Order picking in dense areas – productivity impact of confirmation methods

Patrik Fager (fagerp@chalmers.se)
Chalmers University of Technology,
Department of Technology Management & Economics

Robin Hanson
Chalmers University of Technology,
Department of Technology Management & Economics

Lars Medbo
Chalmers University of Technology,
Department of Technology Management & Economics

Mats I. Johansson
Chalmers University of Technology,
Department of Technology Management & Economics

Abstract

Confirmation methods are applied in supply chain order picking to increase picking quality, but research is lacking about how various confirmation methods affect picking productivity. This paper's purpose is to identify the extent by which the type of confirmation method affects picking productivity in dense areas. Four confirmation methods (button-presses, barcode-scans, voice-commands, and RFID-wristbands) are studied in an experiment. The placement confirmation method is found to greater impact productivity than the picking confirmation method, and RFID-wristbands and button-presses display higher productivity than barcode-scans and voice-commands. The findings are relevant for practitioners and academics involved with designing order picking systems.

Keywords: Mixed-model assembly, Order picking, Picking information systems

Introduction

Mixed-model assembly often involve numerous component variants and the materials supply to assembly is critical. Kitting is a materials supply principle, by which assembly is supplied with kits of components sorted by assembly object (Bozer and MacGinnis, 1992), that has been associated with many benefits when applied in mixed-model assembly (Medbo, 2003), especially when the number of component variants is large

(Caputo and Pelagagge, 2011). Preparation of kits is typically performed by manual labour at designated picking areas, and order batching – meaning to complete several kits during the same picking tour – is commonly applied for improving productivity (Hanson et al., 2015). Batch preparation of kits brings with an added complexity during the picking tour – as more components need to be handled at once and components are distributed across multiple kit-containers (Brynzér and Johansson, 1995) – that can compromise quality. In industry, quality problems with kits can lead to severe consequences for the production system and a high quality outcome of the kit preparation process is critical (Caputo et al., 2017). Previous research dealing batch preparation of kits has shown that the way in which picking information is conveyed to the picker is crucial for both quality (Caputo et al., 2017) and productivity (Hanson and Medbo, 2016). However, industrial applications of picking information systems usually require confirmations for when components are extracted from storage – a *pick-from confirmation* – and when components are placed into a kit – a *place-to confirmation* – to protect against errors during the picking tour. Although pick-from and place-to confirmations are applied to improve the quality outcome of completed kits, they likely also impact the productivity (Guo et al., 2015). Previous research acknowledges confirmations to be important from a quality standpoint (Hanson et al., 2015; Guo et al., 2015; Battini et al., 2015), but literature is very scarce about what productivity effects should be expected from applying various confirmation methods in kit preparation. Given the fast-paced picking that normally characterises kit preparation (Hanson et al., 2017), the productivity effects from applying confirmations may be substantial. Moreover, there is no consensus in industry about what confirmation method should be applied for batch preparation of kits.

Kit preparation is usually performed at dense picking areas and – in difference to typical warehouse order picking contexts (Battini et al., 2015) – the travel time component is typically small and picking is performed at a high frequency (Hanson et al., 2017). Here, interaction with the picking information system can make up a substantial portion of the picking time. There are various methods available for performing confirmations, several which are typically associated with a certain means of information conveyance; for example button-presses or proximity sensors in pick-by-light systems, voice-commands in pick-by-voice systems, or barcode scanners together with pick lists presented on paper or on a monitor (Battini et al, 2015), and confirmation methods involving RFID-reading gloves and wristbands are emerging (Andriolo et al., 2016). However, there are no studies that explains what productivity effects may be excepted from applying confirmation methods in kit preparation. Moreover, it is conceivable that different confirmation methods are beneficial for time-efficient kit preparation when applied as either pick-from or place-to confirmation method. There is a need for research that explains the effects on productivity when confirmations are applied as a means to support the quality outcome in batch preparation of kits.

It is important for practitioners to know how applying confirmations with batch preparation of kits impacts the productivity of kit preparation, so that the trade-off between quality and productivity can be understood and an appropriate confirmation method may be applied. Moreover, it is important for the academic discourse to include the role of various confirmation methods in terms of their relevance for productivity when dealing with information systems applied in the high frequency picking that typically characterise kit preparation. The purpose of the current paper is to determine the extent to which the type of confirmation method – applied as a part of the picking information system to support kit preparation – is related to time-efficient kit preparation when order batching is applied.

To address the purpose of the current paper, a realistic laboratory experiment, simulating batch preparation of kits for mixed-model assembly, is applied. Four methods for performing confirmations – barcode-scans using a ring-scanner, button-presses, voice commands and RFID-scans with two RFID-reading wristbands – are studied by their impact on productivity when used as means to confirm components picked from storage or as means to confirm components placed in the kit-containers. The four methods are selected based on their prominence in recent research and on their typicality of being applied in industry. The kit preparation workspace is set up in a laboratory environment, including typical automotive components from car and truck assembly industries to replicate a realistic kit preparation process utilising order batching of four kits. All four confirmation methods are tested with information conveyance by means of a pick-by-light system, which is one of the most commonly used means for information conveyance in industrial applications of kit preparation. The remainder of this paper is organised as follows: in the next section the theoretical framework around the four technologies is presented and the kit preparation workspace is explained. Thereafter, the method is outlined, describing the premises for the experiment and how the experiment was carried out. Following the method, the results are presented, which are discussed in the section thereafter. In the last section, the conclusions are formulated.

Theoretical framework and experimental settings

Previous studies dealing with confirmation methods and hypothesis formulation

While some literature is concerned with picking information systems applied in warehouse order picking (e.g. Battini et al., 2015; Andriolo et al., 2016) and kit preparation (Hanson et al., 2017), confirmation methods are mostly treated as side-note to means of information conveyance. Guo et al. (2015) compared the productivity and picking accuracy of order picking supported by a paper list, light indicators, a cart mounted display, and a head-up display in an experiment focusing on productivity, accuracy and ergonomic factors of order picking. The study did not include confirmations but suggests confirmation methods to be studied in further research, especially from an productivity standpoint. In warehouse order picking, some research considers confirmations associated to picking items from storage, but no studies have been identified that also considers the case of placement confirmations when order batching is applied.

In kit preparation, Hanson et al. (2015) found batch preparation of kits to be superior over single-kit preparation in terms of productivity when using a cart-mounted display to convey picking information. In that study, confirmations were made by pressing a button on the monitor when an order line had been completed. When discussing the results, Hanson et al. (2015) notes that batch preparation of kits may be problematic from a quality point of view, as distribution of components among multiple kit-containers introduces the risk of placement errors, and suggest further research to study how various technologies, for example RFID, may support the quality outcome of kit preparation. Moreover, Hanson et al. (2017) found that picking information conveyed by means of augmented reality better supports efficient kit preparation than a paper pick list when batch preparation is applied. In that study, the augmented reality based system applied voice-based confirmations to confirm order lines as completed. Relating to quality, Hanson et al. (2017) discusses how different methods for confirmation may be used in association with picking information presented by augmented reality and suggests further research in this direction.

Relating to the purpose of the current paper, the literature review indicates a gap concerning confirmation methods associated to picking activities in previous research, both in warehouse order picking and in kit preparation. Moreover, research that regard the use of confirmations that associate to placing components in kit containers when batch preparation is applied seem particularly scarce.

In warehouse order picking, Battini et al. (2015) compared five picking information systems on basis of economic and technical factors. In that study, various types of confirmation methods were considered when picking items from storage, including barcode scanning by handheld barcode scanner, button presses, voice confirmations and RFID-passive tag scanning by means of an RFID-reading glove. Different methods for confirmation were assigned different activity times and confirmation by means of RFID-reading gloves required no time to perform. That study showed that when the travel time component during the picking tour is smaller, the time spent on administration of the picking information has greater relevance for the picking tour. As kit preparation normally is performed at denser picking areas than in typical warehouse order picking contexts, the administration time associated with performing confirmations when picking from the storage would likely make up a substantial portion of the picking time. On this note, the first hypothesis of the paper is the following:

H1: *When pick-from and place-to confirmations are required with batch preparation of component kits, the applied pick-from confirmation method affects the productivity of kit preparation.*

When order batching is applied in kit preparation, picked components are distributed among multiple kit-containers. Previous research has considered how confirmation by order line – meaning that all components of a part number that are distributed among the kit-containers are confirmed by a single confirmation activity – may impact productivity (e.g. Hanson et al., 2015; Battini et al., 2015). However, as a means to ensure quality in completed kits, industrial applications of batch preparation usually require that each kit-container in which components are placed are confirmed separately. Literature is not clear about the effects on productivity that placement confirmations have in kit preparation. Moreover, how various methods for confirming placements impacts productivity of batch preparation of kits is important knowledge for both practitioners and academics. Accordingly, the second hypothesis of the paper is the following:

H2: *When pick-from and place-to confirmations are required with batch preparation of component kits, the applied place-to confirmation method affects the productivity of kit preparation.*

The knowledge resulting from testing H1 and H2 would make a direct contribution to practice by demonstrating for practitioners working with the design and operation of processes for kit preparation what impact the choice of confirmation has on the productivity of batch preparation of kits. For academia, the knowledge outcome from testing H1 and H2 would contribute to the growing literature around information support systems applied to order picking and in-plant logistics processes, by supplementing the understanding of how various technologies applied on an operational level affects the performance of the larger system, in terms of the plant or the supply chain.

A realistic experiment is applied to test H1 and H2. The experimental settings and the factor levels are described in the next section.

Experimental settings and the kit preparation workspace

In this section, the experimental settings and the levels used for the various factors are presented.

All picking information systems involve the same basic types of activities and follow the same general procedure. The difference between types of picking information systems is that some systems allow some activities to be performed simultaneous with other activities (Battini et al., 2015). With batch preparation of kits, some confirmation methods – for example button presses – would allow placement of components and the associated confirmations to be made two kits at a time, since the picker can press a button with each hand, while others – for example barcode-scanning – only would allow for placing components in one kit at a time, since only one barcode can be scanned at a time. Furthermore, the benefits in terms of productivity may differ for various confirmation methods depending on whether they are applied for picking confirmation or as placement confirmation. On this note, the confirmation method was modelled as two factors: pick-from confirmation method and place-to confirmation method.

The confirmation methods to include were selected based on their prominence in recent research and by their typicality for being used in practice, as has been encountered in several case studies concerned with kit preparation (e.g. Hanson and Medbo, 2016). Each factor was assigned four levels: barcode-scan, button-press, voice-command, and RFID-scan. For barcode scanning, a ring-scanner worn on the wrist was applied, as it is a common method in industry and the ring-scanner design technically allows two hands to be used for picking. For button-presses, typical buttons integrated in a pick-by-light system was used. For voice-commands, a typical pick-by-voice application was modelled by means of a pair of smart-glasses, utilising check-digits positioned in association with all picking and placement locations. For RFID-scanning, double RFID-reading wristbands were selected – meaning that the picker wore one wristband on each arm – that allowed the pickers to confirm with either hand. Each method was combined with the other methods as either pick-from or place-to confirmation method, or both, resulting in 16 confirmation method combinations in total. To avoid having the impact of the means of information conveyance influence the comparison of the confirmation methods, the same means of information conveyance was applied, in form of light-indicators typical for pick-by-light applications used in industry.

The kit preparation workspace was designed as a realistic simulation of an industrial application for kit preparation. A dense picking area was designed so that the travel time component during picking would be small, since travel time was not the focus of the study. The batch size was chosen to replicate the productivity benefits normally associated with batching, and based on previous research (Hanson et al., 2015), a batch size of four kits was deemed sufficient and thereby chosen. To test H1, the methods are compared in terms of productivity when applied as pick-from confirmation, with the four methods varied as place-to confirmation, and H2 is tested by comparing the methods applied as place-to confirmation, with the four methods varied as pick-from confirmation.

Confirmation methods

Here, the four types of confirmation methods that are studied in the current paper are described in terms of how they were applied for picking- and placement confirmation, respectively.

Barcode-scans are typically performed by barcode scanners that can be either handheld or worn as a glove – a so called ring-scanner. In the current setup, a ring-scanner was applied, as it allows hands-free handling of components and is common in industrial applications of both warehouse order picking and kit preparation. When applied for confirming components picked from the storage, the picker scanned a barcode mounted on the shelf supporting the package holding the components. The effective scanning range was up to two meters. The operating scheme for using the barcode scanner for picking confirmation was to perform the barcode-scan immediately after the components had been picked. Similarly, when used for confirming placement of components in the kit-containers, the barcode scan for each kit-container was performed immediately after a component had been placed in the kit-container. The barcodes on the cart were positioned in the centre in front of each kit-container on the shelf which supported the container.

Button-presses is a confirmation method that is commonly used in association with light indicators in pick-by-light systems, but may also be used independent from light indicators in some applications. In the current setup, the buttons were integrated in the pick-by-light system, mounted above each storage package holding the components in the shelf, and above each kit-container on the trolley. When applied for confirmation of picks made from storage, the button press was made immediately after the components had been picked from the storage package. Similarly, a button-press corresponding to each kit-container on the cart was made immediately after components had been placed in the kit-container.

Voice commands are typically used in pick-by-voice systems but are also available for other types of wearable communication devices, for example HUD-systems (Hanson et al., 2017). Here, confirmation by voice command was realised by the microphone in a set of smart-glasses which the picker wore as a necklace. For confirming components picked from storage, the picker spoke the word "Box" followed by two check-digits presented on a label positioned on the shelf holding the storage container, meanwhile picking the components. For confirming placement of components, the four kits on the cart were color-coded in red (kit 1), green (kit 2), blue (kit 3) and yellow (kit 4) and the picker simply spoke the colour while placing the components in the kit-containers.

RFID-scans are based on a technology that has been around for quite some time but never becoming fully adopted by industry. However, more recently different applications for using RFID-scanning as a means for confirmations in order picking have shown promising potentials (Andriolo et al., 2016, Battini et al. 2015). In the current setup, a novel system consisting of two RFID-reading wristbands – one band worn on each arm – was applied. The method consisted of scanning an RFID-tag positioned on the brim of each storage container in the shelf and on each kit-container on the cart. When applied for confirming components picked from storage, the RFID-wristbands automatically scanned the RFID-tag as the picker reached inside the package to grasp the components. Similarly, the RFID-tag on the respective kit-container was scanned when the picker placed the components in the kit-container. The reading range for the RFID-scan was set to 8 centimetres when picking from the shelf and 16 centimetres when placing components in the kits in proportion to the size of the containers in the shelf and on the cart, respectively.

Method

The empirical basis of this paper is a realistic laboratory experiment, set up to simulate a dense picking area for kit preparation to a mixed-model assembly line. The experiment was designed in accordance with the procedure described by Coleman and Montgomery (1993). In line with the study's purpose, the response variable was selected as the average time for picking and placing one component. The methods for pick-from and place-to confirmations were treated as two different variables, each with four levels: barcode-scan, button-press, voice command and RFID-scan. Four pickers – three male and one female between 20-30 years old – without previous experience of order picking were recruited to perform the picking work, each replicating the experiment 7 times. It was a criterion for participating in the experiment to not have previous experience of order picking, as a fair comparison between the technologies was sought and it was considered unlikely to find pickers with equal amounts of experience from using the four technologies. Furthermore, in industry, order pickers tend to have little experience due to the high personnel turnover rates (Glock and Grosse, 2013).

Automotive components from car and truck manufacturers were selected for picking, ranging from small- to medium-sized components. All pickers received a full day of training before the experiment started, practicing with the different confirmation methods. Once the participants individual learning curves had flattened during the training sessions, the actual conditions for experiment were also practiced.

The different technologies were installed in the laboratory environment by the developers of the equipment. To make is possible to combine all four technologies for picking and placement confirmation, a custom software was developed, that ran on a computer located nearby to the kit preparation workspace.

The experiment schedule was randomised for each of the participants, meaning that each picker used the 16 combinations in a randomised order, and that the seven different picking tours also were performed in a randomised order. Randomisation is especially important when dealing with people, as learning effects can be substantial otherwise (Glock and Grosse, 2013).

The statistical analysis involved ANOVA with post-hoc testing, comparing the systems on basis of time per picked component. For hypotheses I and III, Levene's test indicated that homogeneity of variances could not be assumed ($p<0.05$) why Tamhane's T2 test – a procedure that do not require the assumption of homogeneity of variances to be fulfilled – was chosen as post-hoc procedure. For hypothesis II, Levene's test showed that homogeneity of variances could be assumed ($p = 0.428$) and Tukey's honest statistical difference (Tukey HSD) was applied.

Results and analysis

The results indicate several statistically significant differences between the confirmation method permutations, as shown in Table 2.

Hypothesis I: Type of confirmation method associated with picking from storage

The ANOVA showed significant differences between the groups of methods used for pick-from confirmation ($p<0.05$). Post-hoc analysis (Tamhane's T2) revealed the differences between methods shown in Table 1.

Table 1 – One-way ANOVA post-hoc test results (Tamhane's T2) for the four confirmation methods applied as pick-from confirmation.

Method	*Identifier*	*Mean ± 95% CI*	*Std. Dev.*	*Std. Err.*	*Sign. more efficient than*	*Sign. less efficient than*
Button	1	3.82 ± 0.10	0.56	0.05	3, 4	
RFID	2	3.84 ± 0.12	0.66	0.06	3, 4	
Barcode	3	4.12 ± 0.14	0.75	0.07	4	1, 2
Voice	4	4.39 ± 0.11	0.59	0.06		1, 2, 3

Button-presses an RFID-scans was statistically indistinguishable from each other, only 0,02 seconds apart in average picking time per component. Using barcode-scans was more efficient that voice-commands but significantly less efficient than both button-presses and RFID. Overall, the results support that the method used for confirming picking made from the racks affects the productivity.

Hypothesis 2: Type of confirmation method associated with placing in kit-containers
The ANOVA showed significant differences between the groups of methods used for place-to confirmation ($p < 0.05$). Post-hoc analysis by means of Tukey HSD (Levene's statistic showed $p = 0.428$ and equal variances was assumed) showed difference between the methods in accordance with Table 2.

Table 2 – One-way ANOVA Post-hoc test results (Tukey HSD) for the four confirmation methods applied as place-to confirmation.

Method	*Identifier*	*Mean ± 95% CI*	*Std. Dev.*	*Std. Err.*	*Sign. more efficient than*	*Sign. less efficient than*
Button	1	3.58 ± 0.07	0.37	0.03	3, 4	
RFID	2	3.66 ± 0.08	0.40	0.04	3, 4	
Barcode	3	3.98 ± 0.08	0.41	0.04	4	1, 2
Voice	4	4.95 ± 0.08	0.45	0.04		1, 2, 3

Button-presses and RFID-scans was again statistically indistinguishable from each other, although differences between groups was overall larger than between groups of picking confirmation methods. Moreover, barcode-scans were less efficient than both button-presses and RFID-scans, but more efficient than voice-commands. In conclusion, the experiment supported the notion that the method used for confirmation of placements in kit-containers affect productivity of kit preparation when order batching is applied.

Discussion

Methods applied for confirming components picked from storage
The results indicate that the more efficient methods to use for confirming picks made from storage are button presses and RFID-scans. This results likely stems from the small extra motions which are needed by either of these methods. With button presses, the signal that a pick has been successfully confirmed is rather distinct. Furthermore, the buttons were always positioned next to the light indicator, as both were part of the same system, and it was easy to know that the confirmation had been made. However, the button presses resulted in a small extra motion for when a confirmation was made, as the picker had to reach for the button. Mostly, the pickers performed the button presses with little effort, pushing the button immediately after grasping the components in the storage box. The RFID-scans by means of the double wristbands were indistinguishable from the button-presses from a productivity standpoint, and displayed a more fluent but somewhat more hesitant picking. The similar performance between the button-presses and the RFID-bands is an interesting aspect from an implementation standpoint, as the RFID-bands only need a discrete and cheap RFID-tag positioned close to picking location, while buttons usually require either electric wiring or batteries, which involves less flexibility and a higher investment and operating costs than the RFID-solution.

Barcode scans showed to be less efficient than either button-presses or RFID-scans, but more efficient than voice confirmation. While barcode scan requires an extra motion to be performed for making a confirmation when compared with the RFID-bands – the barcode scan also required that the picker was positioned some distance from the shelf for the scan to be possible to perform successfully, causing an interruption to the picking tour. Voice-commands were found least efficient among the methods for pick-from confirmation, likely owing to the restricted overview and small travel time component in the kit preparation workspace. From the results associated to hypothesis I, it seems that confirmation methods that avoid interrupting the picking motion are beneficial to use for confirmation of components picked from storage.

Methods applied for confirming components placed in kit-containers
The experiment supported hypothesis II about the notion that the confirmation method used for place-to confirmation when components are placed in the kit-containers affects the productivity of kit preparation. Button-presses and RFID-scans showed to be the most efficient methods, statistically indistinguishable from each other. A major advantage for button-presses and RFID-scans when contrasted with barcode-scans and voice-commands is that these methods allow for components to be placed and confirmed in two kit-containers at a time, which is not possible with wither barcode-scans or voice commands. In the experiment, when more than one component was picked from storage at the same time, the components could be dispatched to the kit-containers in an efficient way, using both hands, with the button-presses and RFID-wristbands. In contrast, the barcode-scans and the voice-commands required placement of components to each kit-container to be made sequentially, one at a time, for maintaining the association between each placement activity with each place-to confirmation activity. Moreover, the comparatively poor performance of the voice-commands likely stemmed from the pickers having to wait for the command to register – represented by the lit light-indicator on the cart turning off – before proceeding with the placement of the next component in the next kit-container. In contrast with voice place-to confirmations, barcode-scanning confirmation of the next container could be made immediately after the previous one had been completed. By the results pertaining to hypothesis II, it is evident that confirmations that allow both hands to place components and perform confirmations simultaneously is advantageous to use for placement confirmations, as was exhibited by both button-presses and RFID-scans.

Summary of findings
The results regarding the two hypotheses shows that the method used confirming components picked from storage and the method used for confirming placement of components into kit-containers affects the productivity of kit preparation. Figure 1 shows the normalised average picking of the four confirmation methods when applied for pick-from and place-to confirmation.

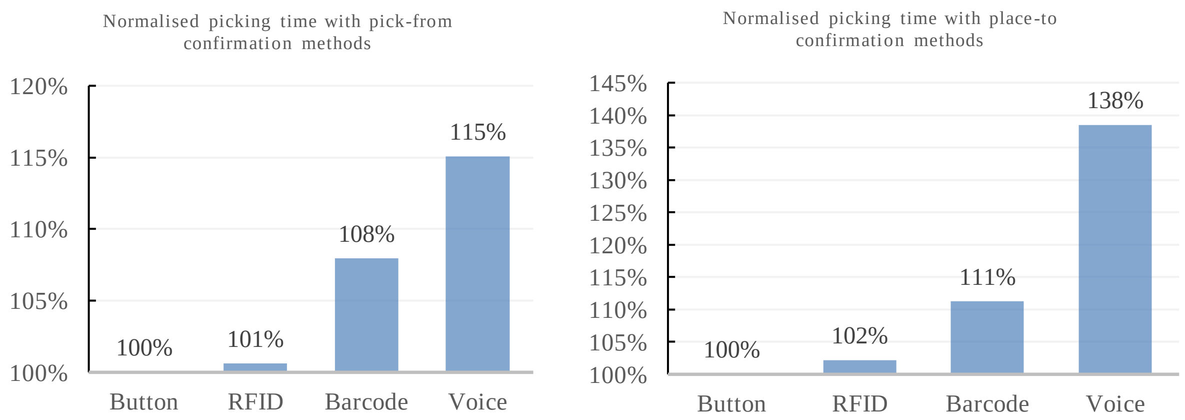

Figure 1 – The normalised average picking time with the four confirmation methods when applied for pick-from (left graph) and place-to (right graph) confirmation in batch preparation of component kits.

Conclusions
A realistic experiment simulating kit preparation for mixed-model assembly was presented, demonstrating the impact of four types of confirmation methods on

productivity of kit preparation when applied for pick-from and place-to confirmation when batch preparation is applied. The results show that button-presses found in traditional pick-by-light applications and RFID-scans with an RFID-reading wristband on each arm – methods that require small extra motions for performing pick-from confirmations and allows for two place-from confirmations to be made at the same time – can lead to high productivity for batch preparation of component kits when compared with barcode-scanning and voice-confirmation. The results also show that barcode scans, when applied as either pick-from or place-to confirmation can be associated with moderately time-efficient kit preparation. Moreover, voice-commands shows to have difficulty keeping up with the high picking frequency in kit preparation normally is associated with. The paper contributes to practice by showing managers how the method used for confirmations, in addition to the means used for information conveyance, is an important choice when time-efficient kit preparation is desired. The paper's theoretical contribution is made by demonstrating that the confirmation method used in kit preparation has a substantial impact on the kit preparation productivity, indicating further research to also account for the confirmation method when studying picking information systems.

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