WSE18

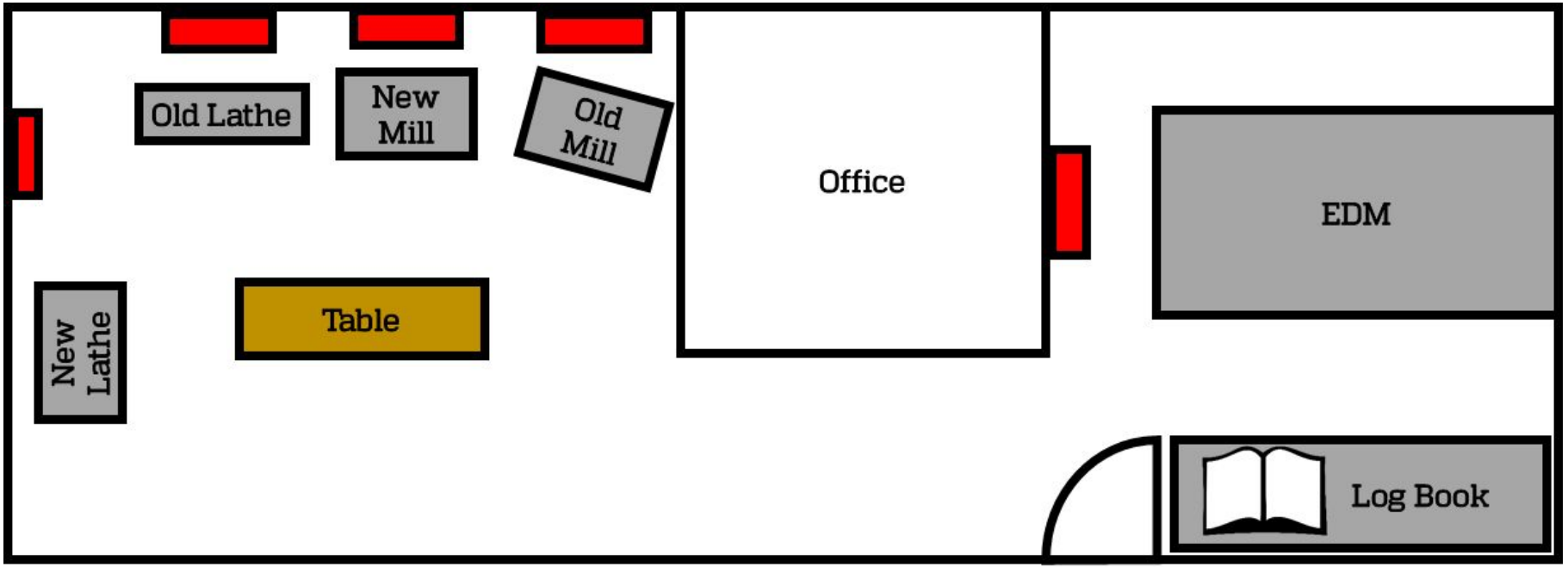
Enhancing the Self Service Shop experience

Geordan Gutow
ggutow1@jhu.edu
920-376-1608

David Samson
dsamson4@jhu.edu
267-221-3054

Stephane Teste
steste1@jhu.edu
248-376-7922

WSE Self-Service Machine Shop

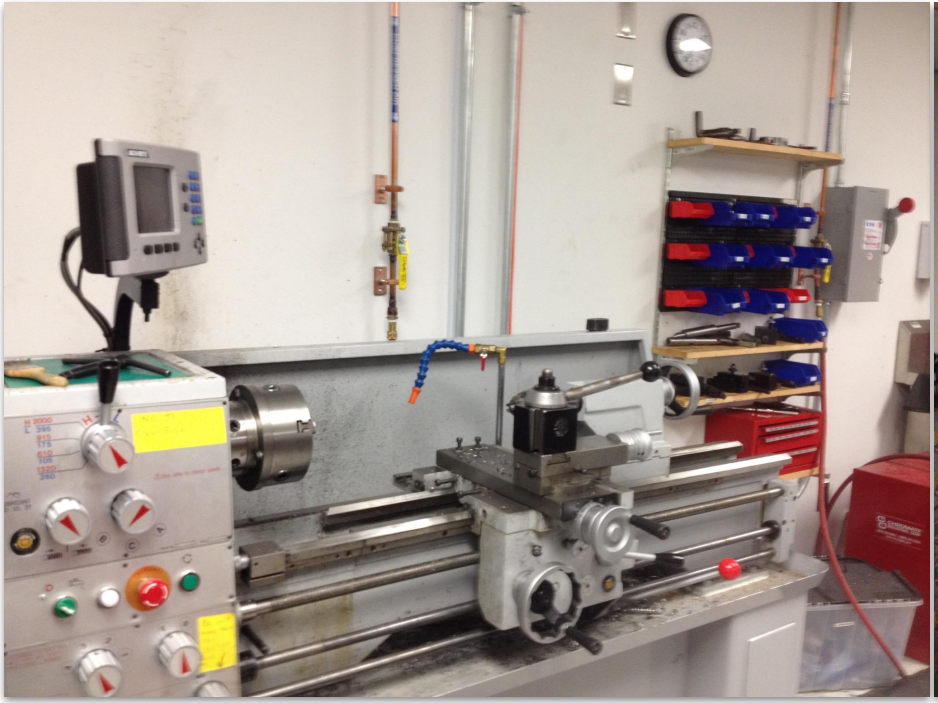


- Machine

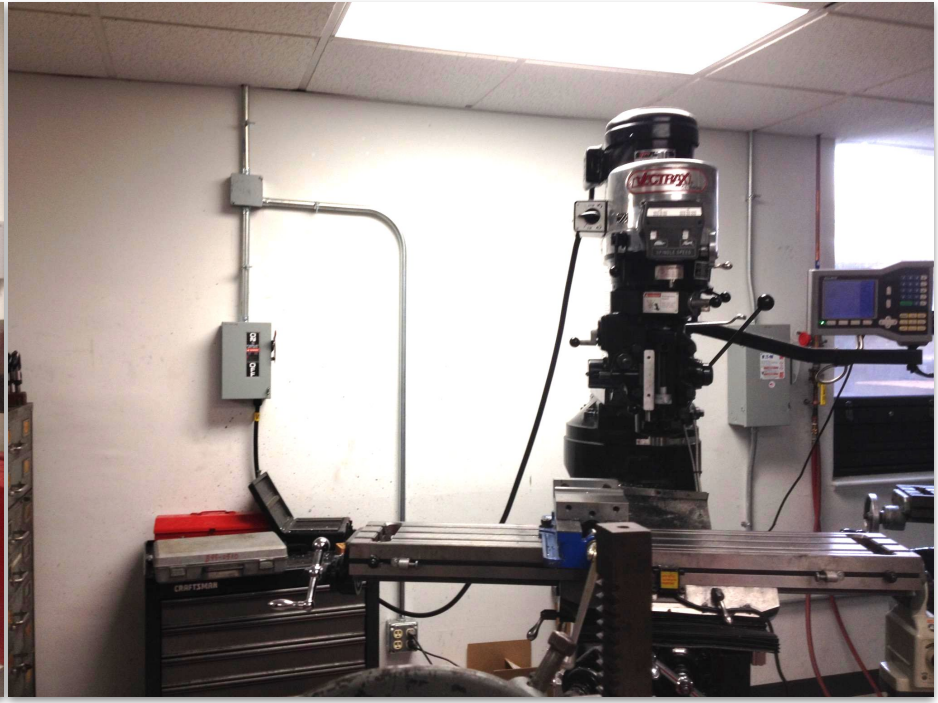
- Power Box

Self Service Shop Layout

Dangerous machines require training

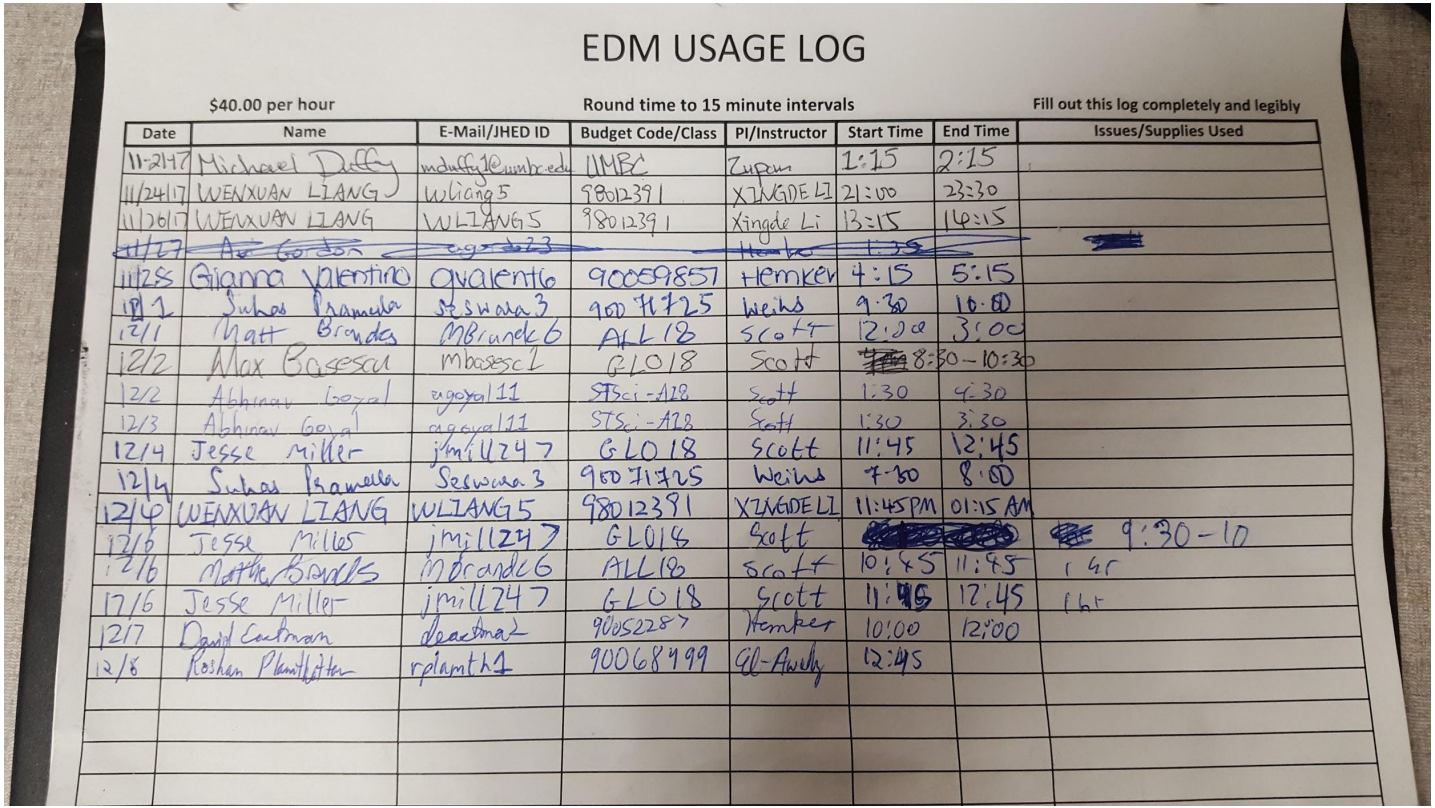


Self Service Shop Lathe



Self Service Shop Mill

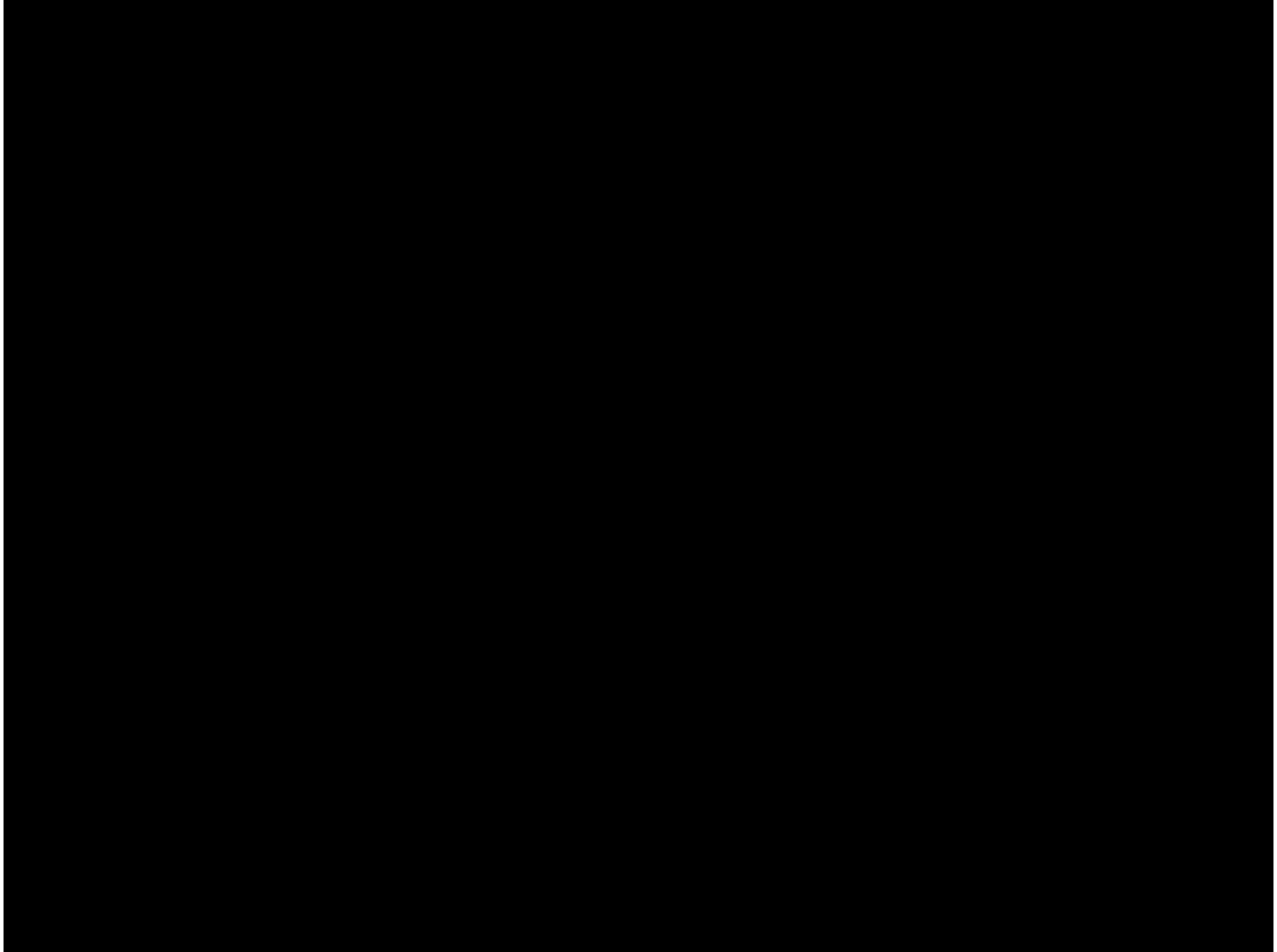
Usage Logs



EDM USAGE LOG

$40.00 per hour | Round time to 15 minute intervals | Fill out this log completely and legibly

Date	Name	E-Mail/JHED ID	Budget Code/Class	PI/Instructor	Start Time	End Time	Issues/Supplies Used
11-21-17	Michael Duffy	mduffy1@umbc.edu	UMBC	Zupan	1:15	2:15	
11/24/17	WENXUAN LIANG	wliang5	98012391	XINGDE LI	21:00	23:30	
11/26/17	WENXUAN LIANG	WLIANG5	98012391	Xingde Li	13:15	16:15	
~~11/27~~	~~Ae Gordon~~	~~eg~~	~~2023~~	~~Hemker~~	~~1:15~~		
11/28	Gianna Valentino	gvalent6	90059857	Hemker	4:15	5:15	
12/1	Suhas Pramada	SPSwara3	90071725	Weihs	9:30	10:00	
12/1	Matt Brandes	MBrandc6	ALL18	Scott	12:00	3:00	
12/2	Max Bassen	mbassen1	GL018	Scott	~~4:30~~ 8:30 – 10:30		
12/2	Abhinav Goyal	agoyal11	STSci-A18	Scott	1:30	4:30	
12/3	Abhinav Goyal	agoyal11	STSci-A18	Scott	1:30	3:30	
12/4	Jesse Miller	jmill247	GL018	Scott	11:45	12:45	
12/4	Suhas Pramada	Spswara3	90071725	Weihs	7:30	8:00	
12/4	WENXUAN LIANG	WLIANG5	98012391	XINGDE LI	11:45PM	01:15 AM	
12/6	Jesse Miller	jmill247	GL018	Scott	[redacted]		9:30 – 10
12/6	Matthew Brandes	MBrandc6	ALL18	Scott	10:45	11:45	1 hr
12/6	Jesse Miller	jmill247	GL018	Scott	11:45	12:45	1 hr
12/7	David Cartman	deartma2	90052287	Hemker	10:00	12:00	
12/8	Roshan Plantlotter	rplantl1	90068499	GL-Awdy	12:45		



Problem Statement

In an effort to **make the shop safer** and improve tracking of shop usage, team WSE18 is tasked with implementing a **tamper-evident system** that **prevents users from activating equipment they are not trained on**. The system is also expected to reduce the manual effort necessary for billing by automatically tracking equipment usage.

High Level Goals

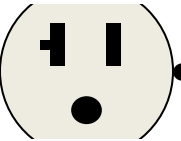
1. Seamless and intuitive
2. Long lasting and low maintenance
3. Scalable

Product design done right.

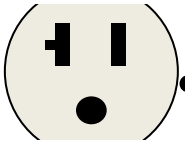
Ref [6]

Introducing the Gatekeeper™

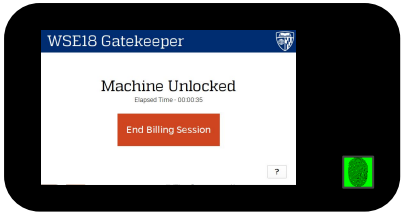
Power is switched off

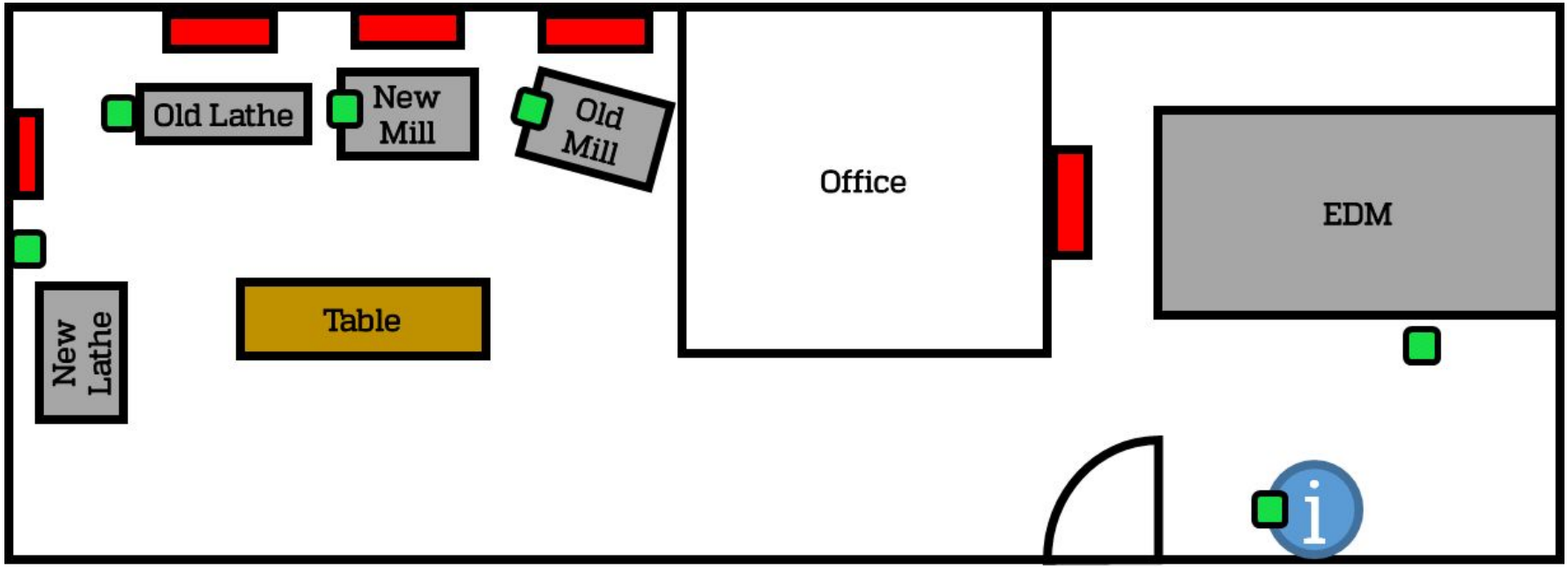


Unlock with your fingerprint



Gatekeeper closes circuit

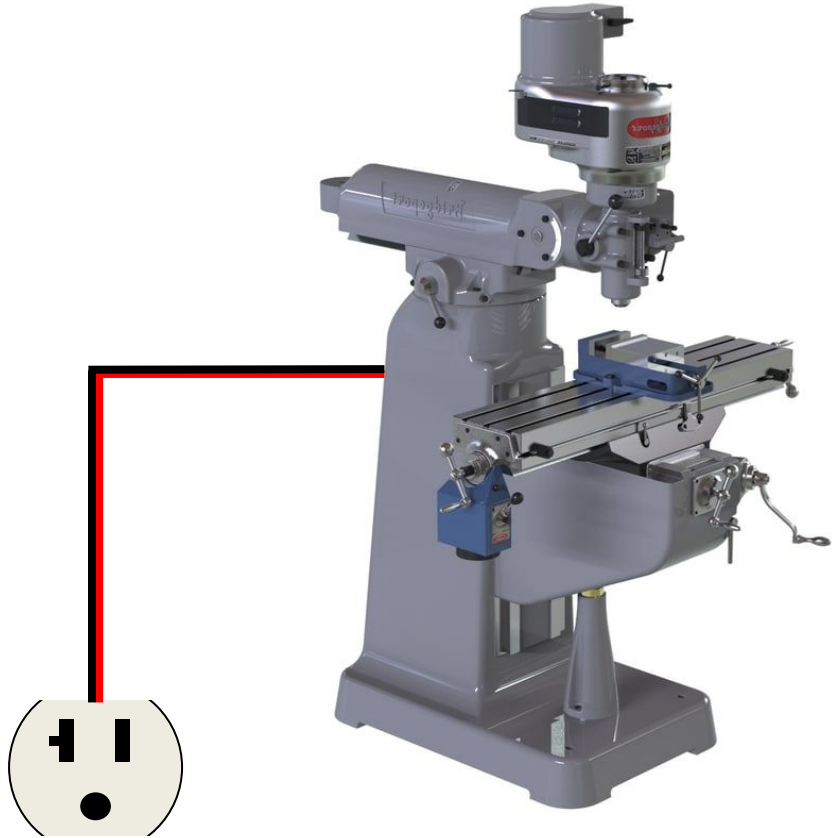




- Machine
- Gatekeeper
- Power Relay
- Information Kiosk

Our System in the Machine Shop

Architecture Overview

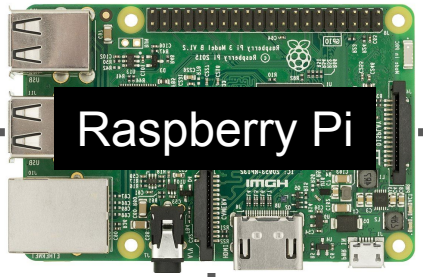


Ref [3]

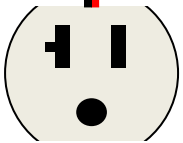
Architecture Overview

Fingerprint Sensor

Database



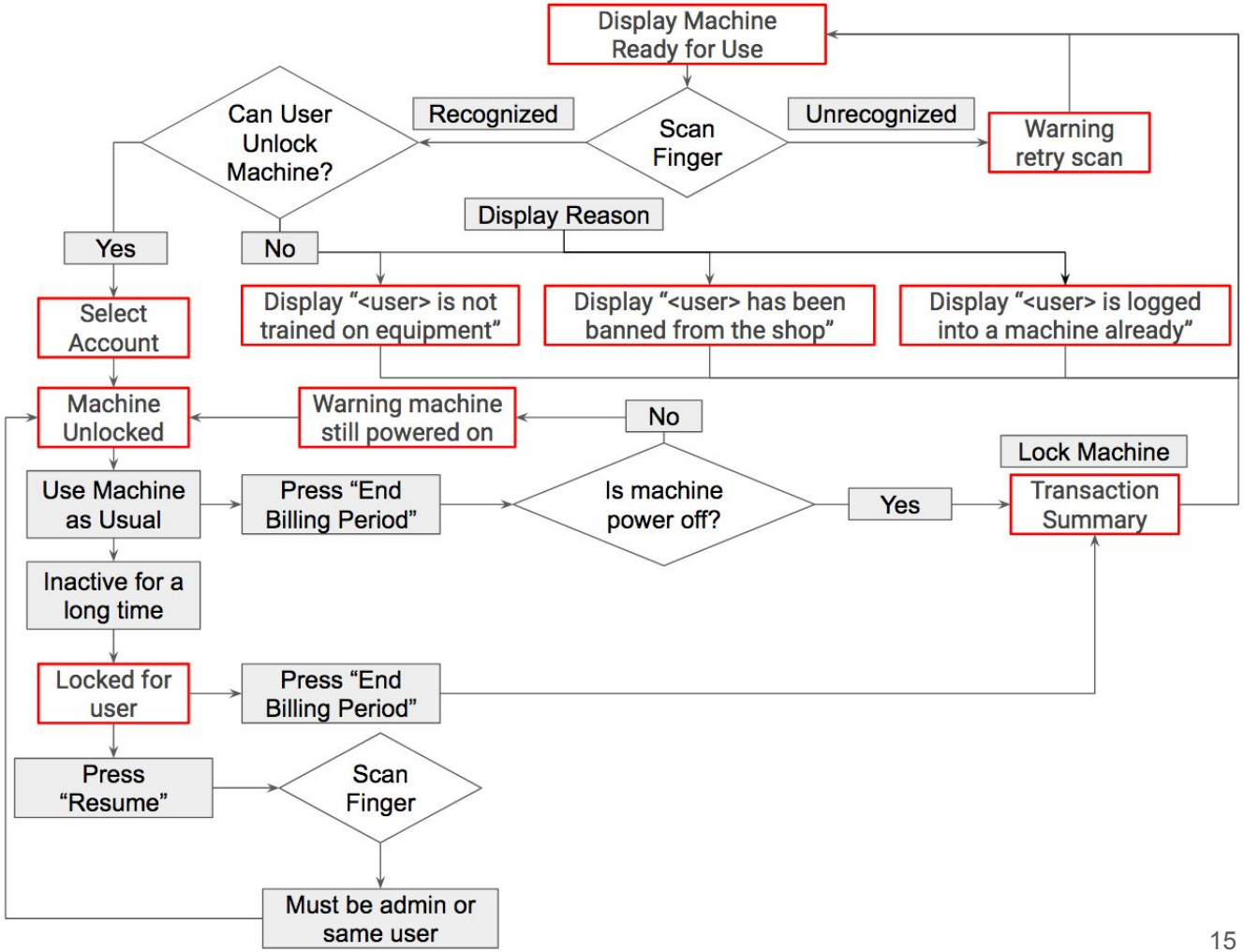
Power Relay



Ref [2]-[5]

The Gatekeeper in Action

Flowchart of Events at the Gatekeeper



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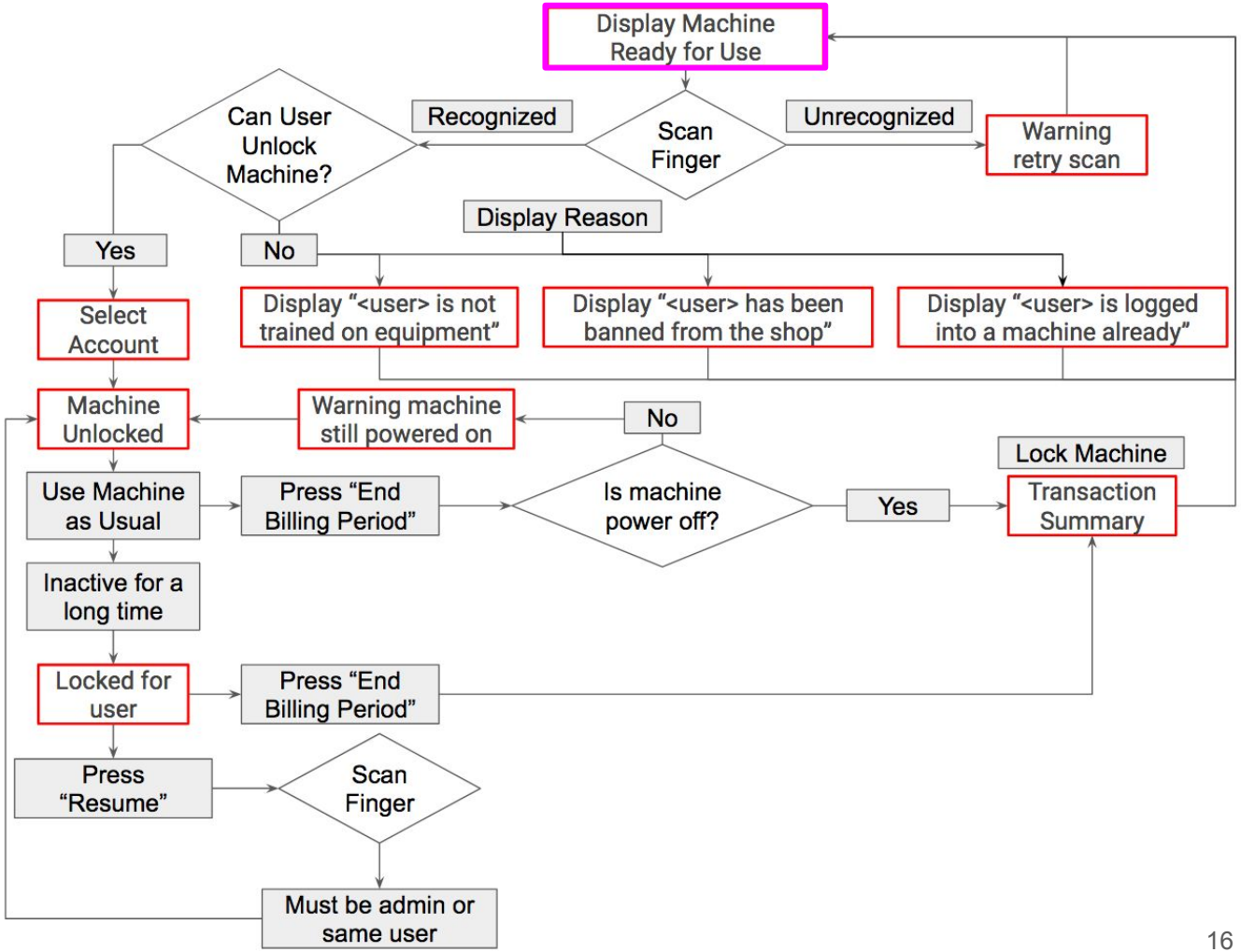

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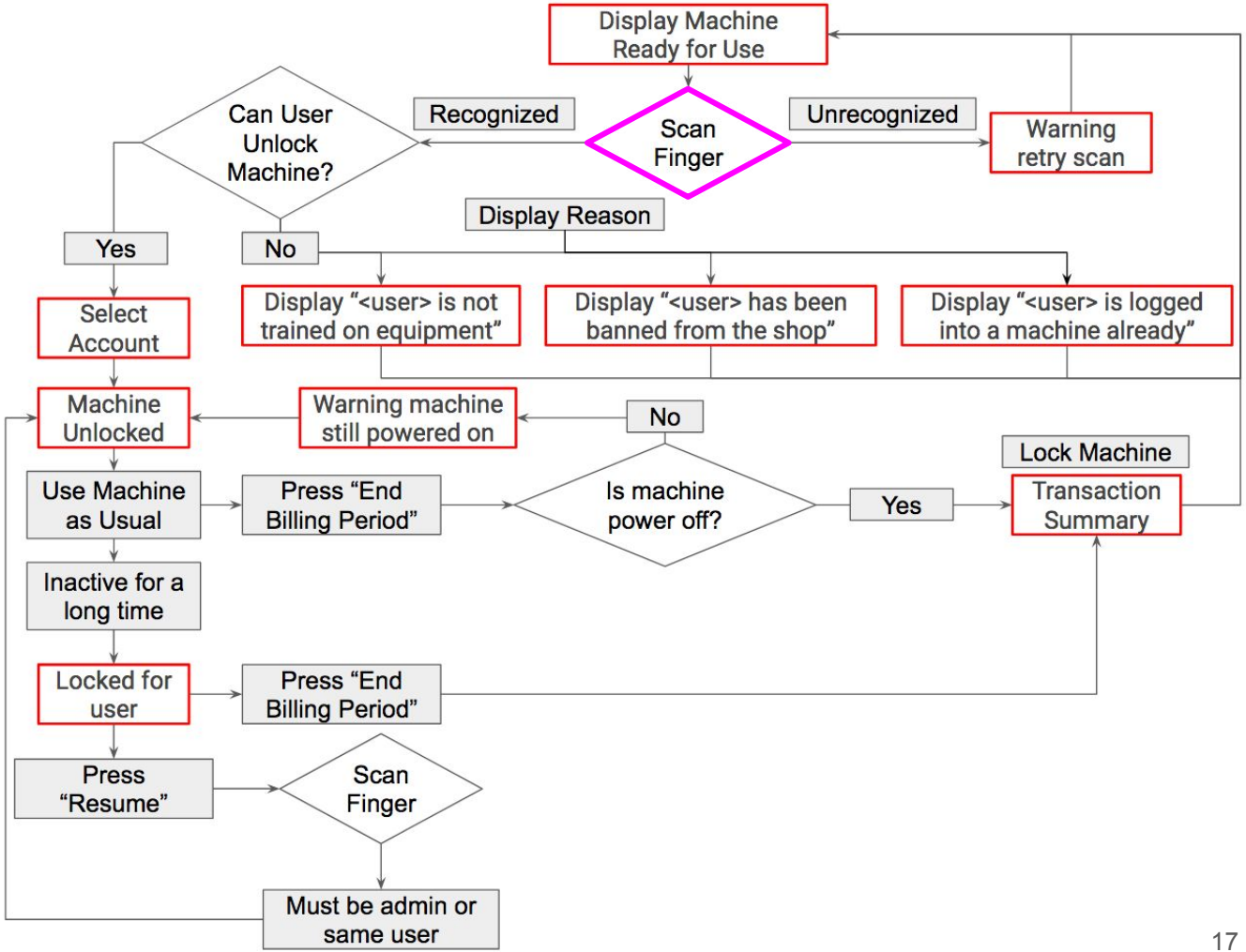

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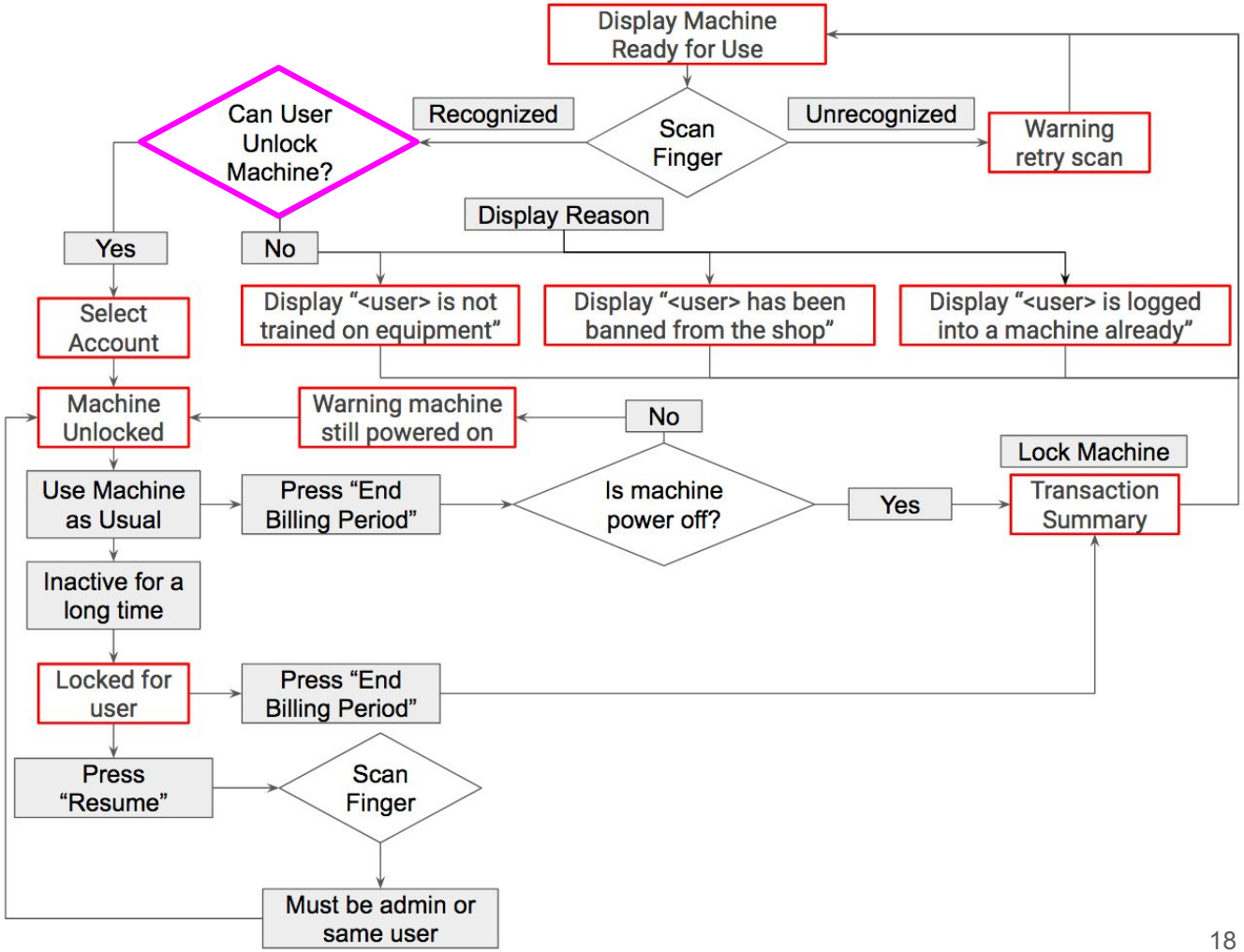

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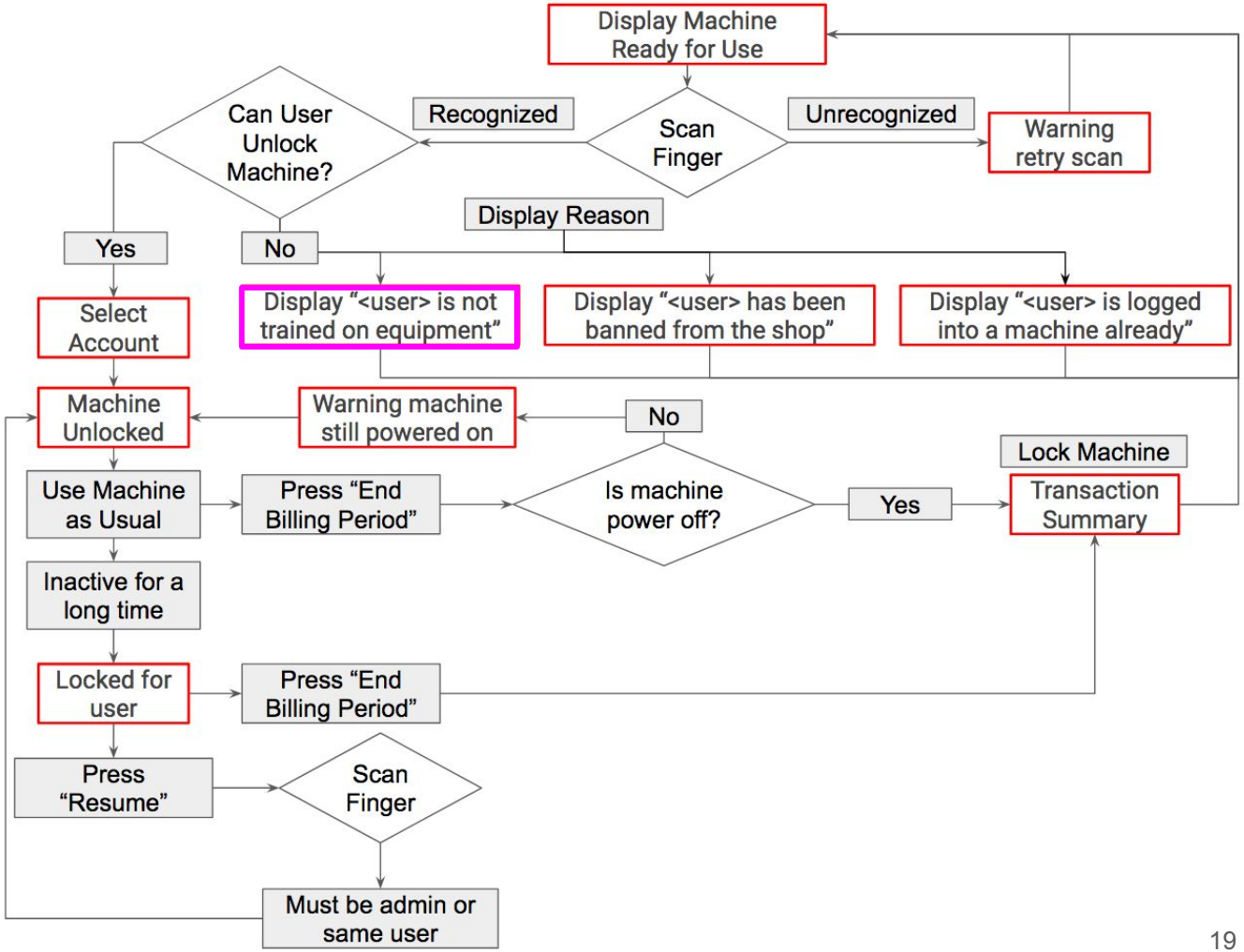

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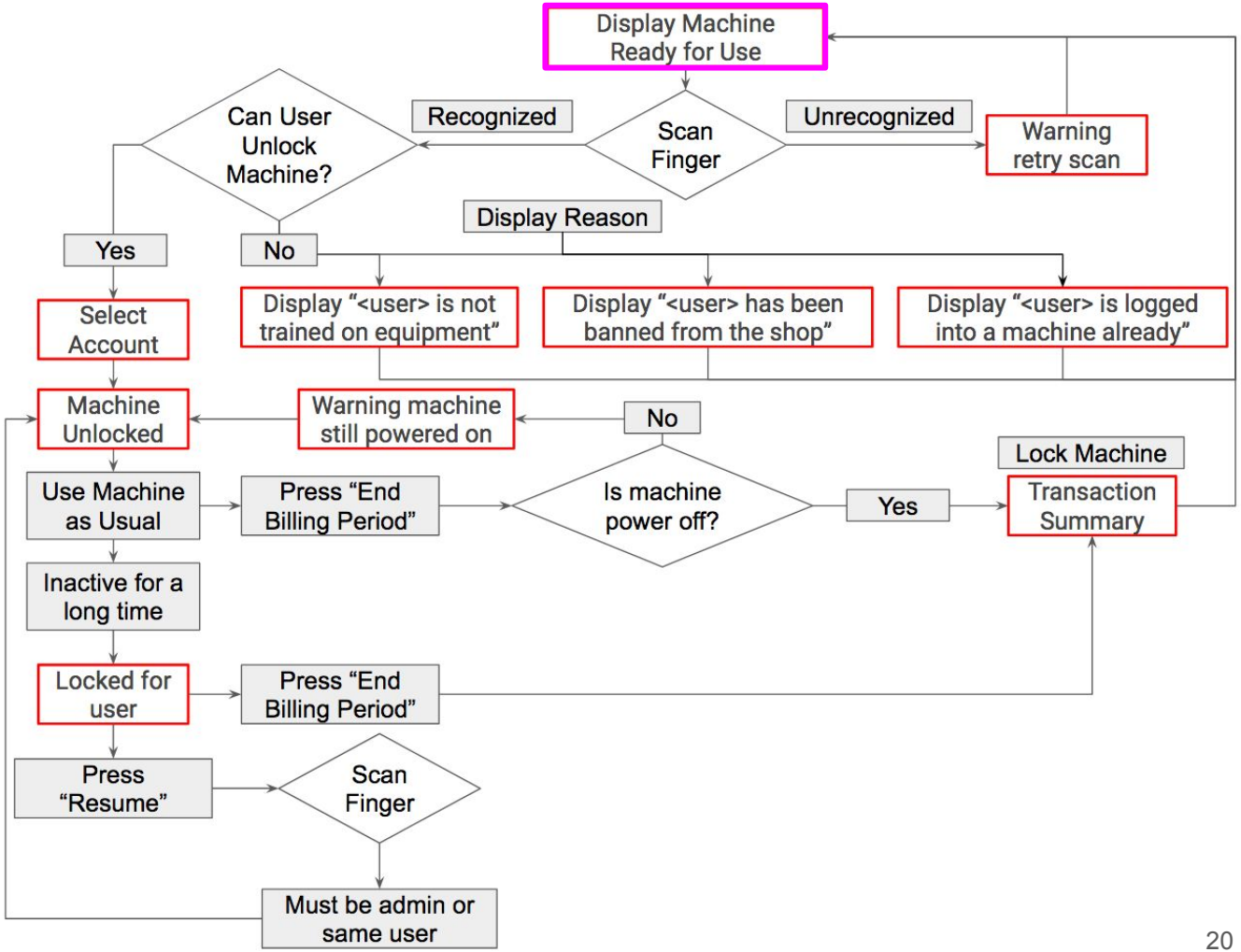

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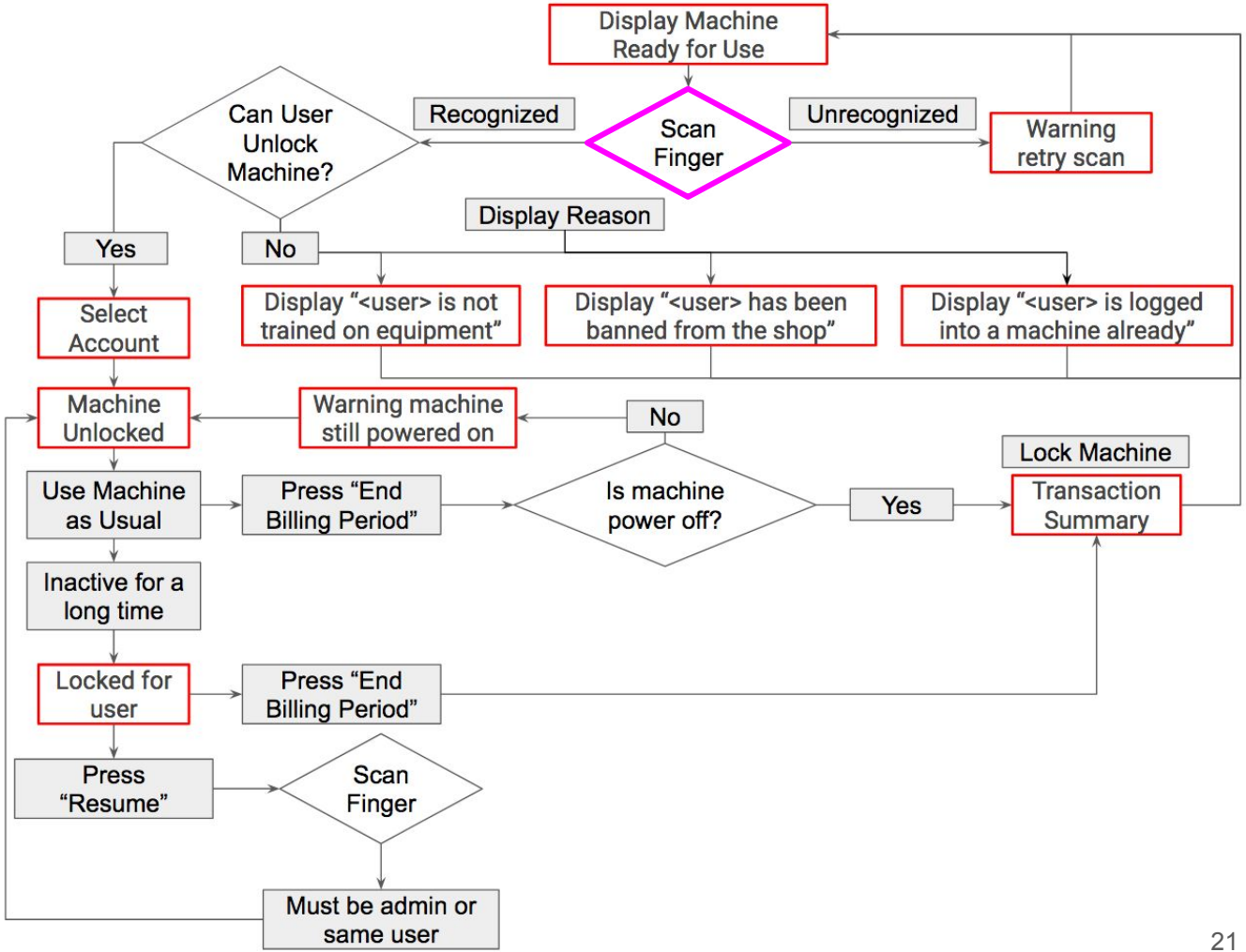

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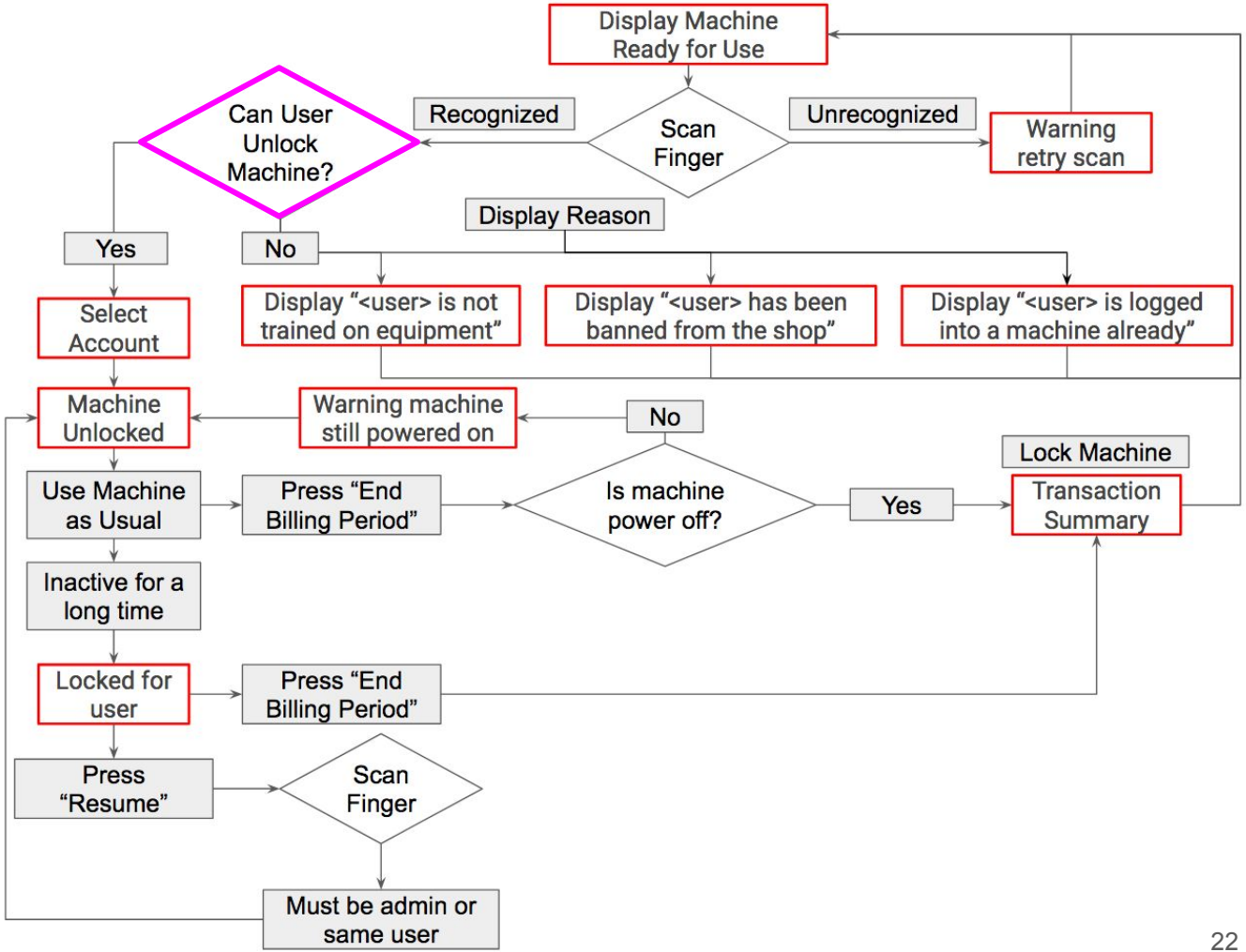

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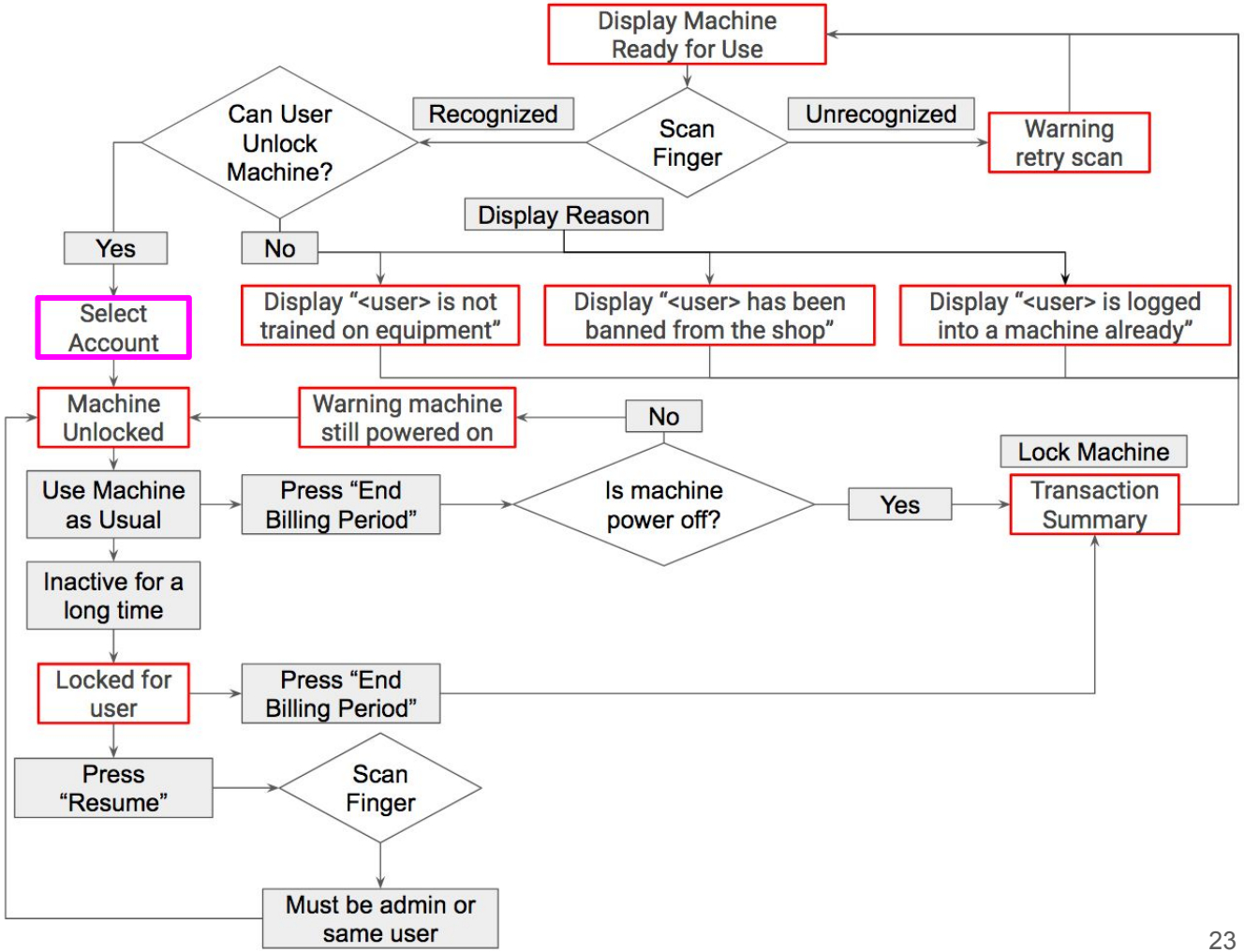

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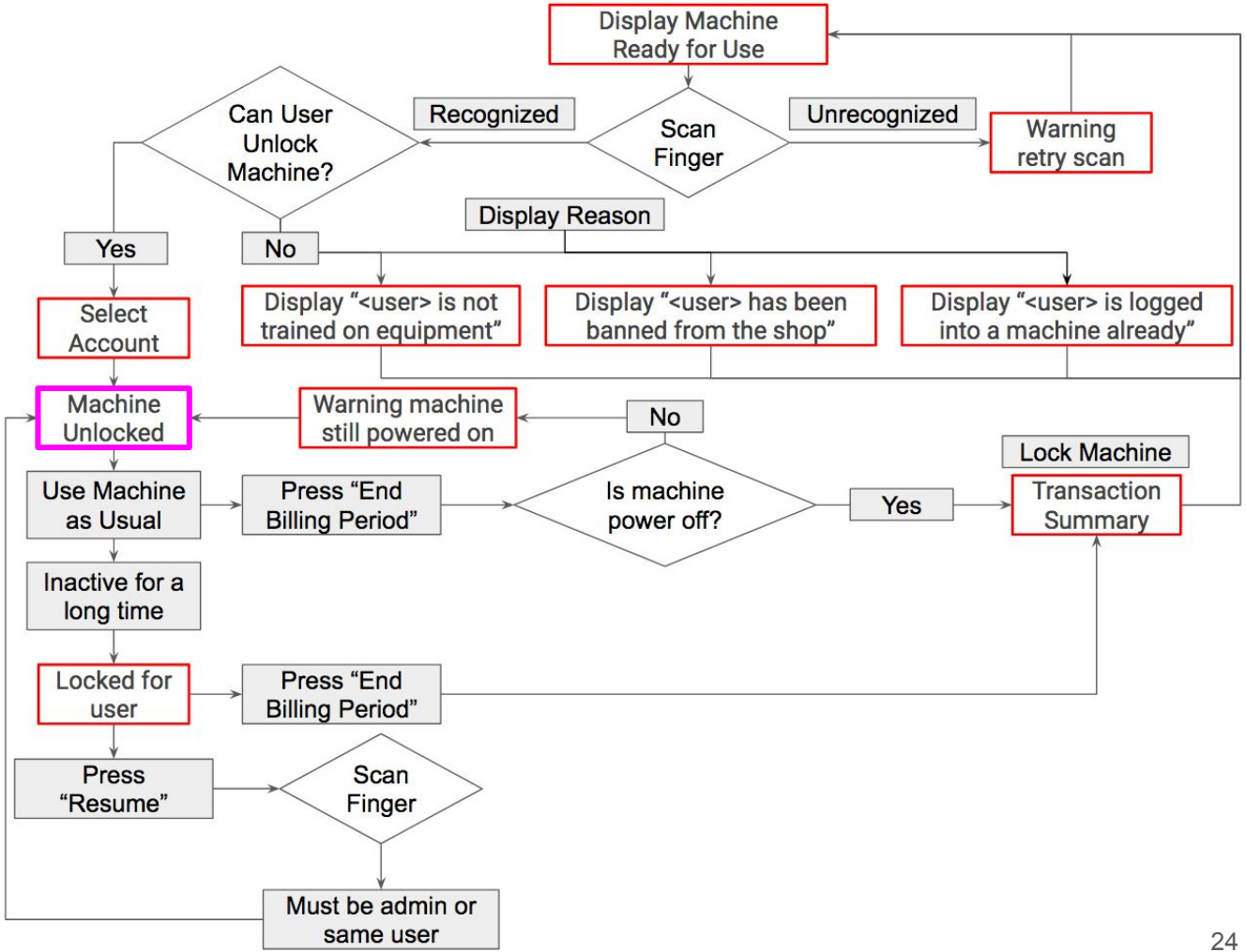

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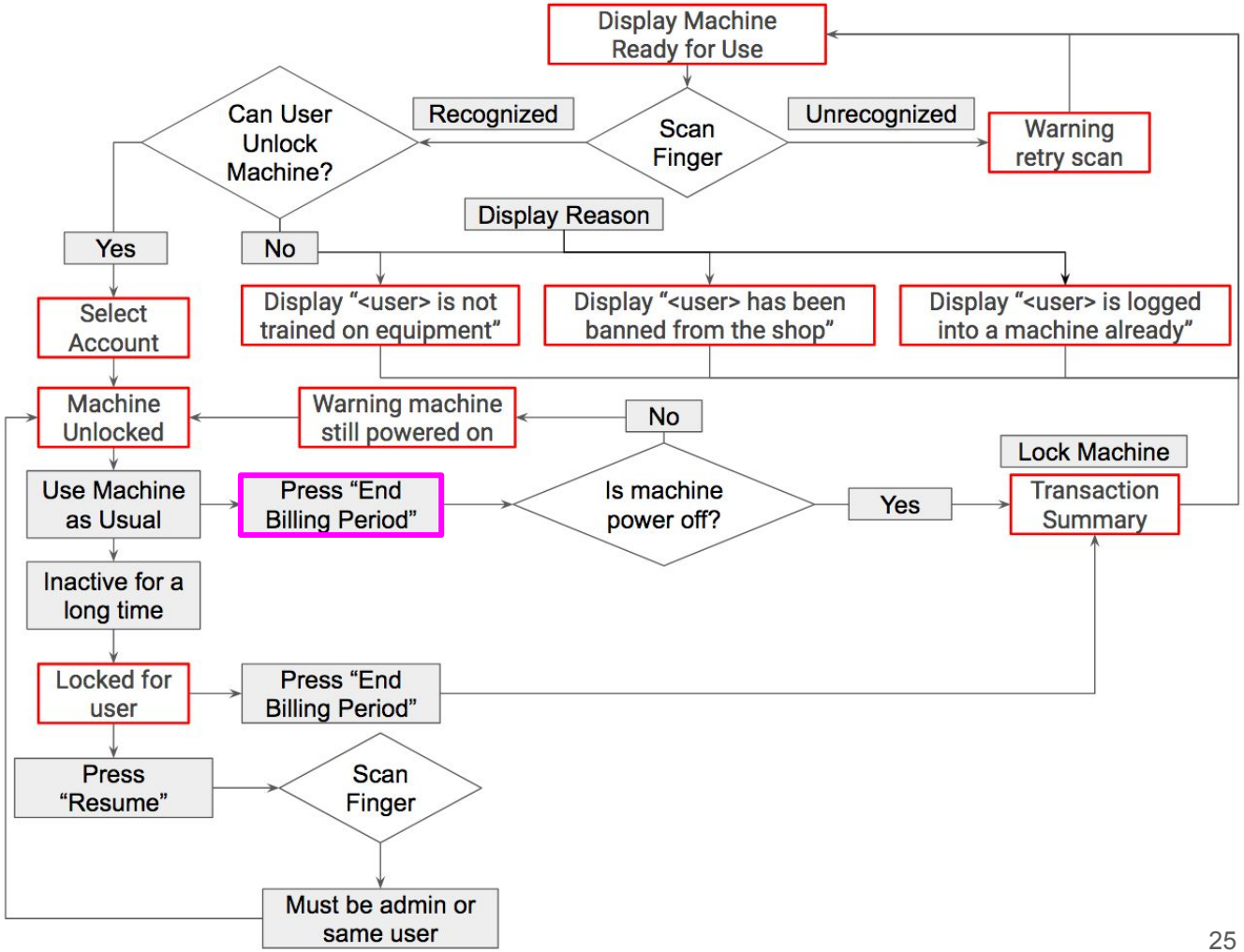

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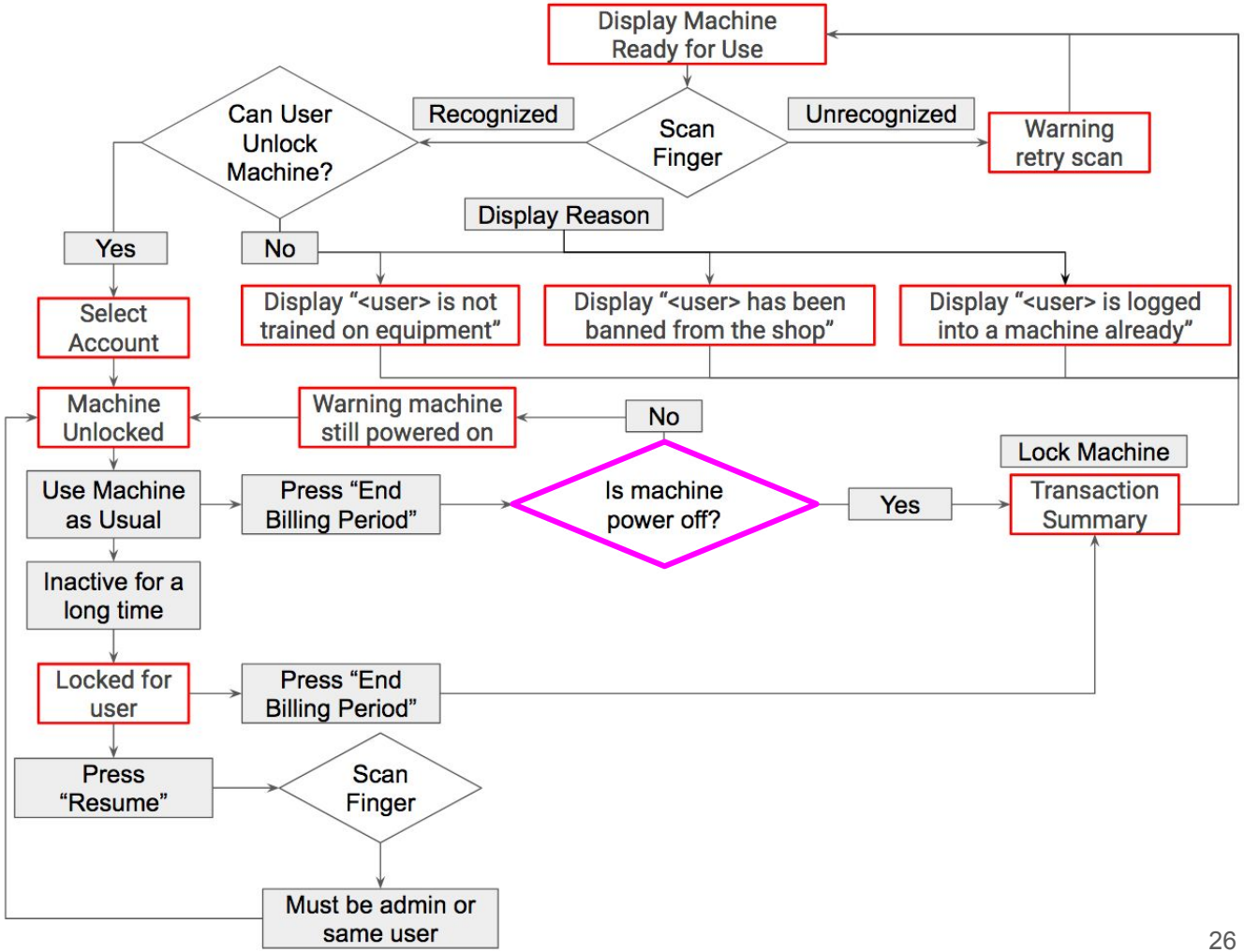

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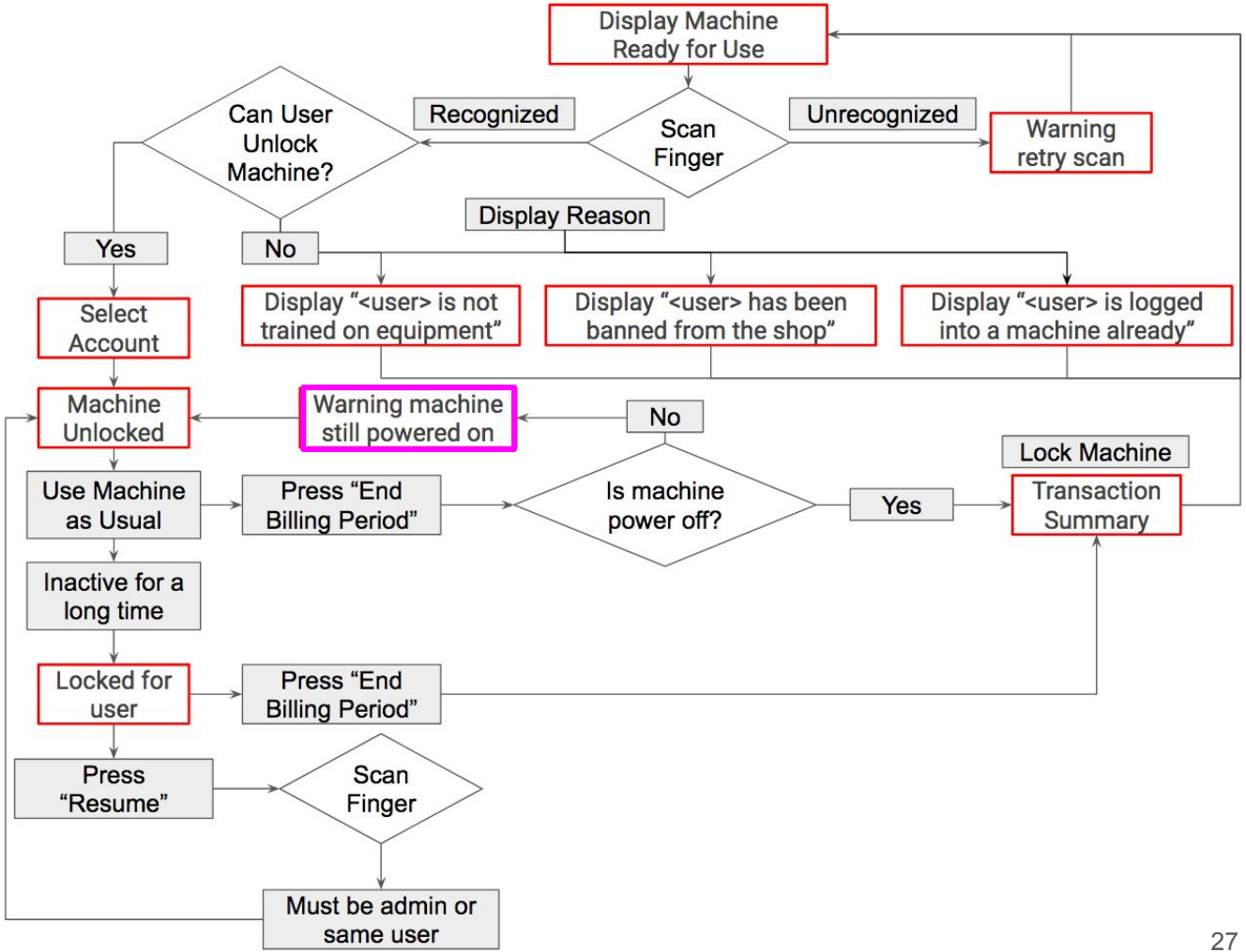

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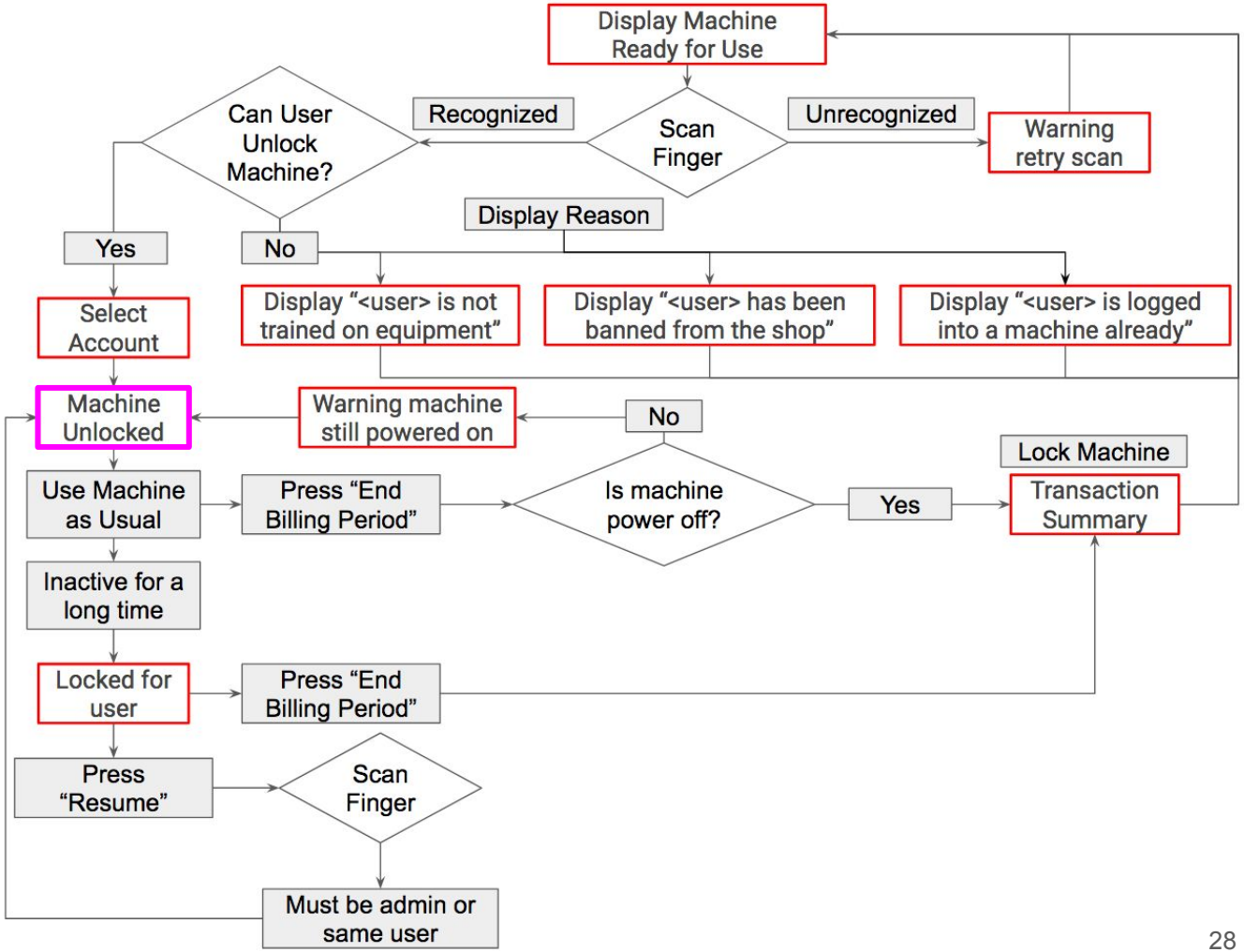

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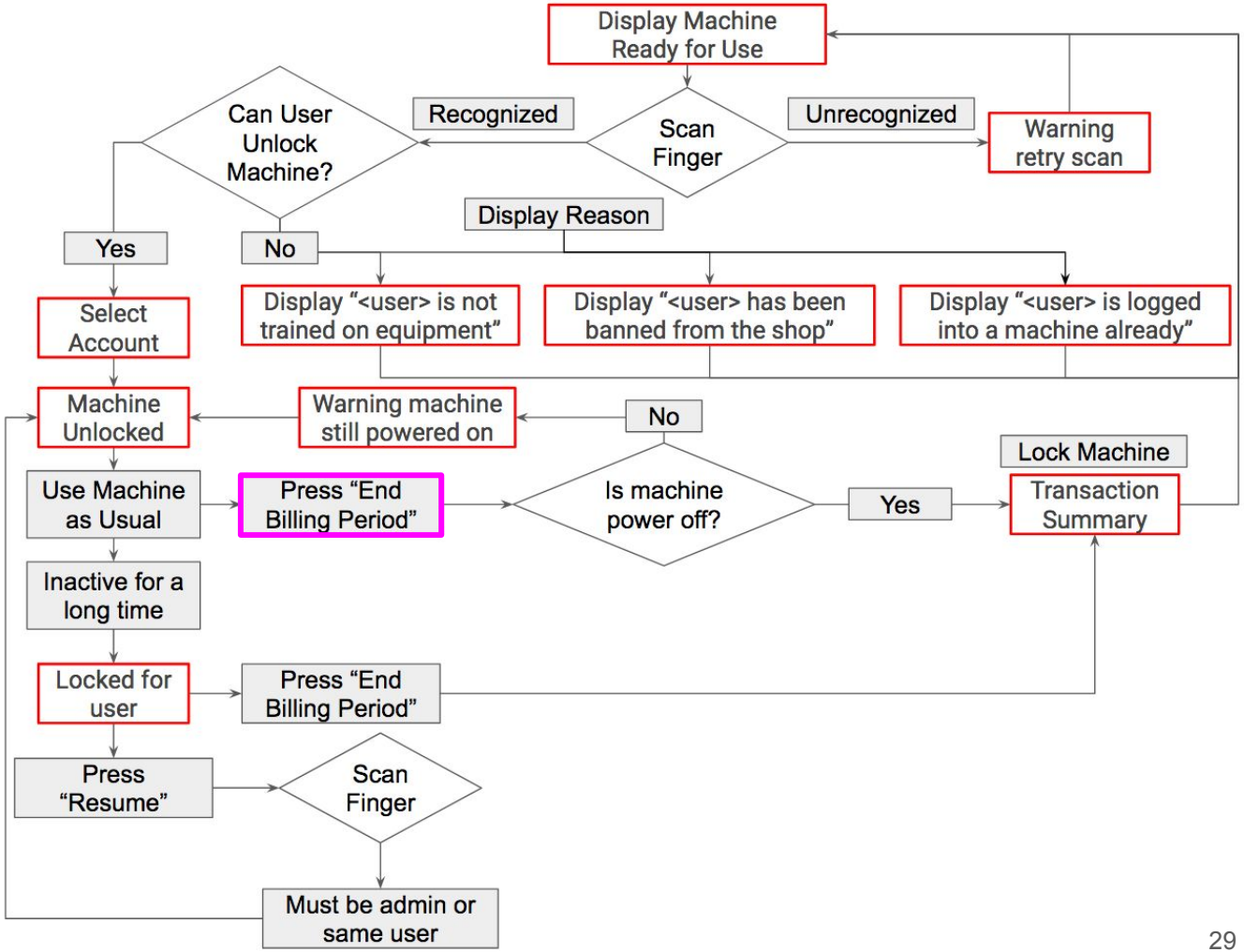

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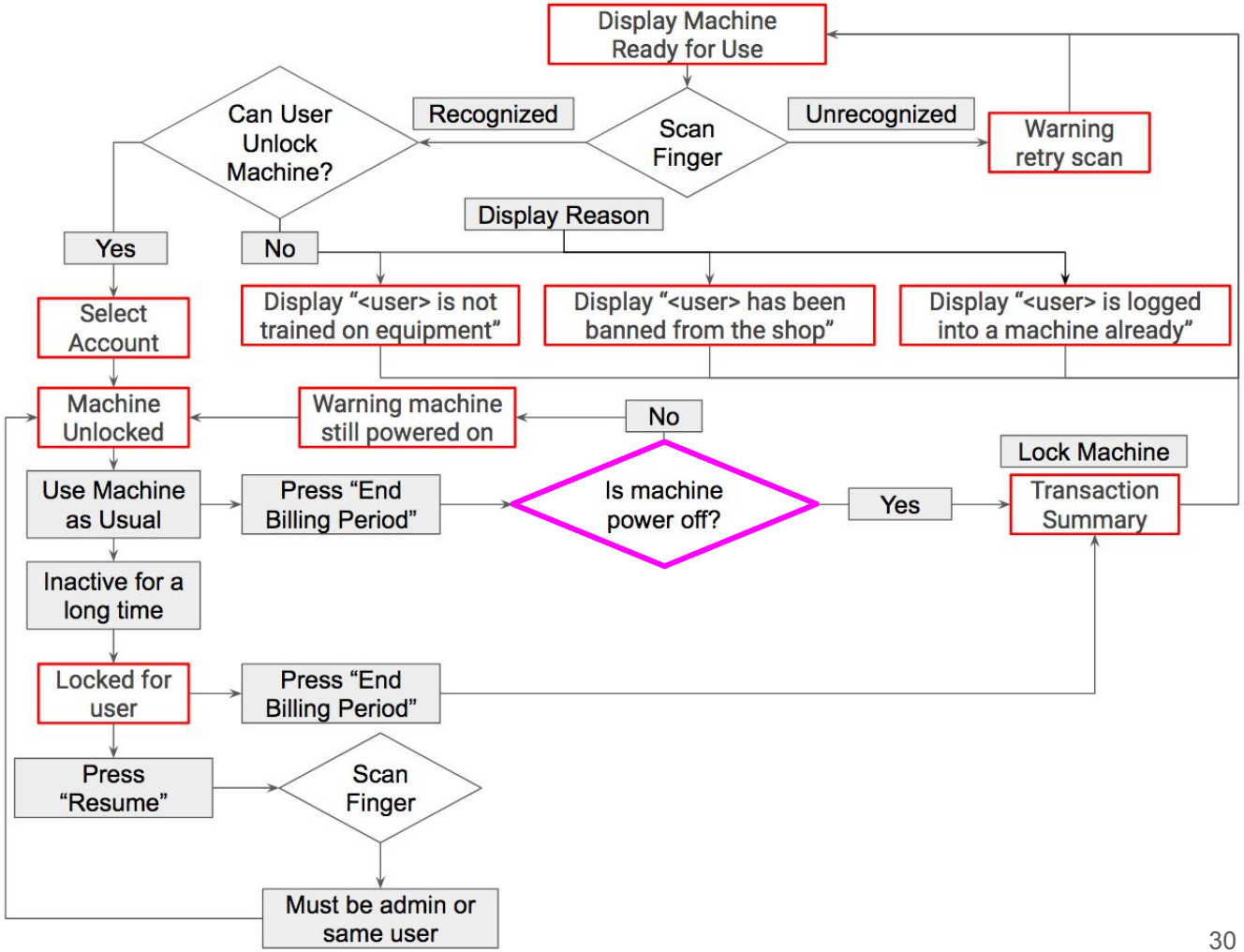

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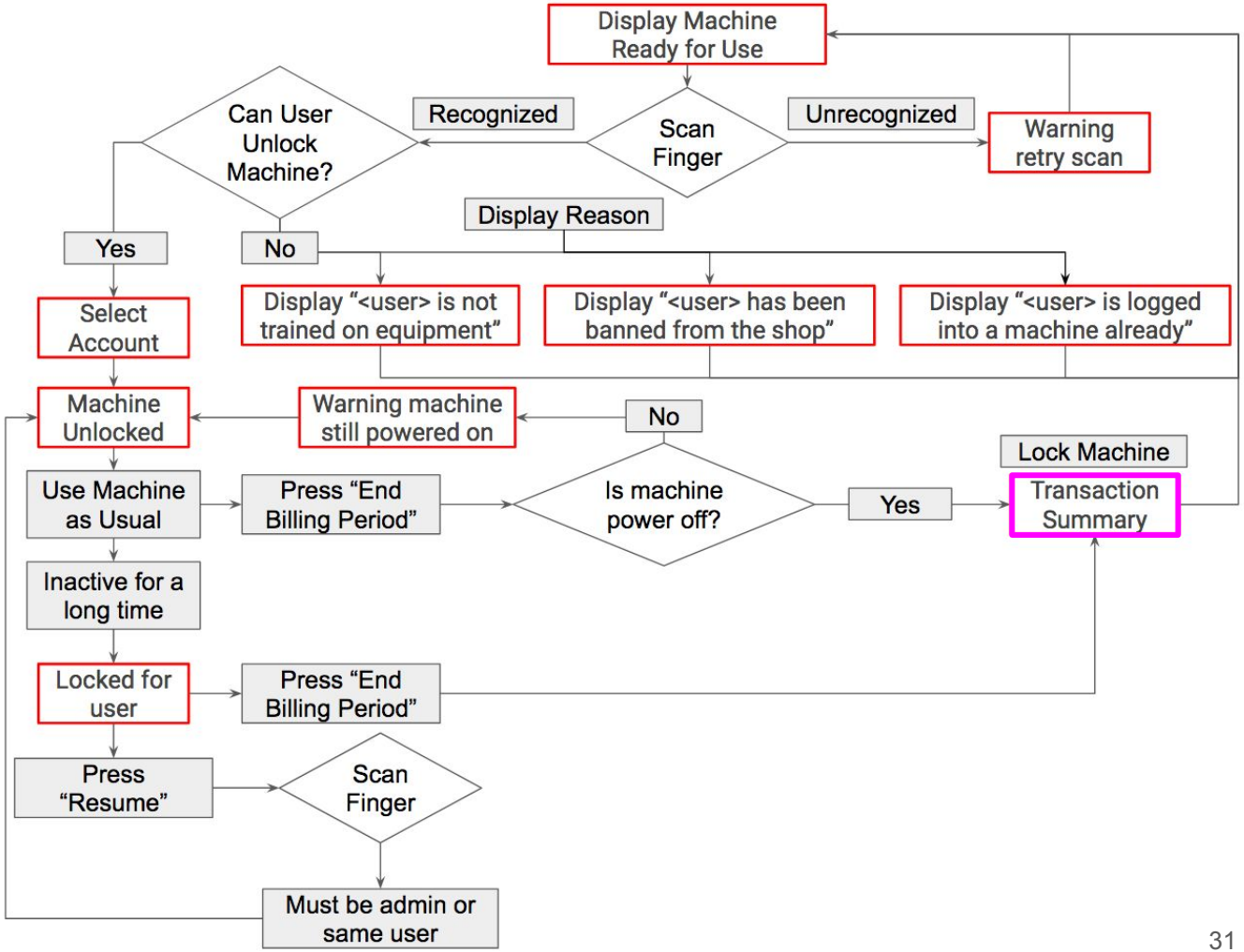

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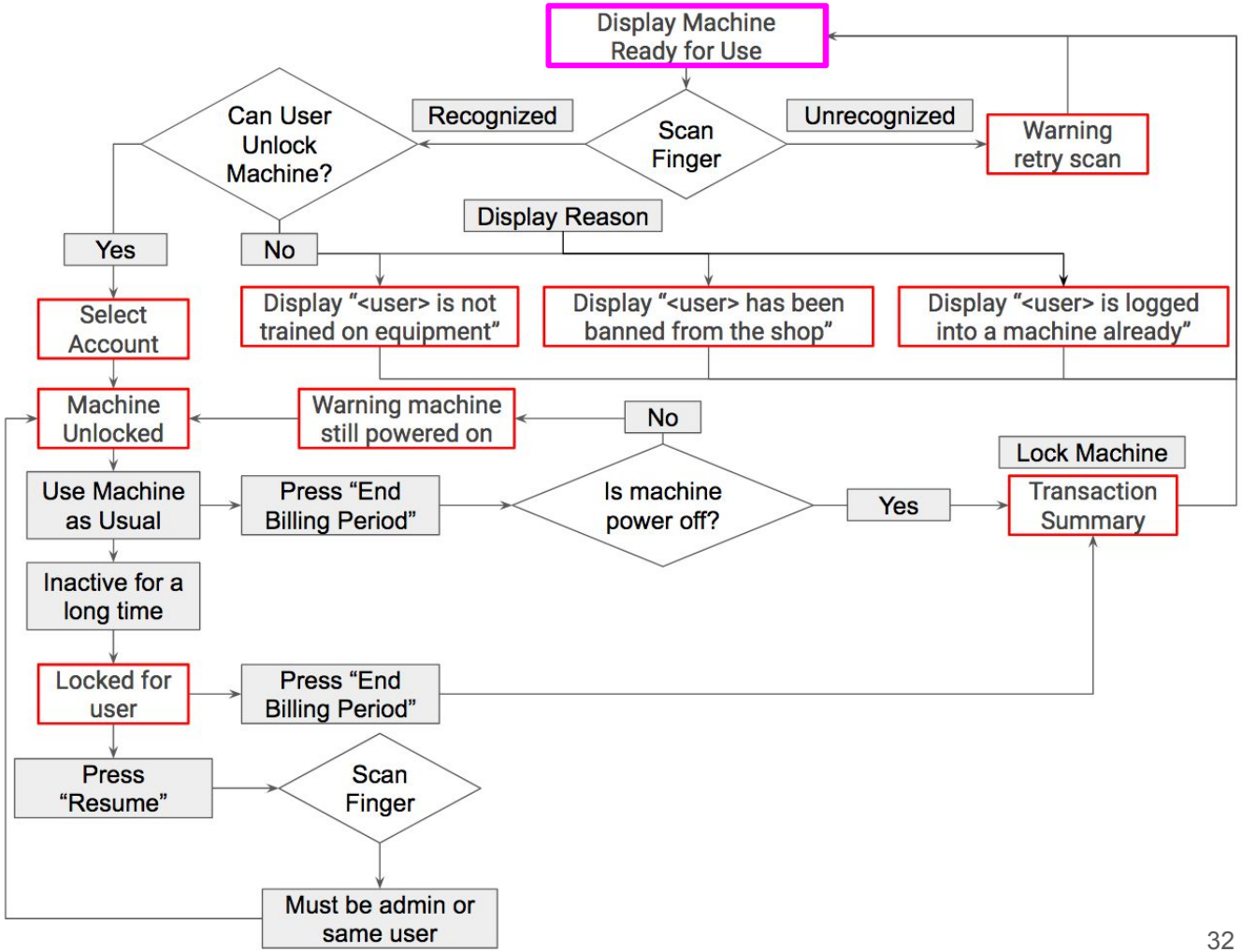
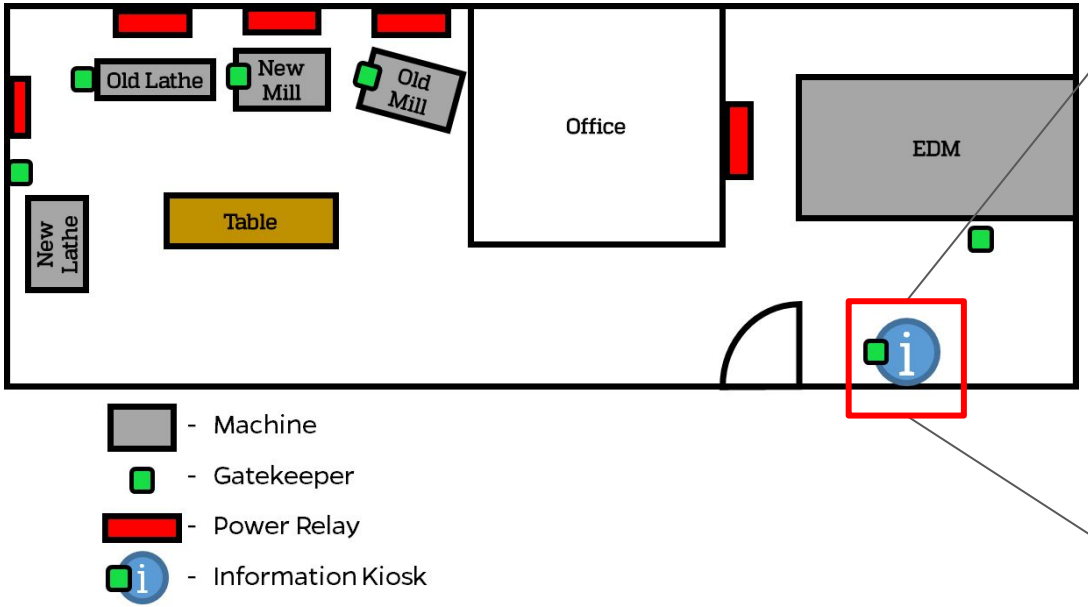
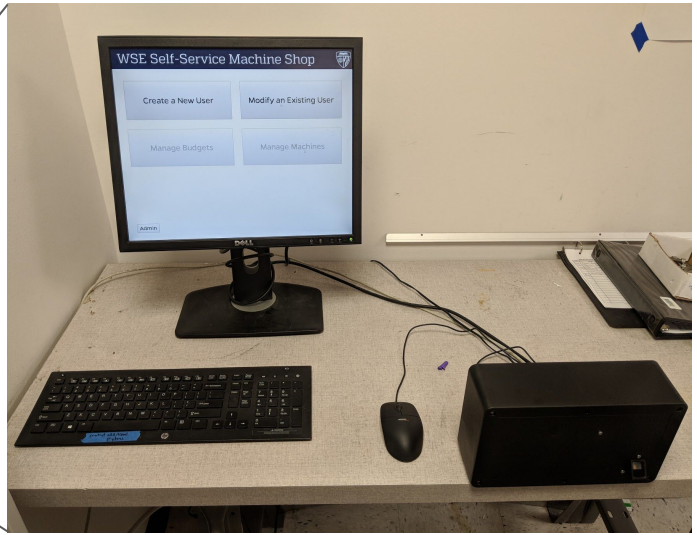


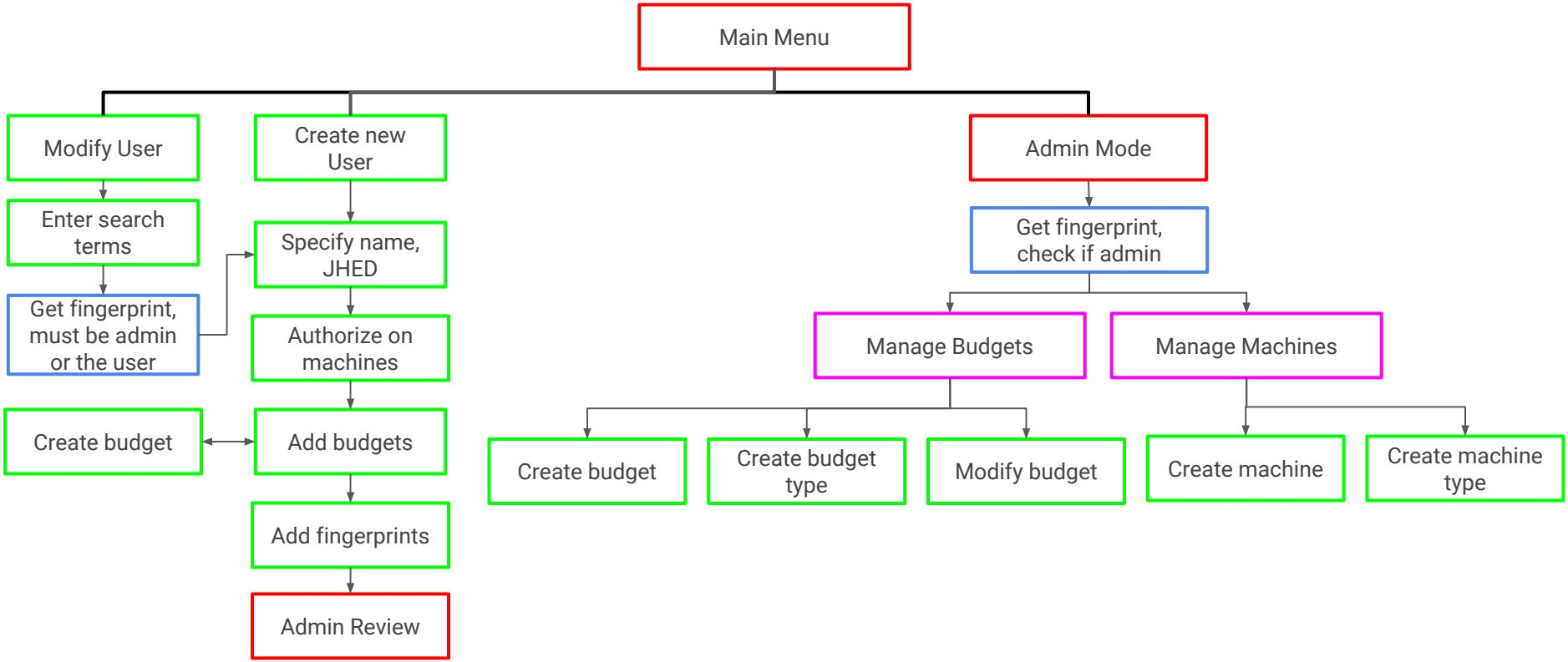
The Kiosk

The Kiosk is the primary mechanism for adding new users, granting users access to new machines, and updating the list of budgets available to a user





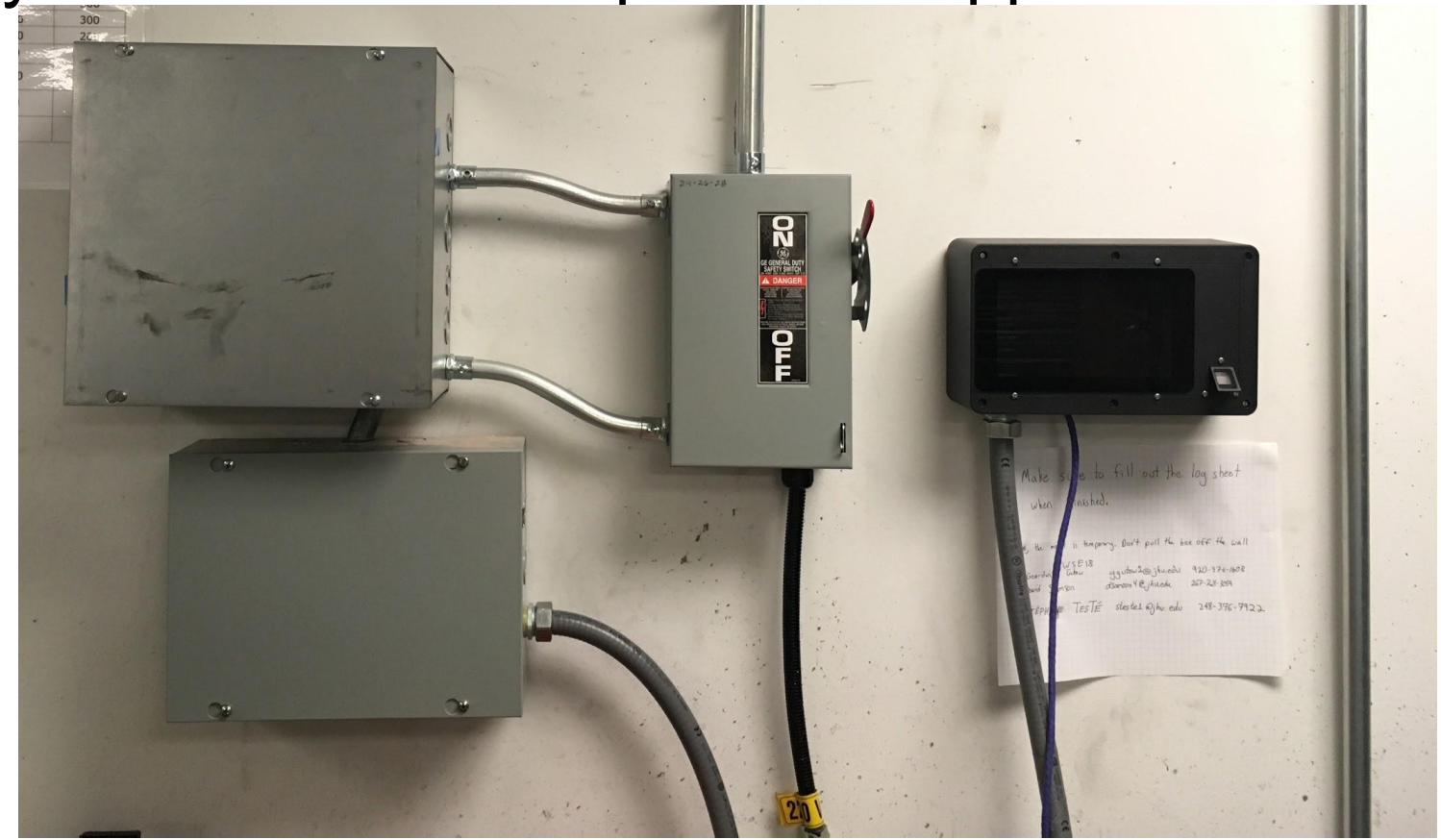
Flowchart of Events at the Kiosk



Return to main menu at end of sequence

Electronics: What makes it click

Fully Installed Gatekeeper and Support Electronics



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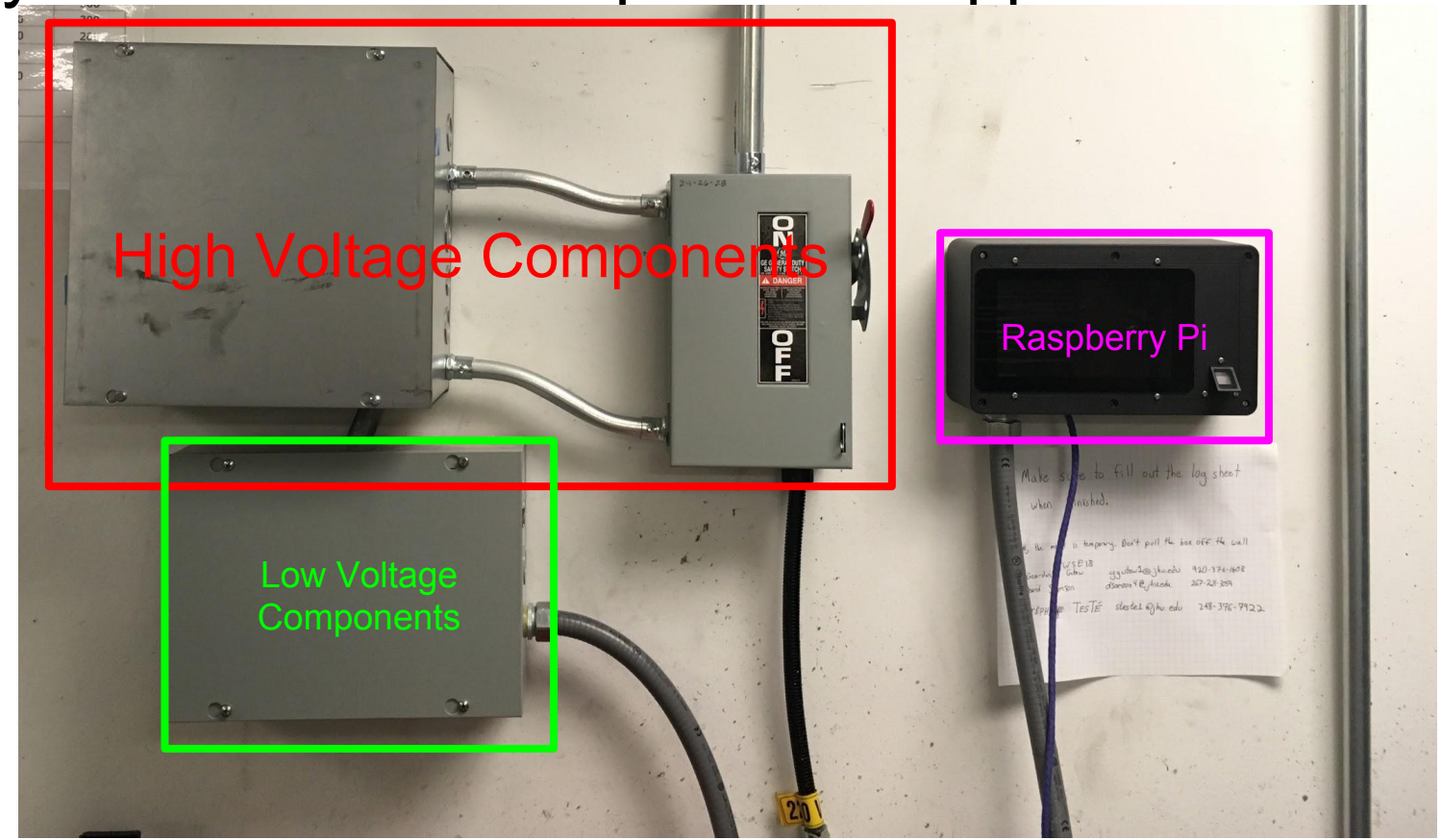
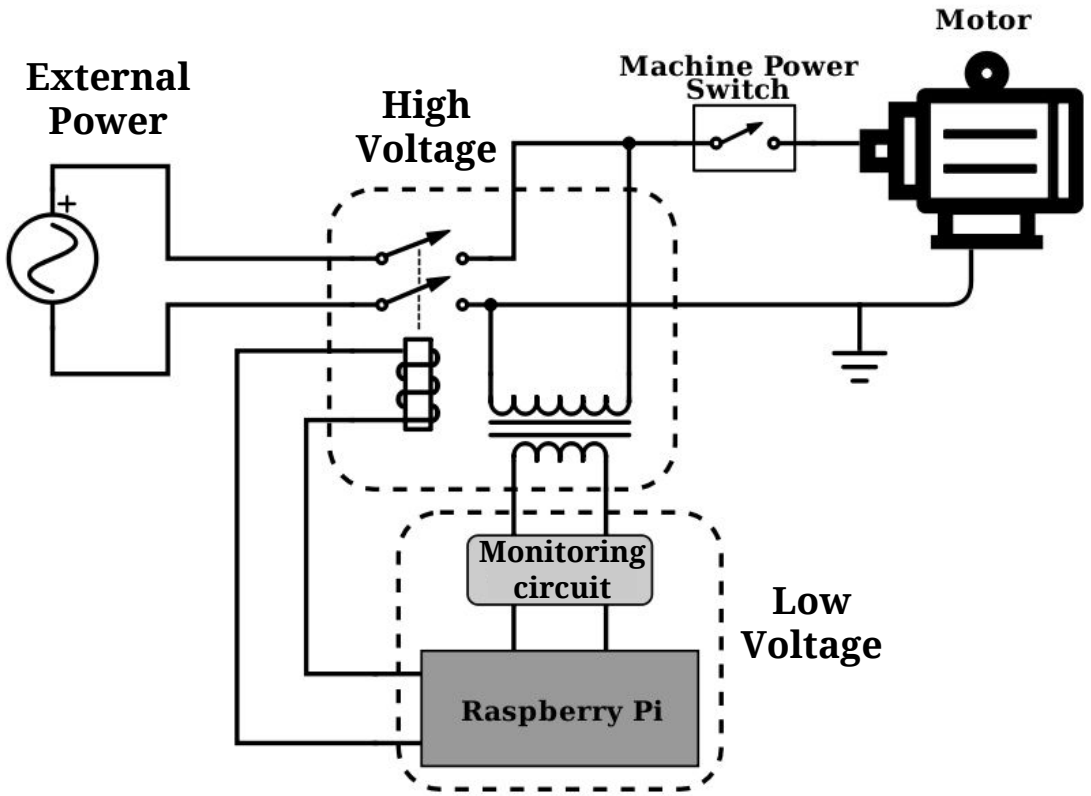


Electrical System

- Pi activates contactor
- Power becomes available to machine
- User uses the machine as normal
- Pi monitors power with monitoring circuit



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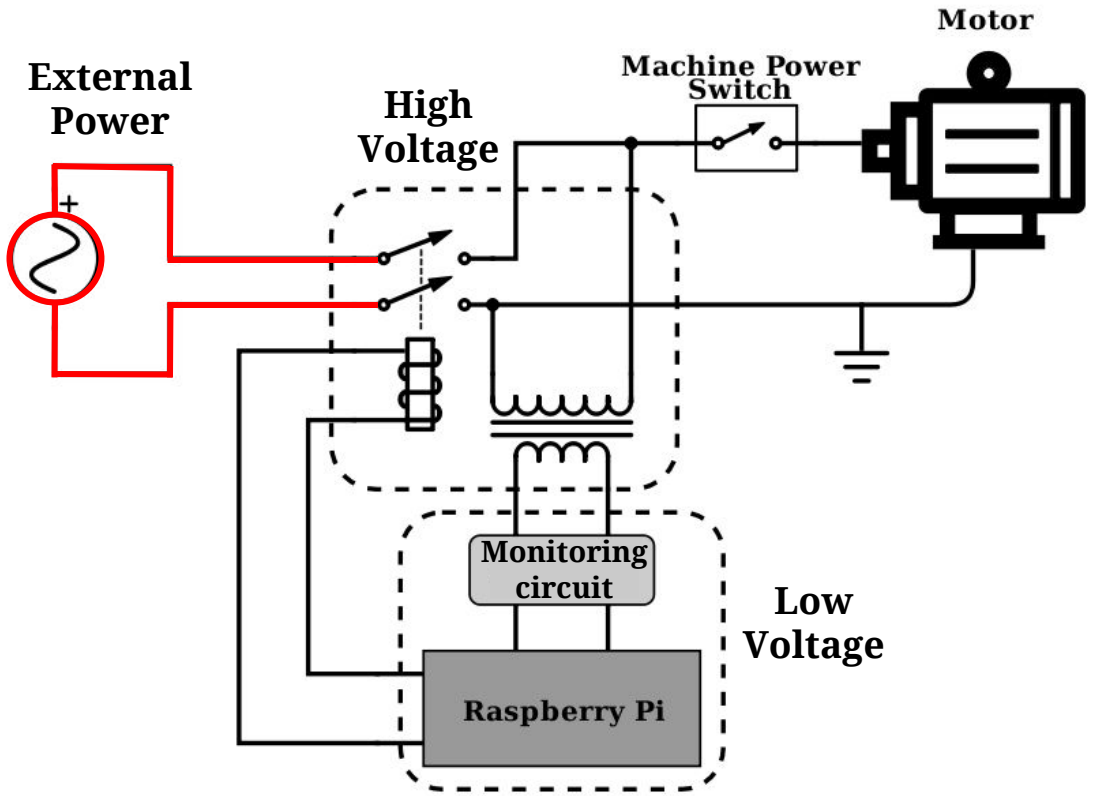

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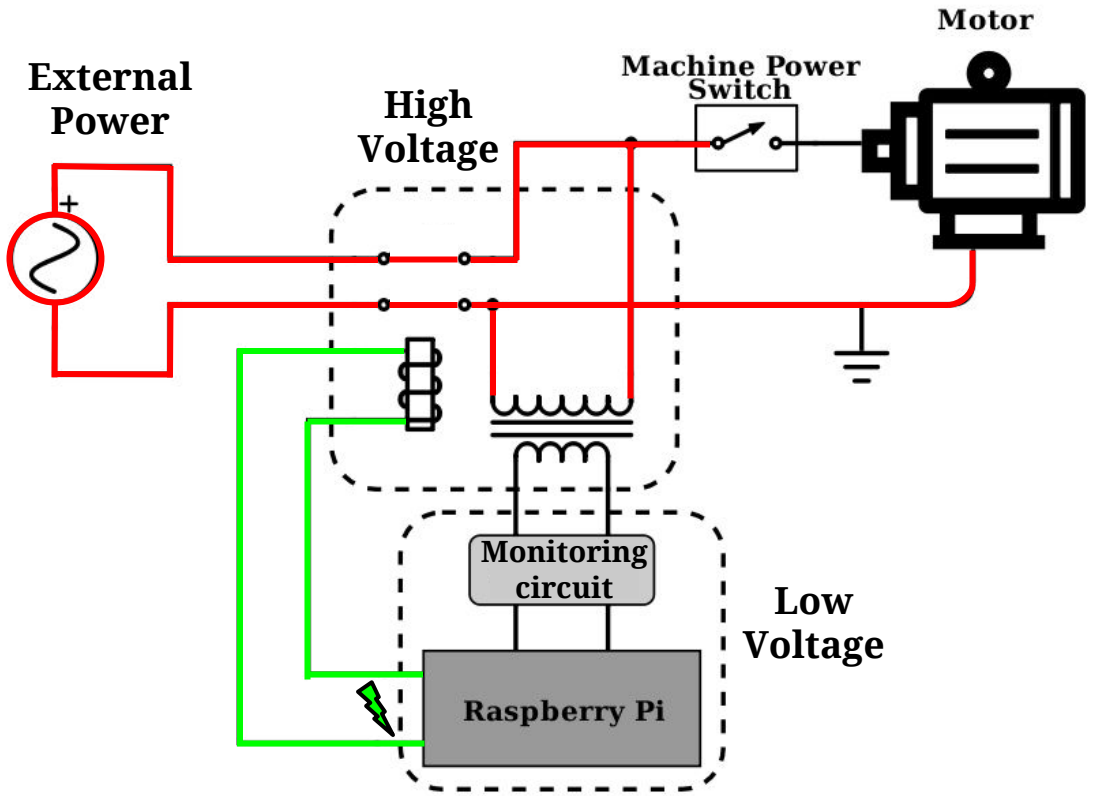

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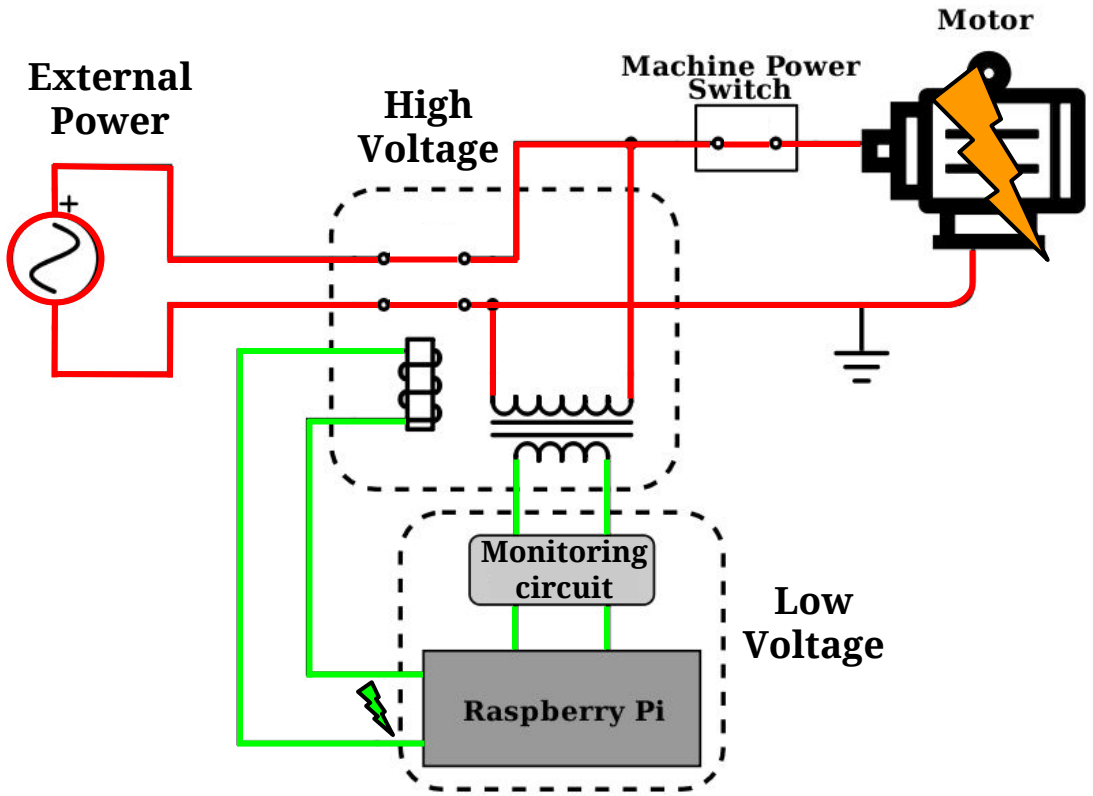


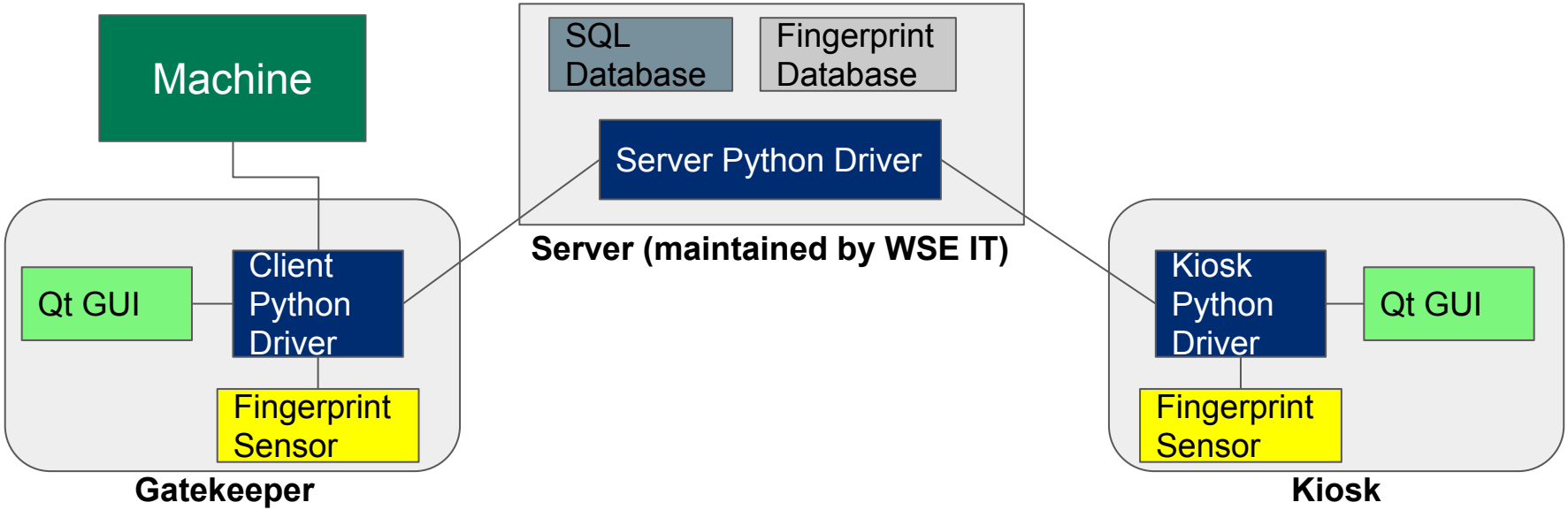
National Electric Code (NEC)

Requirement	Solution	Compliance
Certification required to handle more than 75V	Electrical technicians handle installation of high Voltage	Yes
Maintain Lockout-Tagout	Protocol unchanged by additions	Yes
Consistent insulation	Separate high voltage and low voltages boxes connected by conduit	Yes
Electrical system rated for 6x required current	Use appropriately rated components	Yes
Leads must be capped	Wire connectors	Yes

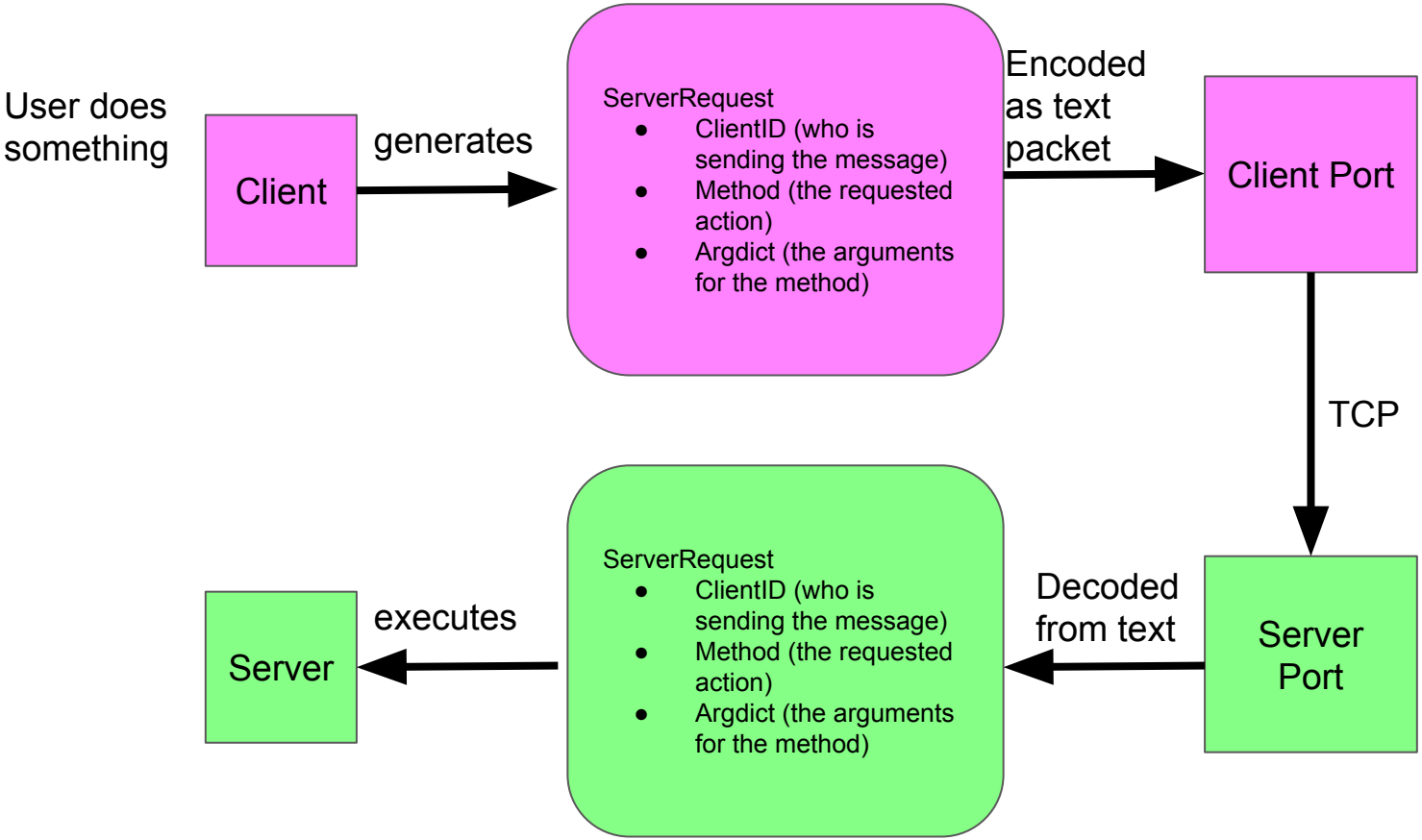
Ref [1]

Backend: What makes it tick

Solution Architecture



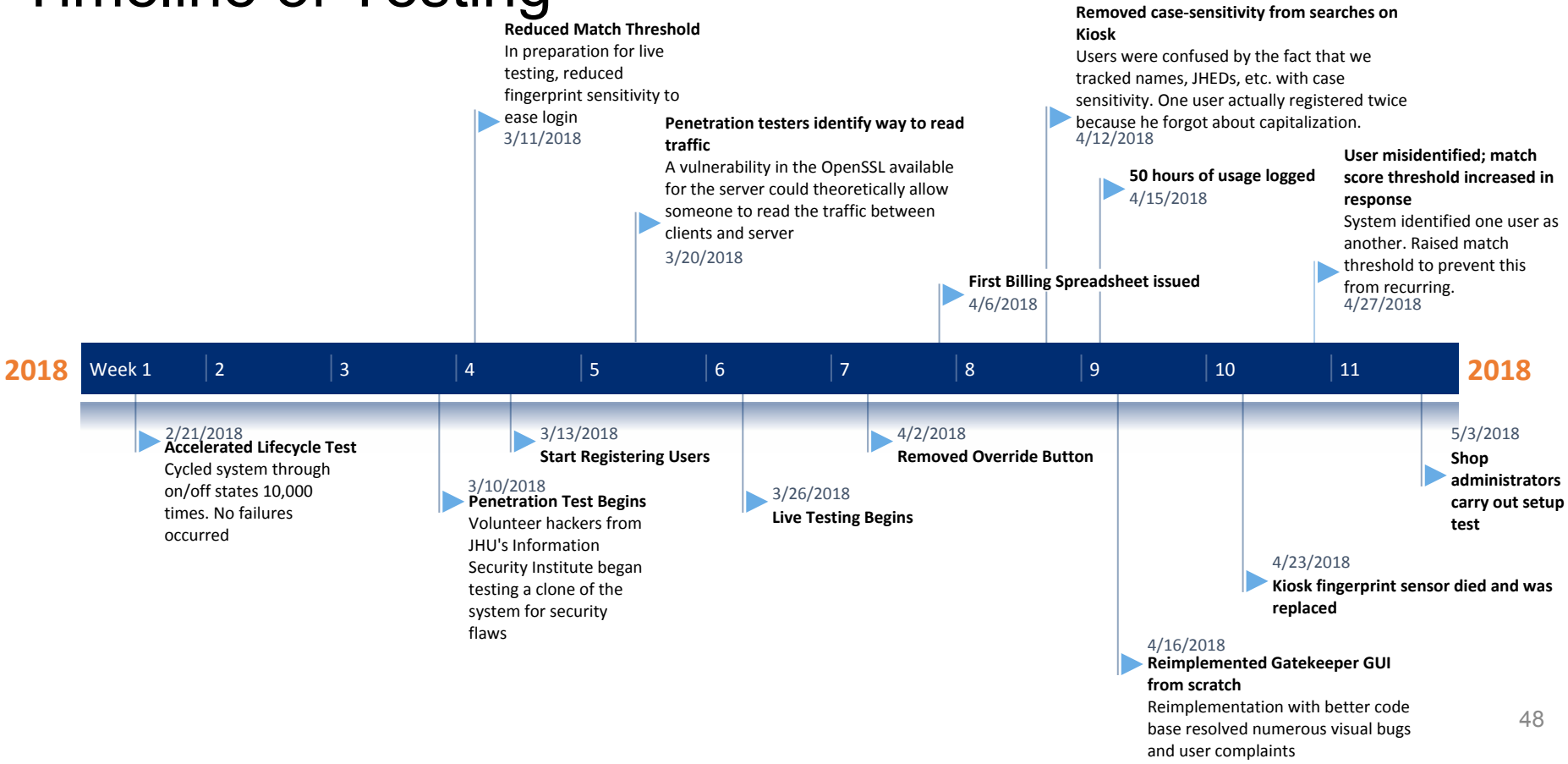
Client to Server Communication Protocol



Evaluation

	Project Requirements	High Level Test Plan	Status
1	prevent untrained users from activating machinery	In-house testing with unauthorized prints, live user testing	Achieved
2	be difficult for a determined user to bypass	Penetration testing by Information Security Institute, live user testing	Achieved
3	be tamper-evident	Penetration testing, Live user testing	Achieved
4	aid in billing	Live user testing	Achieved
5	be minimally intrusive to the user's ability to utilize the shop efficiently	Live user testing	Achieved
6	require minimal maintenance	Accelerated life-cycle testing of hardware	Achieved
7	be expandable to additional machines as the shop grows	Stakeholders setup a machine using only documentation	Achieved
8	not violate relevant electrical and safety codes	Expert evaluation from electricians	Achieved
9	not disconnect power to a machine while in use	In house testing and live user testing	Achieved
10	not cost more than $10,000 to install in student shop	Cost tracking	Achieved

Timeline of Testing



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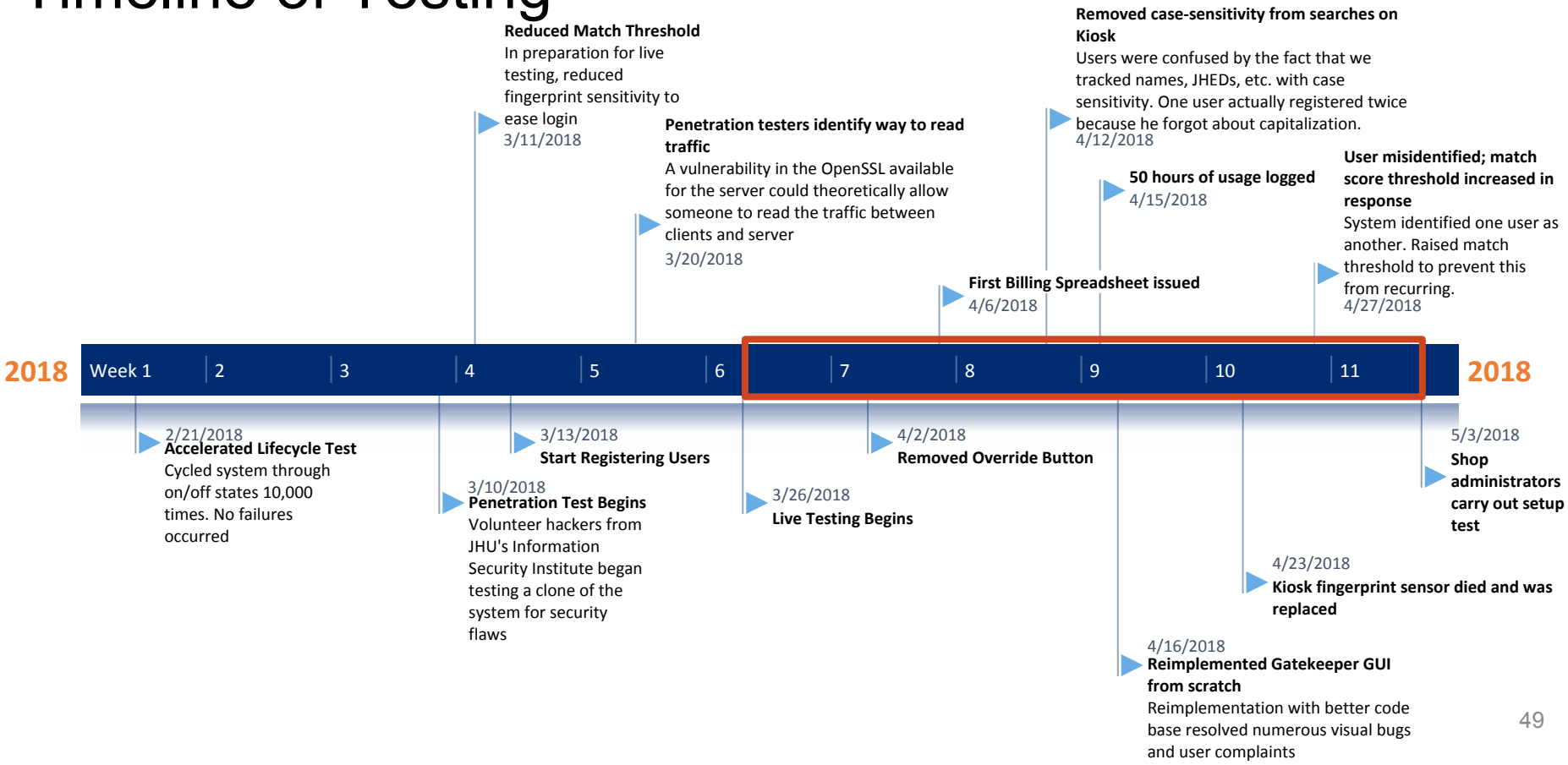

Our system in the hands of real users

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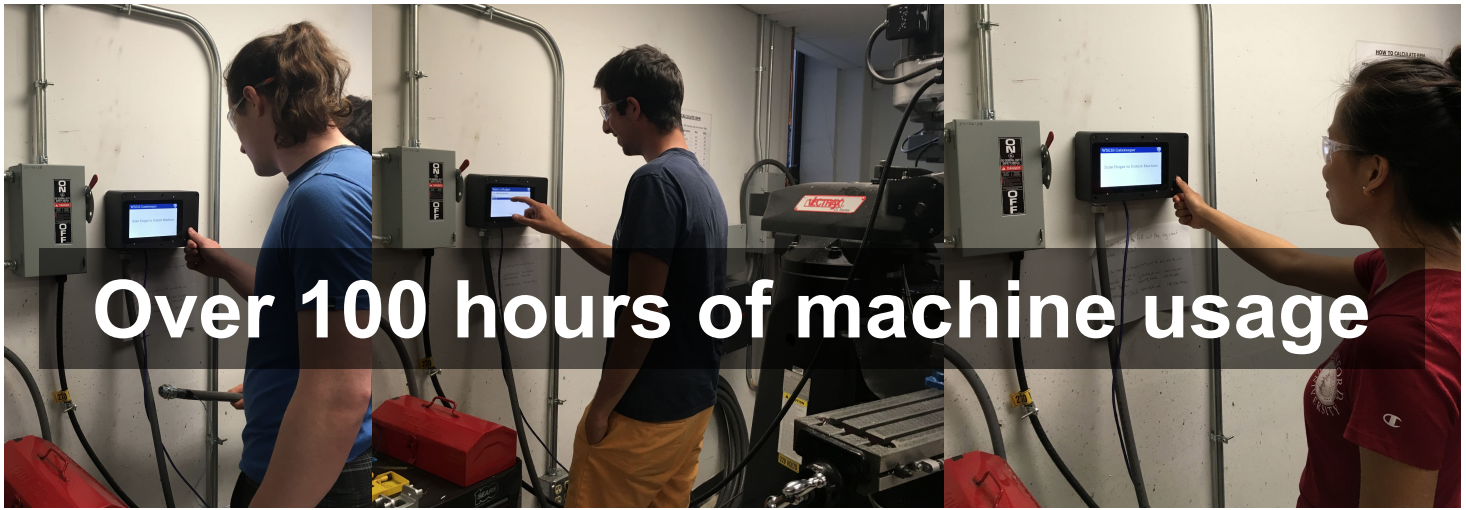

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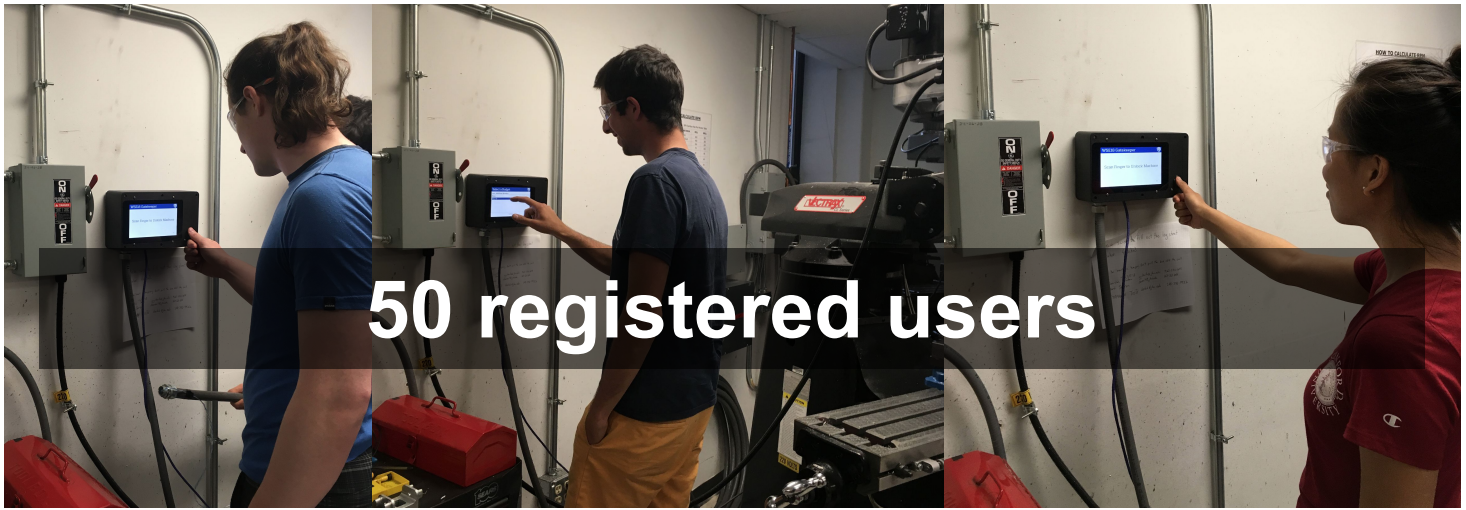

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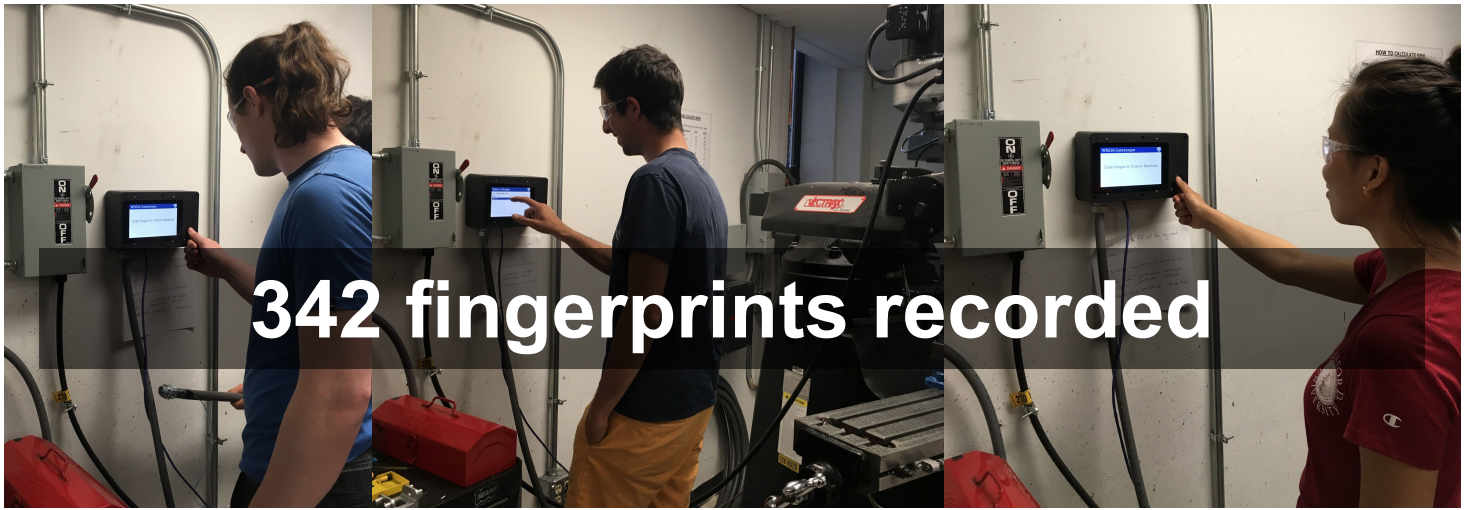

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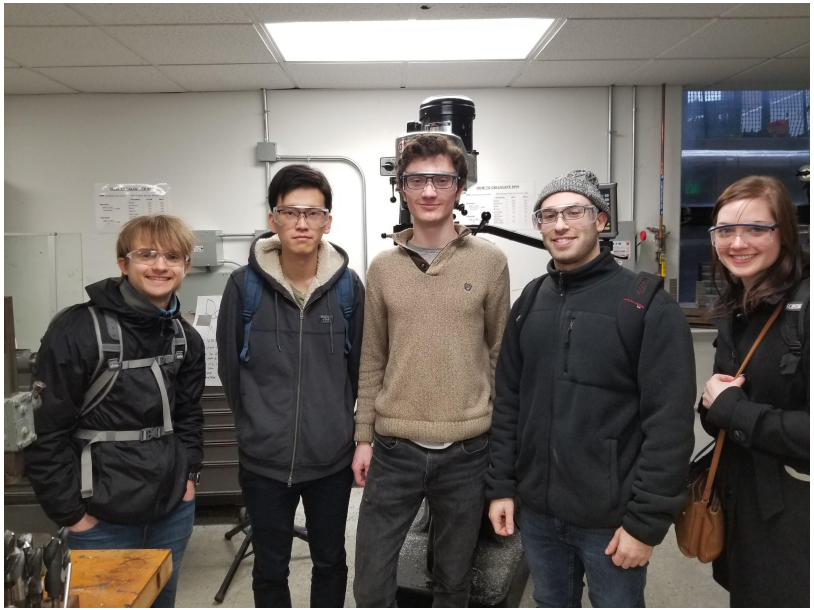
Protecting our users' data

- We partnered with the JHU Information Security Institute and the JHU Cybersecurity Club to test our system for security flaws



Credit: JHU ISI

By the Numbers

- **4 teams** of volunteer hackers
- **2 months** of penetration testing
- **1 way** to read traffic
- **0 ways** to alter data
- **0 ways** to steal sensitive information.

Ensuring system can last

- System has to continue to work, even as the shop changes

Two needs:

1. Maintainable by shop admins
2. Extendable by shop admins

Demonstrating Maintainability

- Low maintenance needs are the first step to maintainability
  - Demonstrated hardware reliability by cycling switching system through on/off states 10,000 times. No failures occurred.
  - Software designed to run unsupervised-records events to human readable log files
  - Carried out over 5 weeks of testing and debugging
- To ensure that the shop administrators can fix issues that do arise, we provided them with comprehensive documentation, including a troubleshooting guide

4. Then you will be asked if you want the serial port hardware enabled. Highlight yes and press enter.
5. You should then be informed that the serial login shell is disabled and the serial interface is enabled. Hit enter.
6. Use the arrow keys to highlight finish and hit enter.

Now we want to confirm that the pins used to communicate with the fingerprint sensor are set to the correct mode. Run:

$ gpio readall

Check that the physical pin number 8 and 10 are in fact in mode ALT5:

BCM	wPi	Name	Mode	V	Physical	V	Mode	Name	wPi	BCM
					Pi 3					
		3.3v			1 || 2			5v		
2	8	SDA.1	IN	1	3 || 4			5v		
3	9	SCL.1	IN	1	5 || 6			0v		
4	7	GPIO. 7	IN	1	7 || 8	1	ALT5	TxD	15	14
		0v			9 || 10	1	ALT5	RxD	16	15
17	0	GPIO. 0	IN	0	11 || 12	0	IN	GPIO. 1	1	18
27	2	GPIO. 2	IN	0	13 || 14			0v		
22	3	GPIO. 3	IN	0	15 || 16	0	IN	GPIO. 4	4	23
		3.3v			17 || 18	0	IN	GPIO. 5	5	24
10	12	MOSI	IN	0	19 || 20			0v		
9	13	MISO	IN	0	21 || 22	0	IN	GPIO. 6	6	25
11	14	SCLK	IN	0	23 || 24	1	IN	CE0	10	8
		0v			25 || 26	1	IN	CE1	11	7
0	30	SDA.0	IN	1	27 || 28	1	IN	SCL.0	31	1
5	21	GPIO.21	IN	1	29 || 30			0v		
6	22	GPIO.22	IN	1	31 || 32	0	IN	GPIO.26	26	12
13	23	GPIO.23	IN	0	33 || 34			0v		
19	24	GPIO.24	IN	0	35 || 36	0	IN	GPIO.27	27	16
26	25	GPIO.25	IN	0	37 || 38	0	IN	GPIO.28	28	20
		0v			39 || 40	0	IN	GPIO.29	29	21
BCM	wPi	Name	Mode	V	Physical	V	Mode	Name	wPi	BCM
					Pi 3					

If either is NOT in mode ALT5, run the following commands:

$ gpio mode 15 ALT5

$ gpio mode 16 ALT5

This should change the mode of wPi pin numbers 15 and 16 (i.e. physical pins 8 and 10, the ones we care about) to mode ALT5. Check that it worked by running:

$ gpio readall

And confirm that pins 8 and 10 are now in ALT5 mode. If they are not, redo the raspi-config steps and try changing modes again.

Once the pins are successfully switched, reboot the Pi. Open a terminal window again and run:

$ gpio readall

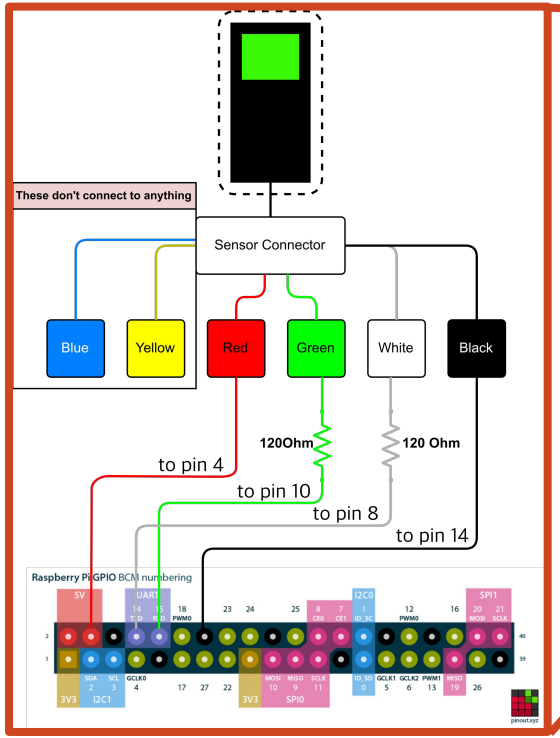
Confirm that the pins are still in the correct mode. If they are not, try raspi-config again.

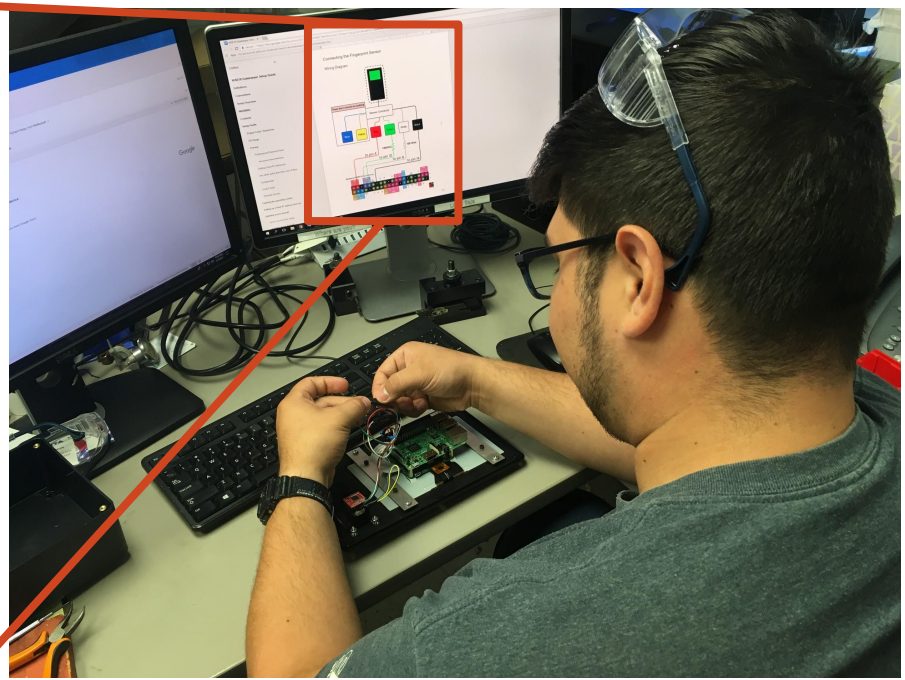
[2]

Sample troubleshooting steps

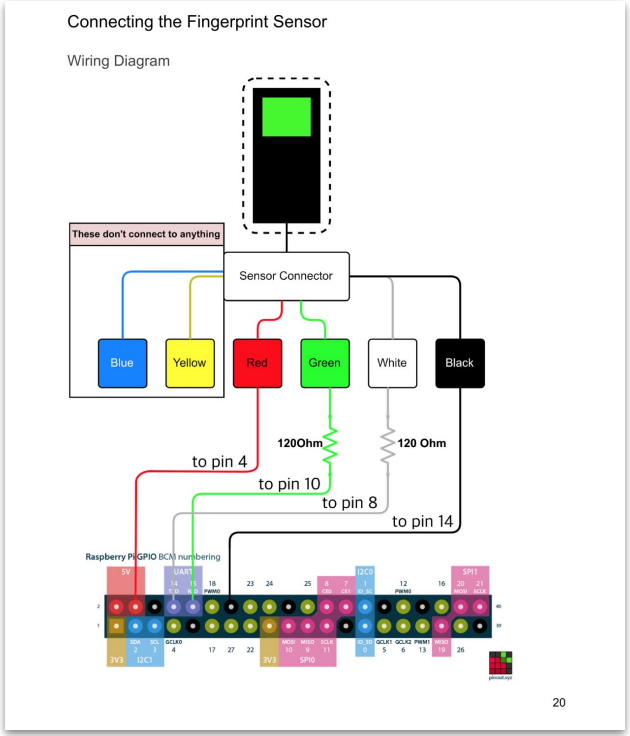
Demonstrating System Extendability

- Shop admin setup test proves ability to expand the system in the future





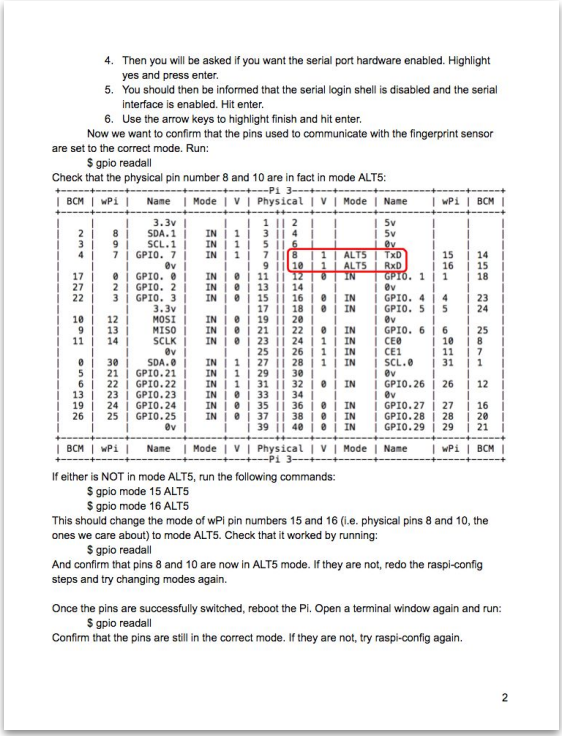
Documentation



Connecting the Fingerprint Sensor

Wiring Diagram

Assembly Guide



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		0v			9 || 10	1	ALT5	RxD	16	15
17	0	GPIO. 0	IN	0	11 || 12	0	IN	GPIO. 1	1	18
27	2	GPIO. 2	IN	0	13 || 14			0v		
22	3	GPIO. 3	IN	0	15 || 16	0	IN	GPIO. 4	4	23
		3.3v			17 || 18	0	IN	GPIO. 5	5	24
10	12	MOSI	IN	0	19 || 20			0v		
9	13	MISO	IN	0	21 || 22	0	IN	GPIO. 6	6	25
11	14	SCLK	IN	0	23 || 24	1	IN	CE0	10	8
		0v			25 || 26	1	IN	CE1	11	7
0	30	SDA.0	IN	1	27 || 28	1	IN	SCL.0	31	1
5	21	GPIO.21	IN	1	29 || 30			0v		
6	22	GPIO.22	IN	1	31 || 32	0	IN	GPIO.26	26	12
13	23	GPIO.23	IN	0	33 || 34			0v		
19	24	GPIO.24	IN	0	35 || 36	0	IN	GPIO.27	27	16
26	25	GPIO.25	IN	0	37 || 38	0	IN	GPIO.28	28	20
		0v			39 || 40	0	IN	GPIO.29	29	21
BCM	wPi	Name	Mode	V	Physical	V	Mode	Name	wPi	BCM
					Pi 3					

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This should change the mode of wPi pin numbers 15 and 16 (i.e. physical pins 8 and 10, the ones we care about) to mode ALT5. Check that it worked by running:

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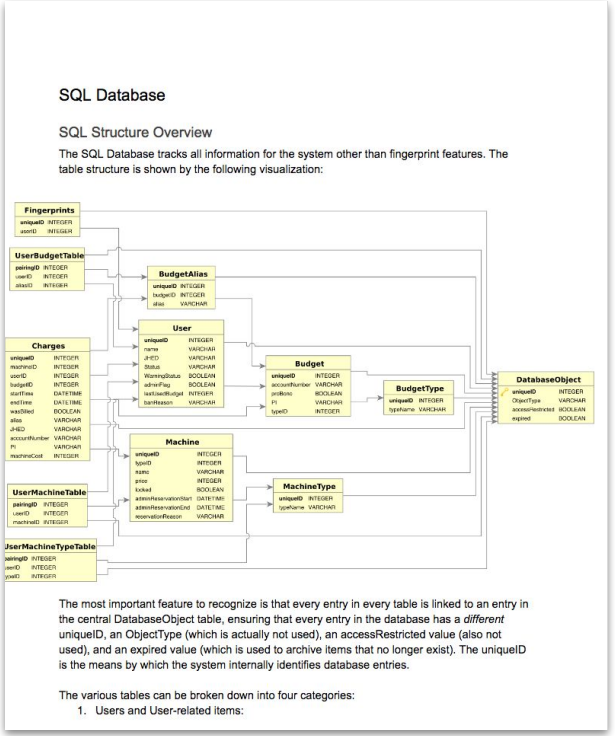
Once the pins are successfully switched, reboot the Pi. Open a terminal window again and run:

$ gpio readall

Confirm that the pins are still in the correct mode. If they are not, try raspi-config again.

Troubleshooting



SQL Database

SQL Structure Overview

The SQL Database tracks all information for the system other than fingerprint features. The table structure is shown by the following visualization:

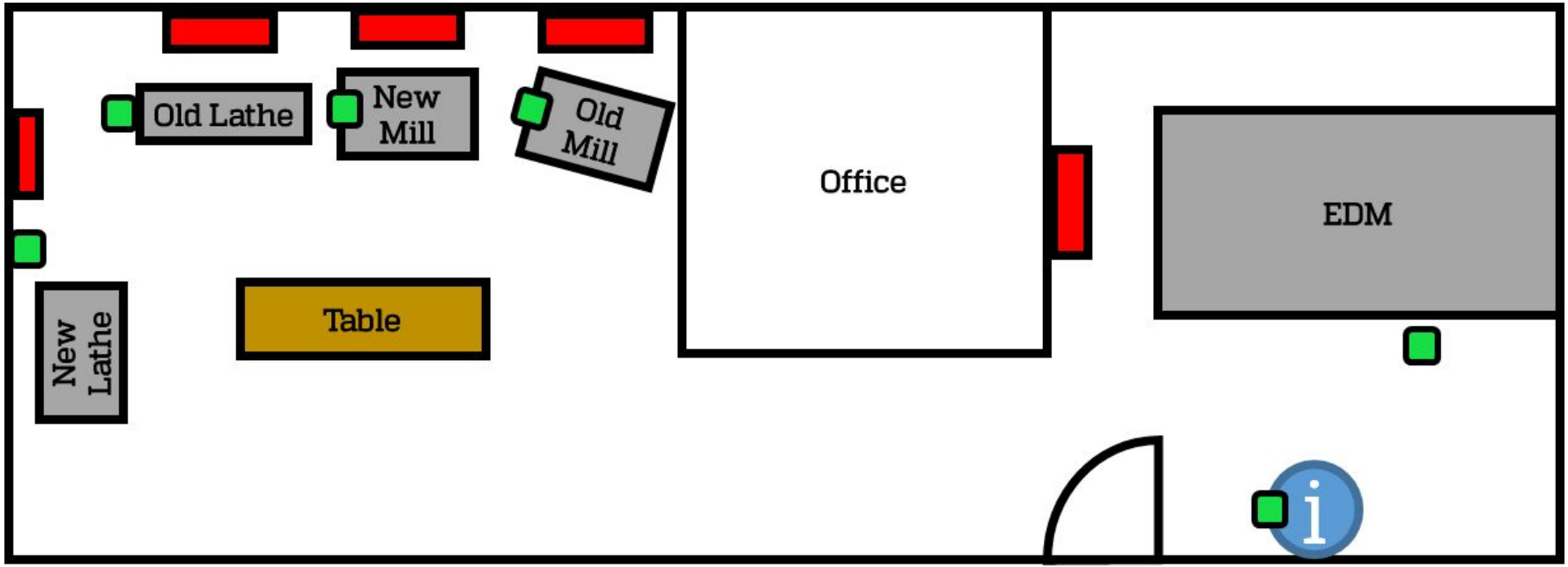
The most important feature to recognize is that every entry in every table is linked to an entry in the central DatabaseObject table, ensuring that every entry in the database has a *different* uniqueID, an ObjectType (which is actually not used), an accessRestricted value (also not used), and an expired value (which is used to archive items that no longer exist). The uniqueID is the means by which the system internally identifies database entries.

The various tables can be broken down into four categories:

1. Users and User-related items:

System Documentation

Conclusion



- Machine
- Gatekeeper
- Power Relay
- Information Kiosk

Our System in the Machine Shop

Budget: $10,000

Expenditure to date: $5043.90

Projected Additional Costs: <$1000

Cost Savings: **40% of allocated funds**

Acknowledgements

Thank you to:

- Rich Middlestadt
- Rich Mejia
- Cynthia Larichiuta

Sponsors

- Colleen Cusimano
- Shawn Suter

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- Soraya Bailey

Senior Design Instructors

- JHU Shops Electricians
- Joseph Carrigan
- The penetration testers

JHU Information Security Institute

- Kimberly Koon
- Sebastian Yllanes

JOHNS HOPKINS

WHITING SCHOOL
of ENGINEERING

References

[1] “Applied Codeology: Navigating the NEC.” Delmar Cengage Learning. 10 Dec 2017.

[2] “Contactor Stock Photo.” Crescent Electric Supply Company.

[3] Gould Studios. “Bridgeport Milling Machine.” Turbosquid. 8 Dec 2017.

[4] “Kookye Optical Fingerprint Reader.” Amazon. 8 Dec 2017.

[5] “Raspberry Pi Touchscreen.” Pihut. 8 Dec 2017.

[6] Steve Jobs. “MacWorld iPhone Introduction.” Apple. 9 Jan 2007.

Original Problem Statement

The WSE18 project aims to install tamper-resistant biometric authentication and iLab in the self-service machine shop.
The main objective is to, first and foremost, ensure the safety of students using the machine shop, then to streamline the billing process.

What is iLab?

iLab is a commercial software product sold by Agilent. It provides tracking of user training on equipment and has the capacity to enable/disable machines via a small set of commercially available controlled outlet devices, like the one to the right.

iLab was eventually removed from the solution due to lacking functionality necessary to implement a biometric authentication system. A revised problem statement, presented on the next page, was used to guide our work from that point onwards.

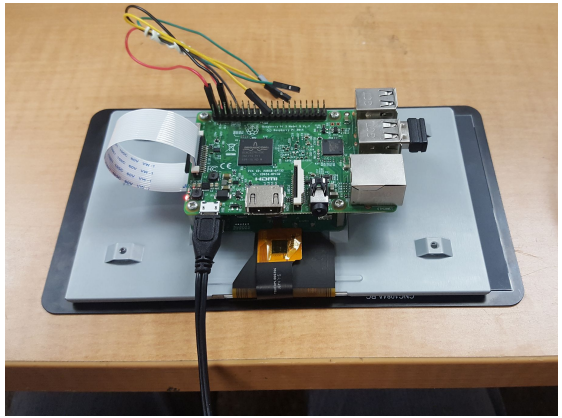
Brainstorming: Authentication Schemes

	Something you have (e.g. JCard)	Something you know (e.g. password)	Something you are (passive) (e.g. gait, or facial scan)	Something you are (active) (e.g. fingerprint)
Pros	● "100%" reliable ● Everyone already has a J-Card ● Already need card out to get into shop->not disruptive	● Cheap ● "100% reliable" ● Might be less likely to share	● User doesn't have to do anything ● Can't give away ● Always have	● Can't give away ● Always have
Cons	● Can give away to untrained user ● Can lose ● Expensive if not JCard ● Reader may be expensive	● Can give away ● Easy to forget ● Annoying to enter	● Accuracy ● Unintentionally unlocking machine ● Expensive cameras/sensors/software ● Privacy concerns ● Speed of identifying a user	● Accuracy ● Privacy ● Annoying to have to provide

Gatekeeper™ GUI Hardware Implementation

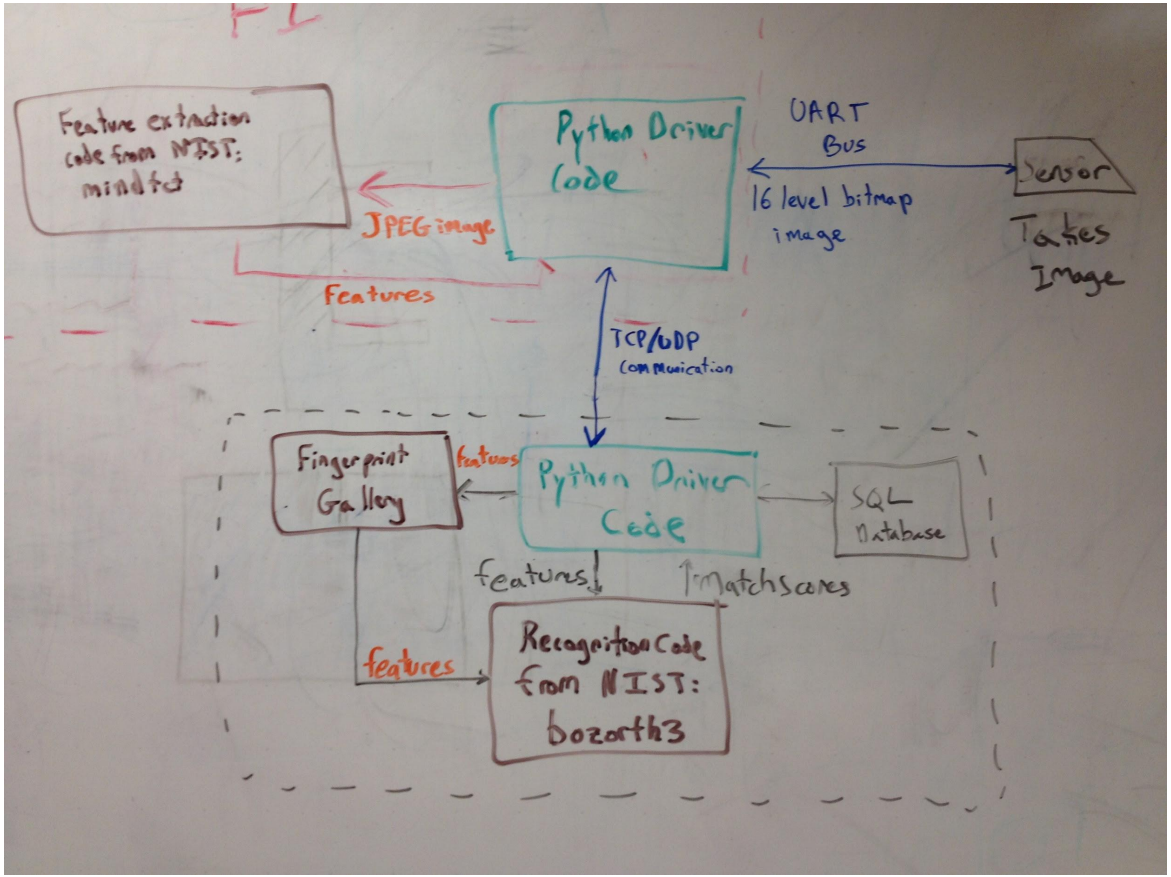
Raspberry Pi 7” touchscreen display

- Full color
- Capacitive Touch Screen
- 800x480 (480p) resolution
- Designed to interface the Pi
  - Screen standoffs connect to pi mounting holes
  - Screen connects directly to Display Serial Interface
- Easy to mount to an external enclosure



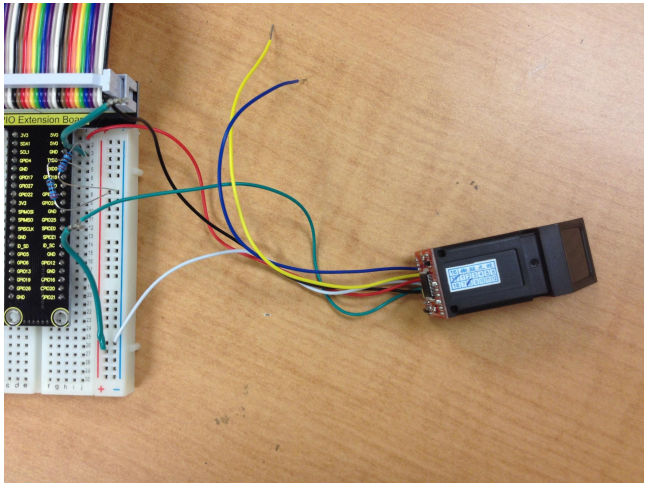
Software Architecture

- sensor is used only to capture images
- Storage and matching are handled by NIST's National Biometric Information Software
- Images never leave the PI and are not saved, improving privacy



Software Architecture

1. The Raspberry Pi uses a commercial fingerprint sensor to capture prints.
2. These prints are feature extracted by mindtct and sent to the SQL database
3. SQL database server maintains authentication, training, and budget records
4. If permitted, the user is asked for a budget
5. Then the Raspberry Pi unlocks the machine

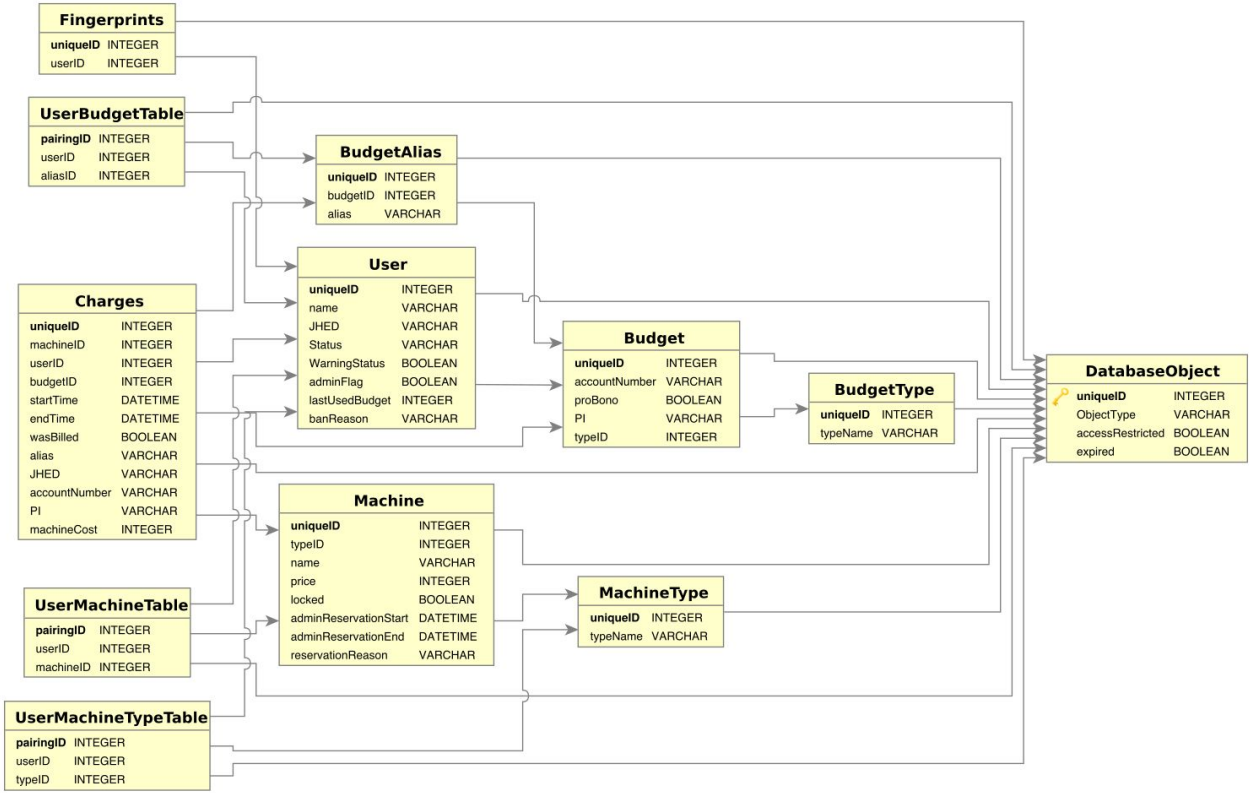


Current Sensor:
Kookye Optical Fingerprint Sensor
Selected for:

1. simple, easy-to-use hardware/software interface
2. Low-cost combined with good resolution
3. Can upload raw image files, meaning we are not forced to use onboard algorithm

Data Management Solution: SQL Database

The data includes information (such as training) that needs to be shared with multiple types of “objects.” A relational database can capture this efficiently



Recording a fingerprint

Sensor captures an image, and...

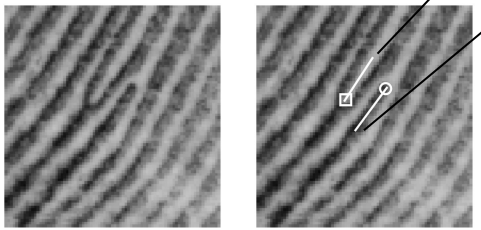


Figure 3. Minutiae: bifurcation (square marker) and ridge ending (circle marker).

...mindtct executable extracts minutiae...

...which are saved as .xyt files...

```
58 59 135 38
70 95 135 75
72 175 124 72
83 39 315 73
```

finger8.xyt
finger27.xyt
finger28.xyt
finger29.xyt

...and tracked in the gallery file and SQL database

Image: User's Guide to NIST Biometric Software

Recognizing a User

finger8.xyt
finger27.xyt
finger28.xyt
finger29.xyt

Gallery of fingerprints

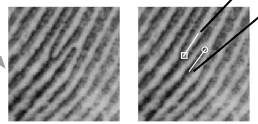
Bozorth3 executable generates match scores...

...which are stored in a text file

3
34
9
2

Finger presented to Gatekeeper™

Sensor captures an image, and...



...mindtct extracts minutiae...

...which are saved as .xyt files...

JHED	VARCHAR
accountNumber	VARCHAR
PI	VARCHAR
machineCost	INTEGER
quantity	INTEGER

Fingerprints	
uniqueID	INTEGER
userID	INTEGER

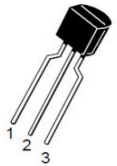
User	
uniqueID	INTEGER
name	VARCHAR
JHED	VARCHAR
Status	VARCHAR
WarningStatus	BOOLEAN
adminFlag	BOOLEAN
lastUsedBudget	INTEGER
banReason	VARCHAR

Scores above a threshold indicate a match with a gallery fingerprint (and thus a user)

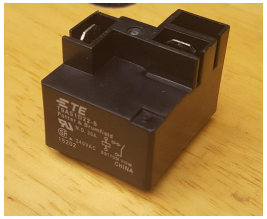
Image: User's Guide to NIST Biometric Software

Signal Transfer

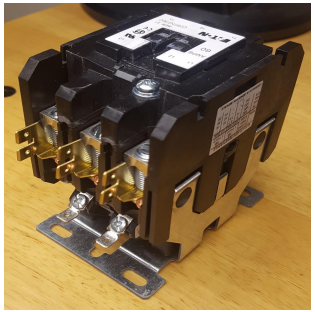
Raspberry Pi



NPN
Transistor

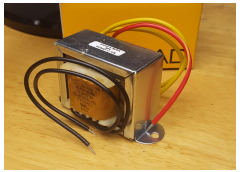


Relay



Contactor

Machine
Unlocked



Transformer

Power
Monitoring

Expenses (Next 5 Pages)

Budget: $10,000

Total Expenditures: $5,043.90

	Budget	10,000					
	Remaining	4,956					
Orders							
Item	Vendor	Order Date	Unit Cost	Quantity	Shipping	Total Cost	Received
1/4" BSPP Female to 1/4" NPT male	McMaster-Carr	9/11/2017	$ 7.59	2	$ -	$15.18	yes
1/4" BSPP Male to Male	McMaster-Carr	9/11/2017	$ 5.51	2	$ -	$11.02	yes
KOOKYE Optical Fingerprint Reader Sensor Module	Amazon	9/11/2017	$ 32.99	1	$ -	$32.99	yes
General Purpose Relays <T9GS1L14-12> 480 VAC SV	Mouser	9/11/2017	$ 1.98	5	$ 15.56	$25.46	yes
General Purpose Relays <T9AS1D22-5> 277 VAC SV	Mouser	9/19/2017	$ 3.84	27	$ 15.56	$119.24	yes
KOOKYE Optical Fingerprint Reader Sensor Module	Amazon	9/19/2017	$ 32.99	1	$ -	$32.99	yes
3.5" TFT 320x480 Touchscreen	Amazon	9/19/2017	$ 35.95	2	$ 7.76	$79.66	yes
Raspberry Pi 3 Official Desktop Starter Kit	Amazon	9/19/2017	$ 55.25	2	$ -	$110.50	yes
HDMI Cables	Amazon	9/25/2017	$ 6.99	2	$ -	$13.98	yes
Sustenance	Ledos	9/28/2017	$ 24.00	1	$ -	$24.00	yes
GPIO Breakout Kit for Raspberry Pi	Amazon	10/2/2017	$ 7.99	2	$ 3.99	$19.97	yes
Sustenance	Pizza Boli's	10/4/2017	$ 8.50	2	$ -	$17.00	yes
Raspberry Pi 7" Touchscreen Display	Amazon	10/6/2017	$ 69.99	1	$ -	$69.99	yes
Sustenance	Pizza Boli's	10/19/2017	$ 8.50	2	$ -	$17.00	yes
Contactor	Amazon	10/16/2017	$ 99.80	1	$ 7.99	$107.79	yes
Team Meal at Ajumma	Ajumma	11/3/2017	$ 37.88	1	$ -	$37.88	yes
ADC - RETURNED	Amazon	11/7/2017	$ 5.01	1	$ 5.01	$10.02	yes

Expenses (cont.)

Budget: $10,000

Total Expenditures: $5,043.90

	Budget	10,000					
	Remaining	4,956					
Orders							
Item	Vendor	Order Date	Unit Cost	Quantity	Shipping	Total Cost	Received
Contactor	Grainger	11/6/2017	$ 137.10	2		$274.20	yes
Pizza	Pizza Boli's	11/15/2017	$ 8.50	2		$17.00	yes
Pizza	Pizza Boli's	11/1/2017	$ 8.50	2		$17.00	yes
Pizza	Pizza Boli's	10/11/2017	$ 8.50	2		$17.00	yes
Team Meal at Ajumma	Ajumma	10/20/2017	$ 37.88	1		$37.88	yes
Raspberry Pi 7" Touchscreen Display	Amazon	11/27/2017	$ 69.99	1	$ -	$69.99	yes
GPIO Breakout Kit for Raspberry Pi	Amazon	11/27/2017	$ 7.99	2		$15.98	yes
Raspberry Pi 3 Official Desktop Starter Kit	Amazon	11/27/2017	$ 59.99	2	$ -	$119.98	yes
Kookye Fingerprint reader	Amazon	11/27/2017	$ 32.99	2	$ 7.98	$73.96	yes
Pyle Pro Adjustable Tripod Laptop Projector Stand, 28" To 41"	Amazon	11/27/2017	$ 30.59	1	$ -	$30.59	yes
Electronics Box	Amazon	11/27/2017	$ 28.77	1	$ 4.99	$33.76	yes
Raspberry Pi 3 Desktop Starter Kit	Amazon	1/31/2018	$ 59.95	1		$59.95	yes
GPIO Breakout Kit for Raspberry Pi	Amazon	1/31/2018	$ 7.99	1		$7.99	yes
HDMI Input to DVI Output Adapter Cable	Amazon	1/31/2018	$ 6.99	1		$6.99	yes
KOOKYE Optical Fingerprint Reader	Amazon	1/31/2018	$ 32.99	1		$32.99	yes
15ft Micro USB Cable	Amazon	2/7/2018	$ 7.99	1		$7.99	
20ft Micro USB Cable	Amazon	2/7/2018	$ 7.99	1		$7.99	

Expenses (cont.)

Budget: $10,000

Total Expenditures: $5,043.90

	Budget	10,000					
	Remaining	4,956					
Orders							
Item	Vendor	Order Date	Unit Cost	Quantity	Shipping	Total Cost	Received
100 Pc Screw Terminal Blocks	Amazon	2/7/2018	$ 10.79	1		$10.79	
Electrical Shop Services	JHU	2/1/18	$ 646.17	1		$646.17	
Pizza	Pizza Boli's	1/31/2018	$ 8.50	2		$17.00	yes
Pizza	Pizza Boli's	2/6/2018	$ 8.50	2		$17.00	yes
Pizza	Pizza Boli's	2/13/2018	$ 8.50	2		$17.00	yes
USB to Ethernet Adapter	Amazon	3/2/2018	$ 7.99	2		$15.98	yes
Raspberry Pi Canakit starter		2/26/2018	$ 49.99	1		$49.99	yes
Arducam Multi Camera Adapter Module	Amazon	2/26/2018	$ 49.99	1		$49.99	yes
Arducam 5 Megapixels Camera	Amazon	2/26/2018	$ 13.49	2		$26.98	yes
Small Right Angle Prism	Amazon	2/26/2018	$ 11.01	1		$11.01	yes
San Disk Micro SD 8GB	Amazon	3/2/2018	$ 6.99	1		$6.99	yes
Raspberry Pi Starter Kit	Amazon	3/2/2018	$ 59.97	1		$59.97	yes
Pack of 10nF Capacitors (1000V)	Amazon	02/26/18	$ 8.17	1		$8.17	yes
PowerLine Communicaitons Adaptor Kit	Amazon	02/27/18	$ 44.99	1		$44.99	yes
3D Printing for sensor prototype	WSE	3/6/2018	$ 184.97	1		$184.97	yes
Current Transformer	Grainger	3/7/2018	$ 47.37	1		$47.37	yes
Plastic Utility Box	Amazon	3/15/2018	$ 23.10	1		$23.10	yes

Expenses (cont.)

Budget: $10,000

Total Expenditures: $5,043.90

	Budget	10,000					
	Remaining	4,956					
Orders							
Item	Vendor	Order Date	Unit Cost	Quantity	Shipping	Total Cost	Received
Solenoid Valve	Grainger	4/27/2018	$ 71.25	1		$71.25	yes
Tamper Proof Screws	Tamperproof Screw Co, Inc		$ 51.20	1	$ 21.86	$73.06	yes
PCB Order	OshPark		$ 97.80	1	$ 35.00	$132.80	yes
McMaster Fasteners Order	McMaster	4/26/2018	$ 11.76	1		$11.76	yes
Gatekeeper Kit	Amazon	4/20/2018	$ 164.33	5		$821.65	yes
Raspberry Pi 3 power supply 5V 3A	Amazon	4/20/2018	$ 10.99	1		$10.99	yes
Plastic Utility Box	Amazon		$ 23.10	3		$69.30	yes
Raspberry Pi 3 power supply 5V 3A	Amazon	5/1/2018	$ 9.99	6		$59.94	yes
Digikey Order	Digikey	5/2/2018	$ 17.94	1		$17.94	yes
Electrical Boxes	Amazon	5/2/2018	$ 37.99	4		$151.96	yes
More Electrical Boxes	Amazon	5/2/2018	$ 23.57	1		$23.57	yes
Pull Box	Amazon	5/2/2018	$ 20.91	3		$62.73	yes
Additional Digikey Order	Digikey	4/30/2018	$ 63.54	1		$63.54	yes
Current Transformer	Grainger	4/27/2018	$ 50.75	5	$ 10.98	$264.73	yes
Contactor	Amazon	4/27/2018	$ 99.80	2		$199.60	yes
USB Wall Charger 3 Pack	Amazon	4/27/2018	$ 8.99	2		$17.98	yes
Original Security Screws Order	Tamperproof Screw Co, Inc		$ 25.60	1	$ 21.86	$47.46	yes

Expenses (cont.)

Budget: $10,000

Total Expenditures: $5,043.90

	Budget	10,000					
	Remaining	4,956					
Orders							
Item	Vendor	Order Date	Unit Cost	Quantity	Shipping	Total Cost	Received
Waterjet Time	WSE		$ 70.00	0.25		$17.50	yes
Laser cutter Time	WSE		$ 30.00	1.25		$37.50	yes
M to F Micro USB Adapter	Amazon	3/26/2018	$ 5.58	1	$ -	$5.58	yes
Jumper Wires for Raspberry Pi	Amazon	3/26/2018	$ 6.98	1	$ -	$6.98	yes
Black ABS Utility Box	Amazon	4/27/2018	$ 23.10	2		$46.20	yes
BSI Super Glue	Amazon	5/1/2018	$ 8.25	2		$16.50	yes

Full expenses spreadsheet can be found at: <https://docs.google.com/spreadsheets/d/12Nj-vAkb6Q3DfC7pEC3eFCeiTTDK5vQEFtAUXouBF-I/edit?usp=sharing>

Projected Deployment Cost

Each Gatekeeper uses components costing $427.49+shipping. Bulk ordering can potentially reduce these costs further.

The work conducted by the electricians to install a system is a variable cost, depending on the state of the electrical system surrounding the machine to be controlled. However, labor is unlikely to cost more than $600 per installation, as that was the cost of the first (and thus most expensive) installation the electricians did.

A detailed cost breakdown, with links for ordering more components, is available here: <https://docs.google.com/spreadsheets/d/1RR1LcHQNt9hPBADR2CIPDq5knEZoumeF0wtRRccP1DI/edit?usp=sharing>