Conditions for achieving high levels of automation in loading and unloading of autonomous trucks

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Abstract

Automation of loading and unloading (LU) is important for fully reaching the suggested benefits from autonomous trucks, but has thus far received limited attention. Current LU solutions automate the physical movement of goods, but many activities are still performed manually. Through a case study consisting of 2 cases, this paper explores automation in LU and has the purpose of identifying conditions for achieving high levels of automation. This paper identifies conditions relating to the interoperability between sender and receiver, and in the activities performed in the material flow, both physical activities and activities in the information flow.

Keywords: Automated loading and unloading, autonomous trucks, interoperability

Introduction

Autonomous trucks have received significant attention in both research and industry (Sindi and Woodman, 2021). There are many suggested benefits from using autonomous trucks such as reducing manhour costs, mitigating driver shortage, saving energy, and decreasing congestion in urban areas (Fritschy and Spinler, 2019; Kim et al., 2022). However, to reap the full benefits of autonomous trucks, the loading and unloading (LU) should be automated in order to enable receiving trucks at all times during the day. This would allow deliveries during night-time when there is little other traffic. As autonomous trucks do not arrive with the capacity of a driver that in most cases today is responsible for the LU (Engholm et al., 2021), it is relevant to consider the automation of LU and the conditions required to do so.

In contrast to many other activities in production and warehousing, LU has not been subject to the same research attention and intense automation development (Winkelhaus and Grosse, 2020). Real-life implementations are rare. The existing solutions mainly involve installations inside the trucks, meaning that trucks are dedicated to a specific flow. The installations, e.g., conveyors in the trucks, matched by conveyors in the LU areas (Xu et al., 2021), are generally used to transfer the entire load of the truck automatically in one move. In contrast, there are solutions that do not rely on installations in the trucks, but where the load transfers are performed by Automated Guided Vehicles (AGVs) (e.g. Ghandriz et al., 2020; Cao and Dou, 2021). The mentioned solutions automate the physical transfer of goods, however LU involves many other tasks. Sanchez-Diaz et al. (2020) show a multitude of tasks performed by the truck driver, including opening gates, securing the goods, managing documentation, etc.

Considering this range of tasks, the existing solutions for LU that have been observed are not fully automated. Full automation of truck transports includes automation of LU as well, in order to replace the truck driver in all parts of the transport (Ghandriz et al., 2020). Analyses aiming at the understanding of automation at various levels have been addressed within the concept of levels of automation (e.g. Frohm et al., 2008; Vagia et al., 2016), covering both physical and informational tasks. The levels range from manual to fully automated. Engholm et al. (2020) indicate that the cost performance of autonomous trucks could be improved by high automation in LU. However, it is not clear under which conditions a high level of automation can be achieved, and there may be several conditions in the physical material flow as well as in the information flow that influence the possibilities of reaching this. By use of a multiple case study, this paper explores automation in loading and unloading and has the purpose of identifying conditions for achieving high levels of automation.

This paper is organised as follows. The next section presents the Literature review. This is followed by a section explaining the Method of the paper. Thereafter, Case descriptions and then Results are presented. The results of the paper are discussed in the Discussion section and the paper is concluded in the last section where Conclusions are presented.

Literature review

First, previous research regarding automated LU is presented. This is followed by a section on interoperability which is important when automated LU is used by senders and receivers of goods. An analysis model is derived from the reviewed literature.

Automated loading and unloading

Automated LU has thus far received limited attention in research. Shen et al. (2019) study automated LU for parcel handling. The authors state there are many factors to consider for LU such as the types of goods, shapes, sizes and weights. The LU may also involve sorting of the goods at the same time which can make the LU more complicated to perform for an automated solution. Echelmeyer et al. (2008) study challenges for automation in logistics processes including automated LU. The type of goods is acknowledged as an important factor for automated logistics. A conveyor LU solution for unloading trucks is suggested by (Xu et al., 2021). The conveyor solution requires that there are conveyors in the receiving and sending facility as well as in the trailer. When a truck arrives, "guiding posts" are used to align the truck with the facility. Cao and Dou (2021) study the use of AGVs for LU of containers. Current problems with using AGVs for container LU include slow speed of operation and issues with reaching sufficient accuracy in positioning. Ghandriz et al. (2020) suggest that AGVs could be suitable to use for automated LU, but there is no standard for the application of AGVs in LU yet. The speed of LU influences the time a truck can be used on the road (Ghandriz et al., 2020), meaning that the frequency and distances of the transport may impact the LU solution. An AGV equipped with a robot arm and a gripper is suggested by Krug et al. (2016) for unloading individual items from a truck or container onto pallets.

Most previous research focus on developing technical solutions for loading or unloading. It is mainly the movement of goods to and from a trailer or container that is automated, i.e. the physical flow but there are additional tasks to perform. The truck driver is usually responsible for several tasks and decisions in the LU like opening of the truck gates and the loading bay gate, load securing and signing documents (Sanchez-Diaz et al., 2020; Sindi and Woodman, 2021). Parasuraman et al. (2000) propose four types of functions where automation can be applied 1) Information acquisition refers to sensing and registering input data. 2) Information analysis mean using the acquired data to, e.g., make predictions, or integrate several input data variables to one which can help human operators. 3) In decision and action selection, actions are selected from a set of available actions. 4) The action implementation refers to performing the chosen action. The four types of functions suggested by Parasuraman et al. (2000) are used in this paper to understand the need for physical automation, as well as automation in the information flow and decision-making.

Interoperability

In a transport chain there is at least one sender and one receiver of goods (Engholm et al., 2021). Automated LU would be needed at both the sender and receiver to manage autonomous trucks at all times of the day. Interoperability is thus important between the sender and receiver as they need to collaborate to use the automated LU. Interoperability refers to the ability of systems to understand and use the functionality of other systems (Chen et al., 2008). Many frameworks and models for interoperability have been developed, for example, EIF, ATHENA, LISI, IDEAS (Chen et al., 2008; Vernadat, 2010) concerning aspects of interoperability such as technical, organisational, semantic, and legal aspects. Although these frameworks mostly concern interoperability in the information flow, in LU there can be physical aspects to consider regarding interoperability as well.

Four layers for interoperability are commonly used, see e.g. the European interoperability framework (EIF). Organisational interoperability regards aligning processes and goals. Semantic interoperability concerns the formatting of data, and that data and information are understood. Technical interoperability refers to infrastructures and applications that connect systems. For LU, this may concern that different unit loads are used, frequencies of transports and as Xu et al. (2021) explain that guiding rails are needed to align the truck with the facility. Finally, legal interoperability regarding that organisations can work together when operating under legal frameworks. The legal aspects may concern different terms regarding the responsibility during transport (Stojanović and Ivetić, 2020), and in relation to LU, the responsibilities of the sender and receivers and ownership of resources may be important. The mentioned interoperability frameworks have been used in academic papers (e.g. Vernadat, 2010; Leal et al., 2019) and in this paper, four layers of interoperability are used to understand conditions for achieving a high level of automation in LU, in the interaction between sender and receiver. It is important to look at the interoperability between the sender and receiver to identify conditions, i.e., beyond the conditions directly related to the material flow.

Analysis Model derived from theory

Figure 1 shows the analysis model created from literature. The material flow activities include all the activities and decisions performed in the material flow, both physical and in the information flow. Here the types of functions presented by Parasuraman et al.

(2000) are used to categorise each activity. As a sender and a receiver are involved in the automated LU, interoperability between them is important and here the four presented interoperability layers are used to identify conditions relating to the interoperability. The model assists in identifying conditions for achieving high levels of automation.

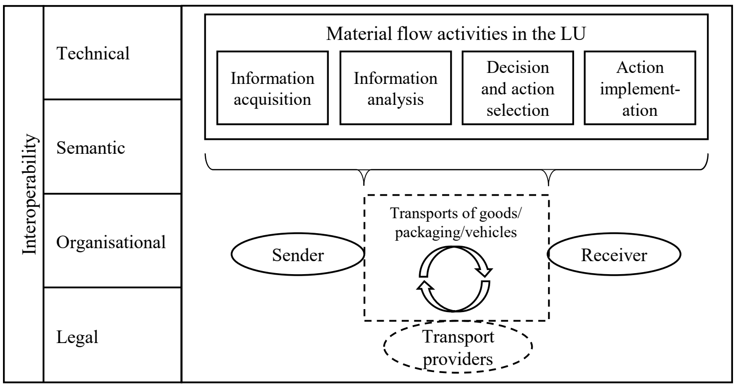


Figure 1 – Analysis model for the paper

Method

This section describes the method of the study. Case selection is described followed by data collection. How the analysis of the paper was conducted is then described.

Case selection

A multiple case study consisting of two cases was conducted in this paper. Studying multiple cases can improve validity as well as reduce the risk of observer bias (Voss et al., 2002). The cases concern industrial material flows, i.e., the deliveries take place between warehouses and production facilities. Case 1 involves the use of dedicated trucks with installations in the trailer and in sending and receiving facilities. In Case 2, AGVs are used for the LU. In Case 2, the sending and receiving facilities belong to the same company, whereas in Case 1, they belong to different companies. None of the studied cases today have fully automated LU, the solutions automate parts of the physical movement of goods to and from a truck. The differences in the cases allows for collecting data on several conditions in the automated LU.

Data collection

The main part of the data collection consisted of interviews. Employees at both the sending company and the receiving company were interviewed. Interviews were performed with employees working with the daily operations using the LU solutions i.e., truck drivers and operators in the inbound and outbound processes providing data on the operational level. Engineers working with more strategic issues and design of the solutions were also interviewed which provided data relating more to the interoperability layers. This provided a comprehensive data set on LU solutions.

In addition to interviews, direct observations of the material flows were performed. The observations along with the interviews provided an understanding for the activities involved in the LU, and which employee roles were involved and at what stages in the process. It also provided a further understanding for the information flow.

The final data source consisted of documents relevant for the purpose of the study. These documents concerned technical descriptions of the LU solution and the responsibilities of the sender and receiver. The three data sources, interviews, direct observations and documents provided opportunities for triangulation which can improve validity (Voss et al., 2002). Additionally, having several data sources for the same phenomenon increases the reliability of the data.

Analysis

The collected data is analysed based on the Figure 1, regarding the layers of interoperability, the types of functions from (Parasuraman et al., 2000) together with the review of previous research on automated LU. The activities performed in the LU are analysed through the four functions, in order to identify conditions for achieving high levels of automation in LU. The interoperability layers facilitate the analysis of the conditions relating to the interaction between sender and receiver.

Case descriptions

The studied cases are described based on the analysis model presented in Figure 1 where the layers of interoperability are presented for each case, and the activities performed in the LU are categorised according to the types of functions of (Parasuraman et al., 2000).

Case 1

Case 1 is within automotive regarding a material flow of palletised goods from a nearby warehouse run by a third-party logistics provider (3PL) to an assembly plant for an original equipment manufacturer (OEM). An automated LU solution involving conveyors is used at the 3PL and at the OEM.

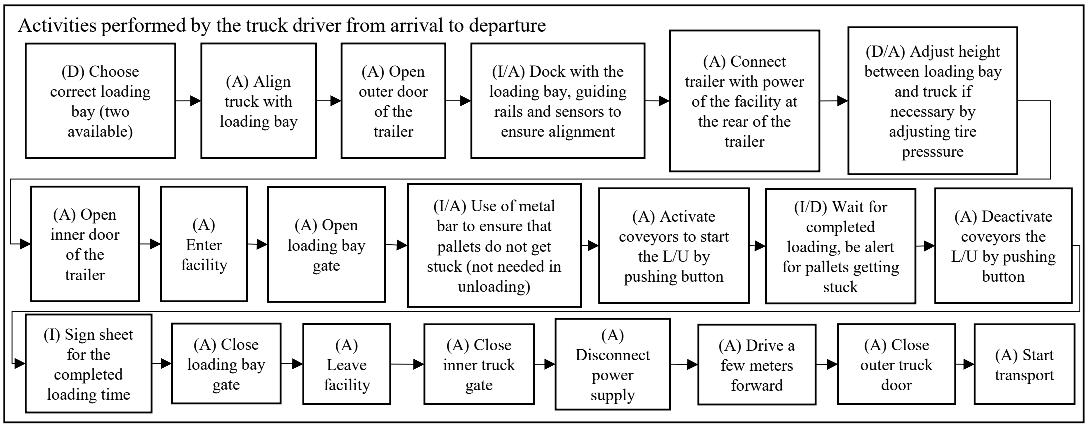
Organisation - This material flow concerns two actors, the automotive OEM and the 3PL operating the warehouse. Nine truck drivers are involved in the flow over three shifts. The transports are run according to a fixed schedule. The truck drivers are employed by the 3PL. The flow is performed almost every day, all day around. Only on Saturdays and Sundays there are no transports in this flow. Two trucks are involved in this flow and a truck arrives every 30 minutes. When a reorder point has been reached for a pallet in the assembly, an order to replenish that pallet is directly received by the 3PL.

Legal - The 3PL owns the trailer and the trucks, and the OEM buys the transport service from the 3PL. If there would be any damage to the goods, the 3PL is responsible and has to compensate the OEM.

Semantic - The 3PL is connected to the OEM's IT systems. Information is transferred between the OEM and the 3PL according to a predefined standard. Information is also transferred in writing on paper when the truck driver signs a sheet at the control panel for the LU solution that a delivery has been completed. In the event of accidents or problems, telephone calls are used to contact the OEM.

Technical - The automated LU solution in this flow consists of conveyors in the trucks, matched by conveyors in facility of the 3PL, and in the OEM. A full truck load is transferred to or from the trailer when the conveyors are activated. The conveyor in the trailer requires that the truck is connected to the power grid of the facility. Guiding rails have been installed at the loading bay gate to align the truck with high precision with the facility for the LU to work. A large metal plate is placed on the ground where the trailer is parked. This plate is supposed to keep the ground flat and help with the alignment of the trailer but due to weather conditions such as snow and rain, the metal plate may shift which can affect the alignment. The LU solution provides benefits in terms of faster turnaround times for the trucks. Palletised goods are delivered to the factory, empty packaging material and pallets are not returned to the warehouse but are managed in another flow. The trucks are thus loaded when going to the OEM and empty when going back to the 3PL. There are a number of different types of pallets managed with different dimensions.

Material flow - The mechanised loading and unloading of the pallets are described in further detail in Figure 2 which describe the activities performed by the truck driver in the LU. Figure 2 shows the activities when arriving at the 3PL until the truck leaves to the OEM. The process is the same for the unloading process with the exception of one activity as indicated in the figure. There have been situations when the truck driver has forgotten to unplug the trailer from the power of the facility, damaging the electrical unit. Many physical activities are performed relating action implementation such as open gates and doors, plugging into the power supply etc. There are also decisions to make, for instance regarding the alignment between the loading bay and the trailer. The truck driver needs to sign a delivery sheet which relates to information acquisition.



I = information acquisition/analysis, D = decision and action selection, A = action implementation

Figure 2 – The activities performed by the truck driver in the LU in Case 1

Case 2

Case 2 regards a material flow between a factory and a finished goods warehouse within a company producing components in mechanical engineering. An automated LU concept is under development but is not fully operational yet. The concept consists of automated LU performed by AGVs to load and unload an autonomous truck driving between the factory and the warehouse. The autonomous truck is controlled remotely when docking to a facility, but driving is autonomous. Part of the route takes place at a public road.

Organisation - The company is both the sender and receiver of goods in this case. An autonomous truck is delivering finished goods from the factory to the warehouse. Finished goods are moved from the factory to the warehouse when a full truck load is achieved. First in first out is applied for moving goods from the factory to the warehouse. The autonomous truck is remote controlled when docking. About ten transports are performed each day.

Legal - The truck transport and the LU is performed within one company, ownership of resources and responsibilities regarding the LU belong to the case company. No specific terms or agreement are used for the LU.

Semantic - Different IT systems are used in the warehouse and in the factory. In order to move goods between the systems, scanning of the pallets is needed in the factory and in the warehouse. The AGV system has its own control system which is connected with the IT systems in the company as well. Communications is performed to and from the autonomous truck.

Technical - AGVs are used for the LU and there are no fixed installations in the truck or in the facility for the LU. An arriving truck does not have to connect with the power supply of the facility. Palletised goods are moved in this flow. The autonomous truck drives a predefined circuit from the factory to the warehouse and then back to the factory.

The truck docks to the same loading bay each time. The truck is loaded when going to the warehouse and empty when going back. When the truck is ready for LU, an AGV moves pallets one by one from/to the loading area to/from the truck. The AGVs work are a slower pace than manual operators in the LU but the AGVs can operate around the clock and the AGVs can work when there are no employees present. The AGVs scan barcodes in the LU. This requires that the barcodes are always located at the same spot on the pallet. If the barcodes cannot be scanned, the AGVs require manual assistance.

Material flow - The activities in the Figure 3 are performed by operators in the factory or warehouse unless otherwise stated. As stated, an operator controls the autonomous trucks remotely when docking to the factory or warehouse. The figure shows that there are physical actions connected to the action implementation like opening gates. The AGVs scans the pallets which is important in the information flow, to make sure that the pallets are moved between systems. The scanning of the pallets is performed automatically. Decisions are made regarding when the truck is ready for loading and ready for departure.

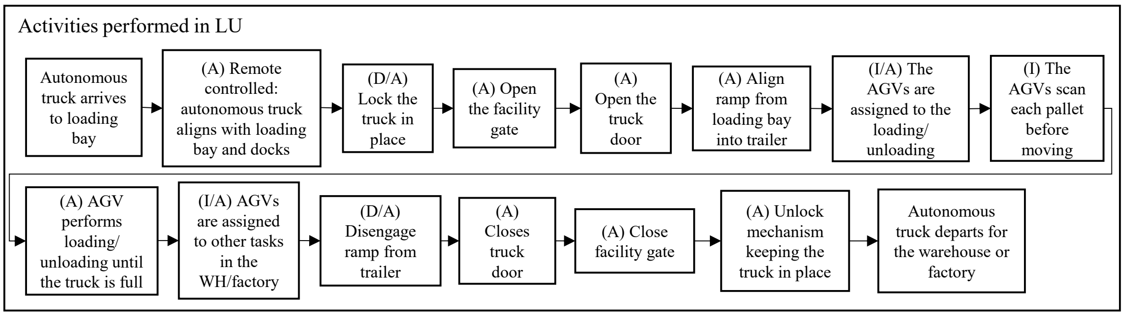


Figure 3 – Activities performed in the LU in Case 2

Results

The results of analysing the cases are presented in this section. Conditions for reaching high levels of automation in each of the interoperability layers are presented as well as conditions related to the activities performed in the material flow.

Organisational

Collaboration between sender and receiver is a condition for reaching high levels of automation when conveyor solutions are used since the trailers are dedicated to the flow. This was seen in Case 1 where both sender and receiver had invested in the same solution and aligned goals regarding the LU. The AGV solution is more flexible in that regard as it does not require investments from both sender and receiver to the same extent. For example, the sender could use AGVs while the receiver does not.

Legal

When there are shared resources and adaptions to make use of the LU solution, responsibilities of the sender and receiver create conditions for the LU, as in Case 1. Terms regarding, e.g. goods damage and payments need to be in place. These legal aspects are important to come to an agreement on. In Case 2, where the truck transport and the LU take place within one company, the legal aspects were not as prominent.

Semantic

A condition from the semantic layer regards being able to send and understand data between sender and receiver since goods need to be moved between systems in addition to being moved physically. The cases highlight that information and data need to be sent and understood between the sender and the receiver. As seen in Case 2, two different systems in the warehouse and the factory where scanning of the pallets is needed to ensure that the goods are moved between systems, even if it is within one company. The cases show that opening facility gates and activating the LU solutions are performed manually. A condition to reach high levels of automation regards the sending and receiving of data from the truck to the facility and vice versa for performing these activities automatically.

Technical

Investments in equipment was needed for sender and receiver in Case 1 regarding purchasing matching conveyors in the facilities, guiding rails to align the truck, connections to the power grid. These adaptions were required in Case 1 where the trailers have dedicated equipment installed. These types of adaptions between the sender and receiver are more limited in the Case 2 where AGVs are used. No additional equipment is needed in the warehouse or the factory in Case 2. However, the AGVs are slower than the conveyor solution meaning that a condition is that there is more available time.

Scanning of the pallets is a condition to ensure that the correct pallets are sent and received as well as for transferring between systems. For high levels of automation in LU, automatically scanning the pallets is a condition. The AGVs automatically scans the pallets in Case 2, but this requires that the barcodes are located at the same spot on each pallet, and if the barcodes would be unreadable, manual intervention would be needed.

Material flow

The cases show that many activities are still performed manually in the LU, in the information flow and physical actions. Judgements by the truck driver in Case 1 and the operators in Case 2 are needed in many situations relating to information acquisition, information analysis, and decision and action selection. For example, scanning of pallets, when is it time to start a transport, is the truck aligned with the loading bay, is the trailer at the correct height, are goods placed correctly in the loading, and is the loading completed. Physical activities connected to the action implementation include, e.g., opening and closing gates, connecting the trailer to the power grid in Case 1, and activating the LU solutions. Automating these activities are conditions identified from the cases to achieve high levels of automation. With autonomous trucks, additional sensors to collect data, and decision-making regarding, e.g., if there is sufficient alignment between the loading bay and the truck, would be necessary. The cases show that physical activities are important connected to action implementation, such as opening and closing gates, scanning of unit loads, connecting the trailer to the power grid for the conveyor solution and aligning the ramp into the trailer with AGV solution. These physical activities are further conditions.

Summarising results

The results from the paper are summarised in Table 1 connecting the results to the interoperability layers and the types of functions that can be automated.

Table 1 - Summarising identified conditions for achieving high levels of automation in LU

Dimension of analysis model	**Condition for achieving high levels of automation**
Organisational	Collaboration between sender and receiver regarding the use of the LU solution need to be in place, especially for the conveyor solution where sender and receiver need to use the same conveyors.
Legal	Terms and agreements in place, responsibilities of sender/receiver in different situations e.g., goods damage being agreed.

Semantic	Connection to IT systems between sender and receiver established, it needs to be possible to move unit load between IT systems at the sender to the systems used by the receiver.
Technical	Adaptions like use of guiding rails, connection to power grid in case of a conveyor solution are required. The AGV solution is more flexible with more limited adaptions needed, however the AGV solution needs more time to complete LU.
Information acquisition and analysis	Signing documents for delivery confirmation and scanning of pallets to know which pallets to move are activities that need to be performed automatically in the information flow
Decision and action selection	Making decisions such as determining when LU is ready to start or when LU is completed should be established without requiring manual interventions
Action implementation	Opening and closing gates, aligning ramp into trailer (for AGV solution), and connecting to the power grid of the facility (conveyor solution) are physical actions that need to be automated.

Discussion

The paper contributes to research regarding autonomous trucks focusing on the LU which has seen limited attention in previous studies. Automated LU is important for autonomous trucks, to be able to fully reap the benefits suggested in literature such as deliveries during off-peak hours and reducing congestions in urban areas (Fritschy and Spinler, 2019; Kim et al., 2022). Of the limited attention paid to automated LU, much of it is directed towards different technical solutions (e.g. Krug et al., 2016; Cao and Dou, 2021; Xu et al., 2021). However, there are many activities and interoperability aspects to consider beyond what has been addressed in these solutions as the studied cases show. This paper shows that many conditions for reaching high levels of automation in the LU are related to activities in the information flow and in the physical activities performed in the material flow where the analysis model derived from theory has been useful for identifying conditions for reaching high levels of automation LU. This paper contributes to practitioners as well as it highlights several conditions for reaching high levels of automation which can help in applying a suitable LU solution and knowing what conditions needs to be fulfilled to reach high levels in LU. The findings from the paper on the conditions for reaching high levels of automation are relevant for LU solutions for manually operated trucks as well as for autonomous trucks. This could potentially improve the speed of the LU in case of conveyors. For the AGV solution this could provide most benefit for autonomous trucks considering that they are slower than a manually performed LU.

This paper has focused on LU in industrial settings where there are loading bays and the unit loads are standardised. Automated LU can be investigated in last-mile deliveries. Deliveries in urban environments may involve more variation, for example, many different loads, loading bays, variations in volume, and many stores, shops and restaurants may be involved in the same delivery round. These variations can add conditions for reaching high levels of automation in LU and could be an avenue for future research. In the paper, transports are performed within one country, further interoperability conditions for automated LU might arise when transports are performed over internationally such as customs and different legal frameworks to comply with. Further research could study automated LU solutions in transports internationally.

Conclusions

Automated LU is important to benefit from autonomous trucks fully when no truck driver is present to perform the LU. This paper has shown that there are several conditions relating to the activities performed in the LU which today are mostly manual.

Interoperability regarding organisational, legal, semantic and technical aspects influence the automated LU as well considering that senders and receivers interact and may share LU solution as well as making adjustments to ensure that the LU performs well.

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