 Functionality

The system functionality is offered to three actors: Borrowers, Lenders/Investors, and Recommenders. The borrower actor can access direct use cases, including: Create Account, Loan Proposal/Request, Join Investment Group, Withdrawal, Payment Installment, and Delete Account. The borrower actors fill out a form username and password. In the loan use case, the borrower's actor put the loan request into the system by determining the loan amount and period. After the loan application has been received, the borrower actor can make payments

according to the agreement's dates. In the last use case, the borrower actor can delete their account if they have finished paying off installments.

The investor actor can: Create Accounts, Fund Accounts, Create Investment Units, Manage Investment Units, Withdraw Funds, and Delete Accounts. Create User Account use case, and investors actor only creates an account if it has never been created before. If successfully creating an account, the investor actor can access the Fund Account use case and make a transfer balance that will be used for investment. The investor actor can access the Create Investment Units case to make an investment selection after transferring funds. In this use case, the investor actor determines the allocation of funds for the type of investment desired. If the investor actor has finished investing, they can withdraw all funds in the withdrawal funds use case. If the investor actor does not continue the investment, the investor actor can delete their account in the Delete Account use case. The recommender actor can access the trustworthiness score use case to give a recommendation score to borrowers. The Lenders/Investors can use the trustworthiness score to make a loan decision.

### 3.3.4 Lending Management

Lending management will provide how the borrowers request some loans, terms, and conditions. The system gives borrowers' Trustworthiness scores after registering with a default value for the first time. The recommendation provides the borrowers with a person who can give good recommendations to propose some loans. An essential part of our lending platform is a recommendation to reduce collateral dependence. Some borrowers' users give good comments. The number of other users who make recommendations will cause the loan application to be granted. Investors will get a message that there are new borrowers who are recommended to be given loans. So that may help convince investors to approve their loans.

There will be no credit score when creating an account, but the borrower can apply for a loan with a certain amount. The system will detect someone who requested a loan. The investors will see an opportunity, so there may be several prospective investors to provide loans. Investors may decide to bear the risk depending on the borrower's profile. Smart contracts as legal agreements (investors and borrowers) are the core of our proposed lending platform. Trustworthiness scores and recommendations are significant factors in lending on this platform that can reduce collateral dependence.

### 3.3.5 Calculating the Trustworthiness Score

The trustworthiness score we propose is a value of borrowers set by the smart contract so that both parties understand each other's obligations and risks that will be accepted. The variables include profile, activity, social recommendation, and loan risk scores, as shown in Equation 3.1. The borrowers can request some loans with their trustworthiness score, determining the maximum loan. Trustworthiness scores will increase alongside the track record of payments from borrowers. The value will get better, and the borrower has the opportunity to get a larger loan in the next submission. The system will reduce the trustworthiness score if the investors and recommenders give a bad report to borrowers.

On the other hand, investors may profit if they get a borrower with a good commitment. With increasing loan plan limits, the borrower will get a high trustworthiness score, making it easier to request loans in the next cycle. The smart contracts management at borrowers, lenders/investors, and recommenders' sides will handle each functionality from the available services on the Ethereum-based blockchain.

### 3.3.6 Sidechains and Ethereum

We propose reducing users' burden by installing the sidechains on the mobile application side of this lending platform. DApp platform lending platform Ethereum-based can handle complex transactions. The users feel more confident in making transactions.

Setting up a recommendation to support the lending process and establishing a high level of trust, allowing users who have already done a transaction without additional costs for making the same transaction, will reduce the cost burden of making transactions. It can also control users' traffic (investors and borrowers) of this lending platform. It allows the user to download only the application client so that it is unnecessary to download the whole Ethereum-based lending platform and reduce the exchanged messages (transactions) through the internet to access the main blockchain (e.g., connectivity problems, internet not available). The weaknesses are to perform off-chain transactions will increase transaction time because all members must be approved. Transaction queueing will occur because each transaction requires action from other users and will impact additional processing time.

Blockchain technology is a combination of trust and consensus in a legal agreement between investors and borrowers, so there is no need to represent data, processes, and transactions on the blockchain to increase the trust's expected value. The permissioned blockchain makes it possible to give all users (investors and borrowers) privileges as described in one complete infrastructure. Users can obtain permission only through the applications and integrate multiple components, such as security, speed, immutability, scalability, resilience, and trustworthiness, including ledgers that cannot be changed except through consensus.

### 3.3.7 Smart Contracts

On our lending platform, smart contracts will regulate conditions from the borrowers' and investors' sides and determine the business logic from the borrowers' side to propose a loan. Investors can capture demand signals to offer an agreement between borrowers and investors regarding interest and other fees (also called gas) until both parties set up a contract. Our lending platform can maintain an access control layer (lending management) compared to existing blockchain-based lending. Users enable specific actions to be carried out only by individual investors or borrowers that can be identified and possibly with predetermined access rights. This smart contract requires a communication model to define a legal agreement as a smart contract.

In addition, the direct involvement of investors and borrowers in managing this lending platform can reduce the risk of failure associated with the execution of smart contracts and regulate the conditions for the existence of privilege given to each user (investor and borrower

side) to keep the service running in the long run and the investor and borrower sides does not need to download the whole blockchain of a lending platform for the client.

### 3.4 Conclusion

In this chapter, we deliver the contribution to propose a personal lending platform that minimizes collateral by introducing a trustworthiness score and replacing the guarantor with a recommendation from family members, colleagues, peers, and small businesses. The transactions are conducted with smart contracts as an enforceable agreement between the borrowers and the lenders/investors. A recommendation will support trustworthiness scores on the borrowers' side and give decision-making on the investors' side. The platform is designed as Blockchain Decentralized Application (DApp), a rapidly growing technology, especially for fintech. The DApp architecture enables borrowers and lenders to transact in a P2P manner, thus eliminating the disadvantages of a centralized loan process.

## Chapter 4

# LAPS (Loan Risk, Activity, Profile, and Social Recommendations)

The credit score is one variable in receiving a loan application from a bank or financial institution that provides credit/loan. Many factors determine whether a borrower gets the loan. One of them is through more valuable collateral than the proposed loan. However, this is not possible for borrowers to provide it. Personal data, job information, salary amounts, assets owned, and valuable documents are usually required to determine a credit score. We build a personal lending platform model based on the trustworthiness score called LAPS (Loan Risk score, Activity score, Profile score, and Social Recommendation score) borrower trustworthiness score. The borrowers' trustworthiness is an absolute requirement to ensure they can repay the loans and installments on time. We present practical ways to select the best features from the Bank Marketing dataset. The feature selection of the dataset applies to blockchain applications. The advantage of LAPS is introducing recommenders' as guarantors to convince the lenders'/investors' and minimizes collateral by implementing a LAPS.

This chapter is based on a published conference paper. The complete reference of the paper is as follows: LAPS: Computing Loan Default Risk from User Activity, Profile, and Recommendations. W. Uriawan, O. Hasan, Y. Badr and L. Brunie. In Fourth International Conference on Blockchain Computing and Applications (BCCA), 2022, pp. 167-172, doi: 10.1109/BCCA55292.2022.9922034 [94].

## 4.1 Introduction

Credit scoring issues will help the bank or financial institution get valid information, and several features describe the eligible borrowers [52]. A personal loan is part of financial services for who person applying for some loan. Traditional mechanisms show weaknesses because it takes time uncertain (it tends to be longer), require many documents, additional costs, etc. Finally, there is no transparency when the borrower is approved or rejected. In the traditional lending application process, persons apply for a loan because they need some funds to support family members, rent a house, buy a car, etc. So they try to find a loan shown in Figure 4.1. Many borrowers have been rejected because they do not meet terms and conditions [95].

Today, banks and financial institutions provide loan terms and conditions that are not easy for borrowers to fulfill these conditions [51]. Banks or Lending marketplaces offer loans and

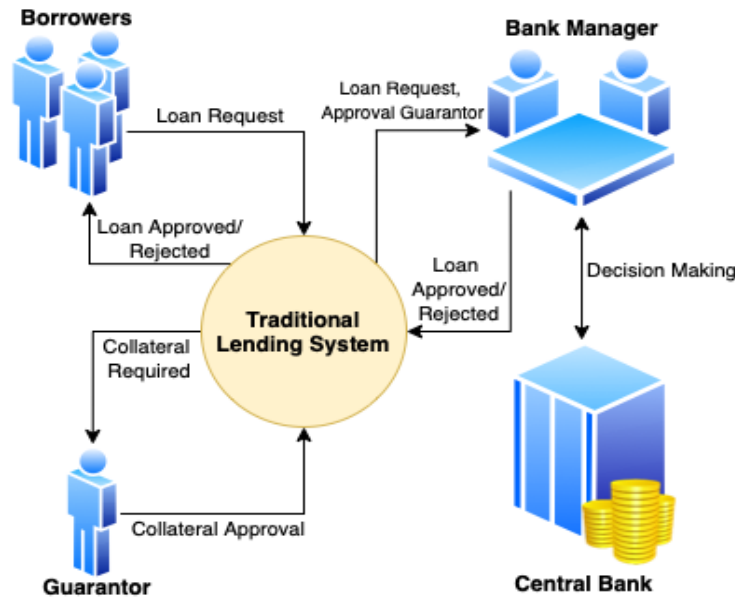


FIGURE 4.1: A Traditional lending system

still require collateral to guarantee that borrowers return their loans. Collateral can be in the form of more accessible assets to become money. A guarantor is a person who gives some guarantees to borrowers while applying for some loans.

The type of debt financing and approval percentages are shown in Table 4.1 below. Borrowers approval rates are shown in Cash Advance Lenders 90% is higher because of fast processing about 1-3 days approval, next followed by Alternative Lenders reach 70% loan processing environs 5-7 days, Traditional Banks about 45%, about 25% time processing about 14-30 days is the last less percentage is Large Banks. Table 4.1 shows the scale of ratio and time processing impacts borrowers' proposal of some loans [15]. Table 4.1 describes it is still difficult to obtain some loans from traditional lending systems. The percentage approval was assumed from 100 borrowers. Of the Large Banks, 25 were approved, and 75 are denied in proposed loans.

TABLE 4.1: Approval Rates

Types of Lenders	Percentage (%)
Traditional Banks	45
Cash Advance Lenders	90
Alternative Lenders	70
Large Banks	25

Source: <https://gudcapital.com/types-of-business-loans/>

We provide the LAPS formula as a solution to the problem above. It contains the Loan Risk, Activity, Profile, and Social Recommendation score as a borrower trustworthiness score. The borrower has confidence after receiving the trustworthiness score. With this score, the borrower does not need any more collateral. From the lender/investor side, they get assurance that the borrower can repay the loan, and the recommender bridges the gap

between the borrower and the lender. With LAPS, all users will get incentives that can be applied safely. In addition, we present the advantages of LAPS when it applies to the Ethereum blockchain-based application [16], which illustrates how to feature selection from UCI Bank Marketing public dataset [96].

## 4.2 Related Work

We found that most of the existing solutions reviewed can still be improved by detailing this research. This section's work review is located in the literature-related documents. The research mentioned how the BLockchain-Enabled Social credits System (BLESS) applied in the system leverages the decentralized architecture of the blockchain network, which allows grassroots individuals to participate in the rating process of a social credit system (SCS) and provides tamper-proof of transaction data in the trustless network environment. The anonymity in blockchain records also protects individuals from being targeted in the fight against powerful enterprises. A smart contract-enabled authentication and authorization strategy prevent unauthorized entities from accessing the credit system. The BLESS scheme offers a secure, transparent, and decentralized SCS. However, they have difficulty implementing technology in social aspects such as public acceptance and mass adoption [95].

Their research is developing a credit-scoring model using logistic regression and multi-variate discriminant analysis applied in Moroccan Financial Institutions (MFIs). The model combines behavioral and descriptive data related to the borrowers (age, activity, level of education, number of unpaid debts, number of loans, etc.) and (amount of credit, duration of credit, number of concluded loans per portfolio manager, etc.). The weaknesses require a more extensive data sample, a deep enough history of the customer's behavior, and more information about variables related to the client's activity and performance to predict the default better [39].

## 4.3 Our Proposal

Features selection is needed to choose high-quality data. The selection process requires a parameter or expected value corresponding to data availability. In particular, personal data, educational background, marital status, family members, financial data, job information, and collateral. The comparative study of several methods like Decision tree [97], statistical and Artificial Intelligent [98], Rough and Tabu search [99] are relevant with research area some authors had to deliver the message bring some information for selection feature, and describe the result. Features collection of datasets is tested to indicate suitability for applying the formula/model. Datasets used from UCI machine learning is a public dataset [96].

### 4.3.1 Dataset Features Selection

Data sources in Figure 4.2 are built with some components to be analyzed, features, and fields with a particular purpose. The analysis phase in Figure 4.3 identifies what needs and is being understood. Features are about what kind of information needs and more specific, and fields



describing an object are analyzed (applicant) [96]. Datasets contain the features collections

	age	job	marital	education	default	housing	loan	contact	month	day_of_week	...	campaign	pdays	previous	poutcome	emp.var.rate	cons.price.idx	cons.conf.idx	euribor3m	nr.employed	y
0	30	blue-collar	married	basic.9y	no	yes	no	cellular	may	fri	...	2	999	0	nonexistent	-1.8	92.893	-46.2	1.313	5099.1	no
1	39	services	single	high.school	no	no	no	telephone	may	fri	...	4	999	0	nonexistent	1.1	93.994	-36.4	4.855	5191.0	no
2	25	services	married	high.school	no	yes	no	telephone	jun	wed	...	1	999	0	nonexistent	1.4	94.465	-41.8	4.962	5228.1	no
3	38	services	married	basic.9y	no	unknown	unknown	telephone	jun	fri	...	3	999	0	nonexistent	1.4	94.465	-41.8	4.959	5228.1	no
4	47	admin.	married	university.degree	no	yes	no	cellular	nov	mon	...	1	999	0	nonexistent	-0.1	93.200	-42.0	4.191	5195.8	no
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4114	30	admin.	married	basic.9y	no	yes	yes	cellular	jul	thu	...	1	999	0	nonexistent	1.4	93.918	-42.7	4.958	5228.1	no
4115	39	admin.	married	high.school	no	yes	no	telephone	jul	fri	...	1	999	0	nonexistent	1.4	93.918	-42.7	4.959	5228.1	no
4116	27	student	single	high.school	no	no	no	cellular	may	mon	...	2	999	1	failure	-1.8	92.893	-46.2	1.354	5099.1	no
4117	58	admin.	married	high.school	no	no	no	cellular	aug	fri	...	1	999	0	nonexistent	1.4	93.444	-36.1	4.966	5228.1	no
4118	34	management	single	high.school	no	yes	no	cellular	nov	wed	...	1	999	0	nonexistent	-0.1	93.200	-42.0	4.120	5195.8	no

4119 rows x 21 columns

FIGURE 4.2: Bank Marketing dataset

and row data in Figure 4.2, which should be analyzed like the data required approaches in this case. We use the association rules and the weighting approach to select suitable features for this research. Some features are selected to represent the variable candidate with the high impact factor. The features selection is essential for choosing the best variable to support personal lending [14].

The process will start with feature collection from datasets seen in Figure 4.3, then continue with features selection by applying a suitable method and testing all the features selected in the same cycle for the following features until found the highest score of features. In this section, the feature prediction phase predicts the appropriate features for the meaning of borrowers' candidates. Then, in the features selection methodology, apply some methods to get the best feature corresponding to the borrowers' profile. After the feature selection has finished, we must test all features sample to ensure it is suitable for our research. Finally, we have the best features selection, supporting the credit scoring for selecting the best applicant with the minimum risk.

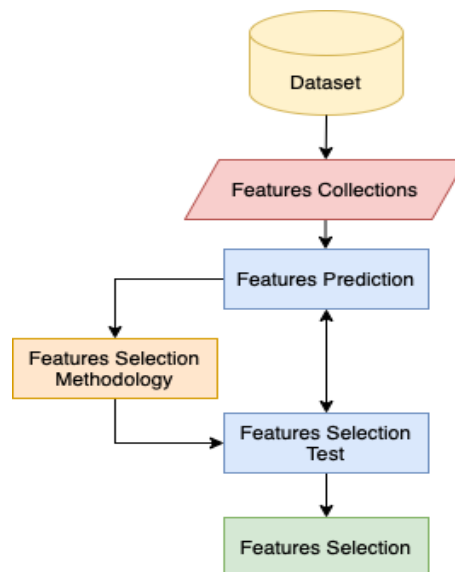


FIGURE 4.3: Model process of Features Selection

### 4.3.2 LAPS Splitting Formula

We briefly discuss membership functions variables rules for making a decision and define the trustworthiness score in terms of four variables [16], namely *LAPS (Loan Risk, Activity, Profile, and Social Recommendation)* as borrowers' trustworthiness scores [100], see Equation 4.4. The authors applied the Bank Marketing dataset from UCI public dataset [96] show in Figure 4.2:

1. *Loan Risk score* is the component for measuring the borrower candidate has another loan such as housing, car, etc. in Figure 4.4 (A), (B) if there is any other loan is risky to allowing get another loan and will decreasing the trustworthiness score, see Equation 4.1.

$$\text{Loan Risk score} = \sum_{i=1}^n (w_i * L_i) \quad (4.1)$$

where:

$w$  = Weight for each variable  $\{w \in \mathbb{R} \mid w \leq 1\}$ , that able to be defined by user.

$i$  = Sequence of weight and variable.

$L$  = Variables (loan, housing), where  $\{L \in \mathbb{Z} \mid L \leq 100\}$ , and scale of values are between 0 to 100.

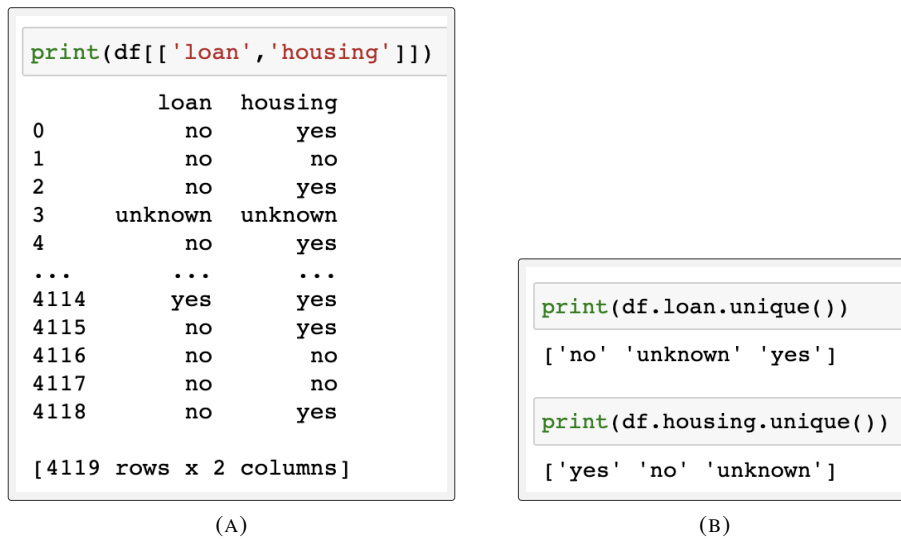


FIGURE 4.4: Loan and Housing Dataset (A) and List of Loan and Housing (B)

2. *Activity score* describing the borrower activity in an occupation such as job or business activity in Figure 4.5 (A), (B), to measure the ability to pay and considering the credit plafond or credit limit that correspond with their activity, if borrower candidate has a good occupation they will get the highest value of *Activity score*, see Equation 4.2.

$$\text{Activity score} = \sum(A) \quad (4.2)$$

where:

$A$  = Variable (Job activity), where  $\{A \in \mathbb{Z} \mid A \leq 100\}$ , and scale of values are between 0 to 100.

```
print(df[['job']])
```

	job
0	blue-collar
1	services
2	services
3	services
4	admin.
...	...
4114	admin.
4115	admin.
4116	student
4117	admin.
4118	management

[4119 rows x 1 columns]

(A)

```
print(df.job.unique())
```

['blue-collar' 'services' 'admin.' 'entrepreneur' 'self-employed'  
'technician' 'management' 'student' 'retired' 'housemaid' 'unemployed'  
'unknown']

(B)

FIGURE 4.5: Job Dataset (A) and List of Job (B)

3. *Profile score* is the personal data of borrower candidates such as age, education level, and marital status in Figure 4.8. These variables support to trustworthiness score. For example, the borrower should be older than 18 years old and 88 years old maximum age shown in Figure 4.6 (A), (B), [101], have an education level in Figure 4.7 (A) to measure the economy and activity in industry or entrepreneur, and have marital in Figure 4.7 (B) status to consider the family dependent. All the variables are summarized in one variable as *Profile score*. The formula to get the *Profile score* is shown in Equation 4.3:

$$Profile\ score = \sum_{i=1}^n (w_i * P_i) \quad (4.3)$$

where:

$w$  = Weight for each variable  $\{w \in \mathbb{R} \mid w \leq 1\}$ , that able to be defined by user.

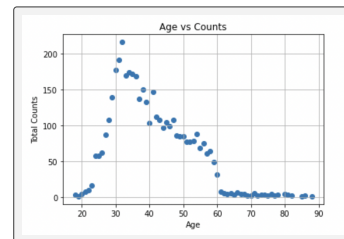
$i$  = Sequence of weight and variable.

$P$  = Variables (age, education, marital) are  $\{P \in \mathbb{Z} \mid P \leq 100\}$ , where scale of values is between 0 to 100.

```
print(pd.unique(variable.age.sort_values()))
```

[18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41  
42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65  
66 67 68 69 70 71 72 73 74 75 76 77 78 80 81 82 85 86 88]

(A)



(B)

FIGURE 4.6: Range of Age (A) and Diffusion of Age (B)



FIGURE 4.7: List of Education level (A) and List of Marital Status (B)

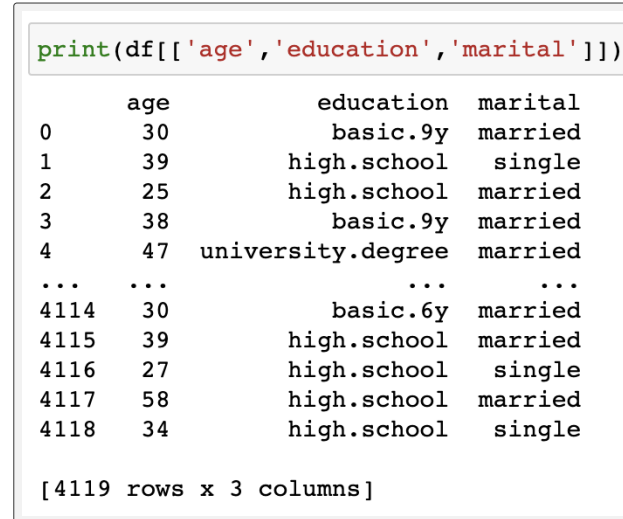


FIGURE 4.8: A Profile Dataset

4. *The social recommendation score* is the primary variable the borrower gets support directly from the other users to add recommendation value. This values as a guarantor for borrowers to get some loan from lenders/investors through the lending platform see in Equation 4.4, 4.5. *Social Recommendation score* = variables  $S$  (Social Recommendation) are  $\{S \text{ in } \mathbb{Z} \mid S \leq 100\}$ , where scale of values is between 0 to 100.

## 4.4 Result

The data test is a sequence of the dataset obtained see Figure 4.9. The features that have been selected results are 6 (six), including age, marital, education, job, housing, and loan. LAPS captured from each feature and then converted to number value see Figure 4.13. The borrowers get value (Loan Risk, Activity, and Profile score) from an example dataset. The Social Recommendation score will get by the other user as Recommenders. This section describes the process splitting formula according to the dataset to obtain the selected suitable features.

1. Age and Marital status features selection in Figure 4.10 (A), (B) have an impact on the ability to pay back the loan. Age and Marital status show the borrowers' family members and condition. The dataset shows the age range distribution with percentage indicated in Figure 4.10 (A). Age is the one important variable that also means the productivity of the borrower. The Marital status dataset shows the list of status borrowers in Figure 4.10 (B). Borrowers of productivity ages and single have the ability to pay installments on time.

	age	job	marital	education	housing	loan
0	30	blue-collar	married	basic.9y	yes	no
1	39	services	single	high.school	no	no
2	25	services	married	high.school	yes	no
3	38	services	married	basic.9y	unknown	unknown
4	47	admin.	married	university.degree	yes	no
...	...	...	...	...	...	...
4114	30	admin.	married	basic.6y	yes	yes
4115	39	admin.	married	high.school	yes	no
4116	27	student	single	high.school	no	no
4117	58	admin.	married	high.school	no	no
4118	34	management	single	high.school	yes	no
4119 rows × 6 columns						

FIGURE 4.9: UCI Bank Marketing dataset

	frequency	percentage
18-25	98	2.38%
26-29	314	7.63%
30-34	893	21.69%
35-39	801	19.45%
40-44	603	14.64%
45-49	493	11.97%
50-56	558	13.55%
57-60	249	6.05%
61-70	71	1.72%
71-88	38	0.92%

(A)

	frequency	percentage
unknown	11	0.27%
divorced	446	10.83%
single	1153	27.99%
married	2509	60.91%

(B)

FIGURE 4.10: Percentage of Age (A) and Percentage of Marital Status (B)

2. Education and Job features selection is shown in Figure 4.11 (A), (B), indicating the borrower candidate with a higher education level will get a good job position opportunity. The impact of education on salary changes significantly. The most substantial effect of education is also expressed at the highest level. Even under other factors, the dominant role of education on salary. The borrowers have higher education returns, particularly above the high school level. In general, we find that the higher the education in line with their salary growth.

frequency percentage		
illiterate	1	0.02%
basic.4y	429	10.42%
professional.course	535	12.99%
basic.9y	574	13.94%
high.school	921	22.36%
university.degree	1264	30.69%
unknown	167	4.05%
basic.6y	228	5.54%

(A)

frequency percentage		
unknown	39	0.95%
student	82	1.99%
technician	691	16.78%
housemaid	110	2.67%
unemployed	111	2.69%
blue-collar	884	21.46%
admin.	1012	24.57%
entrepreneur	148	3.59%
self-employed	159	3.86%
retired	166	4.03%
management	324	7.87%
services	393	9.54%

(B)

FIGURE 4.11: Percentage of Education (A) and Percentage of Job (B)

3. Housing and Loan features selection are at greater risk of housing instability compared to homeowners in Figure 4.12 (A), (B). Among the factors contributing to that risk are financial situations. Debt housing is riskier and far more likely than homeowners to pay more than 30 percent of their income in housing costs.

frequency percentage		
unknown	105	2.55%
no	1839	44.65%
yes	2175	52.8%

(A)

frequency percentage		
yes	665	16.14%
unknown	105	2.55%
no	3349	81.31%

(B)

FIGURE 4.12: Percentage of Housing (A) and Percentage of the other Loan (B)

4. The borrower's trustworthiness score is presented to the eligible borrowers after they have the trustworthiness score. The borrowers' trustworthiness score gives the borrowers scores after registering with a default value for the first time. It will increase the borrowers' activity in the lending process and activity in the payment process (on simulation). The recommenders can give excellent recommendations to borrowers who

propose a loan. An essential part of the personal lending simulation is a recommendation to reduce collateral dependence.

$$\begin{aligned} \text{Trustworthiness Score} = & \text{Loan Risk score} \\ & + \text{Activity score} + \text{Profile score} \\ & + \text{Social Recommendation score} \end{aligned} \quad (4.4)$$

with:

- *Trustworthiness Score*: Borrower trustworthiness score.
- *Loan Risk score*: Information of the record from another loan of Borrower.
- *Activity score*: Business activity or job information of Borrower.
- *Profile score*: Personal information of Borrower.
- *Social Recommendation score*: The recommendation value of Borrowers from Recommender.

5. The LAPS formula is a commitment between borrowers, lenders/investors, and recommenders set by the smart contracts management so that all parties understand each other's obligations and risks that will be accepted. The variables include Loan Risk, Activity, Profile, and Social Recommendation. All data will be assessed as a borrower's trustworthiness score (LAPS). LAPS formula, we add positive weight for each variable, in equation 4.5:

$$\begin{aligned} \text{LAPS} = & (w_l * \text{Loan Risk score}) \\ & + (w_a * \text{Activity score}) + (w_p * \text{Profile score}) \\ & + (w_s * \text{Social Recommendation score}) \end{aligned} \quad (4.5)$$

where  $\{w \text{ in } \mathbb{R} \mid w \leq 1\}$ , and  $w_l, w_a, w_p$ , and  $w_s$  are positive weights of the trustworthiness parameters such that  $w_l + w_a + w_p + w_s = 1$ . The weights of the trustworthiness attributes are predetermined based on their priority value that can modify by consensus. For example,  $w_l = 0.25$ ,  $w_a = 0.2$ ,  $w_p = 0.25$ ,  $w_s = 0.3$ . In this example, the social recommendation is given the highest percentage, and activity is given the lowest value, which shows that the social recommendation is the priority to measure the eligible borrower candidate. Equation 4.5 is the complete formula for the trustworthiness score after weight added is supportive to imprecise conclusions.

After they get the score (see in Figure 4.13 and Figure 4.14), they can propose some loans with their borrowers' trustworthiness score and determine the maximum loan. The borrowers' trustworthiness scores will increase alongside the track record of borrowers' payments. After converting the selection dataset, then grouping the features in line with the LAPS variables formula seen in Figure 4.14, the features are mentioned in the splitting formula. We obtained the selection feature grouping. The data test applied these features selected to a personal lending prototype. The first data test was seen in Figure 4.15 show the borrowers trustworthiness score, and the first user obtains

	age	job	marital	education	housing	loan
0	100	65	100	78	100	100
1	95	70	80	85	55	100
2	55	70	100	85	100	100
3	95	70	100	78	50	50
4	50	85	100	100	100	100
...	...	...	...	...	...	...
4114	100	85	100	71	100	55
4115	95	85	100	85	100	100
4116	55	55	80	85	55	100
4117	60	85	100	85	55	100
4118	100	90	80	85	100	100

4119 rows x 6 columns

FIGURE 4.13: Converted Dataset Selection

	profile	activity	loanRisk	recommendation	Trust Score
0	80	65	100	0	0
1	78	70	66	0	0
2	72	70	100	0	0
3	79	70	50	0	0
4	78	85	100	0	0
...	...	...	...	...	...
4114	77	85	89	0	0
4115	82	85	100	0	0
4116	68	55	66	0	0
4117	73	85	66	0	0
4118	79	90	100	0	0

4119 rows x 5 columns

FIGURE 4.14: Transform Dataset Selection

Platform users								
#	Borrower contract address	Borrower wallet address	Total TScore	Activity score	Profile score	Social recommendation score	Loan risk score	# cycles
0	0x61c36a8d610163660E21a8b7359e1Cac0C9133e1	0x90F79b6EB2c4f870365E785982E1101E93b906	79	65	80	73	100	1
1	0x8EFa1819F5B279077368d44B593a4543280e402	0x70997970C51812dc3A010C7d01b50e0d17dc79C8	74	70	78	82	66	1
2	0xA14d9C7a916Db01cCA55ec21Be1F7665C326928F	0x976EA74026E726554dB6571A54763abd0C3a0aa9	79	70	72	76	100	1
3	0x7fc1375aA5d360Ca90cc443B5c3d3919aA8B9208	0x15d34AAf54267DB7D7c367839AAf71A00a2C6A65	64	70	79	61	50	1

FIGURE 4.15: LAPS result 1



79, following the other users, after the recommender gives the value in the prototype. The LAPS formula will compute the trustworthiness score. The second data test is

Platform users								
#	Borrower contract address	Borrower wallet address	Total TScore	Activity score	Profile score	Social recommendation score	Loan risk score	# cycles
0	0x61c36a8d610163660E21a8b7359e1Cac0C9133e1	0x90F79b6EB2c4f870365E785982E1f101E93b906	88	100	88	73	100	1
1	0x8Efa1819f5B279077368d44B593a4543280e402	0x70997970C51812dc3A010C7d01b50e0d17dc79C8	75	70	80	82	66	1
2	0xA14d9C7a916Db01cCA55ec21Be1F7665C326928F	0x976EA74026E726554d86571A54763abd0C3a0aa9	72	65	79	76	66	1
3	0x71c1375aA5d360Ca90cc443B5c3d3919aA8B9208	0x15d34AAf54267D87D7c367839AAf71A00a2C6A65	73	70	62	61	100	1

FIGURE 4.16: LAPS result 2

shown in Figure 4.16 with different data tests (variables change values). The result of the borrower's trustworthiness score is positive values. The prototype succeeded in computing the features selected with the LAPS formula. The system will automatically increase the value of the borrowers' trustworthiness score (LAPS). The borrower will be able to propose a more significant amount than before if their score rises.

The borrower with a high trustworthiness score will be easier to propose loans with increasing loan plan limits in the next cycle. Smart contracts management at borrowers, lenders/investors, and recommenders sides will handle each functionality from the available services on the Ethereum blockchain. With the limitation of the available digital wallet account tests, the test runs per each account with an equal method for all datasets.

#### 4.4.1 Discussion

Features selection is a part of choosing the best variable for supporting personal lending, and many features could be selected. Credit Scoring is the most important for choosing the best applicant with the minimum risk. Some features will help describe the conditions for the borrower to pay back the loan. On the other hand, lenders/investors cover their risk with these features, and their money can not return. First, data features will be compiled with the standard method, and the result will be analyzed with another method. Secondly, all features try to connect with others and choose the relevant features. The result will show how to adequate the relation between two features. Next, rank each feature with the highest score and follow the following score until finished.

The presented LAPS formula is the challenges and the open problems previously discussed. The formula covers minimizing collateral when borrowers propose a loan. All variables (Loan risk score, Activity score, Profile score, and Social recommendation score) support borrowers in getting loans from lenders/investors. The LAPS formula is well adapted to the personal lending platform to accommodate the recommenders and lenders/investors to decide.

## 4.5 Conclusion

In this chapter, we present the first contribution is to compute the trustworthiness score (LAPS) to provide a reliable borrower. The result obtained the selected features from UCI

Bank Marketing public dataset with the highest impact factor weight. The variables in this context are the categorical type features converted to quantitative. The LAPS formula shows all borrowers' activity by referring to the personal lending prototype, which directly interacts among borrowers, recommenders, and lenders/investors. The LAPS model describes the scoring of trustworthiness that has been successfully applied to the personal lending prototype. Lenders can use the trustworthiness score to decide the eligible borrowers' candidates.



## Chapter 5

# Implementing the Business Logic using Smart Contracts

Financial services are utilities provided by the banking, insurance, and investing sectors. Financial services are critical to the operation of firms, professionals, and individuals. Smart contracts are one of the functionalities of blockchain technology. They can replace the process of intermediation among users. This can be realized in a Peer-to-Peer (P2P) network in a decentralized manner. However, implementing the business logic of complete financial services is a challenge. For example, in order to implement a financial service such as P2P lending, we need to overcome problems such as security, minimization of collateral, and borrower trustworthiness. In this chapter, we demonstrate the implementation of such a financial service using smart contracts. The smart contracts implement the business logic to handle all transactions, including borrowing, lending, and recommending. We describe the pseudo-code of smart contracts and illustrate them in a prototype Decentralized Application (DApp).

### 5.1 Introduction

Traditional financial institutions such as banks offer various financial services to customers, including insurance, investing, and lending. However, the financial services these traditional institutions offer dictate that the customer must rely on and trust large centralized entities.

Blockchain technology is part of the decentralized [102] digital transformation process. We observe the technology's potential to reduce costs and improve operations. The peer-to-peer (P2P) networks can replace organizational networks, reducing hierarchical levels and transaction costs [88]. A smart contract is an autonomous contract that can be used to exchange crypto assets, property or anything of value without dependence on a third party. Smart contracts allow data and transactions to be recorded as they occur and can only be changed by consensus [103]. Smart contracts can be proposed as main programs (e.g., lending platforms) that are fully system-run without human interaction [104].

This chapter focuses on the financial lending service. The business logic of a lending platform must provide features that make it easy for borrowers, lenders, and recommenders to create a quick and secure transaction. One of the capabilities of decentralized applications is that they can work optimally without relying on central servers [105]. Each user can

interact in a decentralized manner and get advantages of blockchain such as decentralization, immutability, and transparency [106].

In addition, this research aims to fill the opportunity by providing a conceptual model for implementing smart contracts in peer-to-peer lending application transactions. In order to implement a financial service such as P2P lending, we need to overcome problems such as security, minimization of collateral, and borrower trustworthiness. The underlying technology design is a significant feature of the lending platform [16], [88], including the consensus and security mechanism, borrowers and lenders management, lending process, interest rate mechanism, withdrawal for borrowers, repayment/installments, and redeem for recommenders and lenders. The lending platform's particular components and recommendations support the trustworthiness component. This research describes how to implement smart contracts on personal lending platforms. We explain the algorithms of smart contracts for personal loan simulations.

## 5.2 Related Work

This section reviews work found in the literature related to smart contracts. We found most of the existing solutions reviewed still can be improved by detailing smart contracts implementation. The research mentioned how smart contracts could provide such an alternative mechanism of contract governance. While the impact of smart contracts is potentially broader and confined argument solely affects contracting and relations with contract law [41].

The fundamental mission of blockchain is to build a trustworthy ecosystem among independent participants in an untrustworthy distributed environment. The autonomous blockchain is a secure system based on chained blocks, peer-peer nodes, consensus-based ledger mechanisms, anonymous accounts, self-regulated data ownership, and programmable smart contracts. Minimal blockchain effort is required, feasible, efficient, and enduring. In addition, unique credit mechanisms are necessary to make blockchain systems creditworthy, although blockchains provide a credit-worthy infrastructure for data-level storage and operations [43].

Their research aims to fill this gap by conceptualizing a model of blockchain-mediated trust in peer-to-peer transactions in the sharing economy. They build on existing trust research in e-commerce and conceptualize an advanced trust model that can apply blockchain technology to increase trust among peers in the sharing economy, decrease intermediation and reduce transaction costs [31]. Another research proposed solution utilizes smart contracts to have code that automates the version control logic and workflow of digital documents to facilitate controlled or restricted data-sharing mechanisms. The smart contract code orchestrates all the interactions among multiple participants (including those approvers and developers) in an entirely decentralized way [107].

### 5.3 Our Proposal

This section presents the lending platform describing its main functions. The architecture shows an Ethereum blockchain-based DApp platform to assist borrowers and lenders/investors in lending. This architecture needs the recommenders to help the borrowers convince the lenders about their trustworthiness. The smart contracts serve as a legal agreement between borrowers, lenders, and recommenders on a personal lending platform. Our Architecture is shown in Figure 5.1. Smart contracts will handle all transactions stored on the Ethereum blockchain. The DID (Decentralized Identity) shows the user's identity from their digital wallet. The Oracles blockchain network helps interact with an institution and bank APIs [108].

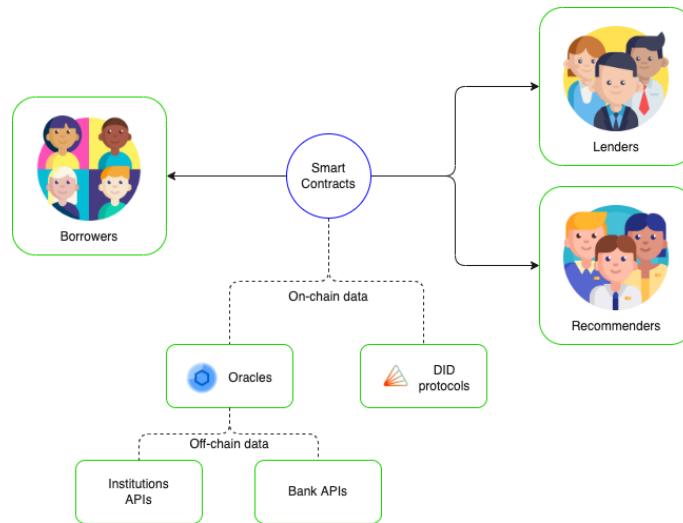


FIGURE 5.1: Lending Platform overview.

#### 5.3.1 Decentralized Application (DApp) Characteristics

The DApp's usual standards coding and algorithm slightly differ from common programming and applications with no server dependencies. The lending platform prototype [16] that we propose have several considerations because it involves security and money (tokens). The security factor is an important thing. In principle, permission rights of specific users to apply outside the lending platform for safe access. The borrowers, recommenders, and lenders are differentiated based on accessibility/purpose.

#### 5.3.2 Smart Contracts Required

The users of smart contracts are shown in Figure 5.1. We can observe the functionality by user activity in Figure 5.2.

1. **Login Stage:** In this stage, users log in with their MetaMask wallet. Each user can login as a borrower, recommender, or lender but cannot simultaneously with two conditions (e.g., borrower and lender) and recommender and lender. The rule of the system protects from users' unauthorized access.

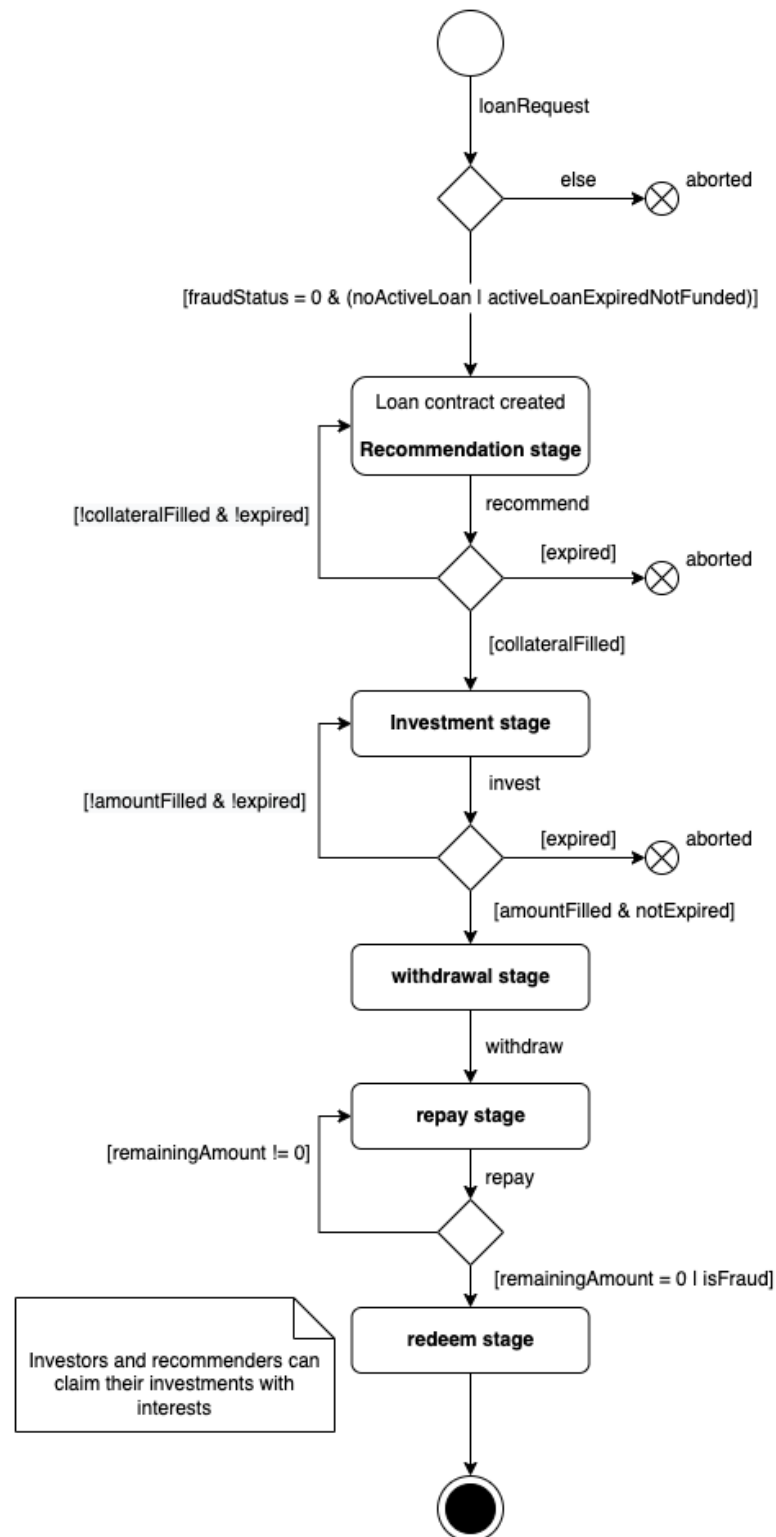


FIGURE 5.2: State diagram of lending platform

2. **Recommender Stage:** Our prototype provides the recommender stage. In this stage, recommenders give the recommendation value to the borrower to get a loan, and the lender is able to make a decision. On the other hand, the recommender stage is the intermediation between borrowers and lenders.
3. **Investment Stage:** In this stage, the lenders grant their loans to the borrowers after the recommenders give the recommendation value. The lenders are more confident after the recommenders give a value, which means they are also responsible for their loans.
4. **Withdrawal Stage:** The borrowers can withdraw their funds or loan after the lenders grant the loan. In this stage, borrowers get the amount of loan corresponding with their loan proposal and should repay the loan (installments). The borrowers can pay the installment amount as they proposed at first.
5. **Repay Stage:** The borrowers can pay the loan at this stage. They will pay appropriately with their loan. For example, if the borrower proposes three installments, the system will accommodate this request in the installment process.
6. **Redeem Stage:** In this stage, the recommenders and lenders can withdraw their funds with interest after the borrowers repay the loan. The prototype provides the formula for applying the annual percentage yield (APY) that all users agreed on.

## 5.4 Implementation

The lending platform prototype that implements the smart contracts is a client-blockchain serverless application. The entire app flow happens between the client and the blockchain, shown in Figure 5.2. This prototype's main actors are users (borrowers, recommenders, and lenders). Borrowers start with loan requests, and loan contracts are created. The recommenders could see how many borrowers propose a loan and need a recommendation. In the recommendation stage, the recommender can give a value for each borrower. The recommendation is required for borrowers who propose an equal loan as guarantors.

In the investment stage, the lenders are able to grant a loan to whom they have recommendations from recommenders. Recommenders' value helps lenders to decide on eligible borrowers. During the withdrawal stage, the borrowers can withdraw their funds when the lenders approve their loans. The borrowers start to repay/installment as defined when they propose a loan, and repayment will repeat appropriately with their proposed. After borrowers finish their installments, the recommenders and lenders can claim their investment with interest in the redeem stage.

The main smart contracts [109], [110] were developed in this prototype, including 1) Users (Borrower, Lenders, and Recommenders), 2) Loan Request, 3) Recommenders, 4) Lend ETH, 5) Claim Investment. The recommenders and lenders/investors call functions in the loan controller to lend/invest and recommend by providing the wallet address of the loan contract. These smart contracts require a communication process and are defined as a legal agreement between borrowers, recommenders, and lenders/investors, as shown in Figure 5.1.



### 5.4.1 Users Smart Contracts

In this section, the borrowers, recommenders, and lenders should have a digital wallet before accessing this prototype of the lending platform. There are many platforms for registering a digital wallet. The users can register online in a digital wallet (e.g., metamask.io).

### 5.4.2 The Loan Request Smart Contracts

In this smart contract in Figure 5.3, the system offers the borrowers who propose a loan to all members. The prototype is shown in Figure 5.6 (A). The other user can become a lender to grant this loan. The lenders can see the loan amount information, trustworthiness score, and description of the borrowers' loans. With this information, the lenders make a decision. The smart contract is shown in Figure 5.6 (B). When the borrowers propose a loan, the system will check the borrowers' addresses to ensure they are not "fraudulent" users and the borrower does not have the other loan. If the borrowers are clear, the system will give the loan address.

```
function applyForLoan(){
    if (user != address(0)) {
        // The user not fraudulent
        if(userFraudStatus == false){
            continue
        }else{return}
        if (usersActiveLoan()!=address(0)&&usersActiveLoan()==isExpiredAndNotFunded()){
            destructActiveLoan()
        }else{
            // The user must not have any loan in progress
            if(userActiveLoan()==address(0)||userActiveLoan()==LoanStateInteresReturns){
                continue
            }else{return}
        } } else{addNewUser()}
    users.startNewCycle();
    loanAddress = LoanFactory.createLoan()
    usersSetActiveLoan(loanAddress);}
```

FIGURE 5.3: Loan Request Smart Contracts

### 5.4.3 Recommender Smart Contracts

This smart contract, shown in Figure 5.4, provides the recommender users with the recommendation value, which will update the trustworthiness score. After the borrowers propose a loan, the system will move to the recommendation stage for the recommendation process, as shown in Figure 5.6 (A). The recommender gives values between 0 to 100 and puts the collateral in ETH format as recommenders wish less or equal to the borrower request loan. The weight and social recommendation score values are updated.

### 5.4.4 Lend ETH Smart Contracts

In this smart contract, with the lender and borrower's address, the system will ensure the lender is not the borrower. It also verifies that the recommendation value has been added.

```

function recommend(score, recommenderAddress) {
    if (recommenderAddress != borrower) {
        print "you can not recommend your own project"
        return
    }
    if( score > minimumRecommendValue && score <= 100)
        continue;
    else return;
    if(!recommenders(recommenderAddress)){
        print "you have already recommended"
        return
    }
    if( moneyValue >= collateral){
        extraMoney = moneyValue - collateral
        if( collateral == moneyValue - extraMoney)
            continue
        else return
        if(extraMoney <= moneyValue)
            continue
        else return
        if (extraMoney > 0) {
            // return extra money to the sender
            refundExtraMoney()
        } else {collateral = collateral - (moneyValue - extraMoney);}
        recommendedAmount = moneyValue - extraMoney;
        (weights, scores) = getRecommendationWeightAndScore()
        updateSocialRecommendation() isNew = false;
        Recommended(recommenderAddress, recommendedAmount);
        if (collateral == 0){updateInvestmentState()}}

```

FIGURE 5.4: Social Recommendation Smart Contracts

Then the lender will be able to put the money (ETH format) according to the borrower's request. The smart contract is shown in Figure 5.5. The prototype will inform the lenders who want to invest their funds in the borrowers (see Figure 5.6 (B)). The system shows the borrowers who propose a loan with the loan amount, loan description, and trustworthiness score from the recommenders stage in this smart contract.

In the recommender stage seen in Figure 5.6 (A), a borrower proposes a loan amount of 20 ETH, a description loan for a house renovation, and the trustworthiness score is 50 with 10% APY (annual percentage yield). The borrower needs the recommendation to ensure the lenders can grant the loan. On the recommender side in Figure 5.6 (A), the recommender is able to give some recommendation values and ETH collateral as they wish (less or equal to the borrower proposed), and the trustworthiness score will be updated.

On the lender side in Figure 5.6 (B), the lenders are able to lend the money after the borrower gets the recommendation and the trustworthiness score is updated. The borrower describes the loan proposed after the recommender gives a recommendation value. The trustworthiness score is raised (53), and the lender is able to grant this loan proposal. On the borrower side, they can withdraw the funds after the lender grants the loan.

### 5.4.5 Claim Investment Smart Contracts

This smart contract provides the service for recommenders and lenders to withdraw their funds. This smart contract is given in Figure 5.7. The system offers the interest with an

```

function Lend(address investorAddress){
    if(investorAddress != borrower){
        print "you can not invest in your own project"
        return}
    if(moneyValue > requestAmount){
        extraMoney = userBalance - requestAmount
        if(requestAmount == userBalance - extraMoney){
            continue
        }else return
        if(extraMoney <= moneyValue){
            continue
        }else return
        if (extraMoney > 0) {
            refundExtraMoney()
        } }
    totalInvestedAmount = totalInvestedAmount + moneyValue - extraMoney
    investedAmounts[investorAddress] = moneyValue - extraMoney;
    Invested(investorAddress,moneyValue - extraMoney);
    if (collateral == 0 && totalInvestedAmount == requestedAmount)
        state = ableToWithdraw();}

```

FIGURE 5.5: Lend ETH Smart Contracts

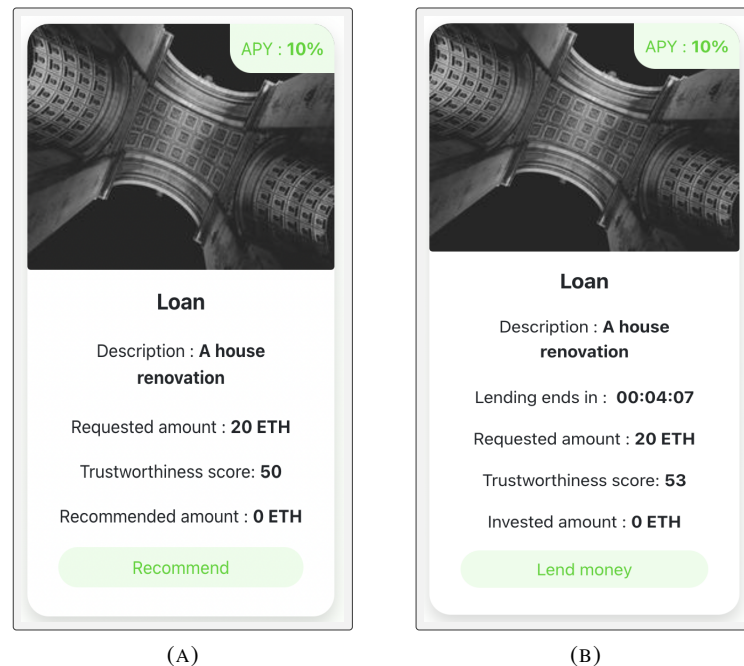


FIGURE 5.6: Recommendation Stage (A) and Lending Stage (B)

annual percentage yield (APY) calculation, which is able to be customized by users. The system will check that no “fraud” has occurred. Then it will calculate the return on investment with interest. The recommenders and the lenders get the return on investment with interest. The interest value gets from the APY formula. If the system finishes the interest calculation, the lenders and recommenders are able to claim this loan project on their pages.

```
function claimWithInterest() {
  checkFraud();
  if(lender == True){
    // Calculate the interest amount to return to the lender
    // multiply the amount by the interest rate
    returnInterestAmount += (((10**interest*(100-recommendersInterestRate)*1e18)
    /10000)*investedAmounts)+investedAmounts}
  if (recomender == True) {
    // Calculate the interest amount to return to the recommender
    if(state != State.fraud){
      recommendedAmount = recommendedAmounts[senderAmount]
    }else{
      recommendedAmount = ((10**((totalRecommendedAmount-repaidAmount))
      /totalRecommendedAmount)*recommendedAmounts);
    }
    // multiply the amount by the interest rate
    returnInterestAmount += ((10**interest*recommendersInterestRate*1e18/10000)
    *recommendedAmount)+recommendedAmount}
  if (returnInterestAmount > contractBalance)
    returnInterestAmount = contractBalance;
  if(contractBalance >= returnInterestAmount){
    continue
  }else{return}
  // Transfer the return amount with interest to the lender.
  payable(Tosender).transfer(returnInterestAmount);
  // Log the transfer to lender.
  createLenderLog();
  // Check if the contract balance is drawned.
  if(contractBalance == 0){
    destruct() } }
```

FIGURE 5.7: Claim Investment Smart Contracts

## 5.5 Discussion

In this section, smart contracts were implemented on a personal lending platform in the context of financial services. This research examines stakeholders (such as borrowers, recommenders, and lenders/investors) integrated into this lending platform. In addition, smart contracts add a trustworthiness score to the borrowers, which convinces lenders to lend.

The main things we found in our experience with smart contracts are summarized as follows. First, smart contracts have been successfully implemented on this lending platform. The trustworthiness score is helpful for lenders to provide loans to borrowers, considering the values submitted by the recommenders. Second, supported by smart contracts, our lending platform has good security, referring to the advantages of blockchain technology, such as immutability and decentralization. Third, even though a risk gap will arise, a personal lending platform based on smart contracts can help borrowers get loans without collateral.

The lenders have more confidence after getting the trustworthiness scores. Smart contracts pay attention to borrower trustworthiness on a personal lending platform so lenders can consider the potential risks incurred. The benefits to all users are aware of the risk and the borrower's trustworthiness. The value of trust among borrowers, recommenders, and lenders has a strong influence on a personal lending platform.

## 5.6 Conclusions

In this chapter, we present the second contribution. This prototype is one of the lending platforms suitable for applying smart contracts as a business logic for financial services. The blockchain advantages that are obtained include decentralization, immutability, and security. These smart contracts also propose to minimize the collateral by introducing the recommendation value to support borrowers and lenders. The prototype is expected to be implemented in social networks and small business groups that can be scalable to many members.

## Chapter 6

# TrustLend: Using Borrower Trustworthiness for Lending on Ethereum

The personal lending marketplace, known as Peer-to-Peer (P2P) lending, has increased globally. However, providing unsecured loans to peers without requiring collateral. We built a platform called TrustLend, to enable trustworthy businesses in personal lending transactions. The platform is based on the Ethereum blockchain to eliminate or minimize the collateral requirement. The trustworthiness score adds to this platform's variable selection rules and can help lenders decide on reliable candidates as borrowers. We also describe the prototype implementing the TrustLend platform based on Ethereum smart contracts that use the trustworthiness score and illustrate it with a Decentralized Application (DApp) case study and customized smart contracts. The prototype demonstrates fundamental features and supports borrowers, lenders, and recommenders in establishing proposals and approvals. Finally, the prototype shows how end-users can easily access loans with reduced collaterals without hidden costs and swift transactions.

This chapter is based on a published conference paper. The complete reference of the paper is as follows: TrustLend: Using Borrower Trustworthiness for Lending on Ethereum. Uriawan, W.; Badr, Y.; Hasan, O. and Brunie, L. (2022). In *Proceedings of the 19th International Conference on Security and Cryptography - SECRYPT*. Lisbon - Portugal. pages 519-524. DOI: 10.5220/0011151900003283 [111]

Additionally, a substantially extended version of the above conference paper has been submitted to the IET Blockchain journal. The first round of reviews was received, the paper was significantly revised, and then resubmitted for the second review. Reference: Decentralized Trustworthiness Score Management with Smart Contracts on the TrustLend Platform. Wisnu Uriawan, Youakim Badr, Omar Hasan, Lionel Brunie. In IET Blockchain journal <https://ietresearch.onlinelibrary.wiley.com/journal/26341573> [111].

## 6.1 Introduction

In general, minor and micro-businesses and individual debtors find it difficult to get loans from banks without access to loan guarantors and collateral [4], [16]. In P2P lending, borrowers directly interact with peer lenders, making financing more accessible so that they can get financing more efficiently [112]–[114], which means a higher credit risk for lenders.

Credit risk is the possible loss a bank or other lender suffers after offering a loan to a borrower. They include the actual risk of the borrower defaulting on the loan on time and the potential risk of default due to a decrease in credit score [112]–[115] or a reduction in the borrowers' ability to repay, and the lending platform is getting profitable [116]–[118].

P2P lending continues to increase worldwide every year. For example, in 2013, it reached 3.5 billion U.S. dollars. In the United States, 26 percent of people have used P2P payments for everyday purposes [17]. In 2018, the value of mobile P2P payments reached 86 billion U.S. dollars and will continue to increase until now [17]. P2P lending is a new trend in the “sharing economy”. An exponential increase is estimated to reach one trillion U.S. dollars in 2050 [16], [17]. However, a P2P lending platform can also create risks for lenders when the borrower cannot make payments according to the agreement. Trustworthiness [16], [52], [91], [119] is a critical component in deciding for lenders whether borrowers are accepted or rejected to get some loans. However, in the end, it burdens borrowers in terms of interest and administrative costs. The bank or financial institutions have taken many borrower assets due to not fulfilling payments or experiencing delays in payments.

Blockchain technology is emerging and successfully applied in many business applications, such as banking and other financial institutions [29], [120], [121]. Blockchain technology encourages our motivation to study the potential of the Ethereum blockchain [11], [122], [123]. Recently, Blockchain technology has been applied to P2P and crowdfunding lending systems [124]–[126]. The benefit of this new technology has led to explosive growth in the blockchain-based application, which exists within a highly secure system. Distributed ledger technology allows transaction and problem settlement without third-party risk [127], [128].

The access to credit provided by the personal lending platform is intended to let the world of blockchains grow beyond the economic limitations of simply traditional money transactions. Loans [2] are not only an important economic factor but also a vital component of personal financial freedom and give individuals greater purchasing power. Like those accessible through the personal lending platform, products offer a revolution in personal finance by granting [129] control over the medium of exchange to lenders of blockchain-based applications who wish to help the people grow assets rather than spend them [130].

This chapter introduces TrustLend as a personal lending platform and presents its fully functional prototype design and implementation details. The prototype shows the features required by borrowers, recommenders, and lenders to enable trustworthiness by implementing trustworthiness scores with Ethereum smart contracts. We describe the prototype architecture and conduct data tests and personal loan simulations.

## 6.2 Related Work

This section evaluates the lending platforms, and in particular, we observe their advantages and disadvantages. The parameters of lending platform services include registration, interest rate, lending or borrowing provided, using own token, and collateral required. These parameters correspond with several existing lending platform features, is shown in Table 6.1.

### 6.2.1 Everex

Everex is a financial technology that creates decentralized, global credit histories and scorings for individuals and SMEs. The Everex supports transfers, borrowing/lending, and trading in any fiat currency from anywhere in the world. Everex uses Crypto cash Ethereum ERC20 tokens, as well as fiat currencies. The Everex is implemented on the Ethereum blockchain and uses Solidity as a smart contract language. Similar to the traditional lending system, the Everex environment still involves fiat money and requires collateral [11]. In contrast to Everex, the TrustLend platform proposed in this work does not involve fiat currencies and does not require collateral.

### 6.2.2 ETHLend

ETHLend is an Ethereum-based decentralized lending platform connecting borrowers and lenders. It allows anyone to lend or borrow with an Ethereum address. ETHLend is decentralized lending on the Ethereum network using ERC-20 compatible tokens or Ethereum Name Service (ENS) domains as collateral. ETHLend reduces the loss of loan capital on default. Some features allow the marketplace to manage, such as interest rate and collateral value. However, the pseudo-anonymous nature of the Ethereum blockchain network opens the possibility of avoiding repayment of the loan since the lender might not have all the necessary details of the borrower to enforce the debt in the borrower's jurisdiction [59].

The TrustLend applies the trustworthiness score to help the lenders/investors to identify the eligible borrowers to minimize the loss. We have an interest rate formula with Annual Percentage Yield (APY) as the standard interest rate that is possible to apply in a blockchain lending platform considering the effect of compounding interest and does not require collateral.

### 6.2.3 WeTrust

WeTrust is an Ethereum blockchain that provides mutual aid on equal footing to borrowers with existing social capital and trust networks. Trusted Lending Circles are proposed to create a Rotating Savings and Credit Association (ROSCA) powered by smart contracts. It eliminates the need for a trusted third party, which cuts fees, improves incentive structures, and decentralizes risks. It will eventually incorporate mutual insurance, voting within reciprocal aid organizations, and P2P lending. However, WeTrust may not be suitable for personal users because it still requires collateral [60]. Our TrustLend platform offers to focus on the P2P lending platform to help people get loans without collateral.

TABLE 6.1: Ethereum Lending platforms Evaluation [58]

Lending Platform	Registration Required	Interest Rate for Loans (Min.)	Lend or Borrow	Own Token	Required Collateral
Everex	Yes	Market	Both	Yes	Yes
ETHLend	Yes	Market	Both	Yes	Yes
WeTrust	Yes	Market	Both	Yes	Yes
TrustLend	No	APY	Both	Yes	No



In summary, we have an opportunity to propose the TrustLend platform with the advantages such as no collateral required, using social recommendations, and cultivating borrowers' trustworthiness scores.

## 6.3 Our Proposal

This section describes the prototype architecture, trustworthiness formula, and TrustLend Prototype development principles.

### 6.3.1 TrustLend Architecture

The architecture shows a DApp platform [131] for Ethereum blockchain-based personal lending to assist borrowers, recommenders, and lenders/investors in the lending process. This architecture minimizes or eliminates the collateral need by assessing the borrower's trustworthiness. The users who interact with the system as borrowers, recommenders, and lenders/investors are shown in Figure 6.1. Smart contracts provide the functionality of the trustworthiness scores, recommendations, and MetaMask wallet. The borrowers', recommenders', and lenders'/investors' transactions will be stored on the Ethereum blockchain.

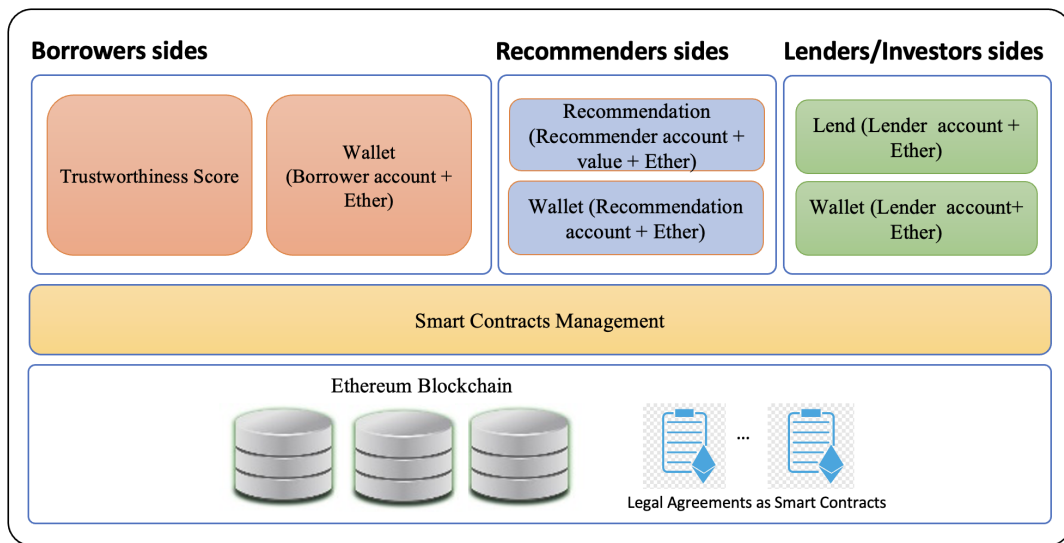


FIGURE 6.1: TrustLend Architecture Design.

### 6.3.2 Trustworthiness Score

The trustworthiness score formula [16] estimation is based on the user behavior attributes of risky attitude, trustworthiness, time preference, and impulsiveness [52]. It can be used to determine the correlation of the behavior as reflected in the credit score. The standards of impatience, trustworthiness, and impulsivity affected credit scores [91]. We adopt the trustworthiness score formula in terms of the reliable borrowers in one online prototype, as

follows Equation 6.1 and Equation 6.2:

$$\begin{aligned} \text{Trustworthiness}_{score} = & \text{Profile}_{score} + \text{Activity}_{score} \\ & + \text{SocialRecommendation}_{score} \\ & + \text{LoanRisk}_{score} \end{aligned} \quad (6.1)$$

And we added positive weight for each variable, as follows:

$$\begin{aligned} \text{Trustworthiness}_{score} = & W_p * \text{Profile}_{score} + W_a * \text{Activity}_{score} \\ & + W_r * \text{SocialRecommendation}_{score} \\ & + W_l * \text{LoanRisk}_{score} \end{aligned} \quad (6.2)$$

Where:

*Trustworthiness\_score*: Borrower credit score.

*Profile\_score*: Personal information of Borrower.

*Activity\_score*: Business activity or job information of Borrower.

*SocialRecommendation\_score*: The recommendation value of Borrowers from Recommender.

*LoanRisk\_score*: Information of the record from another loan of Borrower.

With  $\{W \text{ in } \mathbb{R} \mid W \leq 1\}$ , and  $W_p, W_a, W_r$ , and  $W_l$  are positive weights of the trustworthiness parameters such that  $W_p + W_a + W_r + W_l = 1$ . The weights of the trustworthiness attributes are predetermined based on their priority value that can modify by consensus. For example,  $W_p = 0.25$ ,  $W_a = 0.2$ ,  $W_r = 0.3$ ,  $W_l = 0.25$ . In this example, the social recommendation is given the highest value. In contrast, activity is given the lowest value, which shows that the social recommendation is the priority to measure the good borrower candidate.

The trustworthiness score we propose is a value of borrowers set by the smart contract so that both parties understand each other's obligations and risks that will be accepted. The variables include profile, activity, social recommendation, and loan risk, as shown in Equation 6.1. The borrowers propose some loans with their trustworthiness score, determining whether the lenders/investors are able to grant the loan. The trustworthiness score value will increase, and the borrower can get a more significant opportunity in the next submission.

The system will reduce the trustworthiness score if the borrower receives a bad report from lenders/investors or recommenders. The borrower will get a high trustworthiness score, making it easier to get the loan in the next cycle. The smart contracts management handles the borrowers, recommenders, and lenders/investors from the available services on the Ethereum blockchain.

### 6.3.3 TrustLend Prototype Development Principles

We adopt prototype principles: standards coding and conventions, automated unit testing, and static analysis tools. Some regulations relate to our prototype, as follows [16], [132]:

1. **Layering strategy**, a layered architecture usually results in a software system with a high degree of flexibility because each layer is isolated from those around it. The prototype applies a layers strategy to make every design flexible for all users (borrowers, recommenders, and lenders/investors).
2. **Placement of business logic**, our prototype ensures that business logic permanently resides in a single place for reasons related to performance or maintainability among stakeholders (borrowers, recommenders, and lenders/investors).
3. **High cohesion and low coupling**, our prototype focuses on building small, highly cohesive blocks that do not require too many dependencies to do their job part-by-part development related to our architecture design of the prototype.
4. **Use of the HTTP session**, the HTTP session for storing temporary information between requests. The prototype can often depend on many things, including scaling strategy, where session-backed objects are stored, what happens in the event of a server failure, whether using sticky sessions, and the overhead of session replication.
5. **Always consistent versus Eventually consistent**, prototypes have discovered that it often needs to make trade-offs data to meet complex non-functional requirements, such as updating information is required as fast as possible (e.g., 24/7 services). In this context, consistency is appropriate, but a consistent approach is fundamental.

## 6.4 Implementation

The trustworthiness personal lending platform prototype is a client-blockchain serverless application where the entire flow of the app happens between the client and the blockchain. The client code can be hosted anywhere, and AWS (Amazon Web Services) with S3 (Simple Storage Service) features, Google Cloud, Github Pages, Netlify, other cloud providers, or your server. Our prototype is able to query the blockchain, and we use a web3 provider MetaMask. A browser extension (available for Chrome and Firefox) handles the actual web3 connection to a node shown in Figure 6.2.

For instance, all the business logic, loans, and user history are handled and stored in the blockchain, which is decentralized. But since the Ethereum blockchain platform (or any other EVM (Ethereum Virtual Machines) [133] blockchain-based like Polygon). Charges fees for each written transaction. It is ubiquitous to store the data not used in smart contracts calculations elsewhere to pay fewer fees. We have chosen the IPFS (Interplanetary File System) [134] to store the loan description, images, and necessary data supported. Once the data is stored in the IPFS, the content identifier (CID) is returned and stored in the loan smart contracts to find this data later. We are ready to use NFT (Non-Fungible Token) [76] storage (Free, decentralized storage and bandwidth for NFTs) to store the project's Info in IPFS.

### 6.4.1 Smart Contracts

The main smart contract that the client interacts with is the loan controller. It creates loans and handles investments, recommendations, repayments, etc. From the moment the user applies

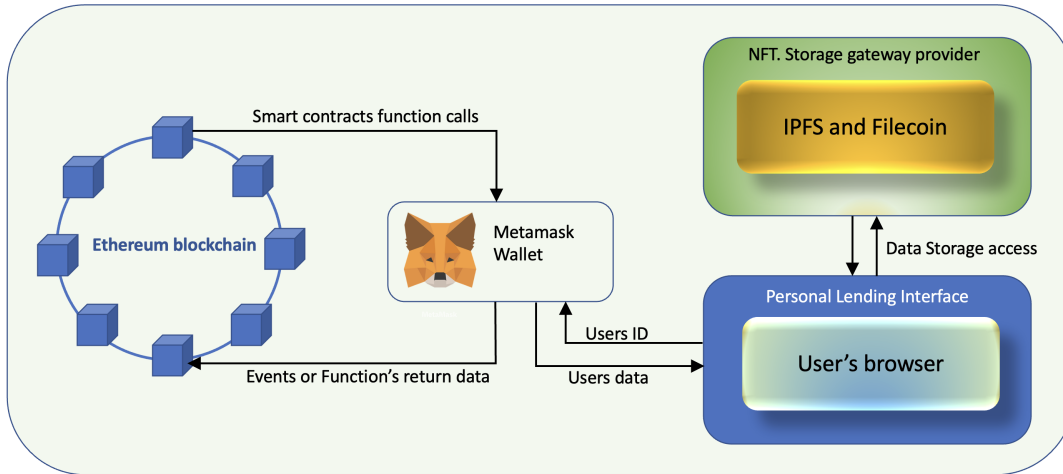


FIGURE 6.2: Prototype of a Trustworthy Personal Lending Platform.

for a loan, the ApplyforLoan function in the LoanController is called and creates a unique loan contract related to the loan in question. The smart contracts necessary for information about the loan:

1. Borrower (represented by User contract instance)
2. Requested amount
3. Repayment's count
4. Interest
5. Loan creation date
6. Last repayment date
7. Return the amount
8. Lenders/Investors(array)
9. Recommenders(array)
10. Tscorecontroller contract (to handle user's trustworthiness score).

The recommenders and lenders/investors can call functions in the LoanController to lend/invest and recommend by providing the address of the LoanContract. These smart contracts require a communication process and are defined as a legal agreement between borrowers, recommenders, and lenders/investors is shown in Figure 6.3.

#### 6.4.2 Implementation of the Trustworthiness Score Formula

The implementation of the trustworthiness score formula is shown in Figure 6.4. The authors used the Bank Marketing subset from UCI public dataset [96]. The borrowers get the value of the loan risk, activity, and profile score by converting the value of the dataset. The social recommendation score will get from the other user as recommenders. The prototype will

```

Tscore Smart Contracts (SocialRecommendations)
pragma solidity ^0.8.0;

import "../TScoreControllerInterface.sol";
import "../User.sol";
import "../Loan.sol";

contract TScoreController is TScoreControllerInterface,
ExponentialNoError {

    constructor() {
        admin = msg.sender;
    }

    function updateSocialRecommendationScore(address _loanAddr,
address _userAddr, uint _recommenderWeight, uint _givenScore)
external override returns (uint) {
        User user = User(_userAddr);
        Loan loan = Loan(_loanAddr);
        Exp memory weightedScore = Exp({mantissa: 0});
        Exp[] memory weights;
        uint8[] memory scores;

        (weights, scores) = loan.getRecommendersWeightsAndValues();
        for (uint i = 0; i < weights.length; i++) {
            weightedScore = add_(mul_(weights[i],
scores[i]), weightedScore);
        }

        user.setSocialRecommendationScore(weightedScore);
        return user.getTScore();
    }

    function updateActivityScore(address _loanAddr, address
_userAddr, uint _recommenderWeight, uint _givenScore) external
override returns (uint) {
        User user = User(_userAddr);
        return user.getTScore();
    }

    function updateProfileScore(address _loanAddr, address
_userAddr, uint _recommenderWeight, uint _givenScore) external
override returns (uint) {
        User user = User(_userAddr);
        return user.getTScore();
    }

    function updateLoanRiskScore(address _loanAddr, address
_userAddr, uint _recommenderWeight, uint _givenScore) external
override returns (uint) {
        User user = User(_userAddr);
        return user.getTScore();
    }

    function updateTScore(address _loanAddr, address _userAddr, uint
_recommenderWeight, uint _givenScore) external override returns
(uint) {
        User user = User(_userAddr);
        return user.getTScore();
    }

    function getTScore(address _userAddr) external view override
returns (uint) {
        User user = User(_userAddr);
        return user.getTScore();
    }
}

```

FIGURE 6.3: Smart Contracts Trustworthiness score.

count each variable to become a trustworthiness score (Tscore), which is used as the final decision from lenders/investors to grant the loan.

Platform users									
Profile ID	Borrower contract address	Borrower wallet address	Total TScore	Activity score	Profile score	Social recommendation score	Loan risk score	# cycles	
0	0x47b36E824631e97E94d462f822181Ed08A459384	0x8626f6940E2eb28930eFb4CeF49B2d1F2C9C1199	71	65	60	61	100	1	
1	0x46BCe031ea52F0A6B2096cc3abFA0CA0AF06C7	0x70997970C51812dc3A010C7d01b50e0d17dc79C8	75	78	80	66	79	1	
2	0x387d05D71155439750751FC78578416660f455	0x06f509F73eefBA36352Bc8228F912C3786100dA	54	56	58	50	57	1	
3	0x8146f37Ec07D3f52A3D93720793D48E5456C2468	0x35CbD98014D4C3825d8486993b9944c7Be56f763	70	78	80	50	79	1	
4	0x7625092439918977e973653CAFA7275CC3BF25b	0x4cFF48a294272A0449d9163E92E6c93ba0C090B5	54	56	58	50	57	1	
5	0x142AB05a3FD31663ea627DB1698639D27061010C	0xe37A5C872eC6987E0E899E0FE8C74dAc99f121	68	65	60	50	100	1	
6	0x448909a30544E601E44F51bA728e7C5108627C55	0x0eC5F4cD22a4EEF3dC63a31c5b6A2418D429193	70	78	80	50	79	1	
7	0x8744b336FC44395DA72850AD96220CF6Ea34962	0x64047426729dceF24d6bD58329bba0BA958a3b0	54	56	58	50	57	1	
8	0xbE1141cD55A685C772E3Ec3CB83e3afbE9b018F	0x1Df10644987013a9536f17092D6Ea647f98f2e2B	68	65	60	50	100	1	
9	0x6858aBC1D6AFc13F9B78b0d83235F622EF4eC7d	0x343B14Ebb982be358cE495eCC7a018247794A945	70	78	80	50	79	1	
10	0x0f280b619020A451C06419c6f0F90E15Fc7f6	0x71d13E61AC7dC6773EB1A17b7f03aB13C38664EE	68	65	60	50	100	1	
11	0x6FebE66a2Ca2cd21199d201e5a843eF635C40fB	0x2Dde3b23908D51027806A99f9ac77079EEB5032	70	78	80	50	79	1	
12	0xd00c64B12C2d4D97CE89457f19F4A092a859	0x67E28cc4C005027f5e2E1F034B228f47C7e5c01F	54	56	58	50	57	1	
13	0x23F2a9441B0eb4c3e1999C377774bCe38fC7008	0xEb9d54Ba366750e0Eb161262a8284c9412CF956b	68	65	60	50	100	1	
14	0xC695D11C702B7D7f1f1Caa030A56bF212eE97B	0x7ADd4eFF69bBcB4666949742eC19428e9d4742A	70	78	80	50	79	1	
15	0x231673f829CB8A09F1050920d5317C954dD53	0xa9B2c325C56d048A1EB5804f89410903D2cDfd8	54	56	58	50	57	1	
16	0xBe928d8E377719681813f5bC34fc6930d0f0aE57	0x13f3fD8A4d1bAdD65D1a241b9b8c86Bf7575a03	50	50	50	50	50	1	

FIGURE 6.4: Implementation of the Trustworthiness Score Formula .

The borrowers' trustworthiness score present is a commitment between borrowers, recommenders, and lenders/investors managed by the smart contract. The objective is for all parties to understand the obligations and its risk. All variables data (loan risk, activity, profile, and social recommendation score) will be assessed as the borrowers' trustworthiness score. After the borrowers get the score, they can propose a loan and get the loan corresponding to their score. The borrowers' trustworthiness scores will increase alongside the record of the borrowers' installment payments.

### 6.4.3 The ERC-20 Token Standard

The Ethereum Request-for-Comments #20 is called ERC-20 standard token, possibly allowing for fungible tokens on the Ethereum blockchain. The standard provides functions that include the exchange of tokens among accounts, such as getting the current token balance of an account and the total supply of the token available on the network.

ERC-20 Token Contracts are the smart contracts correctly implemented and keep the records of created tokens on Ethereum. Ethereum introduced a complete programming language to write and execute smart contracts in decentralized applications on the Ethereum Virtual Machine (EVM) and Ethereum blockchain. Smart contracts are autonomous, immutable, conducted in the EVM manner, and stored in the Ethereum blockchain. The smart contracts are able to hold ETH in ERC-20 tokens [135], [136].

On the other hand, the standards application level for creating tokens, naming, and library register. The ERC-20 tokens became the first standard of crowdfunding, and its applications for Ethereum blockchain-based decentralized applications are able to reduce the complexity. The ERC-20 token standard is applied in our prototype and is able to implement in localhost with ERC20 token based and the testnet KOVANETH running on Optimism Testnet Network [135], [136].

#### 6.4.4 Vulnerability and Countermeasures

The Ethereum blockchain has typical vulnerabilities, including scalability, forking, and security. There are several security vulnerabilities in Ethereum blockchain-based smart contracts, which sometimes do not behave as intended when the users change the network. Limitations of the smart contracts file size impact the DApp performance as well.

Loan default is one of the issues that may be faced by the TrustLend platform, as with any other lending platform. TrustLend implements some conditions for all users (borrowers, recommenders, and lenders/investors) in order to prevent losses for the lenders/investors. To minimize the loss, each borrower may be required to obtain a certain minimum number of social recommendations. The defaulting borrowers' accounts may also be banned after some missed installments.

Another issue is that the borrower and the recommender could be the same individual with different accounts. However, to ensure that identical users cannot cheat on the platform, TrustLend will identify the users (borrowers, recommenders, and lenders/investors) with their MetaMask wallet addresses. This will ensure no similar address accesses with different roles for the same loan. For example, the borrower cannot become the recommender or lender/investor when the borrowers propose a loan, and both are as well. However, we note that this countermeasure is not foolproof at all, and a sophisticated attacker may bypass detection. We hope to strengthen the countermeasures of TrustLend in future work in order to improve security against this attack.

#### 6.4.5 Lending Transaction Process

The app's client is built on React framework, an open-source javascript library. The app the critical main pages:

##### The Main page

The main page describes the main menu of the prototype. It is provided for borrowers, recommenders, and lenders/investors. Users can access the specific menu after being connected to the MetaMask wallet. The prototype combines trustworthiness and consensus in a legal agreement between borrowers, recommenders, and lenders/investors.

Therefore, representing the blockchain's data, processes, and transactions is required. Users can obtain permission only through the prototype and integrating components, such as security, speed, immutability, scalability, and resilience, including ledgers that can be changed through only the consensus. MetaMask wallet is required by prototype, and users are able to install individually with terms and conditions, is shown in Figure 6.5.

The prototyping functionality is offered to three users: Borrowers, Recommenders, and Lenders/Investors. The borrower can access the menu on the borrower page. Before accessing the prototype, they (Borrowers, Recommenders, and Lenders/Investors) should have the MetaMask wallet. The borrower login first to their wallet. After the loan application has been received, the borrower user is able to withdraw the loan and make installment payments according to the agreements.

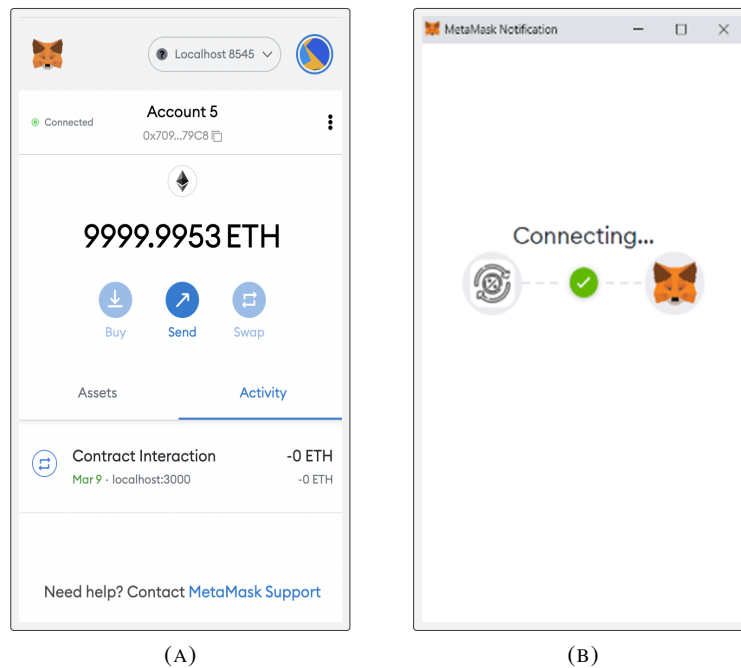


FIGURE 6.5: Trustlend MetaMask Wallet (A) and MetaMask connecting process (B)

The lenders/investors user are able to access their menu and invest with a selection of borrowers who propose the loan. In these cases, the lenders/investors users determine the allocation of funds desired. The recommenders' users can access the prototype menu to give a recommendation score to the borrowers and the ETH values. The lenders/investors can use the trustworthiness score to decide and grant the loan. Users manage the private key to receive the payments per transaction from their wallets. For other transaction payments, unsigned transactions are sent from the wallet to the prototype, verified by the users (borrowers, recommenders, and lenders/investors) on the personal wallet screen, confirmed via MetaMask as a third-party, then signed by the user ID, and sent back to the users' wallet.

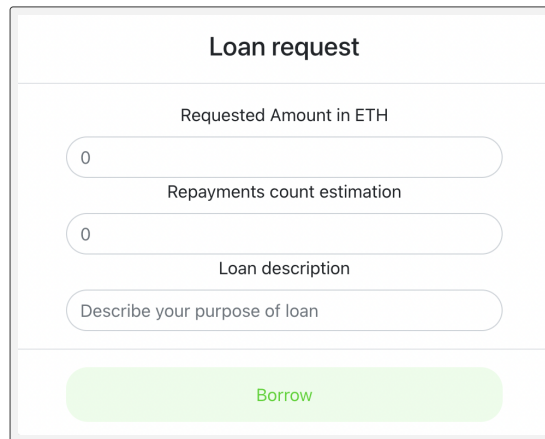
### Borrower page

The borrowers shown in Figure 6.6 can access the prototype; the system provides how the borrowers propose some loans and terms and conditions. Some borrowers' users give some loan information as new borrowers, and signals are sent to all lenders. The borrower page is provided to borrowers when trying to apply for some loans, with the proposed loan amount, installment period, and loan description being the purpose of the loan.

### Recommender page

The recommender can access the lending platform with their wallet. The prototype will provide the borrower who needs recommendations, then the recommender gives some ETH, and the score/value is shown in Figure 6.7. The prototype provides the recommendation page for making sure the lenders/investors are able to grant the borrower's loan proposal. On the





**Loan request**

Requested Amount in ETH

0

Repayments count estimation

0

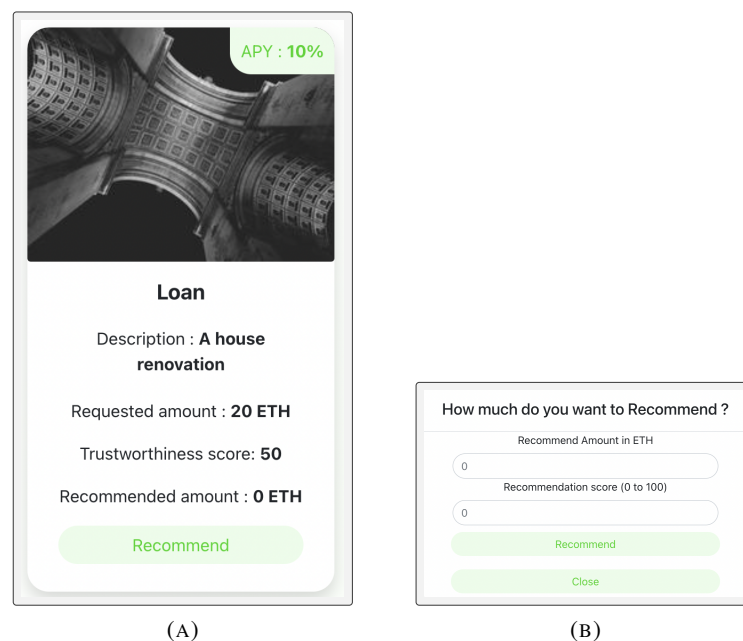
Loan description

Describe your purpose of loan

**Borrow**

FIGURE 6.6: Borrower loan request.

other hand, the recommender can recommend to all the borrowers who request the loan, and then they can make a profit after borrowers finish their installments.



**(A)**

**Loan**

APY : 10%

Description : **A house renovation**

Requested amount : **20 ETH**

Trustworthiness score: **50**

Recommended amount : **0 ETH**

**Recommend**

**(B)**

**How much do you want to Recommend ?**

Recommend Amount in ETH

0

Recommendation score (0 to 100)

0

**Recommend**

**Close**

FIGURE 6.7: The Social Recommendation information request (A) and the Social Recommendation input value (B)

### Lender page

The lender/investor page is provided for lenders/investors to search the eligible borrowers. This page includes information on borrowers, loan amount, and interest in Annual Percentage Yield (APY). It is possible to customizable before the deployment process. The prototype presents the borrowers who proposed a loan. The lenders/investors get an opportunity to choose the eligible borrowers to grant the loans based on the trustworthiness score. The lenders/investors will take a risk if the borrower defaults, as shown in Figure 6.8.

The smart contracts as a legal agreement (Borrowers, Recommenders, and Lenders/Investors sides) are the core of the lending prototype we are proposing. The excellent trustworthiness score of borrowers is a significant factor in this prototype, reducing guarantee dependence replaced by social recommendation, and other variables are supported. Many lending platforms and banks still require a guarantee, which is burdensome to the borrowers because not every borrower is able to provide it.

Figure 6.8 consists of two mobile app interface mockups. Mockup (A) is a 'Loan' request screen. It features a header image of a classical building interior with a green 'APY : 10%' badge in the top right. Below the image, the text reads: 'Loan', 'Description : A house renovation', 'Lending ends in : 00:04:07', 'Requested amount : 20 ETH', 'Trustworthiness score: 53', and 'Invested amount : 0 ETH'. At the bottom is a green button labeled 'Lend money'. Mockup (B) is a 'How much do you want to lend ?' screen. It has a title bar and a subtitle 'Lending Amount in ETH'. Below this is a numeric input field with '0' entered. At the bottom are two green buttons: 'Lend' and 'Close'.

FIGURE 6.8: The Borrower information request (A) and Lender/Investor page input value (B)

### Summary of the Loan Request

The borrower's loan information is described in detail loans proposed for each borrower, including the amount requested, the number of lenders/investors' information, the number of recommenders, trustworthiness score (TScore), activity score, profile score, social recommendations score, and loan risk score.

The prototype informs the amount to return with interest is set by the system with the Annual Percentage Yield (APY) formula, and information about the installments corresponds with the repayment count proposed. The last information of these outputs is the loan status. The current status of the loan is in a "recommendation phase", which means the process in the recommendation phase. After the recommendation phase, the system sent a signal to lenders/investors to make a decision and will change the loan status to "withdrawal" when the lenders/investors grant the loan, then the borrowers are able to withdraw their loans. It seems reasonable to expect a high credit score associated with the payments process if there is evidence of patience with current and future suitable consumptive activity with borrowing is shown in Figure 6.9.

**Your loan request**

**Requested amount : 20 ETH**

Your crowdfunding process end in : **00:09:49**

Investors number : 0

Recommenders number : 0

**Your TScore : 50**

Your activity score : 50

Your profile score : 50

Your social recommendation score : 50

Your loan risk score : 50

**Amount to return : 22.00 ETH**

Installment : 11.00 ETH

Interest : 10 %

Repayment Count : 2 times

**Loan status : recommendation**

**Withdraw**

**Repay**

FIGURE 6.9: TrustLend Borrower Request a Loan.

## 6.5 Discussion

The objectives of this prototype are to avoid impulsive borrowers who have difficulty resisting the temptation to borrow and increase debt for consumptive needs.

Lenders/Investors are able to monitor the borrower and manage their lend/investment by choosing eligible borrowers to minimize their losses. Each lender/investor can choose by determining borrowers who can pay off and get the highest trustworthiness score. The trustworthiness score formula is well defined (such as weight percentage, variables, etc.) before deployment to avoid mistakes.

### 6.5.1 Advantages

Blockchain technology has advantages with immutability, integrity, security, equal rights for all network members to get information, protect users' data from unauthorized access, and encryption. No personal information of borrowers, recommenders, and lenders/investors is shown in this prototype. We provide a prototype with an autonomous transactions process supported by smart contract functions after the deployment phase. Smart contracts pay attention to borrower trustworthiness scores on a personal lending platform, so lenders can consider the potential risks incurred.

The prototype is based on trustworthy personal lending that can provide a loan for borrowers who need it without collateral. The value of trust among borrowers, recommenders,

and lenders/investors has a strong influence on a personal lending platform. The social recommendation as a guarantor convinces the lenders/investors and minimizes the difficulty of granting the borrowers' loans. This prototype is one of the personal lending platforms suitable for P2P lending applications that apply blockchain advantages.

### **Incentives for borrowers, recommenders, and lenders**

The stakeholders (borrowers, recommenders, and lenders/investors) have the following incentives on the TrustLend platform:

- **Borrowers:** The borrowers do not have to provide collateral, which is a significant incentive for them. Most lending platforms mentioned in Section 6.2 still require collateral. However, the borrowers have been held accountable because that need to get good recommendations from social recommenders (the replacement for guarantors) and maintain a trustworthiness score. TrustLend keeps a record of the borrowers' trustworthiness score. The borrowers' have to show strong commitment and willingness to pay back the loan on time to maintain a good record.
- **Social Recommendations:** The recommenders are expected to give honest and frank recommendations about the borrowers because the recommendation scores will impact the trustworthiness score. The recommenders who correct recommendations will be incentivized as valuable recommenders and may gain benefits towards an increased trustworthiness score for the purpose of obtaining loans. Moreover, recommenders may also provide recommendations altruistically for the benefit of their fellow borrowers and lenders without expecting any incentives. TrustLend maintains the records of correct recommendations. When the borrowers pay the loans, the corresponding recommenders will get an incentive from interest profit sharing with the lenders/investors.
- **Lenders/Investors:** The lenders/investors grant the loan and choose the eligible borrowers themselves. Therefore, they know the risk of lending to a particular borrower, and TrustLend provides the trustworthiness score to help them choose the borrower and decide to lend to them. To the best of our knowledge, none of the lending platforms guaranteed the borrowers to pay back their loans, and this is the case in traditional lending systems as well. However, TrustLend maintains the borrowers' trustworthiness score in order for the lender to vet and identify good borrowers. They can also use the history of lending activity to make lenders/investors more confident.

After the borrowers finish installments payments, the lenders/investors get the profit from the interest managed by TrustLend. TrustLend offers lenders/investors to invest their cryptocurrency as an alternative for investment and challenges by sharing profit interest rates using Annual Percentage Yield (APY), which is more progressive and competitive than the conventional approach. Since TrustLend makes loans easier due to the lack of collateral, we expect that the platform will attract a more significant

number of borrowers, providing the lender with a broader group of borrowers to choose from.

### **6.5.2 Disadvantages**

The disadvantage is that performing off-prototype transactions will increase transaction time because of the need for recommendations and lender/investor approval. An increasing number of users can cause problems with scalability and processing times. The most straightforward approach is to increase the bandwidth capacity for borrowers, recommenders, and lenders/investors. Therefore, the developer ensures all the smart contract functions are running well because it is not possible to change after deployment. In particular, all users know the risks and the borrower's trustworthiness.

## **6.6 Conclusions**

In this chapter, we present the third contribution. The architecture design of the prototype of trustworthy blockchain-based personal lending can be concluded that the Ethereum blockchain can be used to create a personal loan to identify the potential of borrowers who are attractive to invest for lenders/investors. Also, we added a social recommendation to support the trustworthiness score component to convince the lenders/investors to grant the borrowers' loans.

This prototype is one of the lending platforms suitable for personal lending applications that apply the Ethereum blockchain advantages dimensions, such as anonymous, decentralized, immutability, and secure. This prototype proposes to minimize the difficulty by introducing smart contracts as a backbone application to support borrowers, recommenders, and lenders/investors. The prototype is expected to be implemented privately, in social network groups, and in small business environments that can be scalable to many members. They have advantages and disadvantages and are able to present in the future.

## **Part III**

# **Discussion, Conclusion, and Future Work**



# Chapter 7

## Discussion

In this chapter, we proposed the main discussion in our research on trustworthiness for personal lending on the blockchain, including lending platform comparatives, regulation and governance of lending platform, lending platform scalability scenario, key affecting factors on scalability for the lending platform, and users' satisfaction of lending platform. In the previous chapter, we presented the trustworthiness score in the lending process, including borrowers, recommenders, and lenders/investors. In addition, implemented the LAPS formula integrated into the TrustLend lending platform prototype to minimize collateral.

### 7.1 Lending Platforms Comparatives

The advantages of TrustLend are shown in Table 7.1 applies the trustworthiness score to help the lenders/investors to identify the eligible borrowers to minimize the loss. First, no registration is required. Users are able to connect with their MetaMask wallet and apply for loans. Next, we have an interest rate formula with Annual Percentage Yield (APY) as the standard interest rate that is possible to use in a blockchain lending platform considering the effect of compounding interest and does not require collateral. TrustLend provides borrowing and lending features. Users are able to become borrowers or lenders/investors. The last, TrustLend does not involve fiat currencies. TrustLend applies ERC-20 as a token to implement in localhost and is ready to use an NFT-based token. The testnet KOVANETH runs on the Optimism Testnet Network. In addition, our TrustLend platform offers to focus on the P2P lending platform to help people get loans without collateral.

TABLE 7.1: Ethereum Lending Platforms Evaluation [58]

Lending Platform	Registration Req.	Interest Rate (Min.)	Lend or Borrow	Own Token	Req. Collateral
Everex	Yes	Market	Both	Yes	Yes
ETHLend	Yes	Market	Both	Yes	Yes
WeTrust	Yes	Market	Both	Yes	Yes
SALT	Yes	5.99%	Borrow	Yes	Yes
BlockFi	Yes	4.5%	Both	No	Yes
Dharma	Yes	Market	Both	No	Yes
Compound	No	Market	Both	No	Yes
MakerDAO	No	3.5%	Borrow	Yes	Yes
LendingClub	Yes	Market	Both	No	Yes
TrustLend	No	APY	Both	Yes	No

We have an opportunity to deploy the TrustLend lending platform with the advantages such as no collateral required, using social recommendations, and enhancing borrowers'



trustworthiness scores as an alternative lending platform. In addition, the platform aims for several other properties: Transparency: all system transactions are traceable and accountable. Automatic enforcement of terms: autonomous transactions by smart contracts are binding for all participants. Reduced costs: we attempt to minimize gas costs for feasible economics. The properties that our lending platform developed further are as follows:

### 7.1.1 Transparency

Chapter 5, each user can interact in a decentralized manner and get advantages of blockchain such as decentralization, immutability, and transparency [106]. Chapter 6, presents the data test. We used the Bank Marketing subset from UCI public dataset [96] with the limitation of the available digital wallet account tests, the test runs per each account with an equal method for all datasets. The results shown in Figure 7.1 describe the borrowers' trustworthiness scores which is the implementation of the trustworthiness score formula (LAPS) and following the other values of variables, including Loan risk, Activity, Profile, and Social recommendations. The borrowers get the value of the loan risk, activity, and profile score by converting the value of the dataset. The social recommendation score will get from the other user as recommenders (input directly). The TrustLend will count each variable to become a trustworthiness score (in the Total Tscore column), which is used as the final decision from lenders/investors to grant the loan. Lenders/Investors are able to choose the eligible borrowers based on the highest trustworthiness scores to minimize their losses.

Platform users								
Profile ID	Borrower contract address	Borrower wallet address	Total Tscore	Activity score	Profile score	Social recommendation score	Loan risk score	# cycles
0	0x47b36E824631e97E94d462F822181Ed08A459384	0x8626f6940CE2eb28930eFb4CeF49B2d1F2C9C1199	71	65	60	61	100	1
1	0x468Ce031ea52F0A6B2096cc3abFA0CA0cAF06C7	0x70997970C51812dc3A010C7d01b50e0d17dc79C8	75	78	80	66	79	1
2	0x387d05D71157543975051FC785784166604455	0x06f509F73eefBA36352Bc8228F9112C3786100d4A	54	56	58	50	57	1
3	0x846f37Eco7D3f52A3D93720793D48E5456C246B	0x35CbD98014D4C3825d8486993b9944c78e56f763	70	78	80	50	79	1
4	0x7625092439918977e973653CA6F7275CC3BF25b	0x4cFF48a294272A0449d9163E92E6c93ba0CD90B5	54	56	58	50	57	1
5	0x142AB05a3FD31663ea627DB1698639D27061010C	0xe37A5C872eC6987E0E899E0FE8C74dAc99f121	68	65	60	50	100	1
6	0x448909a30544601E44F51bA728e7C5f08627C55	0x0eC5F4dC22a4EEF3f0C63a31c5b6A2418D429193	70	78	80	50	79	1
7	0x8744b336FC44395Da72850AD9f6220CF6Ea34962	0x64047426729dceF24d6bD58329bba08AA958a3b0	54	56	58	50	57	1
8	0xbE114A1cD55A685C772E3Ec3CB83e3afbe9b018F	0x1Df10644987013a9536f17092DbeA647f98f2e2B	68	65	60	50	100	1
9	0x6858aBC1D6AFc13F9B78b08d33253F622EF4eC7d	0x343B14Ebb982be358cE495eCC7a018247794A945	70	78	80	50	79	1
10	0x0f280b6190204A51Cd06419c6f0F90E815Fec716	0x71d13E61AC7dC6773EB1A17b703aB13C38664EE	68	65	60	50	100	1
11	0x6FebE66a2Ca2cd21199d201e5a843eEf635C40fB	0x2Dde3b23908D5f027806A99f9ac77079EEB55032	70	78	80	50	79	1
12	0xd00c64B12Cd2d4DD97cE894575f19F4A092a859	0x67E28cc4C005027f5e2E1f034B228147C7e5c01F	54	56	58	50	57	1
13	0x23F2a944180eb4c3e1999C377774BcE38fC7008	0xEb9d54Ba366750e0Eb161262a282B4c9412CF956b	68	65	60	50	100	1
14	0xC695D11C8702B7D771f1Caa030A56Bf212eE97B	0x7ADd4eFF69b8cB4666949742eC19428e9d4742aA	70	78	80	50	79	1
15	0x231673f8f289CB8A09f1050920d5317C954dD53	0xa9B2c325C56d048AA1EB5804f89410903D2CdF8	54	56	58	50	57	1
16	0xbE928d8E3777f9681813f5bC34fc6930d0f0aE57	0x13f3Fd8A4d1bAdD65D1a241b9b8c86Bf757a03	50	50	50	50	50	1

FIGURE 7.1: Implementation of the Trustworthiness Score Formula .

The borrowers' trustworthiness score present is a commitment among borrowers, recommenders, and lenders/investors managed by the smart contracts. The objective is for all parties to understand the obligations and its risk. All variables data (loan risk, activity, profile, and social recommendation score) will be assessed as the borrowers' trustworthiness score. After the borrowers get the score, they can propose a loan and get the loan corresponding to their score. The borrowers' trustworthiness scores will increase alongside the record of the borrowers' installment payments.

Chapter 3, we discuss sidechains on the mobile application side of this lending platform. DApp lending platform Ethereum blockchain-based can handle the complex transaction. It is able to set up a recommendation to support the lending process and establish a high level of trust. It can also control users' traffic on this lending platform. It allows the user to download only the application client so that it is unnecessary to download the whole Ethereum-based lending platform and reduce the exchanged messages (transactions) through the internet to access the main blockchain (e.g., connectivity problems, internet not available). The weaknesses are to perform off-chain transactions will increase transaction time because all members must be approved. Transaction queueing will occur because each transaction requires action from other users and will impact additional processing time.

Our lending platform follows blockchain regulation and scalability. Scalability blockchain would have to develop with an emphasis on resolving all scalability issues comprehensively [137].

- **Improve Consensus Mechanisms:** Previously, blockchains such as Bitcoin relied on the PoW consensus mechanism. Bitcoin suffers from energy-consumption and scalability issues due to this choice of consensus mechanism [138]. Ethereum has recently adopted the PoS consensus mechanism [137]. This change is proposed in order to improve Ethereum network's capacity alongside security and decentralization. PoS ensures consensus by selecting users according to their Ether stakes in the network. In addition, the PoS consensus mechanism does not require miners to solve cryptographic algorithms using massively energy-intensive computational power [137], [139]. This recent adoption of the new consensus mechanism could thus result in improved scalability. TrustLend runs on the Ethereum network thus it would benefit from this improved scalability.
- **Transactions Sharding:** With the increasing number of users of lending platforms, on-chain scaling is one of the common choices for addressing the blockchain scalability problem. Sharding is present in the notable layer-1 scaling for blockchain networks based on distributed databases. Sharding is breaking down into smaller data sets of transactions, then processes simultaneously in parallel mode, and enables queueing. For example, the borrowers' information in TrustLend could be divided among nodes while ensuring data consistency. In addition, shards provide proof for the main chain while interacting with each other for sharing general information, such as age, education level, job, marital status, and balances, by leveraging cross-shared communication protocols [137].
- **Nested Blockchain:** A nested blockchain is an optional solution for scalability problems when the lending platform is implemented in the broader network area. The decentralized network infrastructure leverages the main blockchain for establishing parameters to extend the blockchain network and a good entry among layers. In addition, it also ensures the execution of transactions over an interconnected network of secondary chains [137].

### 7.1.2 Automatic Enforcement of Terms

We provide a TrustLend prototype with an autonomous transactions process supported by smart contract functions after the deployment phase. Smart contracts pay attention to borrower trustworthiness scores, so lenders/investors can consider the potential risks incurred.

Chapter 5, we discuss the autonomous blockchain as a secure system based on chained blocks, peer-peer nodes, consensus-based ledger mechanisms, anonymous accounts, self-regulated data ownership, and programmable smart contracts. Minimal blockchain effort is required, feasible, efficient, and enduring. In addition, unique credit mechanisms are necessary to make blockchain systems creditworthy, although blockchains provide a credit-worthy infrastructure for data level storage and operations [43]. A smart contract is an autonomous contract that can be used to exchange crypto assets, property or anything of value without dependence on a third party. Smart contracts allow data and transactions to be recorded as they occur and can only be changed by consensus [103]. The smart contract code orchestrates all the interactions among multiple participants (including those approvers and developers) in an entirely decentralized way [107].

Chapter 3, we discuss blockchain technology as a combination of trust and consensus in a legal agreement between investors and borrowers, so there is no need to represent data, processes, and transactions on the blockchain to increase trust's expected value. The permissioned blockchain allows all users (investors and borrowers) privileges as described in one complete infrastructure. Users can obtain permission only through various applications and integrate multiple components, such as security, speed, immutability, scalability, resilience, and trustworthiness, including ledgers that cannot be changed except through consensus.

Chapter 4, we discuss the system will automatically increase the value of the borrowers' trustworthiness score (LAPS). The borrower will be able to propose a more significant amount than before if their scores rise. The borrower with the highest trustworthiness score will be easier to propose loans with increasing loan plan limits in the next submission. Smart contracts management at borrowers, recommenders, and lenders/investors sides will handle each functionality from the services provided on the Ethereum blockchain according to the users' role.

Chapter 6, we provide a prototype with an autonomous transactions process supported by smart contract functions after deployment. Smart contracts pay attention to borrower trustworthiness scores on a personal lending platform so lenders can consider the potential risks incurred. The value of trust among borrowers, recommenders, and lenders has a strong influence on a personal lending platform. The disadvantage is that performing off-prototype transactions will increase transaction time because the need for a recommendation score granted by the lender/investor must be approved. In particular, all users are aware of the risk and the borrower's trustworthiness. Smart contracts are autonomous, immutable, conducted in the EVM manner, and stored in the Ethereum blockchain. The smart contracts are able to hold ETH in ERC-20 tokens [135], [136].

Appendix A chapter, we discuss P2P networking, a set group computer or network that can resource sharing by itself autonomously, without central authority needing support by consensus. Asymmetric cryptography is used to ensure the user can access the system and

avoidance from malicious access or unauthority users. With this cryptography model, only privileged and authentic users can access the system [125].

The different factors define blockchain scalabilities, such as networking, throughput, cost, and capacity for lending platform implementation. The continuously growing number of nodes has resulted in the blockchain scalability problem. It is able to inhibit the prospect of blockchain adoption on lending platforms. A network was developed that can interact between users without a central authority so that all users have equal rights to govern and manage transactions in the blockchain. The blockchain scalability problem<sup>1</sup> refers to the limited capability of the blockchain network to handle large amounts of transaction data on its lending platform in a short period. It is related that blocks in the blockchain are limited in size, and frequency [137].

The PoW-based permissionless blockchain networks can offer a transaction throughput of almost ten transactions every second. Furthermore, some technical modifications that do not affect the security aspects of the open blockchain networks could help improve the transaction throughput to almost 100 transactions per second. Otherwise, permissioned blockchain networks could also serve as good answers. The consensus mechanisms in the permissioned blockchain networks could also offer improved speed. This solution is able to implement future lending platforms [137].

### 7.1.3 Reduced Costs

Chapter 4, we discuss that traditional lending mechanisms show weaknesses because it takes time uncertain (it tends to be longer), and require many documents, additional costs, etc. Chapter 3, we also discuss the administrative costs that may be required at the time of submission. Banks offering the interest rates are more significant, making it burdensome for the borrower [89]. Chapter 6, however, in the end, it burdens borrowers in terms of interest and administrative costs when applying for loans.

Chapter 5, we observe the technology's potential to reduce costs and improve processes. The peer-to-peer (P2P) networks can replace organizational networks, reducing hierarchical levels and transaction costs [88]. In TrustLend, we offer to set up a recommendation to support the lending process and establish a high level of trust. Allowing users who have already done a transaction without additional costs for making the same transaction will reduce the cost burden of making transactions. Chapter 6, finally, the prototype shows how end-users can easily access loans with minimum collateral without hidden costs and swift transactions. Appendix A chapter, the current centralized management may not accept this because it is high cost and requires the trust of network users to a third party to operate the system [140], [141].

The critical factors the TrustLend prototype prevents from reducing costs and blockchain scalability are as follows [137]:

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<sup>1</sup><https://101blockchains.com/blockchain-scalability-challenges/>

- **Limitations and Block Size:** Scalability is a principal issue in blockchain based on the limitations in terms of hardware, and it isn't easy to set up and maintain the hardware required for operating the lending platform, such as the Trustlend prototype. Transactions of the Trustlend prototype will increase as a new transactions so that each node updates information regarding the borrowers, recommenders, and lenders/investors' transactions in the ledger and time processing. In addition, the TrustLend networks must maintain accuracy in borrowers' trustworthiness scores data block to protect blockchain network scalability and users' data [137].
- **Response Time:** Building new block transactions require at least 10 minutes to validate. The increase in transactions in the queue will impact the lending platform, such as when submitting all borrowers' proposals. The borrowers' transactions in the Trustlend prototype blockchain network should have passed a validation process from recommenders, and the lenders/investors are the last validator. This case would impact the response time and transaction fees (gas fees). These costs as one of the blockchain scalability problems [137].
- **Fees of Transaction (gas fees):** The next critical factor is the transaction fees. The increasing TrustLend prototype blockchain networks added more complex validating transaction processing. Therefore, It is required higher computation power (e.g., miners). Users have to pay an additional cost to verify transactions (e.g., extra gas fees). However, reducing the number of transactions that remain in the queue during the idle process is also essential. The TrustLend prototype lending platform is able to consider minimizing the hidden costs, such as gas fees, withdrawal, and exchange fees [137], [142].

## 7.2 Users' Satisfaction of Lending Platform

Chapter 3, 4, 5, and 6, we discuss the borrowers do not have to provide collateral, which is a significant incentive for them. The recommenders are expected to give honest recommendations about the borrowers because the recommendation scores will impact the trustworthiness score. The lenders/investors grant the loan and choose the eligible borrowers themselves in the last phase.

Blockchain technology convergence is on the agenda for many companies, such as implementation systems and initiatives in several areas and financial services. Blockchain is an emerging technology that promises to solve transparency problems by creating one version of the truth. The blockchain exists with the ability to see the holdings and transactions of each public address that are opened to multiple environments such as users or systems and actively distributed ledger (transparent). The blockchain offers new concepts to run business processes among stakeholders with the minimized cost of centralized information technology infrastructure and its complexity. This technology also adds advantages, including speed, auditable, accountability, and renewable smart contracts [143].

A TrustLend prototype lending platform offers the chance to support the borrowers' users to become recommenders or lenders/investors and improve access for disadvantaged users.

Banks or financial institutions have an opportunity to make businesses more accountable and increase security in business-customer interactions. All impact the actual user, the overall user experience, and satisfaction since using the lending platform. Finally, the Trustlend prototype enhances the interactions among borrowers, recommenders, and lenders/investors over the chain of lending platforms.



## Chapter 8

# Conclusion and Future Work

Nowadays, P2P lending has grown in the world. Many lending platforms offer secured lending in a P2P manner with collateral. This thesis presents the borrowers' trustworthiness score to be used as an alternative in lending applications. The borrowers are no longer burdened with collateral or guarantors.

### 8.1 Conclusion

This thesis tackled the essential research questions (RQ) about the trustworthiness for personal lending on blockchain in three main contributions as follows:

#### 8.1.1 Trustworthiness Score

*(RQ-1), "How can we compute the trustworthiness score of a user borrower who applies for a loan? The trustworthiness score is used to evaluate whether the user will return the amount according to the stipulated loan conditions."*

Chapter 4 and chapter 6 tackled this research question. We build a borrower trustworthiness scoring model called LAPS. The LAPS formula computes the borrowers' trustworthiness score based on variables such as loan risk, user activity, user profile, and social recommendations. In the LAPS model, we introduce social recommendations in support of a borrower. They get assurance that the borrowers are able to pay back the loans, and the recommender bridges the gap between the borrower and the lender. The borrower has confidence after receiving the trustworthiness score. With LAPS, stakeholders (borrowers, recommenders, and lenders/investors) will get incentives that can be applied safely. The following incentives on our lending platform are as follows:

- **The borrowers:** They get a good recommendation from the social recommenders to replace the guarantors and maintain a trustworthiness score.
- **Social recommendations:** The recommenders with correct and frank recommendations will be incentivized as valuable recommenders and may gain benefits towards an increased trustworthiness score for the purpose of obtaining loans.



- **Lenders/investors:** They know the risk of lending to a particular borrower, but our lending platform provides the borrowers' trustworthiness scores to help them choose the borrower and decide to grant their loan.

### 8.1.2 Smart Contracts Development

**(RQ-2)**, *“Existing lending platforms are based on requiring the borrower to submit collateral. Can we establish a lending platform where user borrowers can get a loan without or minimal collateral? For example, by using trustworthiness score as an alternative.”*

Chapter 5 and chapter 6 tackled this research question. We develop smart contracts that enforce the conditions of lending and borrowing in a P2P environment. The smart contracts are program codes powered by Solidity and Ethereum blockchain that can be realized in a decentralized P2P manner. They can replace the intermediary process between users (borrowers, recommenders, and lenders/investors) and eliminate third parties. We use these smart contracts to enable interactions between users (borrowers, recommenders, and lenders/investors) in a secure way where all agreed-upon rules are enforced. The smart contracts implement the LAPS trustworthiness score formula. The advantage of the LAPS score is that it may help to convince the lenders/investors to provide loans with minimal or no collateral. In addition, the underlying features of our lending platform smart contracts are as follows:

- Implement the LAPS formula to get the borrowers' trustworthiness score to minimize collateral.
- The consensus and security mechanism. We applied a role for each user. The borrowers cannot become recommenders or lenders/investors when they propose the loan, and both are as well. We keep the MetaMask wallet address to ensure no similar account accesses with different roles for the same loan.
- The borrowers, recommenders, and lenders/investors management, including lending process, interest rate mechanism, withdrawal for users, repay installments, and incentives for recommenders and lenders/investors.

### 8.1.3 Lending Platform Prototype

**(RQ-3)**, *“How to build a decentralized lending platform that enables the evaluation of the default risk of borrowers and achieves low cost in lending transactions?”*

Chapter 3 and chapter 6 tackled this research question. We introduce TrustLend as a personal lending platform and present its design and implementation details. We developed a fully functional prototype of TrustLend as a decentralized application (DApp). The prototype shows the features borrowers, recommenders, and lenders/investors require to rely on trustworthiness by implementing trustworthiness scores with Ethereum smart contracts.

TrustLend deploys the smart contracts and applies the LAPS formula to compute the borrowers' trustworthiness scores. We describe the prototype architecture and conduct various personal loan simulations. TrustLend implements some conditions for users (borrowers, recommenders, and lenders/investors) in order to prevent losses for the borrowers/investors, as follows:

- Each borrower may be required to obtain a certain minimum number of social recommenders.
- The defaulting borrowers' accounts may also be banned after some installments are missed.
- TrustLend maintains the borrowers' trustworthiness score in order for lenders/investors to vet and identify eligible borrowers candidates before they decide to grant the loan.

TrustLend presents architectural designs that meet the needs of borrowers, recommenders, and lenders/investors, such as permissionless access, integrity, and security. In addition, the platform aims for several other properties: Transparency: all system transactions are traceable and accountable. Automatic enforcement of terms: autonomous transactions by smart contracts are binding for all participants. Reduced costs: we attempt to minimize gas costs for feasible economics. TrustLend makes loans easier due to the lack of collateral. We expect that the platform will attract a more significant number of borrowers, providing the lender with a broader group of borrowers.

## 8.2 Future Work

The approaches for future work are already discussed in part of the contributions chapters. This research is an opportunity to continue with a new idea and a practical approach. We summarized in the following section possibilities for improvements.

## 8.3 LAPS Formula Improvement

We summarized certain limitations and perspectives of our trustworthiness score formula (LAPS) as follows:

- Improving the LAPS formula based on dynamic variables and measuring the percentage formula for each with high-impact variables. We suggest minimizing the traditional ways to get eligible borrowers' personal information. We are able to use the specific API from other valid resource information (e.g., Banks or Financial institutions) to protect the lenders from fake borrowers. User borrowers' basic personal information supports TrustLend (e.g., social security number).
- The TrustLend, upon interacting with a user account and our smart contracts, guarantees that the users (borrowers, recommenders, and lenders/investors) have minimum gas fees for each transaction.

- We also respect the fundamentals of smart contracts and decentralization to maximize security, privacy, and anonymity. A TrusLend can improve the feature to protect from fake borrowers but is still trustworthy on recommenders' and lenders'/investors' sides. It is simpler without complex terms and conditions.

## 8.4 Deployment TrusLend Prototype

To the best of our knowledge, none of the lending platforms guaranteed the borrowers to pay back their loans, which is the case with traditional lending systems. We summarized certain to improve our lending platform prototype as follows:

- TrusLend maintains the borrowers' trustworthiness in self-evaluation of users' borrowers to ensure that scores correspond with a willingness to repay their loans. TrusLend evaluates and gives more incentives for good recommenders and lenders'/investors.
- In TrusLend, it is possible to develop the interest rate depending on the trustworthiness score. For example, when borrowers with a high trustworthiness score get a low-interest rate, it motivates them to keep their scores up. On the recommenders' side, it is possible to get significant incentives when the borrowers successfully repay their loans on time.
- In TrusLend, each user will get a personal guarantee depending on the lending activity (raising the trustworthiness score) and validates social recommendations.
- With TrusLend, make an opportunity for recommenders and lenders'/investors to help people invest their money in peer-to-peer lending platforms with more significant incentives (e.g., interest rate and payback guarantee).

TrusLend makes loans easier due to the lack of collateral. We expect that the platform will attract a more significant number of borrowers, providing the lender with a broader group of borrowers.

# **Part IV**

## **Appendix**



## Appendix A

# SWOT Analysis of Lending Platforms

Blockchain Technology has become a phenomenal global issue, emerging with bitcoin and IoT. It has been implemented in many areas of human activity. The advantage of blockchain technology is distributed ledger where resources are distributed to all members in the network. Loans or credit as part of human activity in their life. When we need cash for a significant expense, it might be tempting to borrow from a payday lender or max out a credit card. Still, you have other options that will not harm your credit or put you in a cycle of debt, even if your credit record is not all that great. Collateral loans could be a way to borrow the money you need. One of which is the lending platform. Blockchain technology has been implemented in many lending platforms, but there are still any weaknesses that can be refined and optimized. The tool of analysis is SWOT, which describes four analyses: Strengths, Weaknesses, Opportunities, and Threats. This chapter's purpose of analyzing lending platforms is measured by looking for the weak variables and how to optimize that system's performance to improve helping people in the lending process. In addition, this analysis can be used for enhancement recommendations in the system based on the weaknesses and opportunities for making a lending platform robust.

This chapter is based on a published journal paper. The complete reference of the paper is as follows: SWOT Analysis of Lending Platform from Blockchain Technology Perspectives, W. Uriawan, International Journal of Informatics, Information System and Computer Engineering (INJIISCOM), vol. 1, no. 1, pp. 103-116, Dec. 2020 [36].

### A.1 Introduction

Blockchain arose at a good time and was introduced with Bitcoin emerging in the financial crisis in 2008 [144]. At the same time, people needed some money to survive in life. Traditional lender burden people with high interest and long-time payback periods. Another way is individuals can propose lending to traditional financial services, like a bank or financial institutions [145], but it's challenging for accepted because they should give some collateral. On the other hand, people do not have collateral for proposing some credit to financial institutions, and more big proposed loans will have more collateral also [146]. Financial institutions make some conditions for grading lending it depends on the risk. High risk will affect high requirements, and more collateral will be required.

Blockchain has been completed by technology modern for support in lending platform environment in a simple way and faster in processing [7]. The ledger will support for

recorded all transactions on the network with the unique privilege it is working as an individual or organization as well as [147]. Smart contracts are supported to manage transactions with the particular process with high code security and robustness with solidity adaptive language [148]. In peer-to-peer (P2P) lending platforms is possible for a person transacts with another person online in a simple way. Several countries, like China and the United Kingdom, have successfully applied that system. Its method provides for Small and Medium-sized Enterprises (SMEs) and individuals with a population increasing about 110% in 2015-2016 and still developing for the lending industry market with high-risk [19]. The trustworthiness will help the transaction faster because it will reduce many following conditions like transaction credit record and collateral, which many people rejected when applying for lending or credit with small collateral [149], [150].

According to Transparency Market Research, the lending market cap will grow in 2024 to about \$897.85 than before in 2015, about \$26.16 billion [6], [20] is significant and interesting for lending platform development in the future. All kinds of services will provide blockchain technology for financial institutions non-bank. Peer-to-peer networking is a set group computer or network that can resource sharing by itself autonomously, without central authority needing support by consensus. Asymmetric cryptography is used to ensure the user can access the system and avoidance from malicious access or unauthority users. With this cryptography model, only privileged and authentic users can access the system [125]. Cryptographic hashing Merkle tree data structure is used to record all transactions from large datasets with unique authority so that data integrity is well-maintained [151].

The SWOT analysis identifies several factors of organizations or systems adaptation and analyzes present conditions for competitive advantages. Strength will determine the positive value of the current process, and weakness will show vulnerability or error of the current system according to the rotation after organizational evaluation. Opportunity used for identifying in the future besides competitive advantages. Threats are how the system can avoid or minimize the risk today and in the Future [152], SWOT analysis will help the organization better manage all the situations and conditions that also occur for increasing competitive advantages. This chapter describes how to analyze the lending platform by looking for particularly the weaknesses and opportunities that can improve the lending platform's performance. In addition, weaknesses show the system leak or vulnerability so that the organization can fix this weakness to become lending platform strength and robust.

## A.2 Methodology

Blockchain is a coherent data structure as a digital sign. It becomes an identity, then shared and distributed as a database that contains a well-structured log of transactions and chronological information. The database is called a ledger containing many transactions, user logging, and data maintenance. Transactions in the general ledger will be collected into a block, recorded with a time stamp, and cryptographically linked to the genesis block that forms and composes a sequence of events or other blocks as a unit. The structure describes the

data structure, is a form of digital consensus, and is also used in literature, algorithms, or application domains built on the design block structure [140], [141], [153].

Data transmission, resource sharing, and computing are all part of computer networks. Cryptocurrency is a distributed network resource to others with a specific address. The challenge is that the system needs to ensure that the allocated expenses do not double. A traditional transaction such as a bank and non-bank, which acts as a mediator between a third party and a trusted data storage medium, will become a valid ledger block and keep the data up to date. Authority is activated if several parties need to write in the ledger simultaneously with concurrency control and consolidation. The current centralized management may not accept this because it is high cost and requires the trust of network users to a third party to operate the system [140], [141].

### A.2.1 Ledger

A copy of the distributed ledger will be the same held by all users on the network. Consensus will add new data every time there is a change to the ledger if all users agree and the data is valid. Any attempt to change the data by one user, then the other users will be informed of the change, creates immutability [154]. The genesis block is where transactions are stored, and all blocks will be cryptographically linked to each other, which records the data. The nodes in the graph represent transactions, and their edges will show the direction of confirmation between transactions [155].

### A.2.2 Fintech

The Financial Technologies (FinTech)<sup>1</sup> and the Internet of Thing (IoT)<sup>2</sup> [7], [155], [156]. Although both domains require the common features of a decentralized trusted transaction ledger, substantial differences can be found in usage principles, transaction volume, rates, tight security requirements, and transaction fees. At FinTech, the main challenge is ensuring highly secure and reliable financial payments, with a low volume of transaction failures and some tolerance for transaction delays. On the other hand, using multiple devices and a greater volume of transactions in IoT is expected, with micro and nano payments required for IoT assets and data changes. Transaction costs are a relevant issue here, as well as transaction delays required for near real-time operations [157], shown by Figure A.1.

### A.2.3 Ethereum

Ethereum is a blockchain network with an open system. Ethereum and Bitcoin are tools that make it possible to bring the economic system into the software, complete with an account management system and a native exchange unit system for funneling through accounts [158]. Games like Monopoly or something identic. Each player calls a native unit of coins for this exchange, token, or cryptocurrency, but it is no different from tokens on any other system: they are a form of money (or scripts) that can only be used in that system [126]. Ethereum

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<sup>1</sup><https://builtin.com/fintech>

<sup>2</sup><https://www.techtarget.com/iotagenda/definition/Internet-of-Things-IoT>



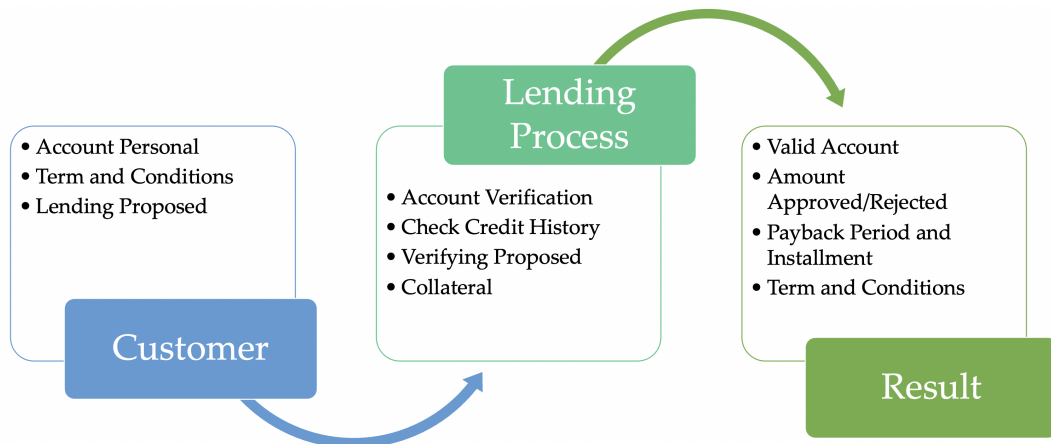


FIGURE A.1: Lending process

is a global transaction-based machine: it starts with block genesis and gradually executes transactions to manipulate them into final blocks. The last block is canonical Ethereum. Genesis blocks available include account balance information, track records, reliable, real-world data, and information; otherwise, anything the computer could manipulate would be accepted. Transaction validation between blocks is essential to avoid invalid fake blocks or valid block changes. Invalid block changes will reduce the account balance without the same renewal and opposite increases elsewhere. Valid block transitions generated by transactions [159].

Decentralized protocols and applications, distributed storage, distributed shared marketplace and other concepts have the potential to enhance the computing industry and the support provided for peer-to-peer protocols for lending platforms. Writing code in Ethereum will get a lot of blockchain functionality, like a programming language beneficial for generating smart contracts functionality and more secure by arbitrary encoding. Users can modify according to the objective [76], [148].

### A.3 Smart Contracts

The assigned and delegated smart contracts will execute the correct input. A distributed ledger is a distributed database of transaction history approved by most participants in its network through a predetermined consensus mechanism. All participants in the network have a copy of the same ledger. Any changes in the ledger will be reflected in the final copy. Assets recorded in the ledger can be financial, legal, physical, electronic, or many other properties. Depending on the network rules, the ledger can be updated by some or all the participants. Important security and consensus issues are generally resolved through cryptographic mechanisms [160]. Smart contracts are computer programs that enforce rules without requiring a third party. In the Bitcoin blockchain, basic versions of smart contracts are implemented through a writing system that can facilitate use cases such as multi-user accounts, multi-wallets, digital signatures, and other services [161].

The security risks associated with blockchain platforms and technology are as follows [162]:

1. It is difficult to implement regulations to avoid money laundering activities due to the high level of anonymity using the protocol.
2. Several cryptocurrencies have been indicated to be used for money laundering purposes and are a challenge ahead to enforce financial penalties.
3. The ineffective tax regulation scheme may be a side effect of the anonymity factor.
4. Many countries have introduced tax regulations for cryptocurrencies to deal with the global cryptocurrency phenomenon and avoid risks for users exposed to cryptocurrency price volatility.
5. In the future, there will be problems of inflation and risks of monetary and financial stability, including the potential loss of control over the amount of currency to be circulated, the level of risk will increase from the cryptocurrency market and increased credit in the economy with the use of cryptocurrencies that are difficult to control.
6. The emergence of cryptocurrency will be accompanied by a series of new problems concerning laws and regulations that can affect public confidence in conventional currencies. Cryptocurrency is like a representation of value transactions, can be traded, and functions generally as money.

Society of Worldwide Interbank Financial Telecommunication (SWIFT)<sup>3</sup> system uses predefined code to pass on transaction details through the SWIFT network. Each transaction is described by a series of SWIFT codes. The code consists of several key identifier components, such as institution code, country code, location code, and branch code to indicate the sender and receiver [163]. SWOT analysis contains relation identification of strengths, weakness, opportunities, and threats from subject research. Strength contra with weakness, opportunity versus threats. Strength will identify resources available and running well, and Weakness to measure how high the risks. Opportunity analyzes represent the marketplaces as the subject, while threats are for preventing or minimizing the risk [163]–[166]. Identifying the lists of positive and negative contribution objectives with the subject evaluation. SWOT analysis is required for the selection of the right method and application. It is very simple, but the result is better, and the recommendation can use for the next process.

## A.4 Result and Discussion

Blockchain has become famous and is present for all daily activities in the economy, business, education, health, and other non-bank financial institutions. Exponential growth has almost changed the world and provides more efficiency and low costs options. The lending activity is an interesting area because many people have experienced it at least once in their life. In

<sup>3</sup><https://www.iso.org/organization/9739.html>

the practice of the lending system, someone will become a lender, and another party will be a borrower. There are many terms and conditions for this loan activity, including collateral, ability to pay back, trust, and the purpose of the loan. Blockchain technology will bridge these activities to reduce transaction times and complicated mechanisms. The traditional lending process will take at least one week to a month, but borrowers cannot wait longer because of urgent needs.

#### A.4.1 Analysis Lending Platform

Smart contracts in blockchain technology have replaced a faster and more efficient lending process, one example of changing from centralization to a process of decentralization, trust, efficiency, and accountability. One of the Spanish multinational banking groups Banco Bilbao Vizcaya Argentaria (BBVA)<sup>4</sup> invested around € 75 million in corporate loans and has taken advantage of the distributed ledger and became the first international bank to implement blockchain technology. SWOT analysis for lending platform variables is blockchain technology, No mediator/Collateral, Competitive Rates, Reduced Risk, Improved Efficiency, Market Cap, and Competitive Advantages. SWOT analysis framework summarized [6], [163] in the following Table A.1.

TABLE A.1: SWOT Analysis Framework

Variable	Strengths	Weakness	Opportunities	Threats
Blockchain technology	✓			
No Mediator/Collateral		✓		
Competitive Rates			✓	
Trustiness	✓			
Reduce Risk				✓
Improve Efficiency	✓			
Market Cap	✓			
Competitive Advantages	✓			

The lending platform will help individuals looking for a place to apply for loans or credit directly from lenders. This process will reduce dependence on financial institutions such as banks and third parties. Blockchain technology adopts the traditional lending process by reducing waste and making decisions quickly. Illustration “if someone needs a loan or credit, they just visit one of the loan platforms and try to propose an amount of credit needed, then the system will respond with the status of accepted or rejected” in just a few minutes. Blockchain technology is helping for better and more profitable transactions such as: safer, simpler operations, generating potential passive income, and people are starting to focus on blockchain development.

Some lending platforms offer convenience to users, but they require a lot of terms and conditions. However, it is still a burden for users, and if the lending platform still requires collateral, users will have difficulty fulfilling it, so users will still be rejected. Finally, they tried to return to traditional loans. Investment in a lending platform is exciting as long as it is completed with new technology that allows it to meet the user experience and needs.

<sup>4</sup><https://www.bbva.es/en/personas.html>

Many lending platforms only focus on profit without considering the user's needs. Lending platforms offer lending products but do not focus on user needs analysis, which will affect a lending platform's success. Current lending platforms are able to implement blockchain technology through third parties, Bitcoin and Ethereum. They referred to the SWOT analysis in Table A.2.

Bitcoin has a limitation in that the bitcoin network will threaten future lending platforms and is quite difficult to develop. Ethereum is still open to development. Therefore it is easier to develop and will grow faster without worrying about restrictions. Third parties it is easier to start installing because third parties develop them, but it will be high cost and require third-party maintenance. Mix (Bitcoin and Ethereum), the opportunity is open to take the lower to upper segment classes, but the system is more complex to handle both transactions.

TABLE A.2: SWOT Technology Platform

Variable	Strengths	Weakness	Opportunities	Threats
Bitcoin				✓
Ethereum	✓			
Third-Party		✓		
Mix (Bitcoin and Ethereum)			✓	

#### A.4.2 Trustworthiness

The most important thing about the lending platform is the level of trust. If the community has confidence, the lending platform will grow faster and have a good influence, so it will be recommended to other users. The best practice of each user will be to transfer their experience; refer to Table A.3 below. Ease of use describes how far lending platforms have accepted from users and records the acceptance and success without complaint and satisfaction: track record acceptance, statistical record acceptance, and success in the lending process. Member complaint, reduction, or minimization of member complaints will indicate a good process. The time needed, how long the lending process will need processing time, time that's shown can cut down complex process. Market Capital, how big the market penetration of the lending platform, and more extensive coverage area will bring trustworthiness to users.

TABLE A.3: SWOT of Trustworthiness

Variable	Strengths	Weakness	Opportunities	Threats
Ease of use	✓			
Track Record Acceptance			✓	
Member Complaint				✓
Time Needed		✓		
Market Capital	✓			

### A.4.3 Improved Efficiency

Efficiency is a keyword of the lending platform performance parameters that will show in Table A.4 below. The use and lending platform usability ratio will describe the overall system performance. Comparison of Lenders and Borrowers, providing statistical data between Lenders and Borrowers so that users will learn the comparison of the two and see future trends. Asset vs. Market, the lending platform must be able to present the asset report and market capitalization to the public. The user will study and analyze the results. For example, the asset must be greater than the market capitalization to guarantee the user's investment. With optimized technology, the loan platform must update the system periodically to keep all transactions up and running efficiently. Errors handler, to minimize errors, is the obligation of the loan platform to ensure the system runs well with zero errors.

TABLE A.4: SWOT of Improve Efficiency

Variable	Strengths	Weakness	Opportunities	Threats
Ratio of use	✓			
Comparative of Lender and Borrower			✓	
Asset vs Market		✓		
Technology Optimized			✓	
Error Handler				✓

### A.4.4 Market Capital

The growth of the lending platform is shown by market capital. Variables of market capital refer to Table A.5 below. Coverage area, how big is the coverage area of the lending platform that will be supported? The wider area will give an opportunity to win the market with the risk of being more complex in managing the system. Kind of Country, the type of user will be influenced by the type of state and shows the user's behavior. The system must be able to handle all the behavior of users who access it. Market segmentation will show the user segment environment; middle to upper or lower class will be used as an evaluation for market segmentation, and corporate or personal trends will also measure the level of communication of the lending platform. Lending variants and products available in various variants and segmentations can open a broader market.

TABLE A.5: SWOT of Market Capital

Variable	Strengths	Weakness	Opportunities	Threats
Coverage area			✓	
Kind of Country		✓		
Market Segment				✓
Variant of lending	✓			

### A.4.5 Competitive Advantages

Each lending platform will compete with many lending platforms in the world. They should prepare variables in Table A.6 below. Performance, the lending platform must have an excellent performance to be the winner or the best choice for the user. Speed is an indicator to measure how fast each transaction can be handled and the success of the transaction process. Driven by technology, the latest technological innovations will help improve performance. In line with the system architecture, the more recent technology will affect the lending platform's adaptability to the latest technology. Security is a classic problem but fundamental to apply to the lending platform. A good system must have a high level of security because many users will access it.

TABLE A.6: SWOT of Competitive Advantages

Variable	Strengths	Weakness	Opportunities	Threats
Performance	✓			
Speed			✓	
Technology driven				✓
Security		✓		

### A.4.6 Comparative of Lending Platform

Comparative of the lending platform will describe how performance their system was built and how the system can handle many transactions with many products offered refers to Table A.7 below.

## A.5 Conclusion

The blockchain technology of the lending platform will affect the overall system performance. SWOT analysis variables show 6 Strengths, 5 Weaknesses, 6 Opportunities, and 5 Threats. All variables describe managing the lending platform at best possible performance. These recommendations will help in the future to develop a better lending platform and system maintenance considering the Strengths and Opportunities, Weaknesses and Threats variables. However, for the best lending platform, focus on weaknesses and threats to make the system more reliable.

TABLE A.7: SWOT of Comparative of The Lending Platform

Variable	Strengths	Weakness	Opportunities	Threats
<b>Blockchain Technology</b>				
Bitcoin				✓
Ethereum	✓			
Third-Party		✓		
Mix (Bitcoin and Ethereum)			✓	
<b>Reduced Risk</b>				
Ease of use	✓			
Track Record Acceptance			✓	
Member Complaint				✓
Time Needed		✓		
Market Capital	✓			
<b>Improve Efficiency</b>				
Ratio of use	✓			
Comparative of Lender and Borrower			✓	
Asset vs Market		✓		
Technology Optimized			✓	
Error Handler				✓
<b>Technology Optimized</b>				
Coverage area			✓	
Kind of Country		✓		
Market Segment				✓
Variant of lending	✓			
<b>Error Accumulation</b>				
Performance	✓			
Speed			✓	
Technology driven				✓
Security		✓		

## Appendix B

# Secure Decentralized Online Gaming with Lending Functionalities

We present a decentralized online gaming platform implemented as a Decentralized Application (DApp) on the Ethereum blockchain. The gaming platform enables secure gaming, where the account balances and the stakes of the players are secured by a smart contract. Moreover, the fair enforcement of the game rules and the deposit of the winnings of the players and the gaming platform into their accounts are guaranteed by the smart contract. The gaming platform proposes lending functionalities that allow players to securely borrow tokens from the gaming platform in order to participate in the games.

This chapter is based on a published conference paper. The complete reference of the paper is as follows: Secure Decentralized Online Gaming with Lending Functionalities. K. Alefs, F. Hartl, L. Newman, B. Özdeveci and W. Uriawan. In Fourth International Conference on Blockchain Computing and Applications (BCCA), 2022, pp. 27-32, doi: 10.1109/BCCA55292.2022.9921994 [167].

### B.1 Introduction

Online gaming comprising of probability games, is a popular application. Examples of probability games include dice rolls, slots, roulette, and blackjack. These games are also called games of chance. This chapter presents a gaming platform implemented as a Decentralized Application (DApp) on Ethereum. The gaming platform also provides lending functionalities. After the initialization of the gaming platform by the owner, users are able to interact with the main smart contract and the various functionalities embedded within it. We propose implementing a token system, which means that users must buy tokens to partake in the functionalities within the game. The smart contract offers a wide range of use cases, such as buying tokens (in the game currency), playing different games, withdrawing tokens to convert back to Ether, and lending tokens to the users.

The advantage of implementing the application as a DApp with smart contracts is that it is decentralized. This decentralization implies that no external third parties can control the application or intervene with the smart contract. As opposed to existing centralized online gaming websites, a third party is not able to declare new unfair rules, fees, or any other parameters to take advantage of users. The only interactions with our gaming smart contract are between individual users and the gaming platform owner.



The gaming scenario is suitable for applying smart contracts since both parties can trust in secure and reliable transactions, and a fair game is established. Upon interaction between a user account and our smart contract, there is a guarantee that the user can withdraw whenever they wish after either winning or losing in the game, which also respects the fundamentals of a smart contract and decentralization. In addition, users who interact with the smart game contract remain anonymous since the only given identifier of a user is their account ID.

Our application is built using Remix, which we use to write, compile, debug and deploy solidity files. For front-end interaction, we use React (javascript) to provide a visual UX for the smart contract. In order to compile our solidity files into code that could be run on our client-side application (React), we used Hardhat. To enable interactions with our smart contract on the blockchain, we use Ether.js. On top of all this, we use MetaMask to help manage accounts on the Ethereum blockchain.

## B.2 Related Work

This section looks at some of the existing blockchain-based online gaming platforms. To the best of our knowledge, none of these platforms currently provide lending functionalities for fungible tokens. In contrast, our gaming platform proposes the possibility of loans to the players.

FUNToken.io [168] is an Ethereum-based gaming platform that offers a large user community. They plan to supplement on-chain transactions with side-chain transactions for lower cost and lower latency. The Atari Token [169] has good integration capabilities with other decentralized applications. Atari Token provides services to individuals and businesses, supports multiple platforms, offers liquidity guarantees and easy payments.

CoinPoker [170] is a blockchain technology-based platform that uses USDT stable coin as the main in-game currency and the CHP cryptocurrency for bonuses. It offers instant and secure transactions using USDT, ETH, BTC, and CHP tokens. The platform allows anonymity with no KYC checks. The BetU platforms [171] include BetU Verse, EarnU, and BetU. It provides a virtual reality platform, prediction games (sports and esports), and a betting platform. BETU tokens are utilized for all winnings, betting rewards, incentives, staking, burning, whale holder benefits, purchasing of NFTs, and governance of the platforms.

LOTTO (The Immutable World Lottery) is a decentralized and cross-border lottery game. The LOTTO [172] lottery runs continuously without a third party. The protocol produces a provably-fair winner using an oracle service. Dotmoovs [173] is a peer-to-peer game playing platform based on an artificial intelligence system. The Moov token is an asset that supports all transactions including buying, selling, and renting.

Exeedme [174] allows gamers to engage and interact with their favorite games. Exeedme provides an earning environment to several gaming communities with one token to fuel the entire platform. Wagerr [175] is a permissionless blockchain-based platform that offers sports betting. Wagerr is supported by Oracles and provides transparency. Wagerr cryptocurrency is designed with a deflationary mechanism that helps the coin retain value under various conditions to protect it from market drops and guard the price to equilibrium over time.

## B.3 Probability Games

The outcome of a probability game [176], [177] depends on the likeliness of certain events to occur. Probability games may also be called games of chance. This section describes some probability games that could be played on our gaming platform.

### B.3.1 Roll the Dice

In this game, the player enters a guess and a stake. She loses or wins six times the stake.

### B.3.2 Slot machine

The player enters the stake. The result is three digits. If two digits are the same,  $Reward = 3 \times stake$ . If three digits are the same,  $Reward = 9 \times stake$ .

### B.3.3 Roulette

The player enters the stake and guesses a number and a color. If the color is correct,  $Reward = 2 \times stake$ . If the number is also correct,  $Reward = 36 \times stake$ .

### B.3.4 Blackjack

- *Goal:* Get more points than the dealer, but at most 21 points.
- Draw 2 cards for yourself and 1 for the dealer.
- *Simplification:* Ace is 11 points and unlimited cards.
- Draw as many cards as you want (one after another).
- If you have more than 21 points, you lose directly.
- The dealer draws cards until they have at least 16 points.
- If the dealer has more than 21 points, you win directly.
- If you have more points than the dealer, you win.
- *Reward:* Twice your stake

## B.4 Use Cases

The use case diagram in Figure B.1 demonstrates the different use cases of the application and who out of the gaming platform owner and user can interact with each use case. The order in which each use case should follow the other is the order in which the use cases are presented in the diagram (top to bottom).

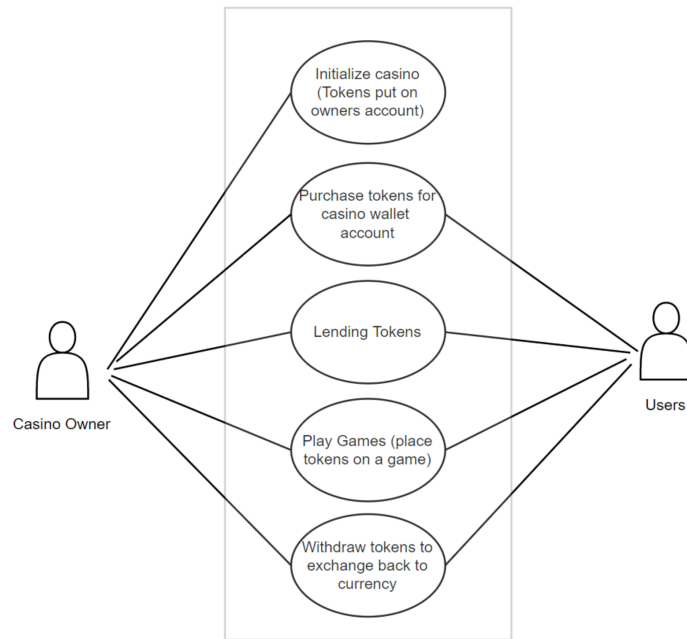


FIGURE B.1: Use Cases

1. **Initialize the gaming platform:** The owner must first initialize the gaming platform by investing some amount of Ether for there to be a “gaming platform bank”. The users can win tokens from the bank or pay tokens to the bank based on the result of their game. Once this is done, the gaming platform is ready to be interacted with by the users.
2. **Initialize the gaming platform:** The owner must first initialize the gaming platform by investing some amount of Ether for a “gaming platform bank”. The users can win tokens from the bank or pay tokens to the bank based on the result of their game. Once this is done, the gaming platform is ready to be interacted with by the users.
3. **Lend tokens:** Token lending is an additional use case implemented where a user can request a loan from the gaming platform owner. Upon approval of this loan, the owner transfers the amount desired, and a record of this loan (along with interest) is recorded within the contract.
4. **Play games:** Once the user has the tokens, they can then play any of the aforementioned games, and based on the result of the game, the user either pays the bank the stake they proposed or receives their winnings. The odds of winning each game are different; hence the returns based on the outcome vary from game to game.
5. **Withdraw tokens:** A user can decide to withdraw their tokens from the gaming platform at any stage. When a user withdraws, their tokens get transferred back into Ether and put back onto their Ethereum account balance.

## B.5 Gaming DApp Design

We designed a Decentralized Application (DApp) for playing probability games. As discussed before, the game options include Roll the Dice, Slot Machine, Roulette, and Blackjack. We also include the lending use case, which allows for novel functionality. As discussed in Section B.2, to the best of our knowledge, this functionality is currently not offered for fungible tokens by existing platforms.



FIGURE B.2: Class Diagram: Gaming Platform

This section serves to describe our design choices for modeling the use cases. To provide a deeper understanding of our ideas, we present several diagrams to explain processes and entities within our DApp. Looking at the actors involved in probability games, we first model users/players that can earn or lose tokens by placing bets on an outcome of a game. We add another type of user, a representative of the gaming platform, who can interact with the smart contract and increases the complexity of our application. A justification for having the

gaming platform as its own actor is that it is needed for the lending use case, where it actively has to approve a loan.

To establish a fair game within the contract, we make sure to collect the stakes from both parties upfront before the game starts and distribute them according to the game's rules. This way, we ensure that once a player and the casino agree on the conditions and start playing the game, both actors will receive their share once they win. In addition, we assume that there is general law enforcement outside of the contract that guarantees that users will pay back their debt since our contract does not inherently provide this functionality for lending tokens.



FIGURE B.3: Class Diagram: Blackjack

We choose to implement a “gaming platform wallet”, an account with which users can manage their spending and losses within the gaming platform. This wallet feature was chosen on the basis that there is a commonly used withdrawal pattern in Solidity programming, a practice that ensures never to let a third user initiate payments to other users. For this reason, instead of distributing tokens to players’ accounts, only they can initiate a payment to themselves by withdrawing tokens from their gaming platform balance.

Gaming platforms, for example, gaming chips, generally work with their own currency. Therefore provides another reason for tokenizing Ether and having a gaming platform account. In addition, it simplifies lending to work with a local currency since it is much safer for the gaming platform to lend out chips rather than actual tokens that might be spent outside of their institution.

Regarding the implementation of our application within smart contracts, we initially considered creating a modular environment in which requesting a loan and playing a game would be part of their contracts, as both situations work under different conditions. Additionally, we planned to have a different contract for each game type. However, for the current prototype, we decided to focus on the functionalities of our application and implement one big contract instead. For future projects, we would choose not to work with a monolithic approach as comprehensibility and maintainability can suffer. A representation of the smart contract and its variables and functions can be seen in the class diagram in Figure B.2 (here, we model smart contracts as classes).

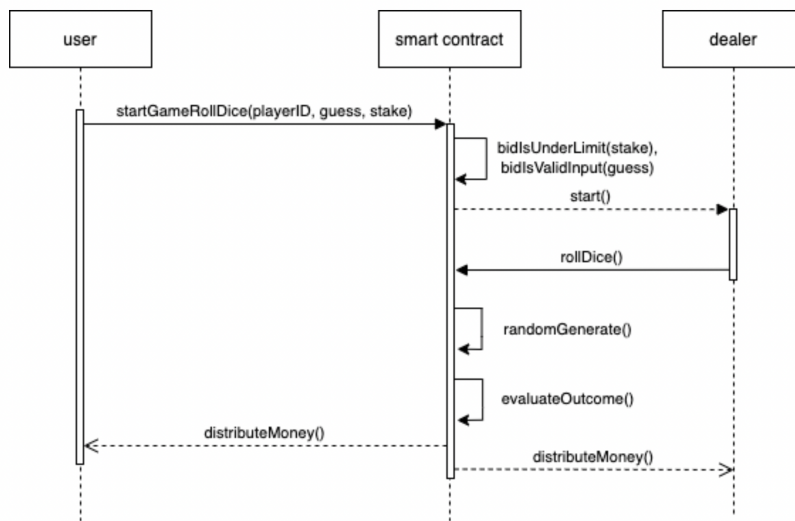


FIGURE B.4: Sequence Diagram: Roll the Dice

We also modeled a hypothetical class diagram for the Blackjack game to demonstrate how such a smart contract could be implemented. The diagram is shown in Figure B.3. To develop a deeper understanding of our design choices, we also include two sequence

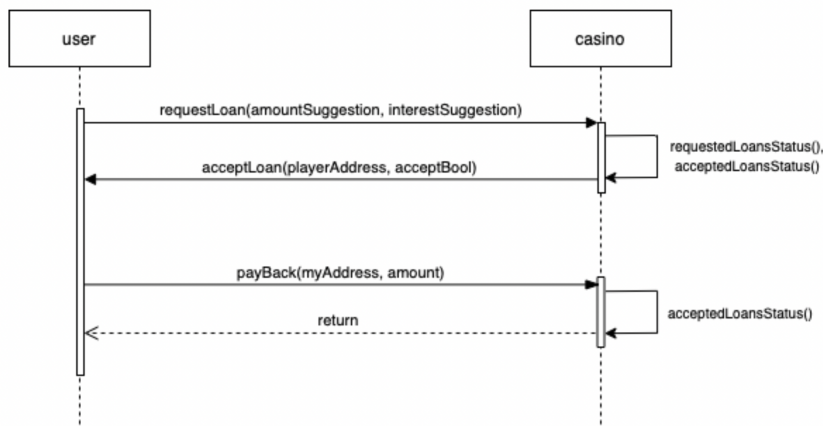


FIGURE B.5: Sequence Diagram: Lend Tokens

diagrams illustrating the roll dice game (Figure B.4) and the lending use case (Figure B.5). Finally, we conclude this section with a state diagram that covers all the states that a user can find themselves in in terms of their financial stability (with respect to tokens).

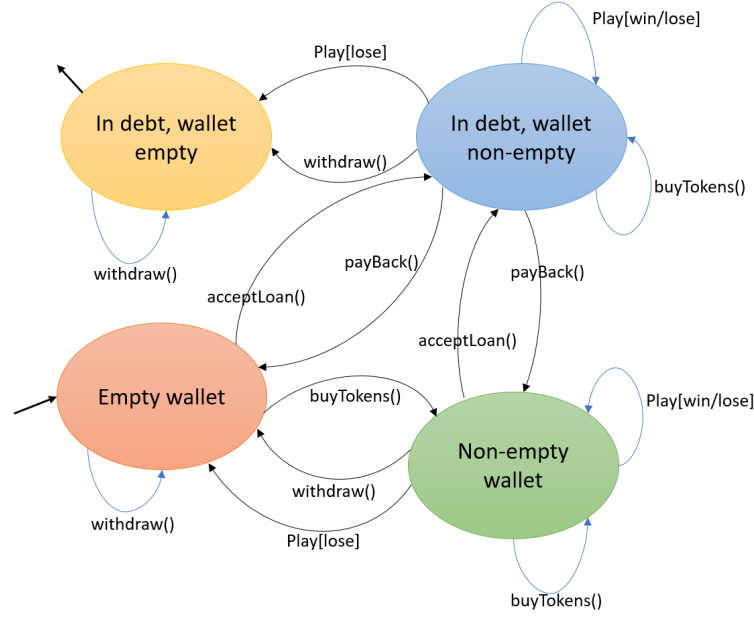


FIGURE B.6: State Diagram

## B.6 Implementation

The front-end aspect of our project provides a graphical user interface for displaying the functionalities of our Ethereum smart contract. For front-end interaction, we use React [178], [179] to provide a visual interface for the smart contract. React is a free and open-source front-end JavaScript library for building user interfaces using UI components. We ran our client-side application (React) in conjunction with Solidity [180] using Hardhat [181]. Similar to tools such as Ganache [182] and Truffle [183], Hardhat is used to develop an Ethereum environment and framework for full-stack development. To enable interactions with our smart contract on the blockchain, we use Ether.js [184]. Similar to Web3.js [185], Ether.js is a javascript web client library, which we use to build our javascript frontend and interact with the Ethereum blockchain. MetaMask [186] is a tool that we used that allows users to store and manage account keys, broadcast transactions, send and receive Ether, and securely connect to decentralized applications through a web browser. In this section, we list the Solidity source code of some of the significant functions of the gaming platform smart contract. The complete source code of the prototype is available on GitHub: <https://github.com/Newman251/CasinoSmartContract>.

### B.6.1 Buy Tokens

This function allows anyone to buy tokens by putting Ether into the contract. At least 10 tokens have to be bought, and a maximum of 1000 tokens can be bought. If the user already has an account on the gaming platform, the newly bought tokens get added to his account. Otherwise, a new account is created for the user to which the tokens are added.

```

//Anyone can buy tokens by putting Ether into the contract.
function buyTokens() external payable{
    require(msg.value > rate*10, "Too low, cost must be greater
than 100"); //At least 10 tokens have to be bought
    require(msg.value <= rate*1000, "Too high, cost must be
less than 10000"); //To prevent fraud at maximum 1000 tokens can
be bought at the same time

    uint256 tokens = (msg.value/rate);

    //check if the user already has a casino account
    bool userFound;
    for (uint i = 0; i < tokenLists.length; i++) {
        //If the user has already a casino account, add the
        //newly bought tokens to his account
        if(tokenLists[i].userId == msg.sender){
            tokenLists[i].amount += tokens;
            userFound = true;
        }
    }
    //If all accounts belong to other users, create
    //a new one for the new customer and add their tokens
    if(!userFound){
        tokenList memory newTokenList = tokenList(msg.sender,
tokens);
        tokenLists.push(newTokenList);
    }
}

```

FIGURE B.7: Buy Tokens

### B.6.2 Request Loan

This function allows players to request a loan by proposing an amount and interest rate. In this function, we make sure that the requested amount is not less than 100 and not more than 10000. Moreover, the interval of the proposed interest rate is also verified. The loan proposal requires approval by the gaming platform owner.

### B.6.3 Accept Loan

The gaming platform owner can accept a loan request by inserting the player's address and a boolean (true = accept) and (false = reject). If the loan is accepted, the smart contract transfers the balance amount to the message sender.

## B.7 Conclusion

In this chapter, we presented a decentralized online gaming platform. The smart contract of the gaming platform provides security for the players as well as the gaming platform itself. This means that all stakeholders are ensured of fairness of the rules of the games, as well as fairness regarding their account balances and winnings. Furthermore, we propose lending functionalities in this gaming platform. This allows players to engage in games using borrowed tokens and playing with their own tokens. We included the implementation details of a platform prototype as a Decentralized Application (DApp) on the Ethereum blockchain. The complete source code of the prototype is available on GitHub.



```

// requesting Loan by proposing an amount and interest rate
function requestLoan (uint256 amountSuggestion, uint256
interestSuggestion) public payable{
    require(amountSuggestion > 100, "You must lend more than
100");
    require(amountSuggestion < 10000, "You cannot lend more
than 10000");
    require(interestSuggestion < 100, "The interest rate needs
to be lower than 100");
    require(interestSuggestion > 0, "The interest rate needs to
be higher than 0");
    require(getBalanceOfOwnerAddress() > amountSuggestion,
"You requested amount is bigger than what the casino can provide");

    uint256 interest = interestSuggestion;
    uint256 amountLended = amountSuggestion;
    uint256 amountToPayBack = amountSuggestion +
(amountSuggestion * interest)/100;

    bool foundRequest = false;
    for (uint i = 0; i < requestedLoans.length; i++){
        if (msg.sender == requestedLoans[i].account){
            foundRequest = true;
        }
    }
    if (!foundRequest){
        loan memory newLoan = loan(msg.sender, amountLended,
interest, amountToPayBack);
        requestedLoans.push(newLoan);
    } else {
        require(!foundRequest, "You already requested a loan
that hasn't been approved yet");
    }
}

```

FIGURE B.8: Request Loan

```

// the casino can accept a loan request by inserting the
players address and a boolean (true = accept) and (false = reject)
function acceptLoan (address payable userAddress, bool accept)
public{
    require((accept == false || accept == true), "The value
must be either 0 (not accept) or 1 (accept)");
    require(debtBalances[userAddress] == 0, "Your still in debt.
Please pay for your past loans first");
    if(accept == true){
        for (uint i = 0; i < requestedLoans.length; i++){
            if (requestedLoans[i].account == userAddress){
                debtBalances[userAddress] +=
requestedLoans[i].amountToPayBack;

                // transfer the balance amount to the message
sender
userAddress.transfer(requestedLoans[i].amountLended);

                loan memory newLoan = loan(userAddress,
requestedLoans[i].amountLended, requestedLoans[i].interestRate,
requestedLoans[i].amountToPayBack);
                acceptedLoans.push(newLoan);

                if (requestedLoans.length > 1){
                    delete requestedLoans[i];
                    requestedLoans[i] =
requestedLoans[requestedLoans.length-1];
                    delete
requestedLoans[requestedLoans.length-1];
                    requestedLoans.length--;
                } else {
                    delete requestedLoans[i];
                    requestedLoans.length--;
                }
            }
        }
    }
}

```

FIGURE B.9: Accept Loan

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## FOLIO ADMINISTRATIF

### THESE DE L'INSA LYON, MEMBRE DE L'UNIVERSITE DE LYON

NOM : URIAWAN  
(avec précision du nom de jeune fille, le cas échéant)

DATE de SOUTENANCE : 02/12/2022

Prénoms : Wisnu

TITRE : Trustworthiness for Personal Lending on Blockchain

NATURE : Doctorat

Numéro d'ordre : 2022ISAL0105

Ecole doctorale : InfoMaths

Spécialité : Informatique

#### RESUME :

Individual borrowers request loans for personal projects or urgent requirements. Small and medium-sized enterprises (SMEs) need loans to scale up their businesses [1]. Most loans given by traditional banks are secured loans, which have terms and conditions that are sometimes not easy for borrowers to fulfill. Banks require collateral or guarantors to guarantee that borrowers return their loans. Collateral can be in the form of assets (i.e., houses, vehicles, savings, deposits, and securities) [2]–[4]. A guarantor is a person who gives some guarantee for the person or SME applying for loans [5], [6]. With a secured loan, the lender can take over an asset provided as collateral if the customer cannot make the loan payments. In addition, many documents may be needed during the loan application process. Administrative costs may be required at the time of application submission as well. There is also little visibility in the centralized process, so the borrower does not know the clear reasons for being accepted or rejected. Moreover, the traditional loan application process is time-consuming.

On the other hand, Blockchain technology is emerging and is successfully applied in many financial applications [7], including Peer-to-Peer lending [8], [9]. In 2020, peer-to-peer consumer lending in Europe (excluding the U.K.) reached 2.9 billion U.S. dollars [10]. P2P lending platforms allow lenders and borrowers to connect without going through a bank. Some of the problems of traditional lending such as burdensome administrative processes can be avoided in P2P lending. A significant increase in P2P lending is estimated to be close to one trillion U.S. dollars by 2050. Today many lending platforms are available supported by Blockchain technology (such as, SALT, BlockFi, ETHlend, etc.), however, they still require collateral [11], which does not help borrowers avoid this burden.

In this thesis, we propose that borrowers' trustworthiness be used as an alternative in lending applications so that borrowers are no longer burdened with collateral or guarantors. The problem is how to reliably calculate trustworthiness. Another problem is how to enforce the conditions of lending and borrowing in a P2P environment. In this thesis, we make several contributions in these areas, which are summarized below.

As a first contribution, we build a borrower trustworthiness scoring model called LAPS. The LAPS formula computes the borrowers' trustworthiness score based on variables such as loan risk, user activity, user profile, and social recommendations. In the LAPS model, we introduce social recommendations in support of a borrower. The advantage of the LAPS score is that it may help to convince the lenders/investors to provide loans with minimal or no collateral. They get assurance that the borrowers are able to pay back the loans, and the recommender bridges the gap between the borrower and the lender.

Our second contribution is to develop smart contracts that enforce the conditions of lending and borrowing in a P2P environment. The smart contracts are program codes powered by Solidity and Ethereum blockchain that can be realized in a decentralized P2P manner. They can replace the intermediary process between users (borrowers, recommenders, and lenders/investors) and eliminate the third party. We use these smart contracts to enable interactions between users (borrowers, recommenders, and lenders/investors) in a secure way where all agreed upon rules are enforced. The smart contracts implement the LAPS trustworthiness score formula.

As the third contribution, we introduce TrustLend as a personal lending platform and present its design and implementation details. We develop a fully functional prototype of TrustLend as a decentralized application (DApp). The prototype shows the features required by borrowers, recommenders, and lenders/investors to rely on trustworthiness by implementing trustworthiness scores with Ethereum smart contracts. TrustLend deploys the smart contracts and applies the LAPS formula to compute the borrowers' trustworthiness scores. We describe the prototype architecture and conduct various personal loan simulations.

TrustLend presents architectural designs that meet the needs of borrowers, recommenders, and lenders/investors, such as permissionless access, integrity, and security. In addition, the platform aims for several other properties: Transparency: all system transactions are traceable and accountable. Automatic enforcement of terms: autonomous transactions by smart contracts are binding for all participants. Reduced costs: we attempt to minimize gas costs for feasible economics. Keywords: Blockchain, Collateral, DApp, Decentralization, Ethereum, Lending, Smart Contracts, Social Recommendation, Trustworthiness, P2P.

**MOTS-CLÉS :**

Blockchain, Collateral, DApp, Decentralization, Ethereum, Lending, Smart Contracts, Social Recommendation, Trustworthiness, P2P.

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