The effect of resource availability on completion time in volume home building

Adnan Fadjar[1], Nick Blismas[2], Ron Wakefield[3], Ehsan Gharaie[4]

Abstract

Volume home builders in Australia generally employ specialised subcontractors in their house construction projects which introduces immense coordination and production challenges. One of the challenges is increasing construction completion times due to resource shortage. The volume home building industry is often considered as the part of the construction industry that is very similar to the manufacturing industry. This paper investigates to what extent resource availability affects the completion time of individual houses when the volume home building production system is viewed as a manufacturing production system. To achieve this objective a typical single storey house construction process, which is based on actual data from a large volume home builder in Victoria, is simulated with a number of different resource availability scenarios using discrete event simulation methods. The simulation results demonstrate that the completion times stay relatively stable up to a certain level of resource availability. However, further reduction in resource availability leads to vast increases in completion times. This research shows how simulation methods can be used effectively to predict the effect of resource shortage on the completion time of individual houses.

Keywords: **Volume home building, house completion time, simulation, resource availability.**

1. Introduction

The Australian home building industry is an important contributor to the Australian economy. The home building industry provides jobs for 370,000 people and builds approximately 140,000 brand new homes, worth about $19 billion, every year and contributes 3.5 per cent of Australia's GDP (Housing Industry Association, 2012).

[1] PhD Candidate; School of Property, Construction and Project Management; RMIT University; RMIT University Building 8, Level 8 360 Swanston Street, Melbourne, Australia; Email: adnan.fadjar@rmit.edu.au

[2] Associate Professor; School of Property, Construction and Project Management; RMIT University; RMIT University Building 8, Level 8 360 Swanston Street, Melbourne, Australia; Email: nick.blismas@rmit.edu.au

[3] Professor; Head of School; School of Property, Construction and Project Management; RMIT University; RMIT University Building 8, Level 8 360 Swanston Street, Melbourne, Australia; Email: ron.wakefield@rmit.edu.au

[4] Lecturer; School of Property, Construction and Project Management; RMIT University; RMIT University Building 8, Level 8 360 Swanston Street, Melbourne, Australia; Email: ehsan.gharaie@rmit.edu.au

The Australian volume home building industry is characterised by massive fragmentation. It consists of many small, medium, and large companies ranging from material suppliers, to home builders, and specialised subcontractors or trade contractors. This array of companies, often linked by poor communication, introduces immense coordination and production challenges; such as increasing construction completion time due to resources scarcity when housing demand is high.

During the period of 2000 to 2008 there was an increase in the average house completion time across Australia, as depicted in Figure 1.

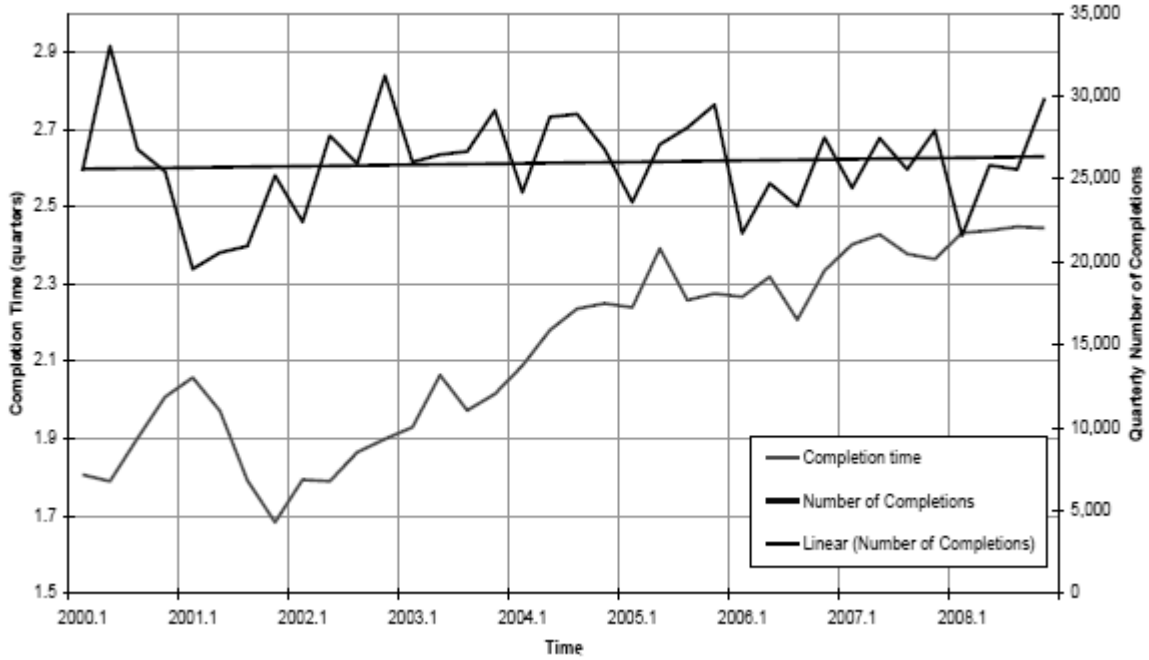

Figure 1: Australia quarterly average house completion times and number (Gharaie et al., 2010b)

Gharaie et al. (2010b) and Gharaie (2011) examined whether house size, in terms of house floor area was responsible for the increasing completion time and reached a conclusion that house size had limited impact on completion time. Dalton et al. (2011) suggest that a possible explanation for the lengthening in completion times could be resource availability which is related to the contract system used in the Australian volume home building industry.

This paper investigates to what extent the completion time of individual houses in the volume home building production system are affected by the availability of resources when viewed as a manufacturing production system. To achieve this, the construction process of a typical detached single storey house, which is based on actual data from a large volume builder in Victoria, has been modelled and simulated with variations in crew availability for one trade (concreter)

2. Context

The Australian volume home builders' contract system consists of three forms of contracts (Dalton et al., 2011), as follows.

- *A Supplier contract* is a contract between the home builder and a building material supplier for the supply of building material only. The home builder will have other contracts with specialised subcontractors to use these materials in the construction of the house.

- *A Supply and install contract* is a contract between the home builder and another company for the supply and the installation of materials on the house construction site.

- *A Subcontract* is a contract between the home builder and a subcontractor, who is usually a tradesperson employed directly to complete a specific job using materials and building components supplied by the home builder. These building components and materials are usually delivered to the house construction site by using a supplier contract.

In a typical house construction there are 108 contracts formed (Dalton et al., 2011) which consist of supplier contract (31%), supply and install contract (53%), and subcontract (16%). This number of contracts in new house construction is quite large and requires sound coordination and scheduling between contractors. Bashford et al. (2003) state that one of the critical factors that determines the successful completion of a residential project is the management of the numerous handovers between predecessor and successor trade contractors.

Dalton et al. (2011) state that each detached house project is delivered by a temporary organisation. Cherns and Bryant (1984) describe the temporary organisation as follows:

> … it is, in fact, a multiorganization since its membership is drawn from representatives of many different organizations; these representatives will eventually disperse, going back to their own organizations or on to some new project, when the building is complete, so it is only a temporary multiorganization. (p. 181)

In the Australian residential housing industry, many of these organisations become part of a multi-organisation comprising of partners or sole traders (Dalton et al., 2011). In the construction industry as a whole, approximately 60% of enterprises were sole traders and about 30% employed between 1 and 4 people (Australian Industry Group and The Australian Constructors Association, 2008). Furthermore, each of these organisations may be involved in other building projects being carried out by other multi-organisations or in other words by other volume builders. For instance, a carpet company is probably supplying and installing carpet material and fixing them in new homes being built by many volume builders. This situation could lead to resource shortages which in turn would increase completion times as jobs are delayed because subcontractors are not available when the volume home builder needs the job accomplished (Master Builders Australia, 2010).

Volume home builder production systems are more comparable to manufacturing production systems where more or less similar houses are being built repeatedly in a limited space. Such views of residential construction as manufacturing production systems have been

discussed by numerous authors (see for example; Ballard and Howell, 1998, Barlow and Ozaki, 2005, Blismas and Wakefield, 2009, Blismas et al., 2009, Gann, 1996, Koskela, 1992, Koskela, 1999, Koskela and Vrijhoef, 2001, Wakefield et al., 2001, Wakefield and O'Brien, 2004, Winch, 2006)

This study attempts to model the effect of resource availability on the completion time of individual houses in volume home building by using simulation methods. This study uses a discrete event simulation approach which has been recognised as a useful technique for quantitative analysis of construction operations (Bashford et al., 2003, Damrianant and Wakefield, 2000, Gharaie et al., 2010a, Gharaie et al., 2010c, Lu et al., 2008, Lucko et al., 2009, Martinez, 2010, Sawhney et al., 2005, Sawhney et al., 2001, Velarde et al., 2009, Wakefield, 1998, Wakefield and A.Sears, 1997, Wakefield and O'Brien, 2004).

3. Definitions and Assumptions

In order to have a clear understanding of the study results, the following definitions and assumptions are used in this paper.

3.1 Definitions

In this paper *project duration* refers to the duration of the construction of 100 houses; *completion time* (CT) refers to the duration of the construction of one house; *inter-arrival time* refers to the time between the construction start of two consecutive houses; *work in process* (WIP) refers to the number of houses under construction; *resources* refers to human resources only; *throughput* (TH) refers to the number of house completed per day; *job* refers to an activity performed by a specific crew.

3.2 Assumptions

All the houses are identical in design and size; inter-arrival time remains constant during the project; there is only one crew available for each job; job durations are deterministic.

4. Simulation of Volume House Production

A simulation model of a single story detached house construction process is developed based on a construction schedule employed by a large volume home builder in Victoria. This model comprises construction activities such as, slab construction, wall framing, roof tiling, etc. Logical relationships between activities is then included in the model to represent activities dependent on preceding activities.

The house construction process model is then simulated using Simul8 software with different scenarios to investigate to what extent the variations in resource availability that occur in day to day operations of volume home builders affect the completion times of individual house in the production system.

4.1 Dynamics of the volume house production

The duration of the jobs vary between 1 and 7 days. There are 100 houses to be constructed and each house construction process consists of 173 jobs performed by subcontractors and suppliers. Figure 2 shows a small section of the Simul8 representation of the construction process. All 173 activities are not included in this paper due to space limitation.

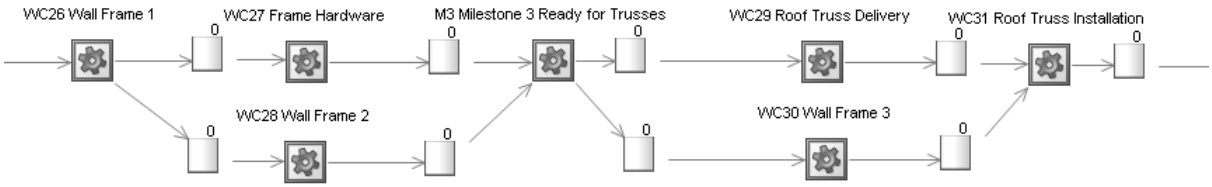

Figure 2: Simul8 representation of the house construction process

4.1.1 Inter-arrival time sensitivity analysis

With the assumption that all resources are always available when needed the simulation is conducted with different inter-arrival times ranging from 15 days to 1 day. These inter-arrival times are arbitrarily chosen in order to find out which inter-arrival time best represents the current situation of supervisors of detached housing, as they are usually responsible for the construction of up to 15 houses at any one time (Dalton et al., 2011). The simulation results as shown in Table 1 are then used to calculate *throughput* and *work in process* as follows.

4.1.2 Throughput and work in process calculation

Throughput of the simulation model is calculated by dividing the *number of houses completed* by the *project duration*. Once *throughput* has been determined the *work in process* can then be calculated using the equation known as Little's law which is a production modelling equation relating WIP to TH and CT (Hopp and Spearman, 2008). Little's law is presented in the following equation:

$$WIP = CT \times TH \quad (1)$$

Where WIP = work in process; CT = completion time; and TH = throughput.

Table 1 shows the result of the simulation runs and the results of *throughput* and *work in process* calculation.

Table 1: Simulation results of different inter-arrival times

Inter-arrival time (day)	Average Completion Time (day)	Project Duration (day)	Number of House Completed (house)	Average Throughput (house/day)	Average Work in Process (house)
15	160	1660	100	0.060	9.64
14	160	1560	100	0.064	10.26
13	160	1460	100	0.068	10.96
12	160	1360	100	0.074	11.76
11	160	1260	100	0.079	12.70
10	160	1160	100	0.086	13.79
9	160	1060	100	0.094	15.09
8	160	960	100	0.104	16.67
7	160	860	100	0.116	18.60
6	209.5	859	100	0.116	24.39
5	259	858	100	0.117	30.19
4	308.5	857	100	0.117	36.00
3	358	856	100	0.117	41.82
2	407.5	855	100	0.117	47.66
1	457	854	100	0.117	53.51

Based on the simulation results in Table 1 it is then determined that a 9 day inter-arrival or about 3 houses start every month which yields work in process of 15 houses is the best inter-arrival time to represent the current situation of the supervisors, as determined by Dalton et al. (2011).

4.2 Various resource availability simulation scenarios

The scenarios shown in Table 2 look at how the production system may behave by altering the availability of the concreter crew while assuming other resources are always available when needed and keeping inter-arrival time at 9 days for each scenario. In scenario number 3, for example, the concreter crew is only available 70% of the time that is 30% of the time the crew is working on other sites for other builders and other supervisors.

Table 2: Overview of the simulation scenarios

Scenario	Select resource availability	Other resources availability	Inter-arrival time (day)
1	Concreter crew 90%	Always available when needed	9
2	Concreter crew 80%		
3	Concreter crew 70%		
4	Concreter crew 60%		
5	Concreter crew 50%		

5. Results

The simulation results in Figure 3 show that up to 80% concreter crew availability yields relatively stable completion times. However, when only 50% of the concreter crew is available the completion times start to increase right after the third house enters the system and the difference in completion time between the earlier and the later houses in the system becomes larger. Take for example the completion times of house number 29 and house number 94 which are 300 and 600 days in length respectively; that is a 300 day difference when the resource is only 50% available. Whereas at 70% resource availability, the completion times of the same houses are 191 and 297 days respectively yielding a 106 day difference.

The simulation results show that the completion times stay relatively stable up to a certain level of resource availability. However, further reduction in the resource availability leads to vast increases in completion times.

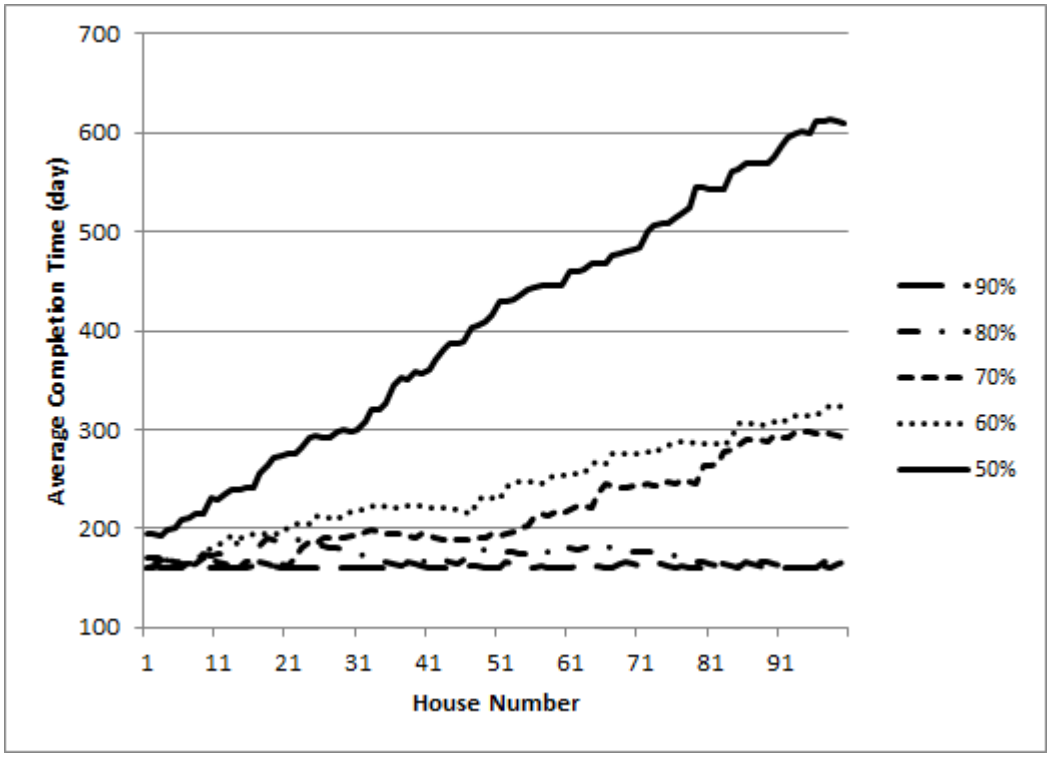

Figure 3: Completion time of individual house at different concreter crew availability

6. Conclusions

The nature of the Australian volume home building industry where subcontractors may work for more than one volume home builder could lead to resource shortages when housing demand is high. This study shows how simulation methods can be effectively used to demonstrate the effect of a key resource shortage on individual house completion times when volume home building production systems are viewed as manufacturing production systems. However, further research in this area is needed to investigate the effect on

completion time when more than one resource shortage exists and when resources entering and leaving the market are taken into account.

References

AUSTRALIAN INDUSTRY GROUP AND THE AUSTRALIAN CONSTRUCTORS ASSOCIATION. 2008. *State of Play - The Australian Construction Industry in 2008* [Online]. Available: http://www.aigroup.com.au/portal/binary/com.epicentric.contentmanagement.servlet.ContentDeliveryServlet/LIVE_CONTENT/Publications/Reports/2009/7219_State_of_Play_construction_report.pdf [Accessed 21/11/2012].

BALLARD, G. & HOWELL, G. Year. What Kind of Production is Construction. *In:* 6th International Conference on Lean Construction, 1998 Guarujá, Brazil.

BARLOW, J. & OZAKI, R. 2005. Building mass customised housing through innovation in the production system: lessons from Japan. *Environment and Planning,* 37**,** 9-20.

BASHFORD, H., SAWHNEY, A., WALSH, K. D. & KOT, K. 2003. Implications of Even Flow Production Methodology for U.S. Housing Industry. *Journal of Construction Engineering and Management,* 129**,** 330-337.

BLISMAS, N. & WAKEFIELD, R. 2009. Drivers, constraints and the future of offsite manufacture in Australia. *Construction Innovation: Information, Process, Management,* 9**,** 72-83.

BLISMAS, N., WAKEFIELD, R. & HAUSER, B. 2009. Concrete prefabricated housing via advances in systems technologies - Development of a technology roadmap. *Engineering, Construction and Architectural Management,* 17**,** 99-110.

CHERNS, A. B. & BRYANT, D. T. 1984. Studying the client's role in construction management. *Construction Management and Economics,* 2**,** 177-184.

DALTON, T., WAKEFIELD, R. & HORNE, R. 2011. Australian suburban house building: industry organisation, practices and constraints. Australian Housing and Urban Research Institute.

DAMRIANANT, J. & WAKEFIELD, R. R. 2000. An Alternative Approach for Modeling of Interference in Discrete-Event Systems. *Civil Engineering and Environmental Systems,* 17**,** 213 - 235.

GANN, D. M. 1996. Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics,* 14**,** 437 - 450.

GHARAIE, E. 2011. *House Completion Time in Australia: Workflow Planning Approach.* A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy, School of Property, Construction and Project Management, College of Design and Social Context, RMIT University, Melbourne.

GHARAIE, E., WAKEFIELD, R. & BLISMAS, N. 2010a. The effect of house design variation on the completion time in a production building operation. *The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors.* Dauphine Université, Paris: the Royal Institution of Chartered Surveyors.

GHARAIE, E., WAKEFIELD, R. & BLISMAS, N. 2010b. Explaining the Increase in the Australian Average House Completion Time: Activity-based versus Workflow-based Approach. *Australasian Journal of Construction Economics and Building,* 10**,** 34-49.

GHARAIE, E., WAKEFIELD, R. & BLISMAS, N. Year. The impact of construction commencement intervals on residential production building. *In:* WONG, J., ed. The 8th International Conference on Construction and Real Estate Management, 2010c Brisbane, Australia. China Architecture & Building Press.

HOPP, W. J. & SPEARMAN, M. L. 2008. Factory physics, New York, McGraw-Hill/Irwin.

HOUSING INDUSTRY ASSOCIATION. 2012. *Housing Australians* [Online]. Housing Industry Association. Available: http://hia.com.au/media/~/media/Files/MediaMicrosite/Submissions/Housing%20Australians.ashx [Accessed 21/11/2012].

KOSKELA, L. 1992. Application of the New Production Philosophy to Construction. *Technical Report No. 72.* Stanford, CA: CIFE, Stanford University.

KOSKELA, L. Year. Management of production in construction: A theoretical view. *In:* 7th Annual Conf. of the Int. Group for Lean Construction, 1999 Univ. of California, Berkeley, California. International Group for lean Construction.

KOSKELA, L. & VRIJHOEF, R. 2001. Is the current theory of construction a hindrance to innovation? *Building Research & Information,* 29**,** 197 - 207.

LU, M., LAM, H.-C. & DAI, F. 2008. Resource-constrained critical path analysis based on discrete event simulation and particle swarm optimization. *Automation in Construction,* 17**,** 670-681.

LUCKO, G., SWAMINATHAN, K., BENJAMIN, P. C. & MADDEN, M. G. 2009. Rapid Deployment of Simulation Models for Building Construction Application. *Winter Simulation Conference.*

MARTINEZ, J. C. 2010. Methodology for Conducting Discrete-Event Simulation Studies in Construction Engineering and Management. *Journal of Construction Engineering and Management,* 136**,** 3-16.

MASTER BUILDERS AUSTRALIA. 2010. *Training for the Future: Master Builders Training Blueprint 2010-2012* [Online]. Available: http://www.masterbuilders.com.au/Content/ViewAttachment.aspx?id=1060&attachmentNo=19 [Accessed 21/02/2013].

SAWHNEY, A., BASHFORD, H., PALANIAPPAN, S., WALSH, K. & THOMPSON, J. Year. A Discrete Event Simulation Model to Analyze the Residential Construction Inspection Process. *In*, 2005 Cancun, Mexico. ASCE, 134-134.

SAWHNEY, A., BASHFORD, H., WALSH, K. & MUND, A. 2001. Simulation of Production Homebuilding Using Simphony. *Proceedings of the 33nd conference on Winter simulation.* Arlington, Virginia: IEEE Computer Society.

VELARDE, G. J., SALONI, D. E., DYK, H. V. & GIUNTA, M. 2009. Process flow improvement proposal using lean manufacturing philosophy and simulation techniques on a modular home manufacturer. *Lean Construction Jurnal***,** 77-93.

WAKEFIELD, R. 1998. Application of Extended Stochastic Petri Nets to Simulation and Modelling of Construction Systems. *Civil Engineering and Environmental Systems,* 15**,** 1 - 22.

WAKEFIELD, R. & A.SEARS, G. 1997. Petri nets for simulation and modeling of construction systems. *Journal of Construction Engineering & Management,* 123**,** 105.

WAKEFIELD, R. & O'BRIEN, M. 2004. Industrializing the Residential Construction Site Phase IV: Production Simulation. Washington D.C. .

WAKEFIELD, R., O'BRIEN, M. & BELIVEAU, Y. 2001. Industrializing the Residential Construction Site Phase Two: Information Integration. Washington, DC

WINCH, G. M. 2006. Towards a theory of construction as production by projects. *Building Research & Information,* 34**,** 154 - 163.