Predictive Tool Development for Residential Solar Installation Duration

Note: The data that Midwest Solar Power (MSP) is providing for the Predictive Tool Development for Residential Solar Installation Duration project is confidential and is to be used for academic purposes only. The intended audience for this data is UVA engineering students who have been selected to work on this project, UVA first year engineering faculty, and teaching assistants who are involved in supporting students and assessing their work. Sharing MSP's data outside of the intended audiences is expressly prohibited.

Background and Problem:

Midwest Solar Power (MSP) is a small solar installation company based in Madison, Wisconsin. In the past few years MSP has begun tracking data for our solar installations. Among other things this data is correlated with the difficulty, and therefore duration, of the solar installation.

MSP is a growing company and has added a lot of new staff over the past five years. The owners of the company are longtime experts in solar installation and are able to roughly predict how long a project will take to install when reviewing all the relevant factors. However, as the company grows, the owners are no longer able to take an active role in every project. As a result, scheduling projects is a more difficult task that can involve long conversations between the installation crew leader, project manager, and salesperson. These conversations can take a long time and are prone to miscommunication, interruption that leaves some details unresolved, and delays or incorrect guesses when not all parties are available to discuss the project far enough in advance. This results in scheduling mistakes that reduce MSP's effectiveness at delivering for our customers and makes life harder for our employees.

For MSP, scheduling is an important equity issue. MSP employs a significant amount of office staff due to the technical nature of solar installations and relatively high administrative burden of permitting. However we are still a construction company and we only earn money by installing solar systems. The installation crew is tasked with installing solar systems, so without the installation crew there is no Midwest Solar Power. Installing solar systems is hard work and it's made more difficult by poor scheduling. The majority of residential solar systems take one or two days to install, so we usually schedule in one day increments. If we're scheduled to finish a project today and it takes three hours longer than expected, there may not be an opportunity to leave and come back the next day because we already have a commitment to install another system the next day. This lack of flexibility disproportionately affects the installation crew compared to the office staff and it is very easy for several scheduling mistakes in a row to compound into a very difficult and frustrating month for the entire crew, and therefore all of MSP.

This project is about utilizing the data that MSP has been collecting over the past few years to help improve our scheduling. An additional benefit would be to train new employees on the impact of the many variables that influence scheduling.

Key Variables:

This is a list of the variables that MSP has collected data on and is providing for the project. MSP has already qualitatively identified that these are the key factors in determining project duration. The qualitative relationship to duration, limitations in data collection, and any additional details are noted next to each variable.

Project #: This is just a reference number to refer to the projects by. They are roughly in the order that projects were completed.. Project 001 was the first project completed in 2021. If you have a specific question about a project I may be able to review that project in more detail to answer your question.

Drive Time: This is the drive time to the project site from MSP's shop. Drive time is included in the total labor hours for the project. Projects that are farther away will take more labor hours to complete. Generally everyone drives from MSP's shop to the job site and back every day that they are on site. However, not everyone is on site every day of an install (for example if someone is out sick, or if the remainder of the work on a project does not require the entire installation crew). Projects that are farther away take 'longer' to install (in that people are on the clock for longer).

Tilt: This is the pitch of the roof. Some projects have solar installed on multiple roofs at different pitches. The pitch of the roof has a slightly unexpected impact on the installation duration. The pitch that takes the least time to install on is ~ 25°. Roofs that are lower pitch take slightly longer to install on. Roofs that are between 25-34° take a little bit longer to install on as well. However there is a step increase in the amount of time it takes to install on roofs above 34° pitch because additional safety gear is required.

Azimuth: This is the orientation of the roof in relation to compass directions. A roof with a 0° azimuth faces due north. 90° is due east, 180° is due south, and 270° is due west. It is very common to have one system with arrays on multiple roof planes at multiple azimuths. Azimuth generally plays a small role in system installation duration, however during the hottest days, west facing roofs provide shade and increase the speed of work while east facing roofs do the opposite. In the early spring, late fall, and winter, east facing arrays are free of frost sooner and allow for work to proceed more quickly, with west facing arrays having the opposite impact.

Panel QTY: This is the total number of solar panels installed. Generally, more solar panels makes for a longer installation.

System Rating (kW DC): This is the electrical rating of the system in kilowatts and is generally referred to as the 'System Size'. In general, system size is the single best indicator of how long it will take to complete the installation. However, for the purpose of this project, I've provided more granular data that I believe entirely captures the impact of system size on the duration including panel QTY, panel weight, panel length, and panel width, Interconnection type, etc. Still, I left this variable in because it gives you a quick way to understand 'how large' the system is that is more accurate than using the number of panels alone. Larger systems take longer to install.

Inverter Manufacturer: Different inverter manufacturers require slightly different installation methods and equipment for the project. Generally this plays a small, but nonzero role in determining installation duration. There's not a clear qualitative effect on installation duration, but it does have a nonzero impact.

Array Type: We install both roof and ground mounted systems. For the purposes of this project we are only interested in the duration of roof mounted systems because we have very few data points for ground mounted systems and they add a layer of additional complexity that is not well captured in our data. Generally ground mounts take longer than roof mounts.

Squirrel Screen: Squirrels love to nest under solar arrays and chew up the wiring. We either install squirrel screening or we do not. Adding Squirrel Screening increases the duration of the project. The amount of time it adds is generally related to the total perimeter of the array(s) as well as the pitch of the roof and the number of stories.

Consumption Monitoring: This lets homeowners monitor their electrical usage. We only have data on this for project 160 and later. Installing consumption monitoring takes 1-2 hours for one person. For projects where this data is not available, there's a 5% chance that we installed it for SolarEdge inverters and a 25% chance that we installed it for Enphase inverters

Truss/Rafter: This category describes the roof framing method. Like System Rating, this variable has a big impact on the difficulty of the installation, but many of the details of what makes these installations more difficult is captured in other locations such as roof pitch (rafters are often associated with very steep roofs) or reinforcements. Rafter roofs often take longer than truss roofs.

Reinforcements: MSP performs structural analysis on all homes to ensure that the roof framing method is strong enough to support the solar system we will be installing. Sometimes the structure needs remediation in order to sufficiently support the solar in which case MSP will install reinforcements. Reinforcements almost always occur when rafters or purlins are used as the framing method. This is just a yes/no on whether or not reinforcements were installed. Reinforcements take longer than no reinforcements

Interconnection Type: This is an internal description that MSP developed to differentiate between different electrical configurations. The interconnection types and definitions are shown below:

Interconnection Type Chart

Category	Outage	Code	What it Means
Load Side	No Outage	A1	Simple Backfed Breaker
	No Outage	A2	Combine Circuits and Backfeed Breaker
	No Outage	A3	Move Circuits around and Backfeed Breaker
	No Outage	A4	Add Subpanel and Backfeed Breaker
	No Outage	A*	Other Non-Outage Interconnection
	Outage	B1	Upgrade Main Panel and Backfeed Breaker
	Outage	B2	Upgrade Main Panel & Service and Backfeed Breaker
	Outage	B*	Other Outage Required Load Side Interconnection
Line Side	Outage	C1	Line Side, Add Tap Kit (MGE Only)
	Outage	C2	Line Side, Meter Upgrade/Swap
	Outage	C3	Line Side, Termination Cabinet
	Outage	C*	Other Outage Required Line Side Interconnection

Generally A takes less time than B or C (which take similar amounts of time). And lower numbers take less time than higher numbers. The *'s indicate non-standard interconnections which often take longer than standard interconnections.

Module Length: The length of the module. Longer is harder to install. This has less of an impact than module width.

Module Width: The width of the module. Wider is harder to install. This has more of an impact than module length.

Module Weight: The weight of each solar panel. Heavier is harder to install.

# of Arrays: An array is a contiguous grouping of solar panels. Each additional array adds some small additional amount of time to the overall installation. A system that has 10 panels and one array will be completed slightly faster than an installation with 10 panels and two arrays.

# of Circuits - This determines the number of sets of electrical wires that have to come off the roof and connect into the home electrical system. More takes longer, but the connection to installation duration is weak.

# of Reinforcements: This is the QTY of reinforcements that were installed. More reinforcements take longer.

Roof Type - Most roofs have asphalt shingles. Standing Seam or ag metal roofs need different types of attachments which are faster to install, but they are also more slippery and harder to walk on. Additionally, ag metal and standing seam roofs are more difficult to work on during inclement weather.

Attachment Type: Mostly corresponds to roof type, however there are a few different attachment types for asphalt shingle roofs. Generally Flashfoot 2 is the slowest, Flashview is slightly faster. RT Mini and Hugs are the fastest and are about the same difficulty.

Portrait/Landscape: Portrait modules require fewer attachments per module than landscape modules, so portrait is faster than landscape. Generally, if a site has both portrait and landscape modules (noted as 'Both'), that's an indication that the design was space constrained and space constrained designs take longer than designs that are not space constrained.

# of Stories: 2 stories takes longer than 1 story, due to the potential additional safety gear and additional time to go up and down the ladders throughout the day.

Install Season: Spring is defined as March - May. Summer is June - August. Fall is September - November. Winter is December - February. Each season has its own difficulties. Winter is the slowest to install in due to the cold. In summer the heat can take a physical toll and result in slower installations. Spring often has inclement weather, and fall has short days that may result in some one day installs becoming two day installs (duplicating drive time). Generally spring and fall have the fastest installations when the weather is good due to improved morale.

Total Direct Time for Project for Hourly Employees (Including Drive Time): This is how much time hourly employees spent on the installation total (including drive time).

Total # of Days on Site: This is the total number of days that MSP had at least one employee working on site on the installation. Each day on site also includes setup and tear down time at the beginning and end of each day.

Total # of Hourly Employees on Site: This is the total number of hourly employees that worked onsite for at least one day on this project. It's not necessarily the case that every employee was on site for every day of the installation. More employees on site makes for a faster install, but only up to a point. Generally between 4 and 5 MSP employees on site is the fastest.

Estimated # of Salaried Employees on Site: We have less data regarding which installations salaried employees worked on and for how long they worked on them. This is the estimated number of salaried workers that were on site for at least one day for the project

Estimated Salary Hours: This is the estimated number of hours that salaried employees spent on the project (including drive time)

Estimated Total Direct Time: This is the sum of the tracked hourly employee time on site and the estimated salaried employee time on site. This is the output that we want the model to provide

Estimated Total # of People on Site: This is the sum of the tracked number of hourly employees on site for at least one day and the estimated number of salaried employees on site for at least one day.

Notes: Be sure to check the notes! I've tried to indicate projects that had unusual situations impacting project duration that are not captured in the data categories that we normally track.

Known Limitations in Data Collection:

There are some variables that MSP knows play a role in determining the duration of a project, however we do not currently have data on them for one reason or another. These limitations include:

Total # of attachments - Installation of an attachment cannot be sped up after a certain threshold of training. Therefore the total number of attachments is important in determining the duration of the project. The amount of attachments is roughly correlated to the total number of panels and whether the panels are in landscape or portrait. However, in some instances, rafter roofs may have more attachments than expected from just these factors.

The amount of experience that each installer on site has - Everyone learns at different rates and measuring the skill over time of each employee is beyond the scope of MSPs abilities. In general though, as projects move forward in time the average amount of experience that each installer has goes down as MSP has more experienced installers taking higher level roles within the organization and hires new employees to replace them on the installation team.

Salaried hours on site: Salaried employees at Midwest Solar Power track their time differently from hourly employees. As a result, historic information regarding how much time a salaried employee spent on site is very difficult to determine. I have done my best to make a rough guess as to their time on site for each project, however even knowing whether a salaried employee was on site or not is difficult to determine, much less how long they spent on site, etc. This means that some data has a very high amount of error for the number of hours spent on site. Generally any data from project 160 or later is much more accurate than any data from before this time.

Weather - It's difficult to quantify the experience of weather on site during an installation. Sometimes a light rain in the summer is welcome, whereas a light rain in the fall slows down work significantly. A morning frost can delay the start of a project and the summer heat can stop a project for the day. Adverse weather is partially captured by the season that the project is installed during. In addition to seasonal weather impacts, 5-10% of projects may be impacted by additional weather such as rain.

Additional uncaptured electrical work - Sometimes we do additional electrical work for customers, such as installing an EV Charger, or bringing a home electrical system into code compliance. These items are not well tracked, but do add time to some projects. Estimated to impact 5% or less of projects.

Trenching and detached buildings - Some projects require electrical wires to be run underground from the location of the solar system to the location of interconnection into the home electrical system. This is fairly well captured from 2023 onwards, but is not compiled in the data I have provided because the difficulty and length of the trench (and therefore time) needed for the installation varies dramatically. Estimated to impact 5% or less of projects.

How tightly packed the system is on the roof: When there is very little space between the edge of the solar panels and the edge of the roof, it takes longer to install. We have not developed a good way to quantify this. Generally if you see that modules were installed in both portrait and landscape it is an indication that the roof is very tightly packed.

New Construction - New construction projects often require a higher number of days on site due to work that must be completed at a certain stage in the construction of the home. I've tried to include in the notes section when projects are new constructions. Estimated to impact 5% or less of projects.

Elements of a Successful Project:

Successful projects will:

- Prioritize reasonable data privacy - this is a lot of detailed and sensitive data that we're sharing. What is your plan to make sure the data is not shared beyond the intended audience, during or upon completion of the project?
- Analyze the relative weight of each variable in the overall duration of the project including highlighting variables that appear to have very little weight or indications that a key factor is not accounted for in the data.
- Overcome limitations in the data collection including uncollected data, estimates in time tracking data, and outliers.
- Prioritize installation team equity by making conservative estimations for project completion time.
- Produce estimated completion times for projects given the input of all of the provided variables.

<u>The projects most likely to make a lasting impact on MSP will also:</u>

- Be a solution that is easy for non technical experts to interface with. For example, the best tool would be one that someone with no coding experience could be trained to use effectively in less than one hour.
- Be able to accommodate new data and remove old data. MSP is always changing and our tracking is only improving as we move forward. In three years, can MSP add new data that has a lower margin of error to the product you develop to produce a more accurate and relevant output?
- Produce estimated project completion times and margin of error, even if some data is missing from the input.