

PRODUCTION IMPLICATIONS OF LARGE-SCALE WILDFIRE RECONSTRUCTION

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ABSTRACT

When natural disasters destroy infrastructure, reconstruction efforts create significant demand spikes for the region. Such events have been increasing in both frequency and severity, at scales that often match or exceed the regional capacity. This paper seeks to characterize the resulting demand patterns and their impact on production rates on nearby areas outside the zone of fire destruction. Single-family residential building permit data were used to examine the reconstruction process for several recent, large-scale wildfire disasters affecting the western United States. Dates for permit application, issue, and final provided a means to assess production rates using a modified Little's Law analysis and provided work in progress and cycle time estimates. Production charts for reconstruction processes are nonlinear with time. Cycle times for the permitting and building processes increase with time in this data set. Some data was also obtained from affected jurisdictions for construction outside of the fire reconstruction efforts. Comparing these data to the fire reconstruction case suggests that cycle times for reconstruction are initially less than those in normal conditions but rise over time. The comparison suggests that the fire reconstruction effort draws capacity and impacts production outside of the disaster area.

KEYWORDS

Production, Work in Progress (WIP), process, disaster reconstruction, residential.

INTRODUCTION

Significant media and government attention is always drawn to natural disasters while they are occurring, but the spotlight dims significantly after the emergency personnel return to their stations. The long-term recovery process, including removing debris and rebuilding, is "...conventional and boring stuff" (Rubin, 2009). Rubin and Popkin (1990) devote considerable attention to the near-term response and post-event mitigation, but little to the reconstruction effort. Rebuilding in general is less commonly treated in the literature, although Mojtahedi and Oo (2012) and Nguyen et al. (2025) pointed out potential improvements in the reconstruction process that could arise through the application of lean construction principles.

The application of lean construction approaches to the single family (Ballard, 2001) and multifamily (Sacks et al., 2005) home construction sector has been taken up for some time now. Walsh et al (2003) summarized the production process for single family homes in the United States, with a particular focus on high-volume builders. The applicability of Little's Law, which relates work in progress (WIP), cycle time (CT), and throughput, has been recognized as an important quantitative method for studying production by the lean community (e.g. Koskela 1999, Antunes et al. 2023). Howell et al. (2001) used this approach to explain the impacts of variability on overall performance. Wildfire and other disasters introduce a large demand spike for reconstruction; this observation largely motivated this study.

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The US residential housing production method is typified by a builder operating with little to no self-performed work but instead a host of specialized trade subcontractors performing within specific trade categories. The subcontractor community that supports residential construction in each region is shared broadly by builders across the region, and will have some finite capacity. The demand for residential construction units is variable of course (Gharaie et al. 2012), ebbing and flowing with factors including economic cycles, regional migration patterns, and mortgage rates. Typically, these factors have relatively long cycles. By contrast, natural disasters can have a tremendous impact on the residential housing stock in a region, producing a significant demand spike. Walsh et al (2004) noted an inverse relationship between construction quality as indicated by inspection pass rates and WIP, suggesting a demand spike could have negative impacts for the region.

The objectives of this study are, first, to analyze data to understand the nature of the demand generated over time by wildfire reconstruction and, second, to assess what, if any, negative impacts this production demand has on residential production rates within the region but outside the area affected by wildfire. In the next section, the impact of large wildfires compared to the magnitude of typical regional production will be presented. In the following section, these numbers will be contextualized via a description of the effort victims must undergo to reconstruct. Next, the applicability of building permit data to study the production effort will be summarized. Production charts will be presented that characterize the wildfire rebuilding effort. These charts will be used in a modified Little's Law analysis to describe production rates, work in progress, and cycle times for fire reconstruction, and some comparisons will be made to "normal" residential production outside of fire contexts. Finally, the implications of these findings will be summarized.

DISASTER IMPACTS

Table 1 summarizes the impact on regional housing infrastructure for several high-profile wildfire disasters in the United States over just the last 10 years. They are listed in order of the number of homes destroyed divided by the average number of new home building permits issued in the 5-year period preceding the disaster.

Table 1: US Wildfire Disaster Impacts on the Housing Stock Relative to Regional Production

Disaster	Year	Location	Homes Destroyed	%Annual ¹	Source
Camp Fire	2018	CA	~14,000	~2800%	Knapp et al. (2021)
Tubbs Fire	2017	CA	~4,700	~950%	CAL FIRE (2019)
Maui Fire	2023	HI	>2000	>175%	FEMA (2025)
Palisades/Eaton Fire	2025	CA	>16,000	>135%	Phillips (2025)
Marshall Fire	2021	CO	1084	65%	FEMA (2023)

¹Homes destroyed as percentage of average number of single-family homes permitted in the relevant Metropolitan statistical area (MSA) of the US Census Bureau (2025) across the preceding 5 years.

Note that the destructive impact of these events in many cases dwarfs the residential production capacity in the respective region. Other types of disasters may have the same or even larger impacts, but the focus here is on fires. This is largely a practical matter: hurricanes tend to affect wide areas, scattering destruction across many jurisdictions (e.g. HUD 2006). This study relied

on building permit data provided by affected jurisdictions, so the more concentrated impact of a wildfire facilitates getting representative data. Major tornadoes (e.g. Kuligowski et al. 2014) in the US tend to be geographically concentrated in areas with relatively small and dispersed building departments, with less data availability. The results of this study are likely broadly applicable to other disasters, however. The impact to housing in Table 1 is normalized to the MSA, which tends to capture a much larger geographic area around which production assets and capacity could be expected to move easily. Further, Stevenson, et al. (2010) noted that reconstruction efforts are not uniformly distributed across the disaster zone but tend to exhibit significant clustering. Thus, even a more widespread event such as a hurricane likely results in a rebuild effort that looks like moving clusters of more focused activity.

WILDFIRE CONTEXT

The Camp Fire ravaged 62 kha (153,000 acres) in November of 2018, engulfing and destroying much of the Town of Paradise, California. Nearly 19,000 structures were destroyed, including some 14,000 housing units, about 10,000 of which were within Paradise town limits (Knapp et al. 2021; Hamideh et al. 2022). When fire strikes, many different processes (Rumbach et al. 2025) must take place to prepare for rebuilding any individual structures that are destroyed or damaged so significantly that they must be entirely replaced (Figure 1). Firefighting may still be ongoing for days or weeks in the immediate area of lost structures, limiting access for homeowners to begin to assess their needs. Once that phase has been completed, the area may still be restricted due to the hazardous nature of ash and partially consumed structure and contents remnants, an aspect that did receive some attention in the media after the devastating Los Angeles fires in 2025 (e.g. Zarei et al. 2025). For major disasters, cleanup operations occur over a large area before homeowners and the design professionals they hire can even access the sites.

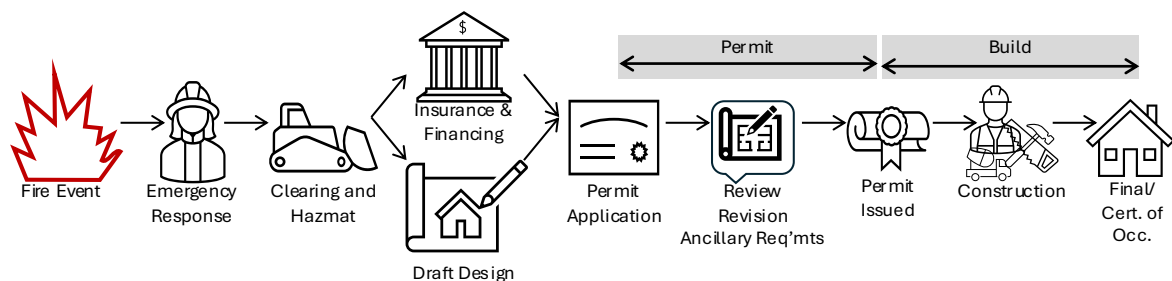


Figure 1: Simplified Depiction of Overall Wildfire Reconstruction Process

The term “rebuilding” after a fire disaster could imply that victims rebuild essentially the same home, but for many reasons this may not be the case. Even once access is available, most affected homeowners must negotiate with insurance and mortgage providers (and, possibly, a defendant in class action suits relating to causation) to obtain financial resources for their rebuilds, which may constrain or expand the scope of their rebuild compared to the lost structure. However, in many cases lost structures were built in compliance with now outdated building codes. It is common for the affected jurisdiction to allow standards that may be relaxed compared to new construction requirements in place immediately before the fire as a cost and time concession to the victims – at least for homes replaced in an “In-Kind” manner. In many cases the jurisdiction may provide a different, easier process for In-Kind replacement by footprint and size, so the homeowner must decide if they wish to rebuild essentially the same structure or adjust/enlarge their intended rebuild. Such benefits often ramp to little to no concession as rebuild plans differ more from the original structure. Depending on the age of the

home lost, even with some concessions the need to comply with updated codes can have a significant impact on design and impose an additional cost burden.

In addition to completing an often difficult and confrontational process to identify their financial resources, victims also must decide *what* to build, and this may well be different from what they lost. Table 2 shows a breakdown of the fraction of homes out of the 375 that have been permitted for rebuilding in Malibu since the 2018 Woolsey Fire. In this case most opted to upgrade in some way, an option that is not confined to the context of a relatively wealthy location such as Malibu. Issler et al. (2025) looked across over 60 wildfires in California and found that rebuilt homes averaged about a 25% increase. On the other hand, many homeowners never rebuild at all – a Pepperdine University study (2026) noted that only about one third of the homes lost in the 2018 Woolsey fire had been rebuilt as of 2025, and many homes are never rebuilt after wildfire. This decision may well be iterative to the cost considerations considering the individual financial situation and insurance outcomes.

Table 2: Scale of Rebuild Elections in the City of Malibu after the 2018 Woolsey Fire

Disaster	Percentage of Rebuilt Homes
In-Kind	23%
In-Kind 10%	62%
Major Rebuild	15%

If they decide to rebuild, the victims must engage design professionals to develop packages for submission to the permitting jurisdiction. Note that Figure 1 presents the insurance and design development phases as parallel, but there is interaction between them. Each homeowner must fight their own individual battles with the multitude of individual circumstances and related service providers. Further, they must do this unexpectedly, they are often traumatized by their personal losses and the loss of their community, they may have no familiarity with any of the processes involved, and they are in competition for resources with other victims.

ANALYSIS OF PRODUCTION PROCESSES

Grey boxes in Figure 1 depict the permit and building processes, within the larger overall effort to rebuild. These two portions could be studied via building permit records at scale, and they are common to “normal” (i.e. not rebuild) activity which supports comparison. Building permit data obtained from several jurisdictions (Table 3) included the date on which an application for a permit was received, the date on which that application was issued (if so), and the date on which the permit was finalized (if so). The period between application for a permit and issuance of that permit is the permit process, and includes time the jurisdiction takes to review and comment, time for the design professional and the homeowner to react to comments, and, in most jurisdictions, time for various related regulatory requirements such as payment of impact or sewerage connection fees. This period is referred to in this paper as the Permit process. The time between issuance of the permit and the finalizing of that permit includes mobilization and construction activities and is referred to in this paper as the Build process. Both may include wait time, but they provide useful proxies for the underlying processes.

Data was sourced through a combination of personal contacts and public records requests, for single-family, whole house rebuilds. In addition, Maui County provided 571 similar records for the year before the fire, and Los Angeles County provided 3861 similar records for 5 years prior to the Palisades-Eaton Fire. In addition to the application, issue, and final dates for the

permits, many jurisdictions provided additional details such as short project descriptions. These details may be used in future research.

Table 3: Summary of Building Permit Data Obtained

Fire	Year	Source	Records
Tubbs	2017	City of Santa Rosa, CA	2675
Thomas	2017	City of Ventura, CA	497
Camp	2018	Town of Paradise, CA	3780
Woolsey	2018	City of Malibu and Los Angeles County, CA	556
Carr	2018	Shasta County, CA	336
Marshall	2021	Cities of Superior & Louisville & Boulder County, CO	944
Maui, HI	2023	Maui County, HI	602
Palisades-Eaton	2025	Los Angeles County, CA	870

The first step in the analysis for each fire was to develop production charts. The data were arranged in date order for each milestone (Application, Issue, and Final) and then cumulated. Figure 2 below shows an example of the resulting production chart for the fire rebuild homes in the aftermath of the 2018 Carr Fire in Shasta County, California.

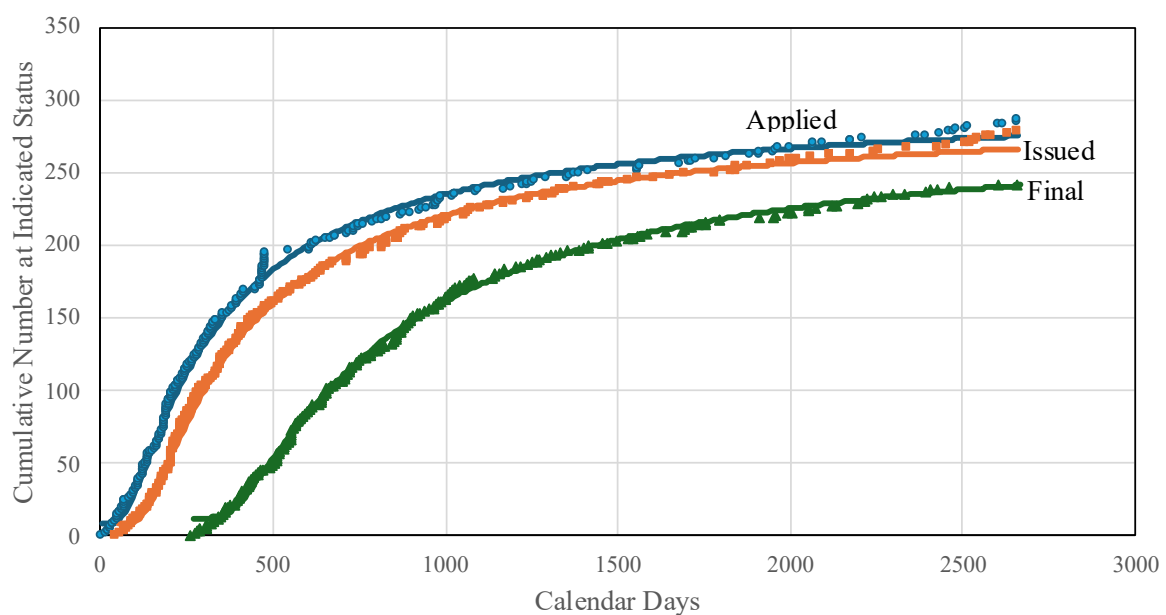


Figure 2: Production Chart for 2018 Carr Fire Home Rebuilds, Shasta County, CA

For each of the milestones, the individual markers represent the cumulative counts against time directly from the data. For example, the “Applied” points represent the cumulative number of building permit applications received for the rebuild homes, plotted against the number of calendar days since the first fire rebuild permit application was submitted. The data exhibit obvious curvature on inspection, a common feature in every case noted in Table 3. Recall the discussion of all the processes that homeowners must navigate to get to starting construction. Hence, it is perhaps to be expected that the rebuild demand is metered out slowly over time –

only about half of the rebuild permit applications received as of this writing for the Carr fire came in over the first 500 days of the record. In order to generalize the pattern of demand (the first objective of this study), many different functional forms were attempted. The best fit to the fire rebuild data in each case was a generalized Arrhenius-type exponential function of the form:

$$N = Ae^{\frac{B}{t}} + C$$

where N is the number of units, t is the time since the first permit in that milestone, and A, B, and C are constants. Correlation coefficients in excess of 0.97 were obtained for every case, with most in excess of 0.99. Example fits to the Carr fire data are shown as the smooth curves among the markers (Figure 2).

Using such charts, a modified Little's Law analysis was conducted. On the production chart, the vertical distance between two curves at any time represents the work in progress (WIP) at that time for the process that occurs between the two. That is, the vertical distance between the permit application and the permit issue lines (or points at the same time) is the WIP for Permit, and between the permit issue and permit final lines is the WIP for Build. Similarly, the horizontal distance between two curves represents the average cycle time (CT) for the process that occurs in between for the units in the system at that time. Importantly, this CT is "all in;" it includes process time and wait time. In the permit review process, it is not uncommon for the municipality to provide comments requiring the designer to make changes and resubmit. Any such iterations would be included in the permit review CT as measured here.

If the two processes were linear and with equal throughput, then the WIP and CT would be a constant and the slope of each would be the throughput, as expressed by Little's Law. Walsh et al. (2007) extended Little's Law for cases with non-linear and unequal input and output rates. Using that approach, WIP and CT functions were developed, with one example presented in Figure 3. The markers represent calculated values directly from the data, while the smoother dotted line curves are from the exponential functions. Work in progress for both processes shows an early rise as expected and then decays over time. Cycle times for both the permit and building phases increase with time, and quite substantially in this specific case. This same pattern occurs for the reconstruction effort for all the fires examined.

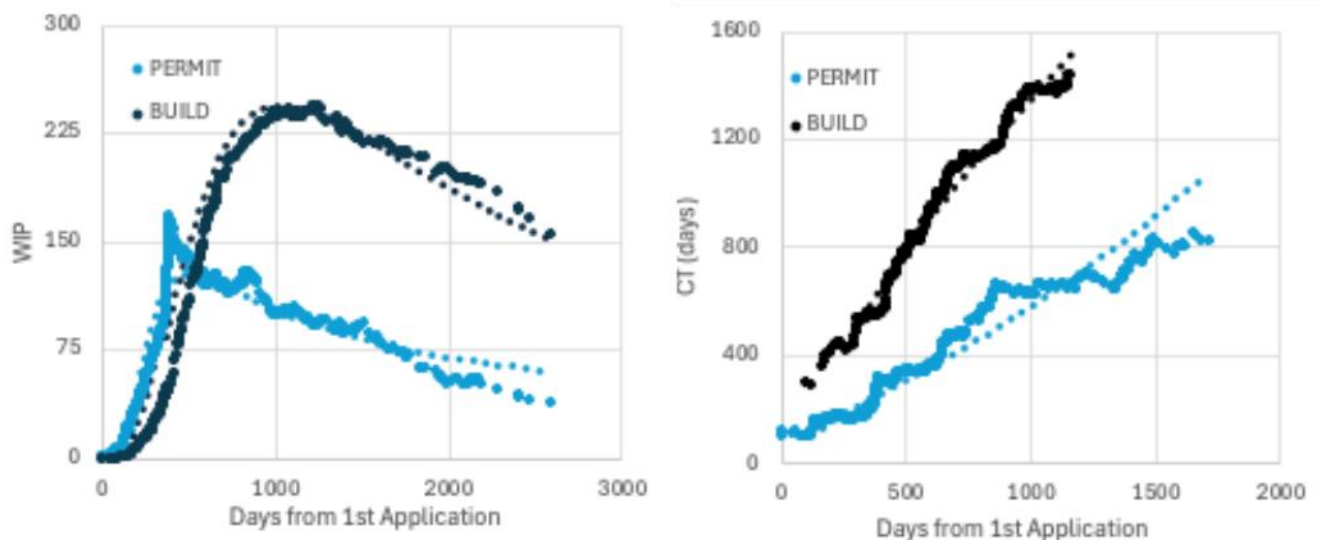


Figure 3: WIP (Left) and CT (Right) for Home Rebuild Construction after the 2018 Woolsey Fire in Los Angeles County and Malibu, California

The second objective for the study was to assess the impacts of the demand generated by the fire reconstruction on the region by comparing the outcomes within the fire zone to those

outside. To address this, similar analyses were conducted outside the fire time or zone. In addition to the building permits from the fire reconstruction efforts, permit data were also obtained for single family homes not within the reconstruction area or time horizon. Los Angeles County provided data for new single family home construction for the period of 2020-2025. Records for homes within that period that were not rebuilds from either the 2018 Woolsey or the 2025 Palisades/Eaton fires were extracted from this data. Maui County, Hawaii, also provided permit data for new single-family homes for the 12-month period before the 2023 Lahaina fire. Figure 4 shows the production chart for single family homes in Los Angeles County for which permit applications were submitted during the period of 2020 through 2024.

In contrast to the fire reconstruction data sets, where the entire production run starts after the fire, here we are coming into the processes while they are underway. As such, there is already WIP in the system in 2020, and so the early portion of our data is system loading and was not used in the fits. In a similar way, 2025 data is excluded from the analysis to avoid the horizon effect, as the build process is on the order of a full year. Residential building outside the fire context, or “normal” context, is effectively a continuous process with an infinite run, so the data in the middle portion of the data set is a better match. For this case, note that the best fits are linear. The slopes are slightly divergent, with the Applied slope being slightly higher than the Issued, which is in turn slightly higher than the Final.

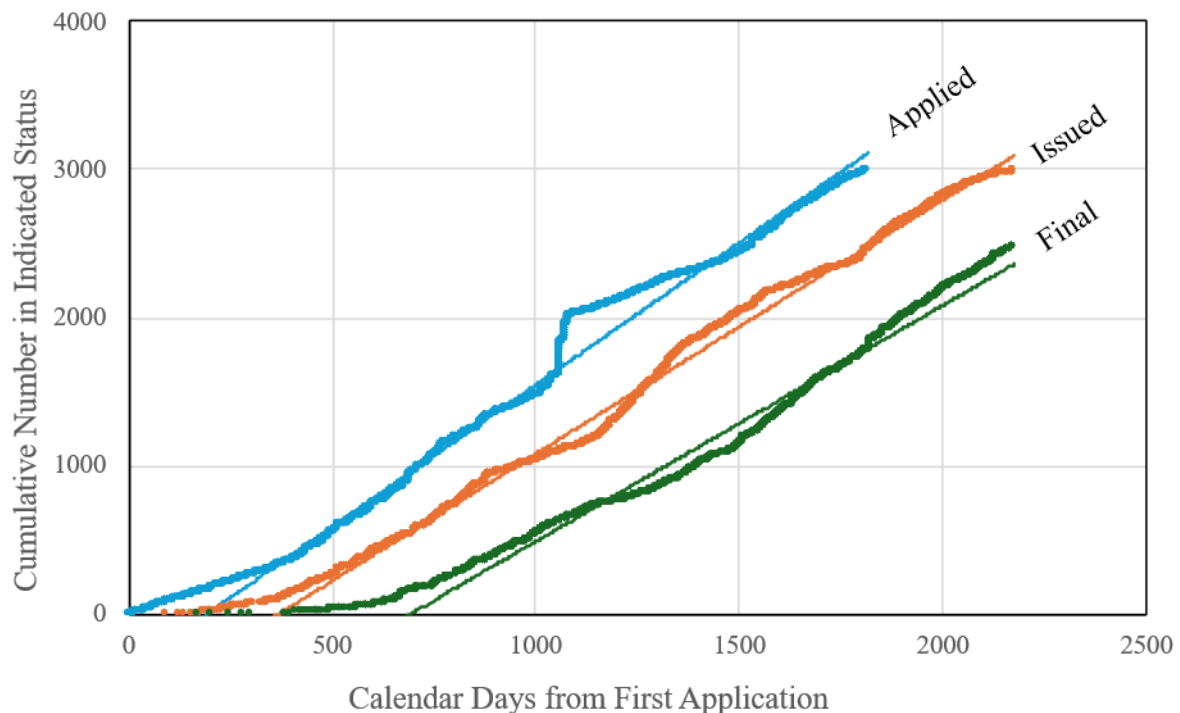


Figure 4: Production Chart for New Single-Family Homes Outside Fire Zones, Los Angeles County, California, 2020-2024

Figure 5 shows the WIP and CT for the Los Angeles County data, along with lines calculated using the best fit lines from Figure 3. A consequence of the divergent slopes described above is that the data, while exhibiting significant fluctuations, exhibit increasing trends for both WIP and CT.

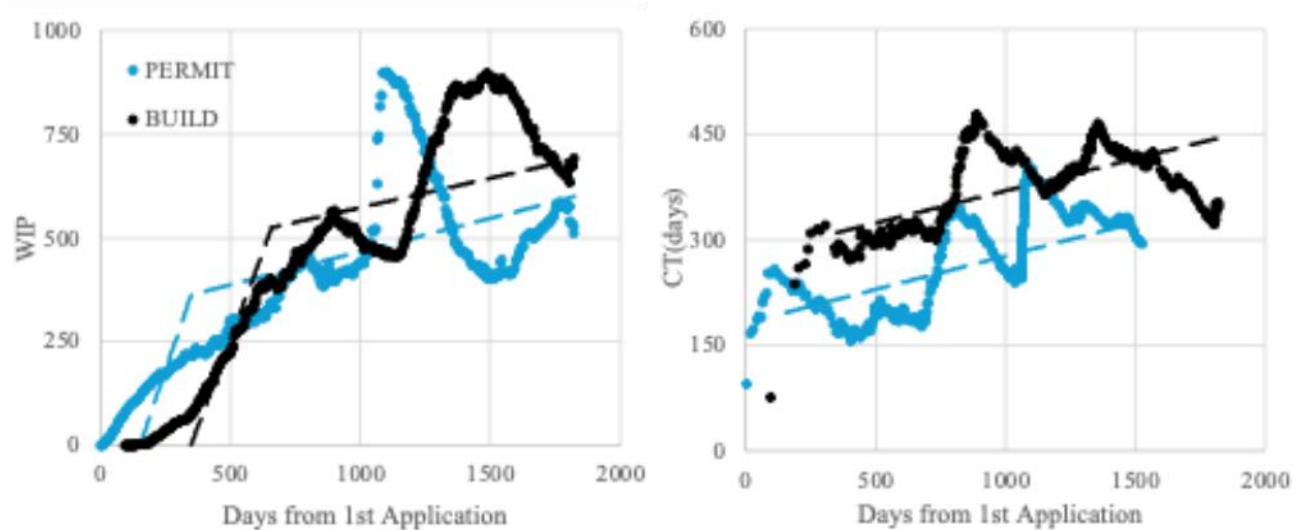


Figure 5: WIP and CT for Los Angeles County, Outside the Fire Zones, 2020-24

Table 4 below provides a summary of the results for all the wildfire cases. Examples of the charts produced (Figures 2 and 3) were provided to illustrate the analysis. Average slopes are shown for best fit lines for Applied, Issued, and Final for each fire. As noted, the best fits for each case were actually non-linear exponential equations. However, the constants for those fits are not easily interpreted and do not provide a physical sense of rate, so the slopes of linear best fits are shown instead to allow comparison. The reconstruction process within LA County from the Palisades/Eaton fires is underway, with over 700 homes under construction and over 2000 permit applications as of this writing, but only 8 had been finished.

Table 4: Summary of Production Parameters for the Fire Reconstruction Process

Fire	Average Slope of Production Chart (Number/Day)			Peak WIP		CT (days)	
	Appl	Iss	Final	Permit	Build	Permit	Build
Tubbs	1.08	1.0	0.99	250	350	40-200	200-1000
Thomas	0.14	0.16	0.18	300	250	100-600	400-700
Camp	1.51	1.47	1.40	200	700	30-200	200-600
Woolsey	0.26	0.23	0.17	150	230	100-800	400-1400
Carr	0.11	0.11	0.11	40	110	80-400	200-1200
Marshall	0.86	0.86	0.83	300	550	50-100	300-550
Maui, HI	0.97	0.88	0.29	125	350	100-150	250-400
Palisades-Eaton	4.72	4.58	0.05*	550	>700*	80-100	150-200

The WIP noted in Table 4 for each process is the highest value (see Figure 3 for one example). Much higher rates for the permit review to issuance can be noted. In all but one of these cases, the average slopes decrease from Applied to Issue to Final, to greater or lesser degrees. In all cases, CTs increase with time, so the range shown represents the lower value in the early portion and the higher value at the end of the data set.

The non-fire data from Maui and Los Angeles County provide a means to compare the production processes for fire reconstruction to “normal” conditions. Production, WIP, and CT charts for the Los Angeles County data (Figures 4 and 5) provided examples of these analyses. Table 5 summarizes the production parameters for these two locations.

Table 5: Summary of Production Parameters for the Non-Fire Data

Location	Average Slope of Production Chart (Number/Day)			Average WIP		CT (days)	
	Appl	Iss	Final	Permit	Build	Permit	Build
Maui, HI 8/22-8/23	1.66	0.67	0.43	200- 250	200-450	200-300	300-600
LA County 2020-24	1.85	1.69	1.54	375- 600	525-700	200-300	300-450

DISCUSSION AND CONCLUSIONS

The objectives of this study were, first, to characterize the demand generated over time by wildfire reconstruction, and second, to assess the impacts of this demand on “normal” construction outside the fire influence. Regarding the first objective, the production charts demonstrated that the reconstruction effort in every case studied resulted in clearly non-linear production. Best fits curves for each case were an exponential form, with higher throughput rates early in rebuilding effort that decay over time. Consequently, work-in-progress and average cycle times also vary over time. WIP levels for both the permit and building processes peak and then diminish, but CT showed an increase with time in every case.

Only limited data were obtained to address the second objective. Comparing the Maui and Los Angeles County data in Table 5 to the Maui and Palisades/Eaton data in Table 4, different pictures emerge for the fire and non-fire cases. Starting with Palisades/Eaton, it is notable that the rates of permit issue are substantially higher and the cycle time for permit review substantially lower for the fire case (Table 4) than in the non-fire case (Table 5). Cycle times are increasing for the permit process, however. Peak Permit WIP for the fire rebuild zone alone is on par with the WIP for all of LA County in normal conditions. Build cycle times are also lower in the fire zone so far – but this must be read with caution as only a handful of homes are completed as of this writing. Peak Build WIP in the fire zone is on the order of that observed regionally in normal conditions as well. Permit and construction cycle times are shorter in the fire reconstruction case, but have been increasing and are now similar to non-fire conditions.

The comparisons for Maui County show a very similar result. Permit applications have come in more quickly for just the fire zone than for the whole of the island in the year before the fire and have been issued more quickly than the year before, although the difference is less dramatic than in Los Angeles County. Both permit and build cycle times for the fire zone are shorter than the averages before the fires. Interestingly, Build WIP in Maui is continuing to rise, as the throughput for finalizing permits is substantially lower than the permit issue rate, and build WIP in the fire zone is already on the order of island-wide levels before the fire.

It has been suggested before that the deployment of lean principles could be expected to increase the speed of reconstruction efforts after large disaster impacts. In fact, process mapping and process improvement efforts are very commonly undertaken by permit agencies as a part of the reason cycle times and throughput for the Permit process are improved. For example, the

Los Angeles County Department of Public Works has brought on additional permit review staff, dramatically reduced the intensity of the permit review checklist, and streamlined planning approval (at least for in-kind replacements). Construction, however, is operated by a dispersed set of general and trade contractors, complicating systematic, broad improvement activities.

The destruction of homes in the wildfire cases presented here affected numbers that represent significant fractions of typical annual production in the respective regions. In many cases, substantially more homes were lost than a typical year's production. For many reasons, including impact on the tax and industry base and simple human compassion, there is strong interest in helping wildfire victims rebuild as quickly as possible. From a lean approach, one can consider the impact that can arise by conceptualizing the regional capacity (the sum total of the general and trade contractor base operating in the residential home market in that region) as a "factory." The Maui and Palisades/Eaton fires destroyed well over a single year's production. The production curves show that the victims do not tend to complete their decision/design/finance processes at such a rate that this entire demand hits the market at once – but peak WIP levels for rebuild were on the order of the regional levels absent fire. Rapidly doubling output of a factory over established, long-term, steady-state levels could be a significant challenge, even for a case of a single factory with direct management. The residential construction industry "factory" is far more dispersed and uncoordinated.

Per Little's Law, even for a non-linear case, the demand for resources represented by the WIP in the fire zone, combined with public interest in rapid assistance for getting victims returned to their communities, has to either drive an increase in throughput (regional capacity), draw resources away from the rest of the region (thus increasing CT or decreasing production in that part of the region), or some combination of the two. At least in the western US (with Maui as an extreme example), drawing resources from other regions may occur, but not that easily due to licensing and construction practice familiarity. The US government's current posture on immigration also puts a brake on the availability of unskilled and less-skilled labor. Capacity increases are still possible, but these factors suggest that construction quality may suffer in such cases, an area of continued research.

One indication that the demand in the fire reconstruction zone impacts production outside the zone can be seen in the data provided by Los Angeles County. Figure 4 showed non-fire data for 2020-2024. The Palisades/Eaton fire struck in the first week of 2025. For areas outside the fire zone, in 2025 the rate at which permits reached final status is only 0.33/day, as compared to about 1.54/day for the 5 years preceding the fire. More research is needed to confirm this finding in other cases.

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